ALTERNATIVE BIOLOGICAL TREATMENT OF MANURE

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ABSTRACT

Biological treatment of organic wastes using worms or fly larvae has been in practice for several years with different levels of success. Worm composting, called vermicomposting, is far more developed than the process using fly larvae. Research in different parts of the world have answered several questions related to how the systems work, biology of the species used, fate of feedstock components, and agricultural benefits of the byproduct produced.

This presentation aims to describe to the audience the result of one study performed in southern Idaho using black soldier fly larvae to process dairy manure and its future prospective as treatment method. We will also present research and practical examples of manure treatment using worms and discuss its applicability in southern Idaho.

INTRODUCTION

Bio-conversion of manure using worms or fly larvae has been studied for many years. Those studies were mainly conducted in lab settings and aimed to answer questions related to the organisms' performance and biology, feedstock processing capabilities, and byproduct characteristics and use. Less research has been conducted to treat large amount of manure on farms, even though some industries and farms around the world have been successfully applying this technology for years. Worm composting is much more developed in its application to farms or industries than the fly larvae treatment is. In addition to being considered small scale emerging technologies (with some exceptions), these type of biological conversion systems are seen as too slow or unable to treat high volumes of organic materials. However, this belief is not totally founded. Even if the volume of waste treated is a portion of the total, the added value of the byproduct generated, and the treatment of part of the waste stream justify the investment in money, time, and manpower that bioconversion technologies may demand.

In this paper we will present the results of research performed in southern Idaho by the University of Idaho and Idaho State University researchers on the use of black soldier fly larvae (*Hermetia illucens)* to process dairy manure and as feed source for the Idaho fish industry. Then we will discuss the opportunities and challenges this technology presents in southern Idaho. We will also discuss some of the research and development related to worm composting (vermicomposting), share success stories and discuss what needs to be done to apply this technology in southern Idaho to treat dairy manure.

The black soldier fly is native to the United States, naturally occurring seasonally in the south. It has been documented in Utah, and there have been anecdotal reports of it occurring in Idaho. The USDA does not consider this insect a plant pest species. As this specie of soldier fly is not well adapted to survive in the cold winter climate of Idaho, its production will be limited to an artificial growing environment (i.e. greenhouse). There are several reasons to choose this specie of fly over other insects for bioconversion of waste. First, the adult flies only live for one to two weeks during which time they mate and lay eggs (Tomberlin, et al. 2002). They prefer to breed and live near decomposing organic materials such as animal waste, having an aversion to areas where there is human activity (Sheppard, et al. 1994). Second, production of black soldier fly larvae has an advantage over other insects in that they have a fast growth rate and larvae will migrate out of the waste to pupate, which provides a window for harvest. Further, they remain in this prepupal stage approximately 20 days (Tomberlin, et al. 2002), which provides ample time to process them. Third, the prepupae are large (1/2 inch to 1 inch long) and high in protein and fat. Finally, there has been 20 years of data collected on manure management in livestock facilities using the black soldier fly (Sheppard, et al. 1998; Sheppard, et al. 1994; Booth and Sheppard, 1984; Tingle, et al. 1975).

A black soldier fly bioconversion system was initially developed using cage-layer poultry operations. The process can be divided into two components: egg production, and larvae rearing. In brief, eggs are introduced (through natural or artificial production) to the manure pit. Once the eggs hatch the larvae feed on the manure or other organic feedstock. At optimal temperatures (between 71^{0}F and 86^{0}F), and with adequate food, larvae can mature to the prepupae stage within a few weeks (Sheppard, et al. 1998). At lower temperatures it takes longer for the larvae to develop. Once the larvae are ready to pupate, they seek a dry environment and migrate out of the manure. This provides an opportunity to inexpensively harvest the prepupae.

Inoculation of manure with black soldier fly eggs is required for this system to be economically viable. A dependable source of eggs is required for seeding of manure beds and this is possible through artificial production. The black soldier fly requires natural lighting, and approximately 60% humidity and between 81^{0} F and 86^{0}F to mate and deposit eggs in an artificial environment (Tomberlin and Sheppard, 2002; Booth and Sheppard, 1984).

The primary use for the black soldier fly has been to control house fly populations and reduce manure volumes in poultry facilities (Sheppard, et al. 1998; Sheppard, et al. 1994). Initially it was observed that poultry barns with black soldier flies did not have house fly problems. In subsequent studies it was determined that manure could be reduced by up to 50% in poultry barns seeded with black soldier fly larvae to control house fly populations. More recently, the principles of manure bioconversion using black soldier fly larvae have been applied to confined swine facilities with belt-conveyor manure collection systems. Total solids in these facilities were reduced by 56%, and nitrogen and phosphorus concentrations in the remaining waste were 55% and 44% less than the original manure, respectively (Tingle, et al. 1975).

