Manual of On-Farm Vermicomposting and Vermiculture

By Glenn Munroe
Organic Agriculture Centre of Canada



Acknowledgements

EcoAction Program of Environment Canada
and
New Ground Vermicomposting, Halifax, Nova Scotia
Jennifer Scott, Centre Burlington, Nova Scotia
Kipawo Holsteins, Grand Pre, Nova Scotia
Holdanca Farms Ltd., Wallace, Nova Scotia

Table of Contents

1 Introduction: Vermiculture and Vermicomposting 1
1.1 The Difference between Vermiculture and Vermicomposting 1
1.2 The Compost Worm 1
1.3 Why Bother? An Overview of Potential Benefits and Constraints 2
1.4 What this Manual Can Do for You 3

2 Working with Worms: The Basics 5
2.1 What Worms Need 5
2.1.1 The Five Essentials 5
2.1.2 Bedding 5
2.1.3 Worm Food 7
2.1.4 Moisture 10
2.1.5 Aeration 10
2.1.6 Temperature Control 10
2.2 Other Important Parameters 11
2.3 Calculating Rates of Reproduction 12
2.4 Projecting Vermicompost Outputs 14
2.5 Pests and Diseases 15

3 An Overview of Vermicomposting Systems 17
3.1 Basic Types of Systems 17
3.2 Windrows 17
3.2.1 Static pile windrows (batch) 17
3.2.2 Top-fed windrows (continuous flow) 20
3.2.3 Wedges (continuous flow) 21
3.3 Beds or Bins 22
3.3.1 Top-fed beds (continuous flow) 22
3.3.2 Stacked bins (batch or continuous flow) 23
3.4 Flow-Through Reactors 24

4 On-Farm Vermiculture 26
4.1 Vermiculture Systems 26
4.2 Methods of Harvesting Worms 26
4.2.1 General 26
4.2.2 Manual Methods 26
4.2.3 Self-Harvesting (Migration) Methods 27
4.2.4 Mechanical Methods 28
4.3 Use of Worms Directly in Agriculture 28

5 The Value of Vermicompost 30
5.1 Results from the Literature 30
5.2 OACC Trials 32
5.2.1 Introduction 32
5.2.2 Indoor Trials 32
5.2.3 Field Trials 33
5.3 Summary: The Value of Vermicompost 34

6 Other Considerations 35
6.1 Environmental Risks and Benefits 35
6.1.1 Worms and the Environment 35
6.1.2 Water Quality Issues 35
6.1.3 Climate Change Factors 36
6.1.4 Below-Ground Biodiversity 37
6.2 Potential Income Diversification: Worm-related Opportunities for Farmers 38
6.2.1 Sale of Vermicompost 38
6.2.2 Sale of Worms 39
6.2.3 Compost Tea 39
6.2.4 Assessing the Opportunity 40

Appendix A: References A1
Appendix B: Sources of Information B1
Appendix C: Vermiculture Trial – Scott Farm C1
Appendix D: Vermicomposting Trials – Holdanca Farms Ltd. and Kipawo Holsteins D1

List of Figures

Figure #	Title	Page #
1	**E. fetida - the compost worm**	2
2	**Initial worm bed on Mentink Farm, OACC Pilot**	3
3	**Okara used to feed worms on Scott Farm, OACC pilot**	7
4	**Vermicomposting windrows of shredded cardboard and manure**	17
5	**Small to medium-scale harvesters**	19
6	**Cinder-block worm beds on Scott farm**	23
7	**Framework for stacked bins**	24
8	**Tomato-plant growth trial at University of Campeche**	31
9	**Lettuce yield – soil 1**	33
10	**Lettuce yield – soil 2**	33
11	**Lettuce yield – field trials**	33
C1	**Average Population of Treatments after 17 Weeks**	C1
C2	**Average Biomass of Treatments After 17 Weeks**	C2
C3	**Cinderblock & mortar worm bins at Scott Farm**	C2
C4	**A chicken foraging for worms in the vermicompost**	C2
D1	**One of the original worm windrows at Holdanca Farms**	D1
D2	**Biomass change over time – Holdanca Farms**	D1
D3	**Covered compost pad at Kipawo Holsteins**	D2
D4	**Original inside vermi windrow at Kipawo**	D3
D5	**Biomass Increase, Kipawo**	D3

List of Tables

Table #	**Title**	**Page #**
1	Common Bedding Materials	6
2	Common Worm Feedstocks	8
3	Results of Windrow Tests, Sackville, Nova Scotia	18

1 Introduction: Vermiculture and Vermicomposting

1.1 The Difference between Vermiculture and Vermicomposting

Vermiculture is the culture of earthworms. The goal is to continually increase the number of worms in order to obtain a sustainable harvest. The worms are either used to expand a vermicomposting operation or sold to customers who use them for the same or other purposes (see "On-Farm Vermiculture" later in this manual).

Vermicomposting is the process by which worms are used to convert organic materials (usually wastes) into a humus-like material known as vermicompost. The goal is to process the material as quickly and efficiently as possible.

These two processes are similar but different. If your goal is to produce vermicompost, you will want to have your maximum worm population density all of the time. If your goal is to produce worms, you will want to keep the population density low enough that reproductive rates are optimized. Both of these processes will be described in some detail in this manual.

1.2 The Compost Worm

There are an estimated 1800 species of earthworm worldwide (Edwards & Lofty, 1972). This manual will focus on just one. **Eisenia fetida** (Savigny) is commonly known as (partial list only): the "compost worm", "manure worm", "redworm", and "red wiggler" (see Figure 1). This extremely tough and adaptable worm is indigenous to most parts of the world and can be found on most Canadian farms wherever piles of manure have been left to age for more than a few months.

Three Types of Earthworm

Anecic (Greek for "out of the earth") – these are burrowing worms that come to the surface at night to drag food down into their permanent burrows deep within the mineral layers of the soil. Example: the Canadian Night crawler.

Endogeic (Greek for "within the earth") – these are also burrowing worms but their burrows are typically more shallow and they feed on the organic matter already in the soil, so they come to the surface only rarely.

Epigeic (Greek for "upon the earth") – these worms live in the surface litter and feed on decaying organic matter. They do not have permanent burrows. These "decomposers" are the type of worm used in vermicomposting.

Information sourced from Card et al., 2004.

Commercially raised worms are usually of the epigeic type. E. fetida is certainly not the only epigeic worm, but it is the one most often used for composting purposes in Northern climates. It can handle a wide temperature range (between 0 and 35^{o}C) and can actually survive for some time almost completely encased in frozen organic material

(as long as it can continue to take in nourishment). Its cocoons (eggs) have been shown to remain viable after having been frozen for several weeks[1]. In addition, it can take a lot of handling and rough treatment. Perhaps most importantly, like most if not all litter-dwelling worms, the compost worm has the capacity for very rapid reproduction. This is an evolutionary necessity for a creature whose natural environment is extremely changeable and hazardous and whose natural supplies of food are of the "boom or bust" variety. All of these characteristics make E. fetida the natural choice for those who wish to do their vermicomposting outdoors, year-round, in climates with harsh winter conditions.



Fig 1: E. fetida - the compost worm

1.3 Why Bother? An Overview of Potential Benefits and Constraints

Why should an organic farmer be interested in vermiculture and/or vermicomposting? The answers are several and may not apply to all organic producers. In summary, they are as follows:

- Vermicompost appears to be generally superior to conventionally produced compost in a number of important ways;
- Vermicompost is superior to most composts as an inoculant in the production of compost teas;
- Worms have a number of other possible uses on farms, including value as a high-quality animal feed;
- Vermicomposting and vermiculture offer potential to organic farmers as sources of supplemental income.

All of the above will be discussed in detail later in this document. At the same time, the reader should take note at the beginning that working with worms is a more complicated process than traditional composting:

- It can be quicker, but to make it so generally requires more labour;
- It requires more space because worms are surface feeders and won't operate in material more than a meter in depth;
- It is more vulnerable to environmental pressures, such as freezing conditions and drought;
- Perhaps most importantly, it requires more start-up resources, either in cash (to buy the worms) or in time and labour (to grow them).

[1] Experiments at Nova Scotia Agricultural College (NSAC) confirmed that the cocoons of E. fetida can survive unprotected freezing for several weeks and remain viable. This species ability, combined with very high and fast reproduction rates, is what allows these surface-dwelling, non-burrowing worms to thrive in regions with long, cold winters.

These constraints and disadvantages will also be discussed in detail in the pages that follow.

Because of the benefits described above, and despite these drawbacks, farmers around the world have started to grow worms and produce vermicompost in rapidly increasing numbers. Warmer climes have tended to predominate so far, with India and Cuba being the leaders to date. Vermicomposting centres are numerous in Cuba and vermicompost has been the largest single input used to replace the commercial fertilizer that became difficult or even impossible to import after the collapse of the Soviet Union (Cracas, 2000). In 2003, an estimated one million tonnes of vermicompost were produced on the island (Koont, 2004). In India, an estimated 200,000 farmers practice vermicomposting and one network of 10,000 farmers[2] produces 50,000 metric tonnes of vermicompost every month. In the past decade, farmers in Australia[3] and the West Coast of the U.S. have started to use vermicompost in greater quantities, fuelling the development of vermicomposting industries in those regions. At the same time, scientists at several Universities in the U.S., Canada, India, Australia, and South Africa have started to document the benefits associated with the use of vermicompost, providing facts and figures to support the observations of those who have used the material.



Fig 2: Initial worm bed on Mentink Farm, OACC Pilot

The **Organic Agriculture Centre of Canada (OACC)** has recently completed a pilot project, funded by **Environment Canada's EcoAction Program**, wherein three Nova Scotia farmers experimented with worms for an 18-month period. The results of their trials provide a major contribution to this manual. The bottom line is that only the individual producer will be able to decide whether or not it makes sense to start working with worms. It is OACC's hope that this document can be of some assistance to Canadian organic (and conventional) producers in making that decision.

1.4 What this Manual Can Do for You

If you have an interest in working with composting worms, this manual can provide you with the following:

- ***A quick course on the basics of growing worms and using them to produce vermicompost***. This includes lists of beddings and feed stocks, optimum environmental conditions and how to maintain them, troubleshooting hints, methods of calculating population increases and product quantities, etc.
- ***An overview of vermicomposting systems.*** These range from simple windrow systems to the flow-through systems used in the United States to

[2] The M.R. Morarka-GDC Rural Research Foundation runs a program that teaches vermiculture and vermicomposting to Indian farmers and also assists them in the development of markets for their product by guaranteeing a floor price for the material until they find their own buyers at equal or better prices.

[3] One of the largest commercial producers of vermicompost is Vermitech Pty Ltd of Australia. Their website – http://www.vermitech.com --documents considerable research on the use of their product on various crops.

produce high-quality bagged product for the home-gardening market. Basic descriptions and instructions are included.

- ***A summary of what is known regarding the value of vermicompost***. This summary includes information from the literature as well as data gathered by OACC and NSAC through recent plant-growth trials.
- ***Information on the inherent value of the worms themselves***, both in agriculture and as a source of protein for animal feed.
- ***A discussion of opportunities for farmers to make money with worms.*** Examples of successful on-farm businesses are presented, along with some guidelines on the pitfalls associated with the business of vermicomposting.
- ***An overview of environmental considerations.*** The environmental pros and cons are discussed; in particular, the potential for mitigation of climate change is considered.
- ***Criteria for opportunity assessment.*** This is a series of questions and associated criteria for farmers to use in assessing the opportunities associated with worms.
- ***A resource list --*** credible sources of information on vermiculture and vermicomposting.

OACC believes that the reader should approach the entire concept of working with composting worms with a pragmatic bent and a skeptical mind. While there do appear to be significant opportunities, there also appears to be a lot of hype. In addition, the vermiculture industry in the United States has a 40-year history of scams and pyramid-style buy-back schemes that have relieved many innocent but naïve people of their life savings. This manual has been designed to help the reader get an accurate sense of what worms can offer a producer, what levels of effort and resources are required, and what associated risks are involved.

2 Working with Worms: The Basics

2.1 What Worms Need

2.1.1 The Five Essentials

Compost worms need five basic things:

1 An hospitable living environment, usually called “bedding”;
2 A food source;
3 Adequate moisture (greater than 50% water content by weight);
4 Adequate aeration;
5 Protection from temperature extremes.

These five essentials are discussed in more detail below.

2.1.2 Bedding

Bedding is any material that provides the worms with a relatively stable habitat. This habitat must have the following characteristics:

- ***High absorbency.*** Worms breathe through their skins and therefore must have a moist environment in which to live. If a worm’s skin dries out, it dies. The bedding must be able to absorb and retain water fairly well if the worms are to thrive.
- ***Good bulking potential.*** If the material is too dense to begin with, or packs too tightly, then the flow of air is reduced or eliminated. Worms require oxygen to live, just as we do. Different materials affect the overall porosity of the bedding through a variety of factors, including the range of particle size and shape, the texture, and the strength and rigidity of its structure. The overall effect is referred to in this document as the material’s ***bulking*** potential.
- ***Low protein and/or nitrogen content (high Carbon: Nitrogen ratio).*** Although the worms do consume their bedding as it breaks down, it is very important that this be a slow process. High protein/nitrogen levels can result in rapid degradation and its associated heating, creating inhospitable, often fatal, conditions. Heating can occur safely in the food layers of the vermiculture or vermicomposting system, but not in the bedding.

Some materials make good beddings all by themselves, while others lack one or more of the above characteristics and need to be used in various combinations. Table 1 provides a list of some of the most commonly used beddings and provides some input regarding each material’s absorbency, bulking potential, and carbon to nitrogen (C:N) ratios. OACC tested the first two materials in Table 1 – horse manure and peat moss – in a separate experiment within the EcoAction-funded pilot project in 2003-2004. Both materials performed well, with the horse manure having the edge. Since horse manure was available free of charge and is a renewable resource, it was used in the balance of the trial (See Appendix C for a full description of this experiment). If available, it is generally considered to be an ideal bedding. Its high C:N ratio (for a manure), good bulking characteristics (because of the high straw content), and relatively good moisture retention make it an excellent environment for E. fetida. It can be improved somewhat

by the addition of a high-absorbency material such as peat moss or shredded paper/cardboard (which will increase absorbency and also increase the C:N ratio a bit – another positive).

Table 1: Common Bedding Materials

Bedding Material	Absorbency	Bulking Pot.	C:N Ratio[4]
Horse Manure	Medium-Good	Good	22 - 56
Peat Moss	Good	Medium	58
Corn Silage	Medium-Good	Medium	38 - 43
Hay – general	Poor	Medium	15 - 32
Straw – general	Poor	Medium-Good	48 - 150
Straw – oat	Poor	Medium	48 - 98
Straw – wheat	Poor	Medium-Good	100 - 150
Paper from municipal waste stream	Medium-Good	Medium	127 - 178
Newspaper	Good	Medium	170
Bark – hardwoods	Poor	Good	116 - 436
Bark -- softwoods	Poor	Good	131 - 1285
Corrugated cardboard	Good	Medium	563
Lumber mill waste -- chipped	Poor	Good	170
Paper fibre sludge	Medium-Good	Medium	250
Paper mill sludge	Good	Medium	54
Sawdust	Poor-Medium	Poor-Medium	142 - 750
Shrub trimmings	Poor	Good	53
Hardwood chips, shavings	Poor	Good	451 - 819
Softwood chips, shavings	Poor	Good	212 - 1313
Leaves (dry, loose)	Poor-Medium	Poor-Medium	40 - 80
Corn stalks	Poor	Good	60 - 73
Corn cobs	Poor-Medium	Good	56 - 123

If available, shredded paper or cardboard makes an excellent bedding (GEORG, 2004), particularly when combined with typical on-farm organic resources such as straw and hay. Organic producers, however, must be careful to ensure that such materials are not restricted under their organic certification standards. Paper or cardboard fibre collected in municipal waste programs cannot be approved for certification purposes. There may be cases, however, where fibre resources from specific generators could be sourced and approved. This must be considered on a case-by-case basis. Another material in this category is paper-mill sludge (Elvira et al., 1996; 1997), which has the high absorbency and small particle size that so well complements the high C:N ratios and good bulking properties of straw, bark, shipped brush or wood shavings. Again, the sludge must be approved if the user has organic certification.

