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Cost and Returns Analysis of Manure Management Systems Evaluated in 2005 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers

TECHNOLOGY REPORT: BLACK SOLDIER FLY (SF)

Prepared as Part of the Full Economic Assessment of Alternative Swine Waste Management Systems Under the Agreement Between the North Carolina Attorney General and Smithfield Foods

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1. Summary

A pilot-scale evaluation of the Black Soldier Fly technology was initiated at the North Carolina State University research facility on Lake Wheeler Road near Raleigh in spring 2002. A Black Soldier Fly facility designed to process solids from about 15 pigs was built. Experiments to digest separated swine manure solids were performed during spring and summer 2003 but steady state operation was never established. Black Soldier Fly larvae and digested residual samples were collected (Newton, et.al).

In the absence of steady state operating and performance data, no estimate of costs and returns for the demonstration can be generated.

The Black Soldier Fly technology demonstration at the Lake Wheeler facility produced invoice construction cost estimates for the pilot scale facility. Those costs are summarized in this report. More research needs to be done, however, in order to estimate cost and performance of a full-scale commercial facility. The technology provider team[1] was working on a design for a full-scale operation and planned on further research at their Georgia facility.

The Task 1 team is not aware of any market for black soldier fly meal and oil so no current market value can be assigned. However, the Task 1 team obtained estimates of the composition of digested residuals and of black soldier fly larvae from the technology providers and published reports. These data make it possible to project some potential future value estimates for SF by-products. The nutritional content of SF larval feedstuff is compared to products derived from swine mortality and spent poultry feedstuffs. Extending Middleton et al’s findings, a price is derived for SF feedstuff based on its relative nutritional value. A reviewer commented that the registration and approval of new feedstuffs is not a simple process and has not been undertaken yet for soldier fly meal and oil. Additional value is possible if SF larval feedstuff is found to be an acceptable substitute for fish meal. Based on Burtle’s work, this seems to be a potential

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[1] The technology provider team consists of:

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future use of SF feedstuff. Also, digested SF residuals are compared to vermicompost to estimate potential value. Unlike vermicompost, however, SF residue had not been empirically demonstrated to increase plant growth yields. While nutritionally similar, more research is necessary on digested SF residuals before market value can be more accurately predicted.

2. Technology Description

The Black Soldier Fly (SF) manure treatment technology demonstration was located at the North Carolina State University research facility on Lake Wheeler Road. Solids for larval digestion were supplied by the Lake Wheeler belt system (formerly referred to as the Gannet-Fleming belt system) located nearby. The solids were separated by the belt system and collected in several barrels outside of the building. Next, they were delivered by manure pump to a manure pit in which Black Soldier Fly larvae were placed. The larvae consume manure, incorporate some nutrients into their biomass and expel residue. The demonstration manure pit was approximately 9'x14' to approximate living space for larvae to digest manure for 18 or fewer pigs.[2] Two opposite walls of the pit were sloped to form a ramp for the prepupae to exit the pit. Larvae crawl into two gutters attached to the pit edge and collect in buckets placed at the gutter ends. This phase of SF development takes approximately three weeks.

Some pre-pupae were collected and placed in the small egg/pupae room (shed) for SF breeding (approximately 3% of daily prepupal production). Adult SF start to emerge approximately two weeks after pupae are moved to the greenhouse. Emerged adults do not need to be fed. Evaporative cooling pads are placed in the greenhouse for watering. Adults mate at two days of age and deposit eggs into cardboard egg traps at four days of age. Cardboard traps are collected daily and moved to the egg/pupae shed. Young larvae hatch in approximately four days and they are moved to the manure digestion pit completing the cycle.

Unit Processes
Black Soldier Fly technology can be divided into following unit processes:

1) Manure Collection and Weighing
2) Larval Basin Building and Manure Basin
3) Egg and Pupae Shed
4) Greenhouse for Breeding

3. Operating Inputs, Prospective Design Considerations, and Costs

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[2] The original Gannet-Fleming design called for pens accommodating 18 hogs. This number was reduced to 15, however, due to construction difficulties. This implies that the SF project had separated solids for larval digestion available from only 15 hogs.

Allocations of funds from the AG/SF/PSF/Frontline Agreements are shown in Tables SF.1 and SF.2. A description of unit processes follows.