Preliminary data on reduction of dairy cow manure by the black soldier fly suggests it is a suitable substrate for the larvae (Tomberlin and St-Hilaire personal observation, 2007; Tingle, et al. 1975). Under laboratory conditions the larvae reduced manure volumes by 48% and nitrogen and phosphorous by 63% and 52%, respectively (Tomberlin, unpublished data).

The by-product of the black soldier fly bioconversion system is a prepupae consisting of 40% protein and 30% fat (Sheppard, et al. 1998). This source of protein has been successfully used as a feed ingredient for chicks, catfish, tilapia, and swine (Bondari, and Sheppard, 1987; Newton, et al. 1977; Tingle, et al. 1975). It has also been shown to be stable at room temperature for over eight months, which indicates the product could be stockpiled if production of a constant supply is not feasible in Idaho. The market value for the prepupae has been estimated between \$330 - 400/2200lb compared to \$900/ton for fishmeal.

The dry matter conversion rates of poultry and swine manure to prepupae mass have been estimated at 8% and 15%, respectively (Sheppard, et al. 1998). A 460 hen caged layer barn in Georgia with an initial seeding of black soldier fly larvae produced 500 lb of prepupae in 5 months. This is approximately 98g of prepupae per chicken. In an experiment with swine manure it was estimated that 0.33 lb of prepupae were produced per pig per day (Tingle, et al. 1975).

Previous research suggests the larvae grow better on fresh manure (SARE project LS93-056). The current practice of daily removal of feces on dairy farms will provide an opportunity to collect fresh manure for the larvae at no additional cost. Application of manure to the larval bed will require an additional step for the producer; however, low-maintenance systems already exist for the application of manure to earthworms on composting farms (www. vermitech. com/ system.htm), and these systems will work for the black soldier fly.

In order for the black soldier fly manure conversion system to be economical it must have minimal energy input. The application of manure to the larval bed will require some energy; however, the greatest energy cost will be to maintain an environmental temperature that is suitable for larval growth and egg production in the winter. Larval containers will have to be maintained between 72^0 F and 86^0 F and the adult colonies will require at least 81^0 F to successfully reproduce and lay eggs (Booth and Sheppard, 1984). To maintain these temperatures in the winter months in Idaho will require additional heat.

Vermicompost is another technology used around the world to treat manure and many other organic wastes. Of the more than 4,000 species of earthworms, only half a dozen are used for vermicomposting worldwide. The earthworm specie most frequently used for vermicomposting is *Eisenia fetida*, which is commonly called Red Wiggler or California red worm (Sherman, R., 2009.). Vermicompost has been successfully used for many years in different parts of the world. Research in the USA (Sherman, 2010), Mexico (Gutierez Vazquez, et al., 2007), and Argentina (Chamorro, et al., 2004; Castillo, et al., 1999), shows the advantage of using bovine manure as one of the main components of the feedstock for worm composting. Some authors suggest a previous thermophylic phase should be done by regular composting to avoid high temperatures that may kill worms (Gutierez Vazquez, et al., 2007; Ndegwa, and Thompson, 2000). The biggest worm composting processor in the USA is American Resource Recovery in Westley, California. In 1998 an estimated 500,000 pounds of earthworms processed 75,000 tons of materials annually on 70 acres of the 320 acres owned by the company. The worms were fed paper pulp generated from recycled cardboard, tomato residuals, manure, and green waste (Sherman, 2000). Proven systems to treat wastes using vermicompost include windrows, wedge system (modified windrows), beds and bins systems, and reactor systems (Sherman, 2000). Those systems can be adapted to different production and size characteristics according to the producer demand, feedstock availability, and climate.