[4] Most of the C:N ratios were obtained from The On-Farm Composting Handbook (see Sources and Reference Sections); the balance were obtained from the other sources listed under References. The former document also compiled the ratios from reports in the literature. The averages or ranges quoted, therefore, are estimates and intended only to provide the reader with a general sense of how each material compares to the others with respect to nitrogen content.

In general, it should be noted by the reader that the selection of bedding materials is a key to successful vermiculture or vermicomposting. Worms can be enormously productive (and reproductive) if conditions are good; however, their efficiency drops off rapidly when their basic needs are not met (see discussion on moisture below). Good bedding mixtures are an essential element in meeting those needs. They provide protection from extremes in temperature, the necessary levels and consistency of moisture, and an adequate supply of oxygen. Fortunately, given their critical importance to the process, good bedding mixtures are generally not hard to come by on farms. The most difficult criterion to meet adequately is usually absorption, as most straws and even hay are not good at holding moisture. This can be easily addressed by mixing some aged or composted cattle or sheep manure with the straw. The result is somewhat similar in its bedding characteristics to aged horse manure.

Mixing beddings need not be an onerous process; it can be done by hand with a pitchfork (small operations), with a tractor bucket (larger operations), or, if one is available, with an agricultural feed mixer. Please note that the latter would only be appropriate for large commercial vermicomposting operations where high efficiency levels and consistent product quality is required.

Some of these materials also have revenue-generating potential, through commercial tipping fees. This aspect of vermicomposting and vermiculture is discussed in more detail in Section 6.

2.1.3 Worm Food

Compost worms are big eaters. Under ideal conditions, they are able to consume in excess of their body weight each day, although the general rule-of-thumb is ½ of their body weight per day[5]. They will eat almost anything organic (that is, of plant or animal origin), but they definitely prefer some foods to others. Manures are the most commonly used worm feedstock, with dairy and beef manures generally considered the best natural food for Eisenia, with the possible exception of rabbit manure (Gaddie & Douglas, 1975). The former, being more often available in large quantities, is the feed most often used.



Fig 3: Okara (waste from tofu production) used to feed worms on Scott Farm, OACC pilot (see Appendix C).

Table 2 summarizes the most important attributes of some of the more common foods that could be used in an on-farm vermicomposting or vermiculture operation. Please note that the provision of instructions for composting high-protein wastes (e.g., animal mortalities) is beyond

[5] The actual amount of food that can be consumed daily by Eisenia fetida varies with a number of factors, not the least of which is the state of decomposition of the food. Manures, which consist of partially decomposed organic material, can be consumed more rapidly than fresh food, and some studies have found that worms can exceed their own weight in daily consumption of manure.

the scope of this manual. For more information on this aspect of on-farm waste management, see *Resources* in Section 8. More detail on vermicomposting methods is provided in Section 3.

Table 2: Common Worm Feed Stocks

Food	Advantages	Disadvantages	Notes
Cattle manure	Good nutrition; natural food, therefore little adaptation req'd	Weed seeds make pre-composting necessary	All manures are partially decomposed and thus ready for consumption by worms
Poultry manure	High N content results in good nutrition and a high-value product	High protein levels can be dangerous to worms, so must be used in small quantities; major adaptation required for worms not used to this feedstock. May be pre-composted but not necessary if used cautiously (see Notes)	Some books (e.g., Gaddie & Douglas, 1975) suggest that poultry manure is not suitable for worms because it is so "hot"; however, research in Nova Scotia (GEORG, 2004) has shown that worms can adapt if initial proportion of PM to bedding is 10% by volume or less.
Sheep/Goat manure	Good nutrition	Require pre-composting (weed seeds); small particle size can lead to packing, necessitating extra bulking material	With right additives to increase C:N ratio, these manures are also good beddings
Hog manure	Good nutrition; produces excellent vermicompost	Usually in liquid form, therefore must be dewatered or used with large quantities of highly absorbent bedding	Scientists at Ohio State University found that vermicompost made with hog manure outperformed all other vermicomposts, as well as commercial fertilizer
Rabbit manure	N content second only to poultry manure, there-fore good nutrition; contains very good mix of vitamins & minerals; ideal earth-worm feed (Gaddie, 1975)	Must be leached prior to use because of high urine content; can overheat if quantities too large; availability usually not good	Many U.S. rabbit growers place earthworm beds under their rabbit hutches to catch the pellets as they drop through the wire mesh cage floors.
Fresh food scraps (e.g., peels, other food prep waste, leftovers, commercial food processing wastes)	Excellent nutrition, good moisture content, possibility of revenues from waste tipping fees	Extremely variable (depending on source); high N can result in overheating; meat & high-fat wastes can create anaerobic conditions and odours, attract pests, so should NOT be included without pre-composting (see below)	Some food wastes are much better than others: coffee grounds are excellent, as they are high in N, not greasy or smelly, and are attractive to worms; alternatively, root vegetables (e.g., potato culls) resist degradation and require a long time to be consumed.

Food	Advantages	Disadvantages	Notes
Pre-composted food wastes	Good nutrition; partial decomposition makes digestion by worms easier and faster; can include meat and other greasy wastes; less tendency to overheat.	Nutrition less than with fresh food wastes (Frederickson et al, 1997).	Vermicomposting can speed the curing process for conventional composting operations while increasing value of end product (GEORG, 2004; Frederickson, op. cit.)
Biosolids (human waste)	Excellent nutrition and excellent product; can be activated or non-activated sludge, septic sludge; possibility of waste management revenues	Heavy metal and/or chemical contam-ination (if from municipal sources); odour during application to beds (worms control fairly quickly); possibility of pathogen survival if process not complete	Vermitech Pty Ltd. in Australia has been very successful with this process, but they use automated systems; EPA-funded tests in Florida demonstrated that worms destroy human pathogens as well as does thermophillic composting (Eastman et al., 2000).
Seaweed	Good nutrition; results in excellent product, high in micronutrients and beneficial microbes	Salt must be rinsed off, as it is detrimental to worms; availability varies by region	Beef farmer in Antigonish, NS, producing certified organic vermicompost from cattle manure, bark, and seaweed[6]
Legume hays	Higher N content makes these good feed as well as reasonable bedding.	Moisture levels not as high as other feeds, requires more input and monitoring	Probably best to mix this feed with others, such as manures
Grains (e.g., feed mixtures for animals, such as chicken mash)	Excellent, balanced nutrition, easy to handle, no odour, can use organic grains for certified organic product	Higher value than most feeds, therefore expensive to use; low moisture content; some larger seeds hard to digest and slow to break down	Danger: Worms consume grains but cannot digest larger, tougher kernels; these are passed in castings and build up in bedding, resulting in sudden overheating (Gaddie, op cit)
Corrugated cardboard (including waxed)	Excellent nutrition (due to high-protein glue used to hold layers together); worms like this material; possible revenue source from WM fees	Must be shredded (waxed variety) and/or soaked (non-waxed) prior to feeding	Some worm growers claim that corrugated cardboard stimulates worm reproduction
Fish, poultry offal; blood wastes; animal mortalities	High N content provides good nutrition; opportunity to turn problematic wastes into high-quality product	MUST be pre-composted until past thermophillic stage	Composting of offal, blood wastes, etc. is difficult and produces strong odours. Should only be done with in-vessel systems; much bulking required.

[6] See www.atlanticcountrycomposting.com.

2.1.4 Moisture

The need for adequate moisture was discussed in relation to bedding in Section 2.1.2 above. The bedding used must be able to hold sufficient moisture if the worms are to have a livable environment. They breathe through their skins and moisture content in the bedding of less than 50% is dangerous. With the exception of extreme heat or cold, nothing will kill worms faster than a lack of adequate moisture.

The ideal moisture-content range for materials in conventional composting systems is 45-60% (Rink et al, 1992). In contrast, the ideal moisture-content range for vermicomposting or vermiculture processes is 70-90%. Within this broad range, researchers have found slightly different optimums: Dominguez and Edwards (1997) found the 80-90% range to be best, with 85% optimum, while Nova Scotia researchers found that 75-80% moisture contents produced the best growth and reproductive response (GEORG, 2004). Both of these studies found that average worm weight increased with moisture content (among other variables), which suggests that vermiculture operations designed to produce live poultry feed or bait worms (where individual worm size matters) might want to keep moisture contents above 80%, while vermicomposting operations could operate in the less mucky 70-80% range.

2.1.5 Aeration

Worms are oxygen breathers and cannot survive anaerobic conditions (defined as the absence of oxygen). When factors such as high levels of grease in the feedstock or excessive moisture combined with poor aeration conspire to cut off oxygen supplies, areas of the worm bed, or even the entire system, can become anaerobic. This will kill the worms very quickly. Not only are the worms deprived of oxygen, they are also killed by toxic substances (e.g., ammonia) created by different sets of microbes that bloom under these conditions. This is one of the main reasons for not including meat or other greasy wastes in worm feedstock unless they have been pre-composted to break down the oils and fats.

Although composting worms O_2 requirements are essential, however, they are also relatively modest. Worms survive harsh winters inside windrows where all surfaces are frozen: they live on the oxygen available in the water trapped inside the windrow. Worms in commercial vermicomposting units can operate quite well in their well insulated homes as long as there are small cracks or openings for ventilation somewhere in the system. Nevertheless, they operate best when ventilation is good and the material they are living in is relatively porous and well aerated. In fact, they help themselves in this area by aerating their bedding by their movement through it. This can be one of the major benefits of vermicomposting: the lack of a need to turn the material, since the worms do that work for you. The trick is to provide them with bedding that is not too densely packed to prevent this movement (see discussion of beddings in Section 2.1.2 above).

2.1.6 Temperature Control

Controlling temperature to within the worms' tolerance is vital to both vermicomposting and vermiculture processes. This does not mean, however, that heated buildings or cooling systems are required. Worms can be grown and materials can be

vermicomposted using low-tech systems, outdoors and year-round, in the more temperate regions of Canada[7]. Section 3 discusses the different vermicomposting and vermiculture systems in use world-wide and provides some basic information on how these systems address the problem of temperature control. The following points are general and are intended to provide background for the more system-specific information in Section 3.

- **Low temperatures.** Eisenia can survive in temperatures as low as 0°C, but they don't reproduce at single-digit temperatures and they don't consume as much food. It is generally considered necessary to keep the temperatures above 10°C (minimum) and preferably 15 °C for vermicomposting efficiency and above 15 °C (minimum) and preferably 20 °C for productive vermiculture operations.
- **Effects of freezing.** Eisenia can survive having their bodies partially encased in frozen bedding and will only die when they are no longer able to consume food[8]. Moreover, tests at the Nova Scotia Agricultural College (NSAC) have confirmed that their cocoons survive extended periods of deep freezing and remain viable (GEORG, 2004).
- **High temperatures.** Compost worms can survive temperatures in the mid-30s but prefer a range in the 20s (°C). Above 35°C will cause the worms to leave the area. If they cannot leave, they will quickly die. In general, warmer temperatures (above 20°C) stimulate reproduction.
- **Worms's response to temperature differentials**. Compost worms will redistribute themselves within piles, beds or windrows according to temperature gradients. In outdoor composting windrows in wintertime, where internal heat from decomposition is in contrast to frigid external temperatures, the worms will be found in a relatively narrow band at a depth where the temperature is close to optimum. They will also be found in much greater numbers on the south-facing side of windrows in the winter and on the opposite side in the summer.

2.2 Other Important Parameters

There are a number of other parameters of importance to vermicomposting and vermiculture:

pH. Worms can survive in a pH range of 5 to 9 (Edwards, 1998). Most experts feel that the worms prefer a pH of 7 or slightly higher. Nova Scotia researchers found that the range of 7.5 to 8.0 was optimum (GEORG, 2004). In general, the pH of worm beds tends to drop over time. If the food sources are alkaline, the effect is a moderating one, tending to neutral or slightly alkaline. If the food source or bedding is acidic (coffee grounds, peat moss) than the pH of the beds can drop well below 7. This can be a problem in terms of the development of pests such as mites. The pH can be adjusted

[7] It may also be possible to grow worms outdoors in Canada's far north (e.g., the Territories and northern regions of BC, the Prairies, Ontario, Quebec, Labrador), but OACC has no experience or knowledge in these areas.

[8] The author has found live worms almost completely encased in frozen bedding/castings mixtures, with only their heads free to move. Upon thawing, these worms have appeared perfectly healthy.

upwards by adding calcium carbonate. In the rare case where they need to be adjusted downwards, acidic bedding such as peat moss can be introduced into the mix.

Salt content. Worms are very sensitive to salts, preferring salt contents less than 0.5% (Gunadi et al., 2002). If saltwater seaweed is used as a feed (and worms do like all forms of seaweed), then it should be rinsed first to wash off the salt left on the surface. Similarly, many types of manure have high soluble salt contents (up to 8%). This is not usually a problem when the manure is used as a feed, because the material is usually applied on top, where the worms can avoid it until the salts are leached out over time by watering or precipitation. If manures are to be used as bedding, they can be leached first to reduce the salt content. This is done by simply running water through the material for a period of time (Gaddie, 1975). If the manures are pre-composted outdoors, salts will not be a problem.

Urine content. Gaddie and Douglas (1975) state: "If the manure is from animals raised or fed off in concrete lots, it will contain excessive urine because the urine cannot drain off into the ground. This manure should be leached before use to remove the urine. Excessive urine will build up dangerous gases in the bedding. The same fact is true of rabbit manure where the manure is dropped on concrete or in pans below the cages.".

Other toxic components. Different feeds can contain a wide variety of potentially toxic components. Some of the more notable are:

- *De-worming medicine* in manures, particularly horse manure. Most modern deworming medicines break down fairly quickly and are not a problem for worm growers. Nevertheless, if using manure from another farm than your own, it would be wise to consult your source with regard to the timing of de-worming activities, just to be sure. Application of fresh manure from recently de-wormed animals could prove costly.
- *Detergent cleansers, industrial chemicals, pesticides.* These can often be found in feeds such as sewage or septic sludge, paper-mill sludge, or some food processing wastes.
- *Tannins*. Some trees, such as cedar and fir, have high levels of these naturally occurring substances. They can harm worms and even drive them from the beds (Gaddie, op. cit.).

Gunadi et al. (2002) point out that pre-composting of wastes can reduce or even eliminate most of these threats. However, pre-composting also reduces the nutrient value of the feed, so this is a definite trade-off.