3.1. Manure Solids Weighing and Transfer

Solids were collected by the Lake Wheeler belt system and delivered by auger to storage barrels located outside of the barn. This was necessary in order to obtain the weight of the manure in order to be able to calculate and verify the outcome of the experiment. If installed on a commercial swine farm, manure storage barrels would not be needed and, each time the belt ran, manure would be delivered from the belt directly to the manure pump, then to the spreader. Therefore, no manual handling would be needed. At the Lake Wheeler facility, however, manure was fed manually into the pump which distributed it over the basin. According to the technology provider team, the custom fabricated manure pump that was used at Lake Wheeler was only suitable for the pilot scale facility. While use of an automated vermiculture spreader was investigated, it was found not to scale down effectively (small amounts of solids from 18 pigs is not enough for it to reach uniform distribution). In commercial practice, the Black Soldier fly team envisions that the belt would discharge into a manure pump, the manure pump would discharge into a vermiculture spreader and when the spreader was loaded, it would distribute the solids down the length of the larvae basin. Manure pump and controls at the Lake Wheeler facility cost approximately $8,000 (Sheppard). The manure pump had a 2-HP compressor that operated approximately for 15 minutes per day. It was estimated by the technology provider team that the monthly operational expenses for the manure pump at Lake Wheeler facility would not exceed $15 per month.

Maintenance of the pump system includes routine inspection, and likely periodic cleaning (maybe 5 - 10 minutes/week); inspection of the air compressor and its air filter, check for and drain accumulated water from the air tank (an automatic drain valve could be installed to eliminate this), and checking the level of oil in the air line oiler, probably once per month (maybe 5 - 15 minutes per month). A larger installation would likely use a more durable compressor which would require a periodic oil change. The pump will be driven by a pump head designed for long term, unattended use in leachate recovery wells, so it should last at least several years with minimum maintenance (lubricated by oil mist in air line).

Solids distribution system and controls cost $ 2,500 This system was intended to spread the manure evenly across the basin after it was pumped into the basin from the barn. The system has significant over capacity for the current installation, but is not capable of handling a typical installation on a commercial farm. A vermiculture spreader would likely be used on a full-scale commercial farm. A spreader that is capable of handling a 200 ft long manure basin was quoted at a price of $ 8,000 (Sheppard).

Operating costs - The distribution system at Lake Wheeler uses one 1/3-HP motor and one ½-HP motor. If they run for 15 minutes per day, electrical usage would be about 8 kWh / month. The technology provider team does not have data available for the commercial vermiculture spreader, but they expect that it would be in the range of 5 - 10

HP. For example, if a 7.5-HP motor was used and it was run 60 minutes per day, it would use about 260 kWh per month. The manure pump located at the Lake Wheeler facility was never run continuously for an extended period of time and therefore the actual energy usage of the system is not available. It can be estimated, however, not to exceed $25 per month.

Maintenance costs - The experimental system at Lake Wheeler requires routine inspection and lubrication at two points where sealed bearings could not be used. Lubrication with a grease gun is estimated to take about 10 minutes per month. Periodic cleaning of the whole system may also be necessary, but no information on regular maintenance is available due to short duration of experiment. No information is available at this time about the maintenance of a commercial vermiculture spreader. If the vermiculture spreader was used, additional modifications of the system including the addition of a track system to the larval basin would be needed. The Black Soldier Fly technology team was developing a design for a full-scale operation but it was not available for this report.

3.2. Manure Basin Building

The manure basin building at the Lake Wheeler facility is a commercially available carport, which cost $535 as erected on the site (including labor cost). The facility was developed for warm weather operation only. Site preparation was handled by NCSU personnel, but would be significant since it was necessary to add fill dirt. Site preparation consisted of fill dirt, geotextile, and gravel (the latter two to make the site all-weather and improve its appearance and ease of maintenance - eliminate mowing). For part-year operation, if side curtains and basin heating were added to extend the SF season, such a building could be commercially viable. The Black Soldier Fly team was quoted a price of $ 4,200 for a 24' x 75' building of similar construction. Side curtains would add about $ 500 (or $ 1,500 for insulated curtain) for a building of this size (24’ by 75’) (Sheppard).