METHODS

The black soldier fly larvae research conducted by the University of Idaho and Idaho State University was funded by a Western SARE grant and included two main research projects. For the first project, researchers tested the development of black soldier fly larvae in small lab containers using dairy manure as feedstock. For the fish feeding trial, a practical-type trout diet was formulated to contain 45% protein, with roughly half of the protein derived from fish meal and the remaining from soybean meal, corn gluten meal and wheat meal. Four test diets were developed by substituting 25% and 50% of the fishmeal component of the control diet with normal (BSF) or enriched (EBSF) black soldier fly prepupae on an amino acid equivalents basis. Dietary fat content was adjusted to approximately 20% lipid using fish oil and poultry fat to provide required levels of essential fatty acids and maintain approximately equivalent fatty acid ratios between the treatments. Diets were fed to three replicate tanks of fish per treatment (15 fish/tank, mixed-sex House Creek strain) for 8 weeks. Trout were reared in 37 gallon tanks supplied with 1.3 gal/min of constant temperature (59°F) flow-through spring water. Bulk tank weights were taken every three weeks until the end of the trial.

During the second project, a small scale on-farm production system was tested. The study was conducted on a 3000 cows dairy in southern Idaho. Small scale containers using 640 gallon water tanks were designed so that fresh manure and black soldier fly eggs could be layered. Small ramps that allowed the larvae to migrate when ready to hatch were built in the containers. At the top of each ramp a hole was designed through which larvae fell into buckets. Other containers used in the study included containers purchased from ESRI International LLC (lab Container) as well as a recycle bin. Prior to initiation of the study, a former structure of manure separator was modified to give shadowed conditions and some wind protection to the larvae. Study started on June 11 2008. Approximately 1,763,100 eggs were distributed into the three previously mentioned containers. On June 27, the larvae were fed fish offal to stimulate their growth.

For vermicompost research, methods and techniques please refer to papers referenced throughout this article.

RESULTS AND DISCUSSION

Fish feeding trials results: Growth of fish fed the EBSF diets was not significantly different from those fish fed the fishmeal-based control diet, while growth of fish fed the BSF diets was less than those fed the control diet. Muscle ratio was not altered by diet but control fish had significantly higher inter-peritoneal fat than those fish fed the EBSF or BSF diets.

A group of 30 untrained panelists did not detect a significant difference in a blind taste test of fish fed the fishmeal control diet as compared to fish fed the EBSF or BSF diets. These data suggest that EBSF can be used to replace up to 50% of fishmeal portion of a practical trout diet for eight weeks without significantly affecting growth or sensory quality of rainbow trout fillets.

On-farm pilot scale manure treatment results: On July 4 2008, the harvest of the first mature larvae started in small amounts. A week later, there was an intensive period of two weeks with 88% of the harvest migrating during this period. Afterward, the harvest decreased dramatically. The shape of the recycle bin container made the migration difficult to accomplish and it was removed from the study. The total harvested quantity from all containers and the floor was 13,238 g (29.2 lb), equivalent to around 93,990 larvae. This value represents only 5.3% of the original population. The large proportion of losses was distributed between immature and dead larvae within the containers. Black soldier larvae reduced manure by 40 percent even in less than ideal conditions. Table 1 shows reductions of different components analyzed. The best behavior and development of the larvae occurred when the maximum environmental temperature exceeded 86° F. For better results, it would be important to design a facility that provides stronger protection against rain, wind and strong changes in temperature. Even during summer, the wide differences in temperatures between day and night could present challenges for growing black soldier larvae outside or without heating supplementation in high desert climates.

Adapting the current poultry and swine black soldier fly bioconversion systems to Idaho dairies will require: 1) modifications to the method of applying manure to the larval bed, 2) a method of maintaining the larval bed at a temperature between 72^{0} F and 86 ^{0}F and 3) an energy efficient system of producing eggs to seed the manure beds. For the black soldier fly system to be adopted by dairy farmers in Idaho it will have to be: 1) low maintenance for the farmer, 2) economical, and 3) there will have to be a market for the prepupae.

For the larval rearing component of this system to be low maintenance it has to be incorporated into the existing dairy farm management practices

On-farm vermicomposting in southern Idaho faces similar challenges as manure treatment using black soldier fly larvae. Temperature variations during the day and between seasons, very cold winters, and dry ambient conditions, are among the main factors affecting the effectiveness and viability of biological waste treatments in southern Idaho. Adaptation of technologies and biological production systems to the area conditions is possible and feasible. More research and full scale field applications are needed to explore the full potential of these technologies as an additional tool available to dairy producers to treat their waste in an environmentally sound and sustainable way.

Table 1. Reduction of components in manure processed by black soldier fly.

Item	Pre-processed manure (Kg)	Post-processed by-product (Kg)	Net reduction (%)
Weight, DM	345.2	212.6	38.4
Total N	10.6	4.8	55.1
Total P	1.97	1.50	23.9
Carbon	156.0	92.5	40.7
Ash	69.0	63.8	7.6

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