2.3 Calculating Rates of Reproduction

Epigeic worms such as E. fetida do reproduce very quickly, given good to ideal conditions. Compost worm populations can be expected to double every 60 to 90 days, but only if the following conditions are met:

- Adequate food (must be continuous supply of nutritious food, such as those listed in Table 2);
- Well aerated bedding with moisture content between 70 and 90%;
- Temperatures maintained between 15 and 30^{o}C;

- Initial stocking densities greater than 2.5 kg/m^2 (0.5 lb/ft^2) but not more than 5 kg/m^2 (1.0 lb/ft^2).

The issues of food, aeration, moisture and temperature are discussed in Section 2.1 above. The issue of initial stocking density, however, was not discussed previously and requires elaboration here. Stocking density refers to the initial weight of worm biomass per unit area of bedding. For instance, if you started with 5 kg of worms and put them in a bin with a surface area of 2 m^2, then your initial stocking density would be 2.5 kg/m^2. Starting with a population density less than this will delay the onset of rapid reproduction and, at very low densities, may even stop it completely. It seems that worms need a certain density in order to have a reasonable chance of running into each other and reproducing frequently. At lower densities, they just don't find each other as often as the typical worm grower would like.

On the other hand, densities higher than 5 kg/m^2 begin to slow the reproductive urge, as competition for food and space increase. While it is possible to get worm densities up to as much as 20 kg/m^2 or 4 lbs per square foot (Edwards, 1999), the most common densities for vermicomposting are between 5 and 10 kg/m^2 (1 to 2 lbs per ft^2). Worm growers tend to stock at 5 kg/m^2 (Bogdanov, 1996) and "split the beds" when the density has doubled, assuming that the optimum densities for reproduction have by that point been surpassed.

If the above guidelines are followed, a grower can expect a doubling in worm biomass about every 60 days. Theoretically, this means that an initial stock of 10 kg of worms can become 640 kg after one year and about 40 tonnes after two years. In practice, this is difficult to achieve, though not impossible. For instance, American Resource Recovery, a recycling firm in northern California, started with 50 pounds of earthworms. In four years, they had enough to cover over 70 acres of windrows, within which the worms convert huge quantities of sludge from a cardboard recycling plant into worm castings (VermiCo, 2004). On the other hand, OACC's three pilot projects accomplished in total only a 10-fold biomass increase over 12 months[9], when in theory the increase should have been by a factor of 64. The factors that kept this number lower than optimum included various problems with bedding, feed, moisture, and temperature control. These are documented in Appendices C and D.

The main barriers to achieving optimum rates of reproduction appear to be the following:

- ***Lack of knowledge and experience***. Growing worms is part science, part "green thumb". You need the knowledge (as in this Manual), but you also need to do it to learn how to do it well.
- ***Lack of dedicated resources***. Increasing worm populations requires paying attention to what is happening and responding accordingly. This takes time and effort. If the beds or windrows are neglected, the worms will likely survive, but the population will not increase at an optimum rate.

[9] It should be noted that in one of the trials (Scott farm) the worms were being harvested, so the rate of increase was lower than it would have been were this not the case. The other two farms averaged increases closer to a factor of 12 and were increasing the rate of increase towards the end of the trials.

- ***Lack of preparation for winter.*** Although harsh winter conditions are unlikely to completely destroy a worm population[10], they can (as in the OACC pilot project) reduce the rate of increase considerably. The various vermicomposting and vermiculture systems have different ways of dealing with this problem. These are addressed in Section 3.

2.4 Projecting Vermicompost Outputs

In the world of conventional composting, the rule-of-thumb is that one ton of inputs results in one cubic yard of compost, the weight of which varies with moisture content but is typically about ½ ton. In other words, 50% of the mass is lost, mostly as moisture and CO_2. Some N is lost as ammonia, but if the process is well managed the N loss is minimized (Rink et al, 1992). Of course, the final weight and volume of product varies with original feedstock, bulking agent used, etc., but the above rule-of-thumb is a handy way to quickly calculate output.

Vermicomposting is a bit more variable. This is because there is more variation in how the process is carried out. In composting, mixtures of high-N and high-C materials are made at the start and nothing is added to the mix thereafter. C:N ratios are calculated at the beginning and these fall as C is lost during the process in greater proportion than is N. In vermicomposting or vermiculture operations, the high-C materials are used as bedding, while the high-N materials are generally feed stocks. Although similar processes are taking place in the bed (including conventional composting due to the action of micro-organisms), some systems encourage the addition over the course of the process of greater amounts of N relative to C than would be the case with conventional composting. This is because the feeds are added to the surface of the pile or windrow incrementally, rather than mixed in at the beginning. Since some high-N materials (e.g., fresh food wastes) can be higher in initial water content than high-C bedding materials, weight losses during the vermicomposting process can be higher. In one flow-through system[11] for vermicomposting fresh food wastes tested in Nova Scotia, the total system output was about 10% of the inputs by weight. Another factor reducing final output quantities in vermicomposting is the amount of material converted into worm biomass. This material is largely lost to the final product because most of the worms are removed from the product prior to completion of the process. Alternatively, vermicomposting processes can also allow for higher amounts of overall C to be processed. For instance, shredded paper and cardboard can be converted into vermicompost with the addition of as little as 5% poultry manure, by volume (GEORG, 2004). The result of this process is a product weight closer to 50% of the initial input weight.

---

[10] The ability of worm populations to regenerate from cocoons after complete decimation of the stock through freezing has been documented in Nova Scotia. In one experiment conducted by Good Earth, 1-ft-high windrows of shredded cardboard and coffee grounds were established in late summer in an unheated building on an asphalt floor. The windrows froze completely through in the winter and no worms were found in early spring. Because the floor was paved, there was no way for the worms to escape into the earth. By July of the same year, the worm population was back to vermicomposting levels (at least 5 kg/m2) and the material was fully processed (GEORG, 2004).

[11] Flow-through systems allow food to be added to the surface indefinitely, while product is removed from below. See Section 3 for a detailed definition and decsription.

In general, outputs from vermicomposting processes can vary from about 10% to closer to 50% of the original weight of the inputs. This will vary with the nature of the inputs and the system used. The greater the proportion of high-C inputs to high-N inputs, the greater will be the weight of final output as a proportion of input weight.

If estimating the amount of output is important, it can be tested by running a bench or pilot-scale trial for several months.

2.5 Pests and Diseases

Compost worms are not subject to diseases caused by micro-organisms, but they are subject to predation by certain animals and insects (red mites are the worst) and to a disease known as "sour crop" caused by environmental conditions. The following is a brief overview of the most common pests and diseases likely to be experienced in Canada.

- ***Moles.*** Earthworms are moles' natural food, so if a mole gets access to your worm bed, you can lose a lot of worms very quickly (Gaddie, op. cit.). This is usually only a problem when using windrows or other open-air systems in fields. It can be prevented by putting some form of barrier, such as wire mesh, paving, or a good layer of clay, under the windrow.
- ***Birds.*** They are not usually a major problem, but if they discover your beds they will come around regularly and help themselves to some of your workforce. Putting a windrow cover of some type over the material will eliminate this problem. These covers are also useful for retaining moisture and preventing too much leaching during rainfall events. Old carpet can be used for this purpose and is very effective[12].
- ***Centipedes.*** These insects eat compost worms and their cocoons. Fortunately, they do not seem to multiply to a great extent within worm beds or windrows, so damage is usually light. If they do become a problem, one method suggested for reducing their numbers is to heavily wet (but not quite flood) the worm beds. The water forces centipedes and other insect pests (but not the worms) to the surface, where they can be destroyed by means of a hand-held propane torch or something similar (Gaddie, op. cit.; Sherman, 1997).
- ***Ants.*** These insects are more of a problem because they consume the feed meant for the worms (Myers, 1969). Ants are particularly attracted to sugar, so avoiding sweet feeds in the worm beds reduces this problem to a minor one. Keeping the bedding above pH 7 also helps (see mites and sour crop below).
- ***Mites.*** There are a number of different types of mites that appear in vermiculture and vermicomposting operations, but only one type is a serious problem: red mites. White and brown mites compete with worms for food and can thus have some economic impact, but red mites are parasitic on earthworms. They suck blood or body fluid from worms and they can also suck fluid from cocoons (Sherman, 1997). The best prevention for red mites is to

- [12] Make sure that the carpet does not have a non-breathable synthetic backing. Also, note that the carpet will eventually break down and be consumed by the worms. This process takes a long time, however, and is a better fate for old carpet than the landfill.

make sure that the pH stays at neutral or above. This can be done by keeping the moisture levels below 85% and through the addition of calcium carbonate, as required.

- ***Sour crop or protein poisoning.*** This "disease" is actually the result of too much protein in the bedding. This happens when the worms are overfed. Protein builds up in the bedding and produces acids and gases as it decays (Gaddie, op. cit.). According to Ruth Myers (1969): "when you see a worm with a swollen clitellum[13] or see one crawling aimlessly around on top of the bedding, you can just bet on sour crop and act accordingly, but fast". Her recommended solution is a "massive dose of one of the mycins, such as farmers give to chicken or cattle". Farmers wishing to avoid these or similar antibiotics should work to prevent sour crop by not overfeeding and by monitoring and adjusting pH on a regular basis. Keeping the pH at neutral or above will preclude the need for these measures.

[13] The clitellum is the noticeable band around earthworms bodies, closer to the head than the tail. These are used in the reproductive process.

3 An Overview of Vermicomposting Systems

3.1 Basic Types of Systems

There are three basic types of vermicomposting systems of interest to farmers: **windrows, beds or bins, and flow-through reactors**. Each type has a number of variants. Windrows and bins can be either batch or continuous-flow systems (see box), while all flow-through systems, as the name suggests, are of the continuous-flow variety.

Batch vs Continuous-Flow Systems

Batch systems are ones in which the bedding and food are mixed, the worms added, and nothing more is done (except by the worms!) until the process is complete. Continuous-flow systems are ones in which worms are placed in bedding, whereupon feed and new bedding are added incrementally on a regular basis.

3.2 Windrows

Windrow vermicomposting can be carried out in a number of different ways. The three most common are described here.

3.2.1 Static pile windrows (batch)

Static pile windrows are simply piles of mixed bedding and feed (or bedding with feed layered on top) that are inoculated with worms and allowed to stand until the processing is complete. These piles are usually elongated in a windrow style but can also be squares, rectangles, or any other shape that makes sense for the person building them. They should not exceed one meter in height (before settling). Care must be taken to provide a good environment for the worms, so the selection of bedding type and amount is important (see Section 2.1.2). In the OACC vermicomposting trials (see Appendix D), the original selection of aged dairy manure as bedding turned out to be a poor choice, and initial worm reproduction was quite slow. After the bedding was supplemented with large quantities of hay and silage, increasing the porosity of the windrows, worm reproduction took off.

In another example, the author was part of a Nova Scotia team of researchers that experimented with static windrows in 2003-4, using shredded municipally collected fibre (boxboard, cardboard, etc.) as bedding and cattle



Figure 4: Vermicomposting windrows of shredded cardboard and manure

and poultry manures as feedstock. The materials were mixed by turning with a tractor bucket, in ratios of 1:9 and 1:19 (poultry manure to shredded fibre) and 1:2 (cattle manure to shredded fibre). They were laid down in windrows that were initially one meter in height, three meters wide, and 50 meters long (see Figure 4). The windrows were inoculated by placing them directly on top of smaller windrows (30 cm high by 1 meter across) that were composed of worm-rich compost. The windrows were established in late August of 2003; they were not covered or protected from the cold. They sat on a clay base that provided no underground escape option for the worms.

By late autumn, the windrows had settled and been reduced in volume through the action of the worms and composting bacteria to about one half of their original height. Worm populations were increasing rapidly. Winter arrived in December and, by Nova Scotia standards, it was a very cold one, with temperatures staying well below zero and with little snow cover until mid-February, when a blizzard dropped about a meter of snow in 36 hours. Thawing occurred over March and early April.

Initial sampling (April 22, 2003) revealed that worm populations were down significantly, but that some adult worms and many cocoons had survived. By July, all the test windrows had large, active worm populations, but there were significant differences in performance between the different feed stocks (see Table 3). The best performance was obtained from the 1:9 mixture of cardboard to poultry manure. Worm biomass had increased by a factor of five and the material was almost completely composted (only the material exposed to the air on the surface was not processed). The material from this windrow was used for plant-growth trials at NSAC and performed very well (see Section 5, below).

Table 3: Results of Windrow Tests, Sackville, Nova Scotia (GEORG, 2004)

Test mixture	Increase in worm biomass at peak[1]	Amount of original material processed at peak biomass[2]
Cattle manure (33%)	1.65x	25-35%
Poultry manure (5%)	2.56x	40-50%
Poultry manure (10%)	5.0x	90-95%
Notes on data in table: 1 The "worm biomass at peak" data represents the estimated worm biomass at its highest point in the summer of 2004, prior to eventual decline due to decreasing availability of food.		
2 The "amount of original material processed at peak biomass" represents the estimated percentage of the material that was converted into vermicompost by the time the worm populations peaked (after 45-50 weeks). Note that the 10%-poultry-manure treatment was the only one that provided sufficient nutrition to allow worm populations to grow large enough to complete processing before worm biomass started to decrease. This does not mean that the other material was not eventually processed; worm biomass levels continued to decline but the material continued to be processed, albeit much more slowly.		

In summary, the tests showed that static vermicomposting windrows can work in a Canadian climate, but that the winter reduces efficiency, resulting in slower processing times than would be experienced indoors. Similar windrows could be established on farms, using horse manure, silage, and other high-carbon materials as bedding and

mixing them with a high-nitrogen feedstock such as poultry manure, seaweed, or partially pre-composted food wastes. Once established, the worm populations can be maintained by laying the following year's windrows each spring adjacent to the established ones and allowing the worms to migrate to the fresher material over the course of the summer. The older windrows can then be removed in the fall and the vermicompost utilized right away or stored for use the following spring.

The following points are important to keep in mind if establishing such a system on a farm.

1 ***Although the windrows do not need to be turned, they will need to be either watered or covered.*** The worms prefer that the moisture content be above 70% and will not thrive much below 60%. As an alternative to watering, moisture can be conserved by covering the windrows. Although it is preferable to use a material that breathes (old carpet or burlap works beautifully), a few holes in a plastic sheet will allow enough air in to keep the worms healthy. If the material is very wet (> 80%) when the windrows are established, a good cover will keep the moisture levels high enough to get the job done. If your area gets a fair bit of rain, a carpet covering will work best, as it allows some precipitation to come through into the material; if it does not, plastic may be better, as it will retain the original moisture for a longer period of time. Both will prevent large-scale leaching of the nutrients into the ground beneath.

2 ***Areas with extremely cold winters, such as the Prairies, should try this on a small scale initially***. The results obtained in Nova Scotia should hold for the other Atlantic Provinces and the southern parts of Ontario, Quebec, and BC. Whether the worms in windrows such as those described above can withstand an Alberta winter and come back in the spring remains to be seen. These areas can certainly use some of the other methods (see below), but should try this approach out on an inexpensive scale first. It is also possible to protect the windrows to some extent by adding layers of straw or other insulating material. Of course, this is more work, but in combination with a high-nitrogen feedstock it can work quite well in even very cold winters[14].