For a proposed year-round installation, the building could be an insulated, clear-span steel building; similar to a swine barn or a poultry house; or, perhaps least expensive, a hoop building (FarmTek had a 30' x 72' hoop building for less than $3,000, without ends, not-erected; would likely need blown-on polyurethane or other insulation). For swine or poultry type buildings, it would likely be necessary that insulated side curtains be used, in addition to overhead insulation. The floor of the building could be concrete, in which case it would also serve as the floor of the larvae basin, or gravel. Rather than heating the building, cool weather operation would likely be supported by supplying most of the heat directly to the larvae basin using resistance heat or circulating hot water within the basin floor. An exception could be if stacked larvae basins were developed, but although such a system would maximize building output, basin residue clean-out could be difficult to mechanize.

The larvae culture basin was constructed by pouring a 12' x 14' concrete slab 3.5" thick (1.8 cu yd) and erecting ramps made from reinforced, aerated, autoclaved concrete (Hebel Concrete from Babb International, Inc. - www.babb.com/aac - supplied without charge) fastened together with screws, and covering 18" of the slab down both sides (to give an interior basin capacity very similar to a 12' x 12' x 1' straight walled basin; although in this study, maximum manure coverage was only ½ the flat, 9'x14' area). The technology provider proposed that such a system be used commercially, since the aerated concrete is light weight (floats in water), is easily transported, and assemblage is much faster than building forms and pouring concrete. The ends of the basin are 1/2" plywood covered with hardware cloth and Surewall (surface bonding material for masonry), but could have been cinder block or preformed, aerated concrete. The basin ends were fabricated before the basin was constructed to save space in the building (compared to block), for ease of transport, and quick erection. A (rough) cost estimate for the ramps and ends was about $ 450 (Sheppard).

Maintenance and cleaning of the larvae basin: It is envisioned that the residue would be removed from the basin once per year (basis for designing basin depth) using a skid steer loader. At this time, there is no estimate of the time and equipment required. For a commercial size operation, the basin would have loader access at each end, and if over 100 feet long, probably additional access points. In order to have a continuous process it may be necessary to have more than one basin, such that all manure could be directed away from the basin to be cleaned-out during some minimum manure production period during the year. Alternately, all manure could be spread on one end of the basin (for example one-half the length) while the residue is removed from the other end. Larvae production would then be re-introduced to the cleaned portion and the residue removed from the remaining end. (It should be possible to remove some of the larval stratum from the remaining end using a loader, dump it into the vermiculture spreader, and distribute the larvae to the cleaned end, such that the entire basin could be cleaned during a single operation without interrupting manure processing.) The technology providers envisioned that the cleaning could be done by individuals or businesses that currently remove and spread poultry house manure on a custom basis, such that the swine producer would not have to purchase loaders and spreaders.

3.3. Egg and Pupae Holding Shed and Greenhouse

A small shed located behind the basin building is intended to be held at a constant temperature of about 80^{o}F for egg and pupae development. According to the technology provider team, sizing is inexact at this time but a small room should be able to serve a commercial farm. It is anticipated this will be the smallest unit in this process and easy to maintain. Egg hatch and pupae holding will probably be done in a small multipurpose workshop/lab on a commercial farm.

3.4. Greenhouse for Breeding

The greenhouse at the Lake Wheeler site was 6' 6" wide by 9' 9" long and was purchased as a kit. The price for this greenhouse was $ 1,049 plus $ 139 for the base ($1,188). In addition, approximately 0.6 cu. yd. of concrete was poured for the floor. Current price for the evaporative cooler installed in the greenhouse is $ 337 (it is 1/8-HP, running 18 hr. / day it would use about 220 kWh of electricity per month).

4. Mass Balance and Performance Data

In 2003, 375.6 pounds of fresh manure solids (150.7 pounds dry weight) were added to the manure basin at the Lake Wheeler Black Soldier Fly facility. A total of 45,000 live black soldier fly larvae were also added to the basin. The manure was converted into 92.5 pounds (dry weight) of black soldier fly residue by the larvae. As a result of this conversion, 37,978 prepupae were available for harvest at a total weight of 58.2 pounds. In a separate trial to determine the potential value of black soldier fly digest as a soil amendment, black soldier fly larvae converted 122.2 pounds (dry weight) of fresh manure to 53.3 dry matter pounds of digested manure within a 14-day time period. This trial demonstrated a 56% reduction in dry weight, and reduction in concentrations between 44% and 56% for N, P, and K. Respective mass reductions were 80%, 76% and 79%. Table SF.3. reports the results of this trial (Newton, et. al, 2005).