Fig 5: Small to medium-scale harvesters such as this one can be used to harvest hundreds of pounds of worms per day.

3 **Don't be afraid to load up on the nitrogen.** As long as the worms have an area into which they can retreat (e.g., a base of maybe 20 cm of bedding only, no feed), you can add fairly high quantities of nitrogen-rich feed in the

[14] One farmer in Nova Scotia covers his windrows with a foot or so of straw followed by sheets of black plastic with holes punched in it to allow some airflow. This has worked very well for him: he has not lost any processing time and his worm populations have always increased considerably over the winters.

overall mix. This is especially true if you set up the windrows in the fall. The high-nitrogen material will create thermophillic conditions that will help to keep the worms warm over the winter. In fact, some worm growers in northern climes set up their windrows in fall with a core of high-nitrogen "fuel" to keep the temperatures above freezing all winter. The worms will move into the nitrogen-rich areas as the temperatures gradually decline. Having sufficient nitrogen in the mix is necessary to ensure that the worms will have sufficient nutrition to get the job done.

4 **Harvesting.** One of the major advantages that conventional composting has over vermicomposting is that in the former there is no need to separate the workers from the product. The aerobic bacteria that do most of the work in a composting windrow can be safely ignored when it comes time to spread the finished product on a field or screen it and put it in a bag. Not so with worms: they take too long to reproduce (compared to bacteria) and thus are much too expensive to abandon with each load of product. In batch systems such as windrows, it is necessary to either run the product through a worm harvester (see Figure 5), or set up the next batch of windrows in such a way that the worms can leave of their own accord (see description on the previous page). Neither system is perfect and worms are always lost; however, if done properly, either system will leave enough worms to keep the system working and probably also enough to gradually expand it over time to accommodate larger volumes of materials.

3.2.2 Top-fed windrows (continuous flow)

Top-fed windrows are similar to the windrows described above, except that they are not mixed and placed as a batch, but are set up as a continuous-flow operation. This means that the bedding is placed first, then inoculated with worms, and then covered repeatedly with thin (less than 10 cm) layers of food. The worms tend to consume the food at the food/bedding interface, then drop their castings near the bottom of the windrow. A layered windrow is created over time, with the finished product on the bottom, partially consumed bedding in the middle, and the fresher food on top. Layers of new bedding should be added periodically to replace the bedding material gradually consumed by the worms.

The major disadvantages to this system are related to the winter conditions experienced in Canada. Unlike the batch windrows described above, these windrows require continuous feeding and are difficult if not impossible to operate in the winter. In addition, if windrow covers are used, they must be removed and replaced every time the worms are fed, creating extra work for the operator. The advantages of top-feeding have mainly to do with the greater control the operator has over the worms' environment: since the food is added on a regular basis, the operator can easily assess conditions at the same time and modify such things as feeding rate, pH, moisture content, etc., as required. This tends to result in a higher-efficiency system with greater worm production and reproduction.

Harvesting is usually accomplished by removing the top 10-20 cm first, usually with a front-end loader or tractor outfitted with a bucket (Bogdanov, 1996). This material will contain most of the worms and it can be used to seed the next windrow. The remaining material will be mostly vermicompost, with some unprocessed bedding. This can be used as is or screened, with unfinished material put back into the process. This is essentially the system used by North America's largest vermicomposting facility, a 77-acre operation run by American Resource Recovery in northern California that processes 300 tons of paper wastes per day (VermiCo, 2004).

A Canadian farm wishing to use this system to process manure or other on-farm waste could consider operating the windows as top-feeding, continuous-flow systems during the summer months, then covering them with up to half a meter of straw or other insulating material in late fall and leaving them for the winter. In spring the insulating cover could be removed and a layer of fresh food placed on top. This will draw the worms to the surface, where they can be scooped off and used to seed the new season's windrows. The material that remains should be well processed and ready to apply to the fields.

3.2.3 Wedges (continuous flow)

The vermicomposting wedge is an interesting variation on the top-fed windrow. An initial stock of worms in bedding is placed inside a corral-type structure (3-sided)[15] of no more than three feet or one meter in height. The sides of the corral can be concrete, wood, or even bales of hay or straw. Fresh material is added on a regular feeding schedule through the open side, usually by bucket loader. The worms follow the fresh food over time, leaving the processed material behind. When the material has reached the open end of the corral, the finished material is harvested by removing the back of the corral and scooping the material out with a loader. A 4th side is then put in place and the direction is reversed.

Using this system, the worms do not need to be separated from the vermicompost and the process can be continued indefinitely. During the coldest months, a layer of insulating hay or straw can be placed over the active part of the wedges. The corrals can be any width at all, the only constraint being access to the interior of the piles for monitoring and corrective actions, such as adjustment of moisture content or pH level. A corral width of about 6 feet, with space between adequate for foot travel, would be ideal. The ideal length will depend on the material being processed, the size of the worm population, and other factors affecting processing times.

The sides of the corrals can be made of any material at all, although insulating value is a consideration. Hay or straw bales will gradually break down over time and be consumed by the worms; as a bale loses its structural integrity, however, it can be added to the contents of the wedge and replaced with a fresh one.

---

[15] The wedge need not have sides at all, in which case it is simply a windrow system where the operator adds feed to one horizontal face, as applied to the top. However, enclosing the sides of the wedge provides a number of benefits, including winter insulation and retention of moisture, so the wedge is discussed here as a 3-sided enclosure or corral.

Operating the wedge system over the winter is challenging, though not impossible. The regular addition of fresh manure to the operating face can create enough heat to produce a “temperate zone” behind the face within which the worms will continue to thrive and reproduce. Another option would be to load up the face with fresh manure in late autumn, cover all of material with a thick layer of straw, and uncover and begin operations again in the spring. The latter was the approach used in the OACC trials; it worked very well (see Appendix D).

3.3 Beds or Bins

3.3.1 Top-fed beds (continuous flow)

A top-fed bed works like a top-fed windrow. The main difference is that the bed, unlike a windrow, is contained within four walls and (usually) a floor, and is protected to some degree from the elements, often within an unheated building such as a barn. The beds can be built with insulated sides, or bales of straw can be used to insulate them in the winter. If the bins are fairly large, they are sheltered from the wind and precipitation, and the feedstock is reasonably high in nitrogen, the only insulation required may be an insulating “pillow” or layer on top. These can be as simple as bags or bales of straw.

The beds built on the Scott farm (see Figure 6) have walls of mortared cinder block. They are on a concrete floor inside the chicken coop, which is the lowest level of an old barn. The area receives some heat from a greenhouse attached to the building, but winter temperatures are consistently well below freezing. The bins are covered in the winter with insulating pillows made by stuffing bats of pink fibreglass insulation inside plastic bags. During the first winter of operation, the top insulation was not added until well into the winter, when it appeared possible that the tops of the bins might freeze over. After the insulation was put on top, the bins came through a very cold winter quite well, with only a slight drop-off in efficiency. The reader should note that these beds were designed for vermiculture, rather than vermicomposting. The goal was to raise worms as feed for organic chickens (see Appendix C).



Fig 6: Cinder-block worm beds on Scott farm

Harvesting vermicompost can be most easily accomplished by taking advantage of horizontal migration. The beds on the Scott farm were built end-to-end, with metal screen separating the different beds. To harvest, the operator simply stops feeding one of the beds for several weeks, allowing the worms time to finish that material and then migrate to the other beds in search of fresh feed. The “cured” bed is then emptied and refilled with bedding, after which feeding is resumed. This is repeated on a regular rotating basis. If the beds are large enough, they can be emptied with a tractor instead of by hand.

Worm beds such as the ones described above are similar to the typical beds used by worm growers in the southern United States. These beds have the advantage of being

more contained than windrows, and thus more controllable in terms of environmental conditions. The main disadvantage to this system is the extra cost of building and maintaining the beds, as well as the cost of shelter (e.g., barn floor space). In the US, where there is a big market for Eisenia as bait worms[16], the cost is easier to justify. In Canada, the economics will depend to a large degree on the purpose of the activity: vermiculture for the production of high-protein organic chicken feed, for instance, may justify this type of system.

3.3.2 Stacked bins (batch or continuous flow)

One of the major disadvantages of the bed or bin system is the amount of surface area required. While this is also true of the windrow and wedge systems, they are outdoors, where space is not as expensive as it is under cover. Growing worms indoors or even within an unheated shelter is an expensive proposition if nothing is done to address this issue.

Stacked bins address the issue of space by adding the vertical dimension to vermicomposting. The bins must be small enough to be lifted, either by hand or with a forklift, when they are full of wet material. They can be fed continuously, but this involves handling them on a regular basis (Beetz, 1999). The more economical route to take is to use a batch process, where the material is pre-mixed and placed in the bin, worms are added, and the bin is stacked for a pre-determined length of time and then emptied. This method is used by a number of professional vermicompost producers in North America.

In an experiment carried out by the author in Nova Scotia in 2003-04 (GEORG, 2004), cattle manure was mixed in a 1:2 ratio by volume with shredded cardboard, placed in stacked bins that were 1.2 m (4 ft) square and either 30 cm (12 in.) or 45 cm (18 in.) in depth (see Figure 7). Each bin was inoculated with 2.27 kg (5 lbs) of worms. The bins were stacked in an unheated building in December and harvested in June, approximately 6 months later. The bins were constructed of 5/8" particle-board and were stacked together within an 8' by 8' framework of 4' by 8' sheets of particle board covered with rigid foam insulation rated at R2. The top was covered by one thickness of standard pink fibreglass insulation covered on both sides by sheet plastic. The material did not freeze over the winter, as the decomposing manure brought temperatures within the bins into the 30 to



Fig. 7: The framework for the stacked bins

[16] Eisenia fetida is a small worm and is not generally considered a good bait worm in Canada, where it has to compete with the Canadian night crawler. The latter is a much larger anecic worm (see p. 1) harvested in huge numbers by worm pickers on golf courses in central Canada. In the southern U.S., where heat-averse night crawlers have to be imported and kept cool until used, raising their price considerably, the bait market has been very well exploited by compost-worm growers, who have developed formulae for "fattening" the worms for bait purposes.

40°C range for the first month or so[17] and then kept them well above freezing for the balance of the winter.

All of the material was completely processed after six months and the worm populations had increased by a factor of 3. Some of the bins had contained aged manure (at least one year), while the others had fresh manure (two weeks). The bins with the fresh manure experienced a 4-fold increase in worm-biomass increase (a doubling period of 3 months), while the aged manure doubled its worm biomass. The vermicompost in all bins was mature and rich. It was tested in plant-growth trials with excellent results (see Section 5).

The main disadvantage of the stacked-bin system is the initial cost of set-up. It requires an unheated shelter, bins, a way to mix the bedding and feed, and equipment to stack the bins, such as a forklift. On a smaller scale, of course, this could all be done by hand. Another disadvantage arises when it comes time to harvest. As with the batch windrow systems, the worms are mixed in with the product and need to be separated. That requires either a harvester (see Figure 5) or another step in the process, where the material is piled so that the worms can migrate into new material (see Section 4).

3.4 Flow-Through Reactors

The flow-through concept was developed by Dr. Clive Edwards and colleagues in England in the 1980s. It has since been adopted and modified by several companies, including Oregon Soil Corporation of Portland, Oregon, and the Pacific Garden Company, based in Washington and Pennsylvania. The latter company was started in the last few years by Dr. Scott Subler, a former colleague of Clive Edwards at Ohio State University. A variation of this system is also used by Vermitech, an Australian company that has built three biosolids processing facilities in that country over the past five years (Fox, 2002). The system operates as follows. The worms live in a raised box, usually rectangular and not more than three meters in width. Material is added to the top, and product is removed through a grid at the bottom, usually by means of a hydraulically driven breaker bar. The term “flow-through” refers to the fact that the worms are never disturbed in their beds – the material goes in the top, flows through the reactor (and the worms’ guts), and comes out the bottom (E. fetida tends to eat at the surface and drop castings near the bottom of the bedding). The method for pushing the materials out the bottom is usually a set of hydraulically powered “breaker bars” that move along the bottom grate, loosening the material so that it falls through. Clive Edwards has stated that a “properly managed” flow-through unit of approximately 1000 ft^2 surface area can process 2 to 3 tonnes per day of organic waste (Bogdanov, 1999).

Commercial versions of this system are available, two of the most notable being the Worm Wigwam (http://www.wormwigwam.com) and the Vermi Organic Digester (http://www.vermitechsystems.com). They do tend to be expensive, however, and a farmer familiar with basic welding could easily construct one (although the hydraulic breaker system would need to be purchased, unless it could be adapted from existing

[17] The 40°C temperatures were at the centre of each bin. Because of the cold air outside, there were always areas of cooler temperatures available near the edges of the bins. This allowed the worms to retreat from the excessively high temperatures that occurred over the first few weeks. If this process were to be carried out in summer, the C:N ratio might have to be higher to avoid cooking the worms.

farm equipment). The reader should note that although the basic concept is in the public domain and not patentable, the companies mentioned above may hold patents (or have them pending) on specific improvements to the system. This should be checked by anyone planning to build their own unit.

There seems to be little doubt expressed in the literature that the flow-through units are the most efficient vermicomposting systems available. They probably represent the future of commercial vermicomposting. The author has had direct experience with one of these units and can attest to their high potential, when managed properly. However, the interested reader should probably start with one of the simpler, less expensive systems before graduating to a flow-through digester. Vermicomposting is basically a type of farming, rather than an industrial process. It therefore makes sense to master the basics and to assess the opportunities (see Section 6.2) before making a significant investment is such specialized equipment.

4 On-Farm Vermiculture

4.1 Vermiculture Systems

Vermiculture focuses on the production of worms, rather than vermicompost. As mentioned earlier, growing worms efficiently requires a somewhat different set of conditions than vermicomposting. The most basic differences are as follows:

- **Population density.** Worm growers usually keep their beds at a density between 5 and 10 kg/m^2 (1 to 2 lbs/ft^2). This ensures a high reproductive rate. Efficient vermicomposting operations would start at 10 kg/m2 and try for even higher densities (although windrows and other low-tech systems will have those high densities only in certain areas, where environmental conditions are closest to optimum, well-managed flow-through systems would operate at these levels or higher throughout the bed).
- **Type of system.** Vermiculture operators usually select systems that give them greater control over the environmental conditions. This means beds or stacked bins as opposed to windrows or wedges. The flow-through reactor could be used for vermiculture, but is generally used for vermicomposting because of its high capital cost and its efficiency in producing vermicompost. Worms can be harvested sustainably from a flow-through system, but doing so will decrease the vermicomposting efficiency.
- **Harvesting methods.** Vermiculture systems require special techniques for harvesting worms, since the systems usually favoured by vermicomposting operators (e.g., vertical and horizontal migration into new bedding) only separate the worms from the finished material. These methods are discussed in Section 4.2 below.

4.2 Methods of Harvesting Worms

4.2.1 General

Worm harvesting is usually carried out in order to sell the worms (see Section 6.2.2), rather than to start new worm beds. Expanding the operation (new beds) can be accomplished by splitting the beds, that is, removing a portion of the bed to start a new one and replacing the material with new bedding and feed. When worms are sold, however, they are usually separated, weighed, and then transported in a relatively sterile medium, such as peat moss. To accomplish this, the worms must first be separated from the bedding and vermicompost. There are three basic categories of methods used by growers to harvest worms: manual, migration, and mechanical (Bogdanov, 1996). Each of these is described in more detail in the sections that follow.

4.2.2 Manual Methods

Manual methods are the ones used by hobbyists and smaller-scale growers, particularly those who sell worms to the home-vermicomposting or bait market. In essence, manual harvesting involves hand-sorting, or picking the worms directly from the compost by hand. This process can be facilitated by taking advantage of the fact that worms avoid light. If material containing worms is dumped in a pile on a flat surface with a light

above, the worms will quickly dive below the surface. The harvester can then remove a layer of compost, stopping when worms become visible again. This process is repeated several times until there is nothing left on the table except a huddled mass of worms under a thin covering of compost. These worms can then be quickly scooped into a container, weighed, and prepared for delivery.

There are several minor variations and/or enhancements on this method, such as using a container instead of a flat surface, or making several piles at once, so that the person harvesting can move from one to another, returning to the first one in time to remove the next layer of compost. They are all labour-intensive, however, and only make sense if the operation is small and the value of the worms is high (see Section 6.2.2 for a discussion of worm prices and markets).

4.2.3 Self-Harvesting (Migration) Methods

These methods, like some of the methods used in vermicomposting, are based on the worms' tendency to migrate to new regions, either to find new food or to avoid undesirable conditions, such as dryness or light. Unlike the manual methods described above, however, they often make use of simple mechanisms, such as screens or onion bags.

The screen method is very common and easy to use. A box is constructed with a screen bottom. The mesh is usually ¼", although 1/8" can be used as well (Bogdanov, 1996). There are two different approaches. The downward-migration system is similar to the manual system, in that the worms are forced downward by strong light. The difference with the screen system is that the worms go down through the screen into a prepared, pre-weighed container of moist peat moss. Once the worms have all gone through, the compost in the box is removed and a new batch of worm-rich compost is put in. The process is repeated until the box with the peat moss has reached the desired weight. Like the manual method, this system can be set up in a number of locations at once, so that the worm harvester can move from one box to the next, with no time wasted waiting for the worms to migrate.

The upward-migration system is similar, except that the box with the mesh bottom is placed directly on the worm bed. It has been filled with a few centimeters of damp peat moss and then sprinkled with a food attractive to worms, such as chicken mash, coffee grounds, or fresh cattle manure. The box is removed and weighed after visual inspection indicates that sufficient worms have moved up into the material. This system is used extensively in Cuba, with the difference that large onion bags are used instead of boxes (Cracas, 2000). The advantage of this system is that the worm beds are not disturbed. The main disadvantage is that the harvested worms are in material that contains a fair amount of unprocessed food, making the material messier and opening up the possibility of heating inside the package if the worms are shipped. The latter problem can be avoided by removing any obvious food and allowing a bit of time for the worms to consume what is left before packaging.

4.2.4 Mechanical Methods

Mechanical harvesters are the quickest and easiest method for separating worms from vermicompost. The following description is from Bogdanov (1996):

> *"...the mechanical harvester...is a trommel device, a rotating cylinder about 8-10 feet in length and 2-3 feet in diameter. The cylinder walls are composed of screen material of different mesh sizes. The cylinder is rotated by a small electric motor mounted on one end of the cylinder. The trommel is set at an angle; at the upper end of the rotating trommel worms and their bedding 9including castings) are added. As the cylinder rotates, the castings fall through the screen. The worms 'ride' the entire distance of the trommel and pass through the lower end into a wheelbarrow."*

A picture of one of these harvesters is presented in Figure 5 in Section 3.2.1. Harvesters are available in the U.S., with prices ranging from about $US1,500 to US$3,500, plus shipping. They are almost essential for anyone selling worms in large quantities, but are not necessarily useful for vermicomposting operations[18]. Farmers wishing to make use of the vermicompost and/or worms on their own land probably do not need a harvester either.

4.3 Use of Worms Directly in Agriculture

The use of compost worms directly in agriculture is so new that there is little written about it in the literature. The following are some of the possibilities that have been noted:

- **Seeding mulch with compost worms.** This has been done in orchards in both California and Australia. Rows of carbon-rich organic materials are placed under the canopies of the fruit trees and seeded with worms. Various feed stocks, such as pre-composted manures, legumes, and fruit-processing wastes are periodically added to the mulch, then covered with more mulch. The worms live in the mulch, consume the feed, and drop their castings near or in the soil. Rain carries the nutrients and beneficial microbes down into the root zone.
- **Wintering worms in raised beds.** The author has had very good success with this method. A trough is dug in the centre of raised vegetable beds in the autumn, then filled with a bedding/feed mixture and inoculated with worms. The bed is then covered with straw or leaves to the depth of half a meter or more. In the spring, the covering is removed and the garden planted. The result is a deep vein of rich vermicompost running through the centre of each bed. These worms then move into whatever is used to mulch the garden (they will live under plastic as well) and provide fertilization services all season.
- **Seeding pasture with cocoons.** Compost worms cannot live indefinitely in soil[19], as they are not burrowing worms and need a loose, porous, fairly moist

---

[18] Vermicompost should be dried and screened if it is going to be sold, but the mechanical harvesters are too small to screen large amounts of material. Therefore, larger vermicomposting operations usually have the much larger trommels used by conventional composters, topsoil makers, etc.

[19] One writer on the internet claims that compost worms can survive in soil. He states that the initial population dies out quickly, but not before reproducing, and that the next generation of worms remain

environment. Cocoons, however, are extremely durable. When vermicompost rich in worm cocoons is spread on pasture, the cocoons will remain viable for long periods, waiting for an animal to drop its manure in that spot. The cocoons will then hatch and the manure will be turned into vermicompost on the spot. The worms will then die, but not before leaving cocoons to take advantage of the next opportunity. Therefore, spreading vermicompost on pasture lands increases the capacity of that ecosystem to quickly process droppings into high quality fertilizer.

---

extremely tiny through their entire lives. They continue to reproduce and go through their entire life cycle at this tiny size, he claims, and can grow to full size in two weeks when put in the right environment. To the author's knowledge, this claim has not been scientifically investigated or documented. However, it would explain the uncanny ability that compost worms have to infiltrate piles of organic materials quickly and in huge numbers in areas where there have been worms living for some time in the past. To investigate further, visit the following website: http://www.jetcompost.com/burrow/index.html.

5 The Value of Vermicompost

5.1 Results from the Literature

Vermicompost, like conventional compost, provides many benefits to agricultural soil, including increased ability to retain moisture, better nutrient-holding capacity, better soil structure, and higher levels of microbial activity. A search of the literature, however, indicates that vermicompost may be superior to conventional aerobic compost in a number of areas. These include the following.

- **Level of plant-available nutrients**. Atiyeh et al. (2000) found that compost was higher in ammonium, while vermicompost tended to be higher in nitrates, which is the more plant-available form of nitrogen. Similarly, work at NSAC by Hammermeister et al. (2004) indicated that "Vermicomposted manure has higher N availability than conventionally composted manure on a weight basis". The latter study also showed that the supply rate of several nutrients, including P, K, S and Mg, were increased by vermicomposting as compared with conventional composting. These results are typical of what other researchers have found (e.g., Short et al., 1999; Saradha, 1997, Sudha and Kapoor, 2000). It appears that the process of vermicomposting tends to result in higher levels of plant-availability of most nutrients than does the conventional composting process.

- **Level of beneficial microorganisms.** The literature has less information on this subject than on nutrient availability, yet it is widely believed that vermicompost greatly exceeds conventional compost with respect to levels of beneficial microbial activity. Much of the work on this subject has been done at Ohio State University, led by Dr. Clive Edwards (Subler et al., 1998). In an interview (Edwards, 1999), he stated that vermicompost may be as much as 1000 times as microbially active as conventional compost, although that figure is not always achieved. Moreover, he went on to say that "...these are microbes which are much better at transforming nutrients into forms readily taken up by plants than you find in compost – because we're talking about thermophillic microbes in compost – so that the microbial spectrum is quite different and also much more beneficial in a vermicompost. I mean, I will stick by what I have said a number of times that a vermicompost is much, much preferable to a compost if you're going in for a plant-growth medium."

- **Ability to stimulate plant growth.** This is the area in which the most interesting and exciting results have been obtained. Many researchers have found that vermicompost stimulates further plant growth even when the plants are already receiving optimal nutrition (see Figure 8). Atiyeh at al (2002) conducted an extensive review of the literature with regard to this phenomenon. The authors stated that: "These investigations have demonstrated consistently that vermicomposted organic wastes have beneficial effects on plant growth independent of nutritional transformations and availability. Whether they are used as soil additives or as components of horticultural soil less media,

vermicomposts have consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity much more than would be possible from the mere conversion of mineral nutrients into more plant-available forms." Moreover, the authors go on to state a finding that others have also reported (e.g., Arancon, 2004), that maximum benefit from vermicompost is obtained when it constitutes between 10 and 40% of the growing medium. It appears that levels of vermicompost higher than 40% do not increase benefit and may even result in decreased growth or yield.



Fig 8: All of these tomato plants received an optimal nutrient supply, but the ones on the right were grown in a mixture that included vermicompost (VC), while those on the left were grown in the same material, minus the VC. The VC plants were bigger and healthier and the yield was substantially higher. University of Campeche, Mexico.

Atiyeh et al further speculate that the growth responses observed may be due to hormone-like activity associated with the high levels of humic acids and humates in vermicomposts: ""...there seems a strong possibility that ...plant-growth regulators which are relatively transient may become adsorbed on to humates and act in conjunction with them to influence plant growth". This important concept, that vermicompost includes plant-growth regulators which increase growth and yield, has been cited and is being further investigated by several researchers (Canellas et al, 2002).

- **Ability to suppress disease.** There has been considerable anecdotal evidence in recent years regarding the ability of vermicompost to protect plants against various diseases. The theory behind this claim is that the high levels of beneficial microorganisms in vermicompost protect plants by out-competing pathogens for available resources (starving them, so to speak), while also blocking their access to plant roots by occupying all the available sites. This analysis is based on the concept of the "soil foodweb", a soil-ecology-based approach pioneered by Dr. Elaine Ingham of Corvallis, Oregon (see her website at http://www.soilfoodweb.com for more details). Work on this attribute of vermicompost is still in its infancy, but research by both Dr. Ingham's labs and the Ohio State Soil Ecology Laboratory are very promising. With regard to the latter institution, Edwards and Arancon (2004) report that "...we have researched the effects of relatively small applications of commercially-produced vermicomposts, on attacks by Pythium on cucumbers, Rhizoctonia on radishes in the greenhouse, and by Verticillium on strawberries and Phomopsis and Sphaerotheca fulginae on grapes in the field. In all of these experiments, the vermicompost applications suppressed the incidence of the disease significantly." The authors go on to say that the pathogen suppression disappeared when the vermicompost was sterilized, indicating that the mechanism involved was microbial antagonism. Arancon (2004) indicates that OSU's Soil Ecology

Laboratory will be conducting significant research in this area over the next few years.

- **Ability to repel pests.** Work in this area is very new and results to date have been inconsistent. Nevertheless, there seems to be strong evidence that worm castings sometimes repel hard-bodied pests (Biocycle, 2001; Arancon, 2004; Edwards and Arancon, 2004). Why this repellency works sometimes and not others remains to be determined. One theory is put forward by George Hahn, a vermicompost producer in California, who claims that his product repels many different insect pests. He feels that this is due to the production by the worms of the enzyme chitinase, which breaks down the chitin in the insects' exoskeleton. Independent testing of his product has, however, produced inconsistent results (Wren, 2001). Arancon (2004) believes that the potential exists, but that the factors are complicated and are a function of the entire soil foodweb, rather than one particular substance such as chitinase. In recent research, Edwards and Arancon (2004) report statistically significant decreases in arthropod (aphid, mealy bug, spider mite) populations, and subsequent reductions in plant damage, in tomato, pepper, and cabbage trials with 20% and 40% vermicompost additions to Metro Mix 360 (the control). They also found statistically significant suppression of plant-parasitic nematodes in field trials with peppers, tomatoes, strawberries, and grapes. Much more research is required, however, before vermicompost can be considered as an alternative to pesticides or alternative, non-toxic methods of pest control.

5.2 OACC Trials

5.2.1 Introduction

As part of the vermicomposting and vermiculture research sponsored by EcoAction, OACC conducted two sets of trials comparing vermicompost to compost. Both materials were produced using the same inputs – cattle manure, with straw used as bedding for the vermicomposting and bulking in the composting process. The products were dried, screened, and applied in various treatments. In general, the results were similar to those reported in the literature, although there were a couple of inconsistencies. The results are summarized below.

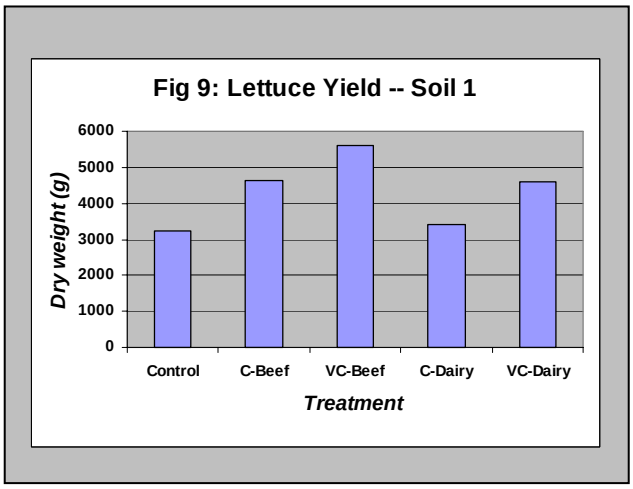
5.2.2 Indoor Trials

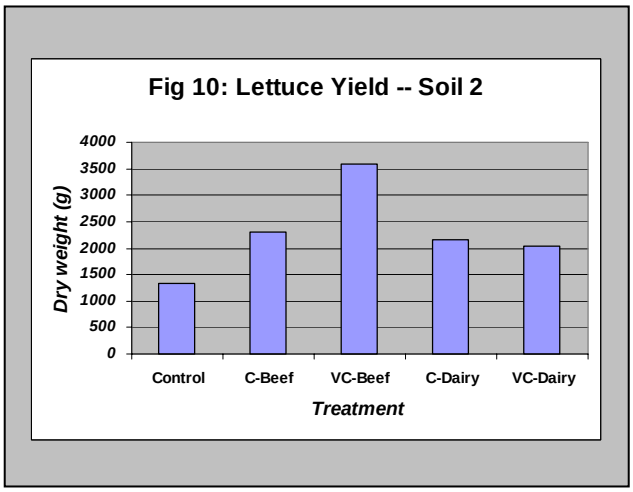
The indoor trials consisted of lettuce grown in pots in a grow-room, arranged in a randomized block design with 4 replicate blocks. Two types of manure, one dairy and one beef, were used. In addition, two types of soil were used, one of medium fertility (soil 1) and the other of low fertility (soil 2), resulting in four different treatments for each material (soil 1, beef; soil 2, beef; soil 1, dairy; soil 2, dairy). The results of the lettuce trials are summarized as follows (Hammermeister et al., 2004):

- Lettuce yields of vermicompost compared to compost were significantly higher for 3 of the 4 treatments (see Figures 9 and 10), with no significant difference in the fourth treatment (dairy manure, low-fertility soil).
- The percentage increases in yield for the vermicompost treatments over the compost treatments were:

- for the medium-fertility soil –
  - 20.8% (VC Beef);
  - 35.6% (VC Dairy)
- For the low-fertility soil –
  - 56.0 % (VC Beef)
  - The compost yield for Dairy exceeded the VC yield by 6.6%

- The vermicompost supplied more nitrogen, phosphorous, potassium, sulphur and magnesium than the compost.
- The PRS™ supply rates[20] of $H_2PO_4^-$-P, K^+, SO_4^--S and Mg^{2+} were all increased by vermicomposting as compared with regular composting, indicating higher plant availability of these nutrients.
- The beef manure significantly outperformed the dairy manure in all treatments.