Similar results from a more extended trial could be used to size a commercial manure basin and building. For example, if 63 square feet (7'x 9') are occupied for 14 days to process 122.2 dry weight of manure solids, then the average loading rate for the manure basin would be 122.2/63/14 = 0.14 pounds dry weight of manure solids per square foot per day to achieve 56% reduction in dry weight.

The following comments were provided by the technology provider team. In other small field trials with swine manure, SF larvae easily digested 0.4 lb dry weight of solids per square foot per day. The schedule for belt operation selected was not optimum for the SF conversion process, as the manure delivered to the larvae basin was dryer than that determined, in earlier trials, to be best for SF culture. In addition, the basin was sized to be able to handle the manure from 18 pigs that were near market weight. In these trials, maximum manure conversion, on a loading rate per square foot, was never achieved. An additional trial, after all the experimental equipment had been successfully "shaken down", would have been necessary to demonstrate maximum conversion, but was not possible. (Sheppard)

5. Valuing Products Derived from Black Soldier Fly Technology

5.1. Valuing By-Product Feedstuff of the Black Soldier Fly Manure Management System

Using the black soldier fly (Hemetia illucens) to convert manure into larval biomass reduces manure residue by about half (Newton, et. al). Black soldier flies incorporate nutrients (N and P) into their biomass and become a potential relatively high-value feedstuff (Sheppard, Newton). A value is estimated here by comparing SF larval feedstuff to existing feedstuffs based on nutritional content. Assuming the larval feedstuff will be produced using the same technology as existing feedstuffs and assuming comparable nutritional content, a range of potential values for SF larval feedstuff is projected.

Black Soldier fly larvae can, according to Sheppard and Newton, replace soybean or fish meal in a formulated diet. Studies on various animals (cockerels, pigs, and catfish) have generally concluded that soldier fly larval meal is a suitable substitute for conventional protein and fat sources (Sheppard, Newton). The dried SF prepupae contain 42 % protein and 35 % fat. These percentages include favorable fractions of both amino acids (Table SF.4) and fatty acids (Table SF.5). See Table SF.6 for the mineral content and proximate analysis of dried soldier fly larvae. Table SF.7 compares the amino acid content of black soldier fly larvae to that of other by-product feedstuffs.

Based on Sheppard and Newton's findings as presented in Tables SF.4 through SF.7, dried soldier fly larvae are compared to other feedstuff that are similar in protein and fat content. Specifically, the findings of Middleton et al. are used to compare SF larval feedstuff to feedstuff produced from swine mortality carcasses and spent laying fowl. The process used for the poultry and swine products and assumed for the SF larvae is dehydration, extrusion and expeller press technology. Extrusion and expeller press technology is utilized to fractionate oils and by-product feed meals (Middleton, et al.). Existing research has proven that it is technically feasible to apply expeller press technology to spent laying fowl and swine mortality carcasses mixed with soyhulls. Before utilizing the expeller press, carcasses must first undergo a flash dehydration and an extrusion stage. The operational parameters for the various stages differ depending on the product being treated.

Efficient flash dehydration requires products that enter the dryer to be friable, with maximum exposed surface area available for dehydration (Middleton, et al.) Blending the product with the optimal amount of soy hulls ensures that the mixture will be suitably friable for efficient flash dehydration. Spent hen product is flash dehydrated using an 80% ground meat and 20% soy hulls mixture. Swine mortality product uses a 90% ground meat and 10% soy hulls mixture for flash dehydration. Because of the relative ratios of soy hulls, flash-dehydrated swine products have a higher crude protein level than flash-dehydrated poultry products. Other differences in the operational parameters for swine products versus poultry products include the drying temperature. Swine products have both higher air inlet and air outlet temperatures and, accordingly, a higher finished product temperature than poultry products. The finished temperature is 160°F for swine products versus 127°F for poultry products. The processing rate also differs depending by product. Swine products were processed at 1,304 lbs. / hour, while poultry products were processed at 731 lbs. / hour (Middleton et al.).

After the flash dehydration stage, the product enters an extrusion process followed by an expeller pressing process. The extrusion operational parameters in Middleton et al.'s report are similar between swine products and poultry products with one notable exception. Swine products required amperage of 108 versus 84 for poultry products. The increased amperage is attributed to the higher percentage of bone or ash in the swine material relative to the poultry material (a pre-extrusion ash % of 11.15 vs. 4.26). Soldier fly prepupae have no bones at all, so amperage should be less than for either swine or poultry. Post-extrusion amounts of oil also differed, as poultry products resulted in 14.25 lbs of oil per 100 lbs of extruded material entering the presser (dry matter basis) compared to 5.05 lbs of oil per 100 lbs of dry material entering the presser for swine products. Amperage was also the most notable difference in expeller press operational parameters: 25 for poultry products versus 20 for swine products (Middleton et al.).

Middleton et al. concluded that using an expeller press resulted in significant increases in crude protein and significant decreases in crude fat concentration in the meal. The composition of amino acids was not significantly affected by using the expeller. Post-expeller percentages of protein and fat differed across product. Poultry products contained 33.97% protein while swine products contained 48.27% protein. Poultry products contained 45.02% fat (crude fat plus bound fat) as compared to 36.27% in swine products. The composition of SF larval feedstuff is very comparable to the poultry and swine-processed feedstuff in both its protein (42%) and fat (35%) percentages. Further, the composition of essential amino acids in the SF larval feedstuff is comparable to the poultry and swine-processed feedstuffs (see Table SF.7). It is projected that production of SF larval feedstuff using the flash dehydration, extrusion, and expeller press process will result in meal with composition of protein, fat, and amino acids that is similar to that of the meal produced by processing spent laying fowl and swine mortality carcasses using the same technology. Therefore, the SF larval feedstuff is valued here in the same manner as the spent hen and swine mortality products.

Middleton et al. used a least-cost linear programming model (University of Georgia's UFFDA software) to value the post-extruder and post-expeller meals. This value was estimated as the shadow price of the meals for inclusion in 100% NRC corn/soy based diets for broilers (Middleton, et al.). Values were estimated for birds of three separate age groups: 0-3 weeks, 3-6 weeks, and 6-8 weeks. The results are summarized in Table SF.5. The value of extruded meals is greater in all cases than the value of expelled meal plus expelled oil and fat. Based on 2001 market prices used by Middleton et al., the higher-fat meals (post-extruded) have higher value than the lower-fat meals (post-expelled) plus expelled oil and fat. Prices used by Middleton et al. in this study were taken from the September 3, 2001 edition of "Feedstuffs." Corn, soybean meal, and wheat middlings were priced at $93.57/ton, $201.00/ton, and $51.00/ton respectively. Poultry fat and lard were priced at $0.12/lb and $0.155/lb respectively in September of 2001.

Table SF.8 summarizes the value calculated for a ton of swine or poultry product using the flash dehydration, extruder, and expeller press technology. Using some assumptions, these values can be used to project profits and costs of the process for the two products. Table SF.9 contains the assumptions that are necessary to calculate profits and total fixed costs. Table SF.10 shows capital expenditures, including the costs of dryers, extruders, and expellers. Table SF.11 shows gross profits (value of product minus cost of ingredients), direct and fixed costs, and net annual profits. Direct costs include fuel and electricity used in the drying, extruding, and expelling stages, as well as labor costs. Fixed costs include depreciation and interest. Consistent with the values in Table SF.8, extruded poultry and swine meal will have higher profits than expelled poultry and swine meal plus expelled oil and fat using Middleton et al.'s 2001 prices and assumptions.

Following Middleton et al.'s analysis, a range of values is predicted for SF larval feedstuff. The 2001 post-extruded meal value for feeding a 3-6 week-old bird ranges from $208.71 per ton for spent hen product (with its 34% protein and 45% fat content) to $232.11 for swine mortality product (48% protein and 3 % fat). Given that SF larval feedstuff content of 42% protein and 35% fat content falls in the same general range as the poultry and swine products, we consider their predicted values to be a reasonable predicted range for the value of the SF product. For post-expelled meals (again assuming a 3-6 week-old bird), the range is $194.13 per ton for spent hen product and $222.62 for swine mortality product.