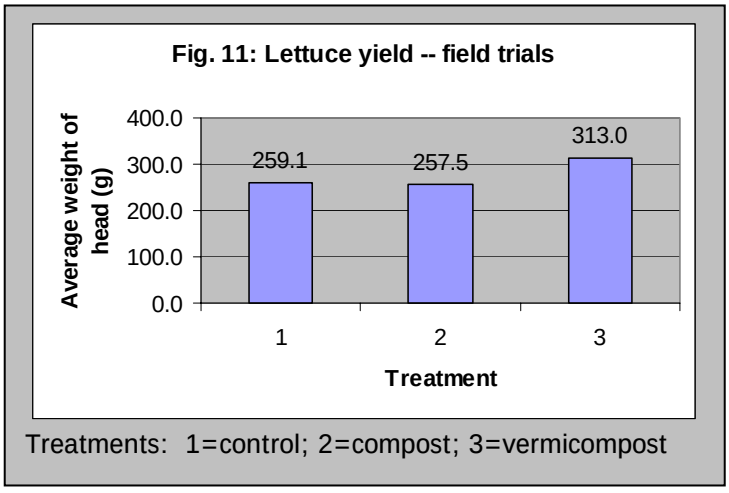




The above study included a number of other treatments that were not reported here. A paper fully describing the study and its results was submitted to **Bioresource Technology** (see Appendix A, References) in December, 2004.

5.2.3 Field Trials

Two field trials were carried out in the summer of 2004. Both used three treatments (control, compost, vermicompost) with four replicates in a randomized block design. The first trial was conducted on the Mentink farm (see Appendix D) and used barley as the test plant. The second was conducted on the Scott farm (see Appendix C) and used lettuce as the test plant. The same compost and vermicompost were used in both trials; it was made from dairy manure generated on the Mentink farm (the same dairy manure used in the



[20] Nutrient availability was measured by means of Plant Root Simulator (PRS) probes (Western Ag Innovations, Saskatoon, SK, Canada).

indoor trials described in 5.2.2). Both trials used plots with dimensions of 1 x 1.4 meter. Ten kg dry weight of amendment was added per treated plot just prior to planting, then raked into the soil. No other amendments were added.

The results of the two trials were quite different. The average wet-weight yield in the barley trial did not vary significantly between the control, compost and vermicompost-amended plots. The lettuce, on the other hand, showed a significant growth increase in the vermicompost plots (see Figure 11), also based on wet-weight measurements. The compost and control were not significantly different, but the vermicompost yield was 20% greater than the others. This difference was found to be significant at a 99.5% confidence level.

The outdoor lettuce trials were consistent with the indoor trials, suggesting that vermicompost can provide significant yield increases compared to conventional compost made from the same input materials. It is not known why the barley did not respond in the same way, but there are several possible reasons, including the fact that the soil in the barley trials had higher initial nutrient levels than did the soil in the lettuce trials. It could also be the case that the nutrients, moisture-holding capacity, and/or microorganisms provided by this particular type of vermicompost are better suited for fast-growing crops such as lettuce. Finally, the timing of the barley trial did not allow the project team to take it to the end, so that the barley could be threshed and final yield assessed; the figures used were for fresh weight of immature plants.

5.3 Summary: The Value of Vermicompost

In Argentina, farmers who use vermicompost consider it to be seven times richer than compost, so that only one seventh of the quantity is required (Pajon, no date). Growers in Australia and India report similar findings (Vermitech, 2004; Bogdanov, 2004). The literature is fairly consistent in reporting benefits from the use of vermicompost ranging from increased growth and yield to disease suppression and even possible insect repellency. OACC's own research suggests that vermicompost provides distinct advantages over conventional compost, although not necessarily for every crop and in every situation.

It is certain that there is sufficient evidence of the benefits of vermicompost to justify further research, both at the University and on-farm levels. Whether the evidence is sufficient to interest an individual organic farmer in trying out the process for him or herself is an individual decision. For more information in making such a decision, see Section 6.2 below, as well as Appendix B, Sources of Information.

6 Other Considerations

6.1 Environmental Risks and Benefits

6.1.1 Worms and the Environment

> *"Nobody and nothing can be compared with earthworms in their positive influence on the whole living Nature. They create soil and everything that lives in it. They are the most numerous animals on Earth and the main creatures converting all organic matter into soil humus providing soil's fertility and biosphere's functions: disinfecting, neutralizing, protective and productive."*

- **Anatoly M. Igonin[21], Ph. D., Professor at the Vladimir Pedagogical University, Vladimir, Russia, as quoted in Casting Call 9(2), Aug 2004.**

Aristotle called worms the "intestines of the earth" and Charles Darwin wrote a book on worms and their activities, in which he stated that there may not be any other creature that has played so important a role in the history of life on earth (Bogdanov, 1996). There can be little doubt that humankind's relationship with worms is vital and needs to be nurtured and expanded. The following sections touch on some of the most important areas in which our natural environment can be preserved and sustained through a partnership with these engines of the soil.

6.1.2 Water Quality Issues

One of the early concerns with vermicomposting was that this process, because it did not reach the high temperatures of conventional composting, did not destroy potentially dangerous pathogens. In recent years, however, strong evidence has surfaced that worms do indeed destroy pathogens, although the manner in which this occurs is still unknown. The best information in this regard comes from Florida, where the Orange County Environmental Protection Division carried out a study to assess the ability of the vermicomposting process to meet Class A standards for biosolids stabilization. The results of this study showed that vermicomposting could indeed be used as a method for destroying pathogens, with a success rate equal to conventional composting (Eastman, 1999; Eastman et al, 2000). More recently, Dr. Elaine Ingham has found in her research that worms living in pathogen-rich material, when dissected, show no evidence of pathogens beyond the first five millimeters of their gut. In other words, something inside the worm destroys the pathogens, leaving the castings pathogen-free (Appelhof, 2003).

These findings have implications that go beyond the protection of water quality during vermicomposting, although that is important in itself. They also suggest that:

---

[21] Dr. Igonin is one of the world's leading authorities on earthworms. According to Mary Appelhof (see http://www.wormwoman.com), Dr. Igonin practiced selective breeding of E. fetida and has developed a patented strain that is even more resistant to the cold than the strains already found in northern climes.

- Vermicompost spread on farm land will not result in pathogen contamination of ground or surface waters
- having pasturelands seeded and re-seeded with E. fetida cocoons (as they would be if vermicompost were routinely applied) could help to prevent water contamination by pathogens, since fresh manure dropped by grazing animals will be quickly colonized by compost worms.

In addition, vermicompost, like conventional compost, binds nutrients well, both in the bodies of microorganisms and through their actions. This means less nutrient run-off. This is an extremely important environmental benefit of both composting and vermicomposting. Nutrient run-off from agricultural land is a major environmental problem worldwide, with eutropication of surface waters as its principal manifestation.

Finally, there appears to be some potential in using compost worms as part of natural filtration systems. This work is still in its infancy, but seems to have some potential[22].

6.1.3 Climate Change Factors

Climate change is one of the most serious and pressing environmental problems of our time. Farms are a significant contributor to climate change, largely through the release of carbon from soils and the generation of methane gas from livestock and their manure. Both composting and vermicomposting address these issues.

One of the principal benefits of both composting and vermicomposting occurs through carbon sequestration. This is the process of locking carbon up in organic matter and organisms within the soil. Because composts of all types are stable, more carbon is retained in the soil than would be if raw manure or inorganic fertilizer were applied. Soils worldwide have been gradually depleted of carbon through the use of non-organic farming systems. The consistent application of compost or vermicompost gradually raises the level of carbon in the soil. Although carbon is constantly leaving the soil as more is being sequestered, the use of composts can increase the equilibrium level, effectively removing large amounts of carbon permanently from the atmosphere.

The composting process itself is thought to be neutral with respect to greenhouse gas generation. The United States Environmental Protection Agency (US EPA) assessed the GHG impact of composting yard wastes a few years ago as part of a larger assessment of recycling and climate change. Their findings were that the composting process results in the same level of GHG emissions as if the materials were allowed to decay naturally, as on the forest floor. The EPA study acknowledged the potential gains from other factors, such as those discussed below, but did not include them in their analyses.

Other researchers (e.g., Paul et al, 2002) have pointed out that the GHG benefits from composting do not come from the process itself, but from the avoided processes at both the front and back ends. Front-end savings occur when the organic material, such as manure on farms, is not stored under anaerobic conditions or spread raw on farmers'

[22] For more information on worms in natural filter systems, see http://www.biolytix.com or http://www.alternativeorganic.com.

fields, both of which result in high emissions of methane and or nitrous oxide. The back-end savings result from the displacement of commercial fertilizer by the compost, since the production and transport of fertilizer over long distances result in high levels of GHG emissions. Unfortunately, these benefits have not as yet been systematically quantified.

The potential advantages of composting described above also apply to vermicomposting. In theory, however, vermicomposting should provide some potentially significant advantages over composting with respect to GHG emissions. First, the vermicomposting process does not require manual or mechanical turning, as the worms aerate the material as they move through it. This should result in fewer anaerobic areas within the piles, reducing methane emissions from the process. It also reduces the amount of fuel used by farm equipment or compost turners. Second, vermicompost's increased effectiveness (5 to 7 times) relative to compost in promoting plant growth and increasing yield, implies that five to seven times as much fertilizer could be displaced per unit of vermicompost, decreasing the GHG emissions proportionately. Finally, analysis of vermicompost samples has shown generally higher levels of nitrogen than analysis of compost samples made from similar feedstock. This implies that the process is more efficient at retaining nitrogen, probably because of the greater numbers of microorganisms present in the process. This in turn implies that less nitrous oxide is generated and/or released during the process. Since N_2O is 310 times as potent a GHG as CO_2, this could be a significant benefit.

On the other hand, some preliminary measurement work at the Worm Research Centre in England indicates that, contrary to the above reasoning, large-scale vermicomposting processes may in fact be a significant producer of NO_2. Levels in their process were significantly higher than in comparable windrow processing. They are calling for further research to determine the scope of this potential problem and to assess means of mitigation if it proves to be well founded (Frederickson & Ross-Smith, 2004). It should be noted by the reader that the centre was vermicomposting pre-composted mixed fish and shellfish waste, which are high in nitrogen, so the same results may not be found with manure-based operations. Also, it has not been determined if these emissions are large enough to offset the other gains described above Nevertheless, this is a significant development that should be closely monitored by anyone interested in large-scale vermicomposting. The Worm Research Centre intends to continue to investigate this issue. Their website is at http://www.wormresearchcentre.co.uk.

6.1.4 Below-Ground Biodiversity

This is not an issue that has been discussed much, if at all, in the media or the political arena. Nevertheless, it is a significant issue. Biodiversity is declining rapidly worldwide, so much so that some scientists fear that we are heading for a mass extinction event similar to several that have occurred in Earth's ancient past. These events require millions of years to reverse once they occur, so it is vital to prevent that occurrence.

Earthworms have an extremely important role to play in counteracting the loss of biodiversity. Worms increase the numbers and types of microbes in the soil by creating conditions under which these creatures can thrive and multiply. The earthworm gut has been described as a little "bacteria factory", spewing out many times more microbes than the worm ingests. By adding vermicompost and cocoons to a farm's soil, you are

enriching that soil's microbial community tremendously. This below-ground biodiversity is the basis for increased biodiversity above ground, as the soil creatures and the plants that they help to grow are the basis of the entire food chain. The United Nations Environment Program (UNEP) has acknowledged the importance of below-ground biodiversity as a key to sustainable agriculture, above-ground biodiversity, and the overall economy (see http://www.ciat.cgiar.org/tsbf_institute/csm_bgbd.htm for more information on this issue).

6.2 Potential Income Diversification: Worm-related Opportunities for Farmers

6.2.1 Sale of Vermicompost

Vermicompost has a high potential value, but that potential has not been realized in most areas of Canada. This is unfortunately also true of compost in general. For instance, an Atlantic Canada market survey of compost and vermicompost markets a few years ago found the following:

- Percentage of nurseries in Atlantic Canada that sell any kind of bagged compost: 30%
- Percentage of garden centres in Atlantic Canada that sell any kind of bagged compost: 29.4%
- The percentage of nurseries or garden centres that sell vermicompost (3% each) or want or have plans to sell it (19% nurseries, 7% garden centres) is very low;
- "...internet prices ranged from $226/tonne for bulk vermicompost to $31,000/tonne for pure castings in bagged form. In general, bulk castings prices were in the hundreds of dollars per tonne while bagged product sells for $1000/tonne and up. While these prices are very high compared to the prices quoted earlier in the Guide for ordinary compost, the reader should bear in mind that the market for castings is quite small, as very little is currently being produced. A great increase in supply caused by the development of a vermicomposting industry will undoubtedly bring these prices down.[23]"

Any farmer wishing to go into the business of making and selling vermicompost has to consider it to be a long-tern investment, and one with some considerable degree of risk. A Nova Scotia farmer started such an operation a few years ago and is still looking for significant markets for a growing supply of high-quality vermicompost. Alternatively, a New Brunswick based nursery has been quite successful marketing their certified-organic vermicompost in the northern United States. Selling in bulk will probably require a period of a few years at low prices, in order to create a market, before reasonable prices can be charged. This was the case for American Resource Recovery, in northern California. They began by giving the material away and only after several years of operation have begun to be able to charge premium prices for their product. They were able to accommodate this waiting period because they were making money on tip fees.

[23] Page 18, *Compost Markets for Nova Scotia and Atlantic Canada*, July 2000, Metro Food Bank/RRFB Nova Scotia

Selling vermicompost or pure worm castings in bags is an option if the market is local. Selling through the large retail chains is difficult and requires a very large-scale operation. As in the market survey described above, however, many vermicomposters in the U.S. sell vermicompost at very high prices over the internet. It is not known, however, how much they actually sell.

6.2.2 Sale of Worms

As discussed earlier, the main market for worms in Canada is in the area of vermicomposting, both small-scale (individual homes) and large-scale commercial operations. The bait market, which is potentially larger and more lucrative, is hard to develop in Canada because of the competition from the huge supplies of night crawlers harvested in Ontario. Other potential markets, such as animal feed and pharmaceutical production, have not yet been developed in North America[24]. Compost worms sell for anywhere from $10 to $40 a pound (about 1000 worms/lb), with the high end usually reserved for small purchases of a pound or two, to start a home vermicomposter. Larger amounts are usually in the range of $10 to $20/lb.

The market for worms is not large in Canada. Breeders in the U.S. and Europe have much larger, more mature markets to exploit. It used to be quite easy to ship worms to the U.S., but restrictions at the border have tightened and it is much more difficult now. Theoretically, however, compost worms shipped in peat moss are allowed to cross the border for commercial purposes, so sale to the U.S. and other countries is definitely feasible. The difficulty usually lies in the fact that some customs officials are not used to worm shipments and can hold them up for long periods while they find out if they are permitted. This can result in the death of the worms, since they are not usually shipped with feed included (they do eat peat moss, but it has little nutrition and they will lose weight after a few days and then begin to die off).

Those who might be interested in getting into the business of raising worms commercially should review the sources of information in Appendix B. In particular, Peter Bogdanov's book on **Commercial Vermiculture** has a lot of useful information on harvesting, packaging, shipping, market development, etc.

6.2.3 Compost Tea

The subject of compost tea is a huge one and beyond the scope of this manual. A reader interested in the subject is referred to Dr. Ingham's website (http://www.soilfoodweb.com) and to her comprehensive manual, entitled **The Compost Tea Brewing Manual**, available on her website. Another good site for discussion of compost teas is the Rodale Institute's New Farm newsletter at http://www.newfarm.org.

Suffice to say here that vermicompost is usually preferred over compost in the production of compost teas. This is because of the relatively higher starting number of microorganisms. Therefore, any organic farmer wanting to get into the production of

[24] Worms are in demand in Asia as a source of collagen in the manufacture of pharmaceuticals and ceolomic liquid (the fluid inside the worms) in the making of antibiotics (Pajon, no date). In China, worms are also used as a feed for fish. They are also a very good protein source for animal feed, but the prices per pound are very low for this end use.

compost tea as a business (or for their own operation, for that matter), should look into the production of vermicompost.

6.2.4 Assessing the Opportunity

A Canadian farmer considering vermicomposting or vermiculture will need to consider first of all the main goal of the activity. The following are possible motivations, with a few comments attached for guidance.

- ***The management of on-farm organic wastes.*** If this is the only reason to be considering vermicomposting, the reader should probably think more about composting. In general, composting manure is just as fast and has fewer hassles associated with it than does vermicomposting.

- ***The production of vermicompost and/or worms for on-farm use***. Whether this makes sense for an individual producer will depend on how important it is to have higher-value compost product and whether they have a use for the worms on-site (e.g., to feed chickens). If either or both of these are the case, it will make sense to at least investigate vermicomposting and/or vermiculture.

- ***The production of vermicompost and/or worms for commercial purposes.*** As discussed above, markets for both products are generally fairly limited in Canada. However, this will vary somewhat from region to region. It is probably best to investigate this option thoroughly before making any serious investment.

- ***The production of vermicompost for the purposes of brewing compost tea, either for on-farm use or for commercial purposes.*** If you are planning to use and/or sell compost tea in the future, or already do so, it is probably wise to seriously consider starting a vermicomposting operation to supply the innoculant.

Other factors to consider will include space availability, capital and operating costs, severity of climate, and access to the various bedding materials and feed stocks. The reader should refer to Section 2, as well as to many of the resources listed in Appendix B, for help in making the final assessment.

Vermicomposting and vermiculture are environmentally beneficial processes that have great potential as components of sustainable agriculture. The rapid growth in the use of compost worms in countries such as Cuba, India, Argentina, and Australia attest to the value inherent in the partnership between the dominant above-ground species (humanity) and the dominant below-ground species (worms of all kinds). Every farmer depends to some degree on worms; whether you have them work below the ground only, in your fields, or whether you bring them upstairs to extend the partnership into waste management, vermiculture, and compost-tea production, will be an individual choice based on need, opportunity, and interest. OACC hopes that this manual has been of some help in making that choice.

Appendix A: References

Appelhof, Mary. 2003. "Notable Bits". In WormEzine, Vol 2(5). May. Available at http://www.wormwoman.com

Arancon, Norman. 2004. *"An Interview with Dr. Norman Arancon".* In **Casting Call**, 9(2), August.

Atiyeh, R.M, S. Subler, C.A. Edwards, G. bachman, J.D. Metzger, and W. Shuster. 2000. *"Effects of vermicomposts and composts on plant growth in horticultural container media and soil".* In **Pedo biologia**, 44, pp. 579-590.

Beetz, Alice. 1999. *"Worms for Composting (Vermicomposting)."* ATTRA-National Sustainable Agriculture Information Service, Livestock Technical Note, June, 1999.

Biocycle. 2001. *"Vermicompost as Insect Repellent".* Jan 01, p 19.

Bogdanov, Peter. 1996. Commercial Vermiculture: How to Build a Thriving Business in Redworms. VermiCo Press, Oregon. 83 pp.

Bogdanov, Peter. 2004. *"The Single Largest Producer of Vermicompost in the World".* In **Casting Call**. 9(3). October. http://www.vermico.com

Canellas, L.P., F.L. Olivares, A.L. Okorokova-Facanha, and A.R. Facanha. 2002. *"Humic Acids Isolated from Earthworm Compost Enhance Root Elongation, lateral root Emergence, and Plasma Membrane H^+-ATPase Activity in Maize Roots".* In **Plant Physiology**, Vol 130, December. Pp.1951-1957.

Card, A.B., J.V. Anderson and J.G. Davis. 2004. *Vermicomposting Horse Manure*. Colorado State University Cooperative Extension no. 1.224. Available at http://www.ext.colostate.edu/pubs/livestk/01224.html

Cracas, Paula. 2000. *"Vermicomposting Cuban Style",* in **Worm Digest**, Issue #25.

Dominguez, J. and C.A. Edwards. 1997. *"Effects of Stocking Rate and Moisture Content on the Growth and Maturation of Eisenia andrei (Oliogochaeta) in Pig Manure".* In **Soil Biol Biochem** Vol 29, #3,4, pp 743-6.

Eastman, Bruce R. 1999. *"Achieving Pathogen Stabilization Using Vermicomposting".* In **BioCycle**. November. Page 62.

Eastman, Bruce R., Philip N. Kane, Clive A. Edwards, Linda Trytek, Bintoro Gundadi, Andrea L. Stermer, Jacquelyn R. Mobley. 2000. *"The Effectiveness of Vermiculture in Human Pathogen Reduction for USEPA Biosolids Stabilization".* **Orange County, Florida: Environmental Protection Division**.

Appendix A

Edwards, C.A. 1998. *"The Use of Earthworms in the Breakdown and Management of Organic Wastes".* In: Edwards, C.A. (ed) Earthworm Ecology. St. Lucie Press, Boca Raton, pp. 327-354.

Edwards, C.A. 1999. "Interview with Dr. Clive Edwards". In: **Casting Call**; Peter Bogdanov, Ed., VermiCo, Merlin, Oregon. 4(1), June Issue.

Edwards, C.A. and J.R. Lofty 1972. Biology of Earthworms. London: Chapman and Hall Ltd. 283 pp.

Edwards, C.A. and N. Arancon. 2004*. "Vermicomposts Suppress Plant Pest and Disease Attacks"*. In **REDNOVA NEWS**: http://www.rednova.com/display/?id=55938

Elvira, C., M. Goioechea, L. Sampedro, S. Mato, and R. Nogales. 1996. *"Bioconversion of Solid Paper-Pulp Mill Sludge by Earthworms".* In **Bioresource Technology**, 1996, Great Britain, pp 173-177.

Elvira, C., L. Sampedro, J. Domonguez, and S. Mato. 1997. *"Vermicomposting of Wastewater Sludge from Paper-Pulp Industry with Nitrogen Rich Materials".* In **Soil Biol. Biochem.,** 29 (3/4), pp 759-762.

Elvira, C., L. Sampedro, E. Benitez and R. Nogales. 1997. *"Vermicomposting of sludges from paper mill and dairy Industries with Eisenia andrei: A Pilot-Scale Study".* In **Bioresource Technology**, Great Britain, pp 205-211.

Fox, Douglas. 2001. *"The Worm that Earned".* In **New Scientist**, September 15, 2001, pp. 32-34.

Frederickson, James, Kevin R. Butt, Richard M. Morris and Catherine Daniel. 1997. *"Combining Vermiculture with Traditional Green Waste Composting Systems".* In **Soil Biol. Biochem.,** 29 (3/4), pp 725-730.

Frederickson, J. and S. Ross-Smith. 2004. *"Vermicomposting of Pre-composted Mixed Fish/Shellfish and Green Waste".* The Worm Research Centre. SR566. July. Available at http://www.wormresearchcentre.co.uk

Gaddie, R.E. (Sr.) and Donald E. Douglas. 1975. Earthworms for Ecology and Profit. Volume 1: Scientific Earthworm Farming. Bookworm Publishing Company, Cal. 180 pp.

GEORG, 2004. *Feasibility of Developing the Organic and Transitional Farm Market for Processing Municipal and Farm Organic Wastes Using Large-Scale Vermicomposting*. Good Earth Organic Resources Group, Halifax, Nova Scotia. More information available from http://www.alternativeorganic.com.

Gunadi, Bintoro, Charles Blount and Clive A. Edwards. 2002. *"The growth and fecundity of Eisenia fetida (Savigny) in cattle solids pre-composted for different periods".* In **Pedobiologia** 46, 15-23.

Appendix A

Hammermeister, A.M., P.R. Warman, E.A. Jeliazkova, R.C. Martin. 2004. *"Nutrient supply and lettuce growth in response to vermicomposted and composted cattle manure".* Submitted to **Bioresource Technology**, Dec, 2004.

Pajon, Silvio. No Date. "The Worm's Turn – Argentina". Intermediate Technology Development Group (ITDG), Case Study Series 4. http://www.tve.org/ho/doc.cfm?aid=1450&lang=English

Paul, John W., Claudia Wagner-Riddle, Andrew Thompson, Ron Fleming, and Malcolm Mac Alpine. 2002. *"Composting as a Strategy to reduce Greenhouse Gas Emissions".* 14 pp. Available on ManureNet Website: http://res2.agr.ca/initiatives/manurenet

Myers, Ruth. 1969. The ABCs of the Earthworm Business. Shields Publications, Eagle River, Wisconsin, USA. 64 pp.

Rink, Robert (Editor), 1992. Authors: Maarten van de Kamp, George B. Wilson, Mark E. Singley, Tom L. Richard, John J. Kolega, Francis R. Gouin, Lucien Laliberty, Jr., David Kay, D.W. Murphy, Harry A. J. Hoitink, W.F. Brinton. On-Farm Composting Handbook. Natural Resource, Agriculture, and Engineering Service (NRAES-54), Ithaca, NY.

RRFB Nova Scotia. 2000. "*Compost Markets for Nova Scotia and Atlantic Canada"*. 89 pp. Website: http://www.rrfb.com

Saradha, T. 1997. *"The culture of earthworms in the mixture of pond soil and leaf litter and analysis of vermi-fertilizer".* **J. Ecobiology**, 9(3), pp. 185-188.

Sherman, Rhonda. 1997. *"Controlling Mite Pests in Earthworm Beds".* North Carolina Cooperative Extension Service, Raleigh, NC. http://www.bae.ncsu.edu/people/faculty/sherman

Sherman, Rhonda. 2000. *"Commercial Systems Latest Developments in Mid-to-Large-Scale Vermicomposting".*In **Biocycle**, November 2000, p. 51.

Short, J.C.P., J. Frederickson, and R.M. Morris. 1999. *"Evaluation of traditional windrow-composting and vermicomposting for the stabilization of waste paper sludge (WPS)."* In Diaz Cosin, D.J., Jesus, J.B., and Trogo, D. (Eds), 6th International Symposium on Earthworm Ecology, Vigo, Spain, 1998. **Pedobiologia.** 1999. 43(6), pp. 735-743.

Subler, Scott, Clive Edwards and James Metzger. 1998. *"Comparing Vermicomposts and Composts".* In **BioCycle**, July. Pp. 63-66.

Sudha, B. and K.K. Kapoor. 2000. *"Vermicomposting of crop residues and cattle dung with Eisenia foetida".* In **Bioresource Technology**, 73. pp. 95-98.

VermiCo. 2004. http://www.vermico.com.

Vermitech. 2004. http://www.vermitech.com. See http://www.vermitech.com/rd_fr.htm for specific information on research into their product, Bioverm.

Appendix B: Sources of Information

BOOKS & PERIODICALS

Note: A number of the listed websites (see below book list) sell most if not all of the following books.

Bogdanov, Peter. 1996. Commercial Vermiculture: How to Build a Thriving Business in Redworms. VermiCo Press, Oregon. 83 pp. A very practical book of interest to anyone considering growing worms as a business.

Bogdanov, Peter. Editor. Casting Call. A bi-monthly periodical on the subjects of worms and the worm industry. See VermiCo website for details.

Bogdanov, Peter. Editor. Worm Digest. This is a quarterly, not-for-profit magazine that covers the vermicomposting industry, but also education, small-scale vermicomposting, and related stories. Less commercially focused than Casting Call. See Worm Digest website for details.

Edwards, C.A. and J.R. Lofty 1972. Biology of Earthworms. London: Chapman and Hall Ltd. 283 pp. The classic textbook on earthworm biology by one of the world's leading authorities.

Ernst, David. 1995. The Farmer's Earthworm Handbook. Lessiter Publications, Brookfield, Wisconsin. 112 pp. This book has a lot of information about burrowing worms and their relationship to farming, It does not deal directly with compost worms, but it has a lot of good information.

Gaddie, R.E. (Senior) and Donald E. Douglas. 1975. Earthworms for Ecology and Profit. Volume 1: Scientific Earthworm Farming. Bookworm Publishing Company, California. 180 pp. A very comprehensive book on the vermiculture business. Not as up-to-date as Peter Bogdanov's book, but full of useful information.

Ingham, Elaine. 2000. The Compost Tea Brewing Manual. Unisun Communications, Corvallis, Oregon. 67 pp. The complete story on aerobic compost teas, including assessments of commercial tea makers. Available on website (see below).

Myers, Ruth. 1969. The ABCs of the Earthworm Business. Shields Publications, Eagle River, Wisconsin, USA. 64 pp. A somewhat out-of-date but entertaining, lively book about one woman's experiences as a worm grower in the United States in the 1960s.

Rink, Robert (Editor), 1992. Authors: Maarten van de Kamp, George B. Wilson, Mark E. Singley, Tom L. Richard, John J. Kolega, Francis R. Gouin, Lucien Laliberty, Jr., David Kay, Dennis W. Murphy, Harry A. J. Hoitink, William F. Brinton. On-Farm Composting Handbook. Natural Resource,

Agriculture, and Engineering Service (NRAES-54), Ithaca, New York. This is an invaluable guide to on-farm composting. It has very practical instructions on everything from assessing inputs to buying equipment and to marketing the product. Since many vermicomposting systems require a pre-composting phase, this book is especially valuable.

Tyler, Rodney. 1996. Winning the Organics Game. The Compost Marketer's Handbook. ASHS Press, Alexandria, Virginia. 269 pp. Lots of practical information on marketing compost. Although vermicompost is not considered in the book, many of the points and tips are relevant and useful in planning a commercial vermicomposting operation.