Adopting the assumptions from Table SF.9, a range of net annual profits can also be predicted for SF larval feedstuff. Annual profit estimates are based on an installation processing about 5,000 tons (dry weight) of material annually. No transportation costs or on-farm production and collection costs are included in the estimates. For extruded larval feedstuff, the range of predicted net annual profits was from $13,862 (spent hen product profits based on 2001 prices) to $47,239 (swine mortality product profits with 2001 prices). The range of net annual profits for expelled larval feedstuff will extend from (-$13,784) (spent hen product profits with 2001 prices) to $14,290 (swine mortality product profits with 2001 prices). See Table SF.11 for a detailed breakdown of net annual profits. Based on these numbers, post-extruded larval feedstuff appears to generate a profit above processing cost. The post-expelled larval feedstuff predicted margin ranged from losses to net profits for the modeled 5,000 ton per year facility.

To demonstrate the effect of higher feedstuff prices on the estimates, prices from the January 26, 2004 edition of "Feedstuffs" are used to recalculate projected profits. The prices reported then for corn, soybean meal, and wheat middlings were $120.00 per ton, $286.00 per ton, and $90.00 per ton respectively. Poultry fat and lard prices were $0.1325/lb and $0.22/lb respectively. Soyhulls, an input in the flash dehydration stage, were priced at $60.00 per ton in September, 2001 and $100.00 per ton in January, 2004. Based on these updated prices, the least-cost linear programming model utilized by Middleton et al. (UFFDA software) was used to calculate a new range of values for SF larval feedstuff (Table SF.7. 2004 values). The post-extruded value of larval feedstuff product (for the diet of a 3-6 week-old bird) ranges from $263.86 to $307.56 per ton. The range for the post-expelled value of larval feedstuff (for the diet of a 3-6 week-old bird) extends from $255.17 to $301.30 per ton. The higher 2004 prices increase the predicted value of SF larval feedstuff. It is also of note that the product of the expeller technology becomes more profitable with 2004 prices. The value differences between post-extruded meals and post-expelled meals plus expelled oil and fat decreased for all products and bird ages between 2001 and 2004. In some cases (swine mortality product for birds 0-3 and 3-6 weeks), the expeller press technology actually generated higher profit estimates.

As relative prices for low-fat meals continue to increase, the profitability of post-expeller products also continue to increase.

Higher predicted profit margins are also predicted for SF larval feedstuff using the 2004 prices. The predicted gross profits (sales value minus soyhull cost) on post-extruded meals will increase by 19.7 % to 37.0 % using 2004 prices. The predicted gross profit range on post-expelled meals increases by 17.6 % to 41.9 % with 2004 prices. Application of 2004 prices results in predicted net profits above processing costs for both post-extruded and post-expelled larval feedstuffs.

Additional by-product profits are possible if larval feedstuff can be used as a substitute for fish meal. A catfish feeding trial conducted by University of Georgia's Gary Burtle suggests that this use for larval feedstuff is feasible. Burtle's study involved adding five rates of black soldier fly (SF) prepupae to the base diets of catfish. The rates of SF prepupae ranged from 0 % to 30% and were compared to a baseline commercial catfish diet. Feed-to-gain ratios improved (decreased) as higher percentages of SF prepupae were used. Moreover, the rate of weight gain per day also improved (increased) with increased rates of SF prepupae in the diet. Diets consisting of 22.5 % and 30 % SF prepupae clearly outperformed the commercial catfish diet and even diets with as low as 7.5 % SF prepupae performed similarly to the baseline diet. Based on Burtle's study, it appears that SF larval feedstuff can perform as a substitute for fish meal. In the January 19, 2004 edition of "Feedstuffs", fish meal was valued at $530.00/ton. Compared to the 2004 range of estimated values for post-expelled larval feedstuff for broiler diets ($255.17-$301.30), SF larval feedstuff may be more valuable as a fish meal substitute. St. Hilaire et al. (in press) reports that replacement of fish meal by SF meal at up to 25% results in the same growth in rainbow trout. She also reports that SF larvae can recover omega-3 fatty acids from fish offal.

5.2. Valuation of Black Soldier Fly Residual

The residual after Black Soldier Fly larvae have digested swine manure solids is compared here to vermicompost. Vermicomposting involves the use of earthworms to process organic waste and transform it into nutrient-bearing castings. Castings are created when worms feed on micro-organisms growing on the surface of the waste and subsequently excrete particles of smaller size. It is important to make the distinction between castings and vermicompost: castings are the actual worm manure whereas vermicompost includes a mixture of castings, aerobically decomposed organic materials, and partially decomposed organic material (Sherman).

The overall market for compost has been growing in recent years and is characterized by increasing segmentation. Composters are divided into a "dollar" market and a "volume" market, with "dollar" composters selling a unique product that can command a higher price and "volume" composters selling a standard product that can generate revenues when sold in large amounts (Doherty and McKissick)

Vermicompost is currently sold primarily by retail home and garden stores and internet retailers. Internet retailers typically sell worms and worm composting materials in addition to vermicompost. The market for vermicompost is described by Jim McNelly as a "high price, low volume" industry relative to the overall compost market. It is usually sold in bags ranging from 1 to 30 pounds with prices ranging from $0.50 to $1.00 per pound (USCC, Doherty and McKissick). Prices cover a wide range and vary more than those in established compost markets. A market value for bulk vermicompost is projected here based on research at The Ohio State University (OSU). Researchers at OSU conducted a study to link the use of vermicompost to actual plant growth yields. Their research utilized a 10 % to 20 % vermicompost sphagnum and perlite soil mix where the vermicompost was derived from 2 % nitrogen pig manure fed at a 10 % worm density for 60 days. Using this soil mix in greenhouse trials, researchers found increases of 20 % to 200 % (or the same growth in less time) in plant growth when compared to control composts containing zero percent worm castings (Edwards, Burrows). Additional research has proven that incorporating 10 % or 20 % of vermicomposted pig solids into a standard commercial potting medium (Metro-Mix 360) will significantly enhance the growth of marigold and tomato seedlings as compared to the Metro-Mix 360 alone (Atiyeh, et. al). If these results can be realized consistently, a vermicompost product could command a price of $140/ton delivered to the point of soil mixing. This price is based on comparison to the price of a delivered bale of sphagnum peat moss and the assumption that the vermicompost soil mix will be 3 times as valuable (USCC).

Because vermicompost is not a singly-defined product, there exist appreciable differences in nutritional content produced by different earthworms and with different media. Regardless of how it was produced, vermicompost generally contains higher percentages of carbon and nitrogen than standard farm manure or a commercial potting medium (Atiyeh, et al.). Carbon:nitrogen ratios vary across vermicompost, and are in the range of 18:1 to 25:1 for vermicomposted swine solids. In general, vermicomposted swine solids have a nutritional profile that is similar to that of Black Soldier Fly digested swine manure. See Table SF.12 for a nutritional comparison of the two products. Because of their similar nutritional profiles, the markets for Black Soldier Fly residue and worm castings are likely similar.

A well-established national market for vermicompost does not appear to exist at this time. Local markets do exist, but prices differ across these markets with seemingly no regard to product quality (Doherty and McKissick). Based on growth trials, an implied price of $140 per ton of vermicompost was derived (USCC). With a similar composition of nutrients, SF larvae residue may have similar value. Much more work remains to be done to establish markets and confirm these estimates.

If residue is sold there would be a savings in avoided manure land application costs where solids are already being separated. Also, if manure is used on the farm, there may be an avoided land application cost associated with the mass reduction produced by SF.

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Tables SF.1 through SF.2: Invoiced Construction and Operating Costs for the Lake Wheeler Black Soldier Fly Facility

Table SF.1. Budget Allocation (Use of Agreement and non-agreement funds) (Sheppard)

Supplies/Operating	$17,798
Travel	$7,502
Student	$5,798
Labor/Technical	$22,942
Fringe Benefits	$7,310
Indirect Cost	$7,094
Total	**$68,444**

Table SF.2. Supplies/Operating (Detail) and Other Funds (Sheppard)

Building for larvae basin	$945
Larvae basin	$950 (including $600 for unused heating strips)
Greenhouse and evaporative cooling unit	$1,586
Journal charges	$528
Laboratory analysis	$398
Hatching/Egg shed	$800
Misc. charges for gas, lab supplies, etc.	$447
Manure pump	$8,000 (never used)
Other materials	$1,194
Labor	250 hours
Total Supplies/Operating	**$14,848**
Other funds:	
Donated air-floated concrete	$100
Donated fabric for siding	$160
Donated wire	$150

Table SF.3: Mass Balance and Nutrient Reductions Associated with the Conversion of Swine Manure to Black Soldier Fly Digested Manure

Table SF.3: Mass Balance and Nutrient Reductions Associated with the Conversion of Swine Manure to Black Soldier Fly Digested Manure (Newton, et. al)