WEBSITES

Listed below are some interesting and informative websites dealing either directly or indirectly with vermicomposting or vermiculture. Most of these websites are commercial, but have much good information freely available. Non-commercial websites are identified as such.

http://www.alternativeorganic.com This is the author's website. Alternative Organic International Inc. s a Nova Scotia company specializing in adding value to organic-waste resources through composting and vermicomposting. The site provides information on some of the leading-edge research being conducted in Nova Scotia on vermicomposting and on the use of worms as part of filter systems for leachate.

http://www.atlanticcountrycomposting.com Atlantic Country Composting is a farm-based business in Nova Scotia. They produce compost from paper-mill sludge using a windrow system and certified-organic vermicompost from manure, bark, and seaweed.

http://www.biosci.ohio-state.edu/~soilecol/index.html This is the home page of the Soil Ecology Centre of Ohio State University. This is the Centre led by Dr. Clive Edwards, probably the world's leading authority on vermicomposting. The site includes many scientific papers that can be downloaded free of charge. This is a non-commercial site.

http://www.jollyfarmer.com Jolly Farmer is a plant nursery in New Brunswick that produces certified-organic vermicompost and compost tea. They also sell bait worms.

http://www.linksorganic.com/uk/links_redirect.asp?ID=2850 This is the site of Ogopogo Worm Farm in BC. They produce vermicompost for use on vineyards and golf courses. They also raise bait worms. A good example of a Canadian "worm farm".

http://www.vermico.com Peter Bogdanov is the Editor of both **Casting Call** and **Worm Digest** (see Books & periodicals, above). In addition, VermiCo sells many different industry-related products and organizes yearly seminars on Best Practices in Vermicomposting. A good site to get an overview of the commercial side of vermicomposting.

http://www.vermitech.com This is the site of an Australian company that uses a flow-through digester system to vermicompost sewage sludge. They have also done, in

association with local universities, considerable research into the value of worm castings and specifically their product Bioverm. The site is a good one for information on the technology and the products.

http://www.vermitechnology.com A U.S. company that has been in the vermiculture and vermicomposting business for many years. Informative website.

http://www.wormsargentina.com Vermicomposting is a rapidly growing industry in Argentina. This website provides some good information, in both Spanish and English, on techniques used in that country and on the uses they have for the product.

http://www.wormdigest.org The home site of the Worm Digest quarterly magazine. See Books & Periodicals above.

http://www.wormresearchcentre.co.uk The Worm Research Centre in England is a project of The Open University and has several corporate sponsors. They have conducted several major studies on vermicomposting and the reports are available on-line at no charge. They have plans to continue their research indefinitely, so this is an important site for those interested in the on-going development of commercial vermicomposting. This is a non-commercial site.

http://www.wormwigwam.com This is the site of one of the original commercial flow-through vermicomposting systems. Good information on these systems and their prices.

http://www.wormwoman.com This is the site of Mary Appelhof – the Worm Woman – who is the author of “Worms Eat My Garbage”, the classic little book on vermicomposting that has now sold over 35,000 copies worldwide. Ms Appelhof puts out a WormEzine (subscription is free) that covers interesting happenings in the international world of worms. She also has lots of information and products relating to the education of children regarding the environment and vermicomposting in particular.

Appendix C: Vermiculture Trial – Scott Farm

Jennifer Scott operates a small organic poultry operation as part of a farming cooperative in Centre Burlington, Nova Scotia. OACC worked with Jennifer in an 18-month project to assess the opportunity for raising compost worms as a feed for her chickens. In Nova Scotia, organic grain is difficult to get and expensive. It was hoped that the worms could provide the high-quality protein necessary and eliminate the need for importing grain. The trial had two phases.

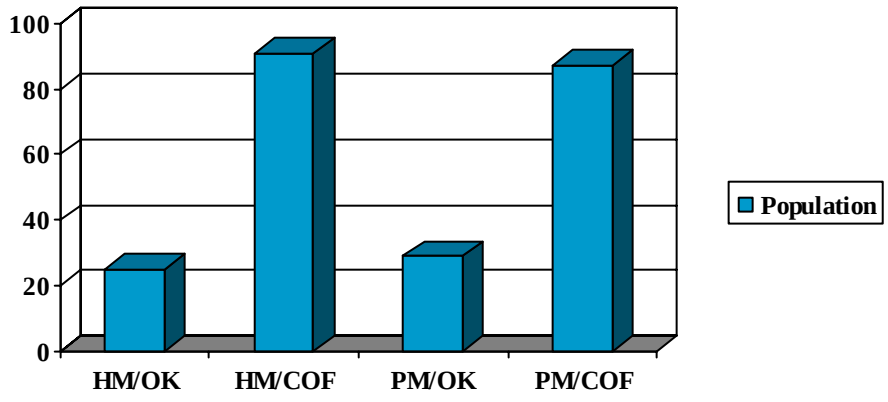
Phase 1

In phase 1, two beddings -- horse manure and peat moss – and two foods – coffee grounds and okara[25] -- were tested. This was done by setting up a series of vermicomposting bins using small plastic totes. The trial consisted of 12 treatments with 3 replicates each of the following four combinations:

- Horse manure bedding with coffee grounds as food source;
- Horse manure bedding with okara as food source;
- Peat moss bedding with coffee grounds as food source;
- Peat moss bedding with okara as food source.

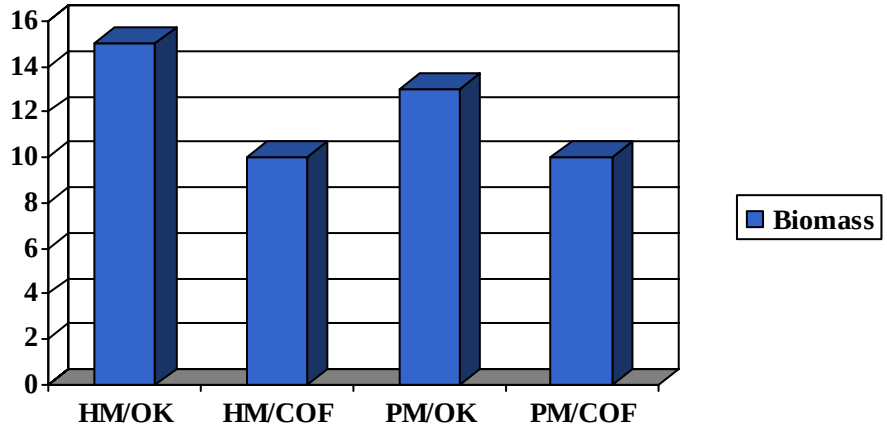
The changes in population and biomass are shown in Figures C1 and C2 on the following page. These were based on the average number of worms and weight of worms in a one-liter sample at the conclusion of Phase 1 (17 weeks). The horse manure/coffee grounds and peat moss/coffee grounds produced the most worms; however the okara combinations produced the greatest biomass. This is because the average weight of the okara-fed worms was much greater than the average weight of the coffee-fed worms. In general, the horse-manure bins slightly outperformed the peat-moss bins, so it was decided to use horse manure as bedding for phase 2 and to use okara as the feedstock.

Figure C1: Average Population of Treatments after 17 Weeks



[25] Okara is the curd left over from the production of tofu from soybeans. It is a wet, high-protein material that heats easily. The Scott farm had free access to this waste, which is produced by a local certified-organic tofu producer.

Figure C2: Average Biomass of Treatments After 17 Weeks



Phase 2

Worm bins were constructed in the chicken house from cinderblock and mortar (see Figure C3). The bins were built with wire mesh separating them. This mesh allows the worms to move freely between the bins but keeps the bedding and food separate for harvesting purposes. The bins were filled to half their volume with dampened horse manure and the worms from Phase 1 were added to the bedding. The system operates as follows:

Each week, several forkfuls of worms and compost are removed and placed on a specially designed wheelbarrow (see Figure C4). The chickens are allowed to forage on the wheelbarrow until all the worms have been consumed. The vermicompost that remains is dumped into a curing pile and the process is repeated until the weekly harvest is complete. The worms are fed their weekly rations of okara right after the harvest so that most of the food has been consumed by the following week. This keeps the harvested vermicompost relatively free of okara.



Figure C3: The cinderblock & mortar worm bins are at the back of the chicken house



Figure C4: A chicken foraging for worms in the vermicompost

This system has worked very well. The area of the worm bins is six m^2. This produces a sustainable yield of 4 kg/week of worm biomass. The system also produces about 6 m^3 of high quality vermicompost per year. Jennifer Scott plans to expand her flock and increase the size of the worms' beds. She is using the worms to substitute for expensive imported organic grain.

Appendix D: Vermicomposting Trials – Holdanca Farms Ltd. and Kipawo Holsteins

Vermicomposting trials were conducted on two Nova Scotia farms as part of the EcoAction-funded OACC study. The following are brief descriptions of the pilots and their results.

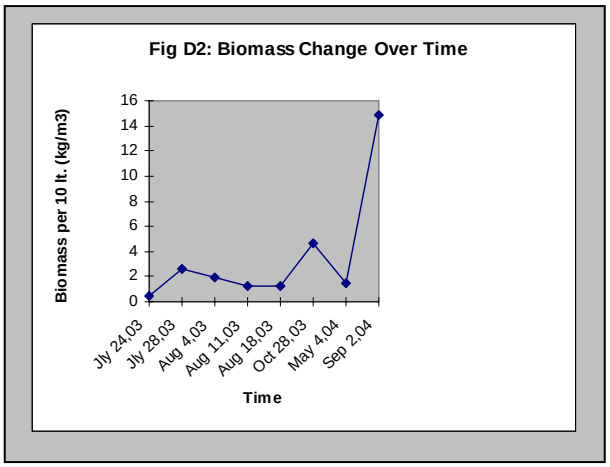
Holdanca Farms Ltd.

This farm is operated by John Duynisvelt and is located near Wallace, Nova Scotia. The farm is not certified organic but is run using organic methods, without any pesticides, commercial fertilizers, or other restricted inputs. The farm produces free-range beef, poultry, and pork, all of which is sold locally. About 200 tonnes of manure is produced by the animals in the barn during the winter months.

The pilot on the Holdanca Farm used the simplest possible system. Two piles of aged manure and bedding were seeded with worms in the summer of 2003 (see Figure D1). Fresh manure and occasional water was added to the piles periodically over the summer and fall. In late fall, the piles were covered with a last layer of manure and about a half meter of straw. Nothing was added over the winter. In spring the process was begun again. The piles were monitored for worm population and biomass changes, moisture content, and pH.



Figure D1: One of the original worm windrows at Holdanca Farms



The change in biomass over the course of the pilot is shown in Figure D2. An initial rise was followed by a long, slow decline over the summer months. This was due to an initial error: the bedding used was aged manure mixed with a small percentage of straw. This turned out to be subject to packing and drying out, so that the worms' habitat was not ideal. In late summer, a significant amount of straw and hay from the stalls in the barn was added to the pile and mixed by turning the pile a few times with the tractor bucket. More manure was then added to the top. The increase in biomass that resulted from that action can be seen in the spike in late October.

Appendix D

The winter of 2003-2004 was severe and the worm populations were reduced significantly by spring – almost back to the original seeding density. However, in the summer of 2004 the worms had a superior habitat for the entire season and the results can be seen in the final counts taken in September, where the biomass density is 37 times the original seeding density. While this may seem to suggest that the biomass doubled on a monthly basis over the summer of 2004, such is probably not the case. The May counts were low because of winter kill-off, but they do not take into account the cocoons buried deep in the piles or the ground beneath. Nevertheless, the trial showed that worms can be cultivated outdoors in Nova Scotia using a simple windrow method. The key lessons learned were as follows:

- The original bedding must contain a high percentage of bulking material, such as straw; aged cattle manure by itself will not provide a good environment for worm reproduction;
- The manure on the Holdanca Farm is brought from the barn in the spring. Much of it is already aged and compacted. This material can be used, but must be well bulked and supplemented with fresh manure if good results are to be achieved;
- Both good protection and a source of heat (from fresh feed) are required in winter if processing is to continue. In this case, the worms came back because of the cocoons, but a lot of processing time was lost. This is a problem for situations such as this one where the animals are free range and there is not a lot of fresh manure available in the fall. It is probably necessary to add fresh manure over the winter months by removing the straw cover, adding the feed, and replacing the cover. This adds time and effort, of course, but it will allow for more material to be processed. As worm populations increase, this step may not be necessary, as the number of cocoons created each fall will provide sufficient worms to process all of the manure the following summer.
- Worm populations do rebound well from harsh winters and there is no reason to believe that outdoor windrow vermicomposting can't be carried out successfully in most parts of the country.

Kipawo Holsteins



Figure D3: Covered compost pad at Kipawo Holsteins

Kipawo Holsteins is a dairy farm in Grand Pre, Nova Scotia, (just outside Wolfville), owned and operated by Herman Mentink. The farm has a large covered pad (see Fig D3) where all of the manure produced by the 60-odd cows is composted using a standard windrow composting technique.

Two vermicomposting windrows were set up on the farm originally. Both were on the concrete pad, but one was under cover (near the rear door shown

in the photo – See Figure D4), and the other was outside, to the right of the pad.

The windrows were set up in a similar manner to the ones on Holdanca Farms, except that these sat on a concrete base. The same initial error was made: the bedding used at the start of the pilot was aged cattle manure. This resulted in poor initial growth by the worm populations. In addition, the windrow set up inside was too difficult to keep moist. The prevailing wind came in through the open door and dried out the windrow faster than the farmer could water it (since it was inside, it got no rain).



Figure D4: Original inside vermi windrow

By the end of the first summer (2003), the indoor windrow was abandoned and the few remaining worms added to the outdoor windrow. As on the Holdanca Farm, more straw was added to the mix in late summer. This provided better bedding and resulted in better worm biomass development from that point on. The windrow was covered with fresh manure in the late fall and then covered again with a thick layer of straw.

Figure D5 shows the overall biomass increase from start-up to May, 2004. There was a 14-fold increase over the 10 months, from an initial stock of 9.2 kg (including the worms in the failed windrow), to the May estimate of 139 kg. The lack of a winter kill-off similar to what was experienced at Holdanca Farms was probably due to the large amount of very fresh manure added to the pile prior to covering it with the insulating straw.

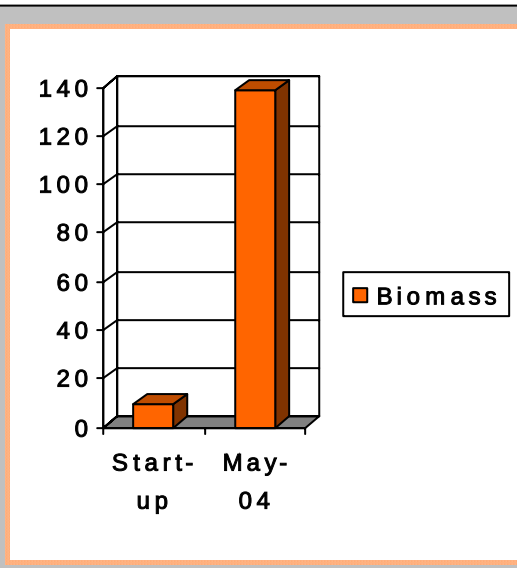


Figure D5: Biomass Increase, Kipawo

The results from this trial support the findings from the other vermicomposting pilot. They indicate that outdoor windrow vermicomposting is feasible in a Canadian climate. The other key findings from this pilot were:

- If windrows are to be put under shelter, they should be protected from the wind and other drying agents, watered regularly, and kept covered to conserve moisture;
- Fresh manure added in late fall will help provide heat over the winter, resulting in greater worm reproduction and more effective processing.