	Pig Manure	Black Soldier Fly Residue	% Reduction
Element			
Dry matter weight (lbs.)	122.2	53.3	56.4%
N (ppm)	923.7	414.5	55.1%
N Mass (g)	51.2	10.0	80.5%
P (ppm)	676.2	378.0	44.1%
P Mass (g)	37.5	9.1	75.7%
K (ppm)	358.7	169.3	52.8%
K Mass (g)	19.9	4.1	79.4%

Tables SF.4 through SF.7: Nutrient and Amino Acid Content of Black Soldier Fly Larvae

Table SF.4. Amino Acid Content of Dried Soldier Fly Larvae, Dry Matter Basis (Sheppard, Newton)

Amino Acid	**Percent**	**Amino Acid**	**Percent**
* Methionine	0.9 %	Tyrosine	2.5 %
* Lysine	3.4 %	Aspartic acid	4.6 %
* Leucine	3.5 %	Serine	0.1 %
* Isoleucine	2.0 %	Glutamic acid	3.8 %
* Histidine	1.9 %	Glycine	2.9 %
* Phenylalanine	2.2 %	Alanine	3.7 %
* Valine	3.4 %	Proline	3.3 %
* Arginine	2.2 %	Cystine	0.1 %
* Threonine	0.6 %	Ammonia + unidentified	1.3 %
* Tryptophan	0.2 %		

* Essential

Table SF.5. Concentrations of Some Fatty Acids Present in Soldier Fly Prepupae Oil, Dry Matter Basis (Sheppard, Newton)

Fatty Acid	Percent
Capric	1.6 %
Lauric	53.2 %
Myristic	6.6 %
Palmitic	8.4 %
Stearic	1.7 %
Oleic	12.4 %
Linoleic	8.8 %

Table SF.6. Mineral Content and Proximate Analysis of Dried Soldier Fly Larvae, Dry Matter Basis (Sheppard, Newton)

Mineral Content		Proximate Analysis	
P	1.51 %	Crude Protein	42.1 %
K	0.69 %	Ether Extract	34.8 %
Ca	5.00 %	Crude Fiber	7.0 %
Mg	0.39 %	Ash	14.6 %
Mn	246 PPM	NFE	1.4 %
Fe	1370 PPM	Moisture	7.0 %
B	0 PPM		
Cu	6 PPM		
Zn	108 PPM		
Al	97 PPM		
Sr	53 PPM		
Ba	33 PPM		
Na	1325 PPM		

Table SF.7. Content of Five Essential Amino Acids Among Various By-Product Feedstuffs (Shepard, Newton)

	Spent Hen Product	Dried Soldier Fly Larvae	Swine Mortality Product
Lysine	2.20 %	3.4 %	2.575 %
Threonine	1.265 %	0.6 %	1.410 %
Tryptophan	0.405 %	0.2 %	0.39 %
Phenylalanine	1.24 %	2.2 %	1.535 %
Arginine	1.745 %	2.2 %	2.585 %
Totals	6.855 %	8.6 %	8.495 %

Tables SF.8 through SF.11: By-Product Value of Black Soldier Fly Larval Feedstuff

Table SF.8. Value of Products in NRC Broiler Diets ($/ton) (Middleton, et al.)

	Spent Hen Prod.		Swine Mortality Prod.	
	2001	**2004**	**2001**	**2004**
Value of post extruded meal (a)				
Birds 0 to 3 weeks	198.29	250.61	243.40	321.91
Birds 3 to 6 weeks	208.71	263.86	232.11	307.56
Birds 6 to 8 weeks	192.27	245.86	217.62	282.84
Value of post expelled meal (b)				
Birds 0 to 3 weeks	184.92	243.46	236.96	319.52
Birds 3 to 6 weeks	194.13	255.17	222.62	301.30
Birds 6 to 8 weeks	174.11	233.44	205.07	269.14
Value of expelled oil/fat (c)				
Birds 0 to 3 weeks	240.00	265.00	310.00	440.00
Birds 3 to 6 weeks	240.00	265.00	310.00	440.00
Birds 6 to 8 weeks	240.00	265.00	310.00	440.00
Value difference between (a) and (b + c)*				
Birds 0 to 3 weeks	-5.52	-4.08	-2.75	3.69
Birds 3 to 6 weeks	-8.04	-7.29	-5.05	0.74
Birds 6 to 8 weeks	-8.77	-7.92	-7.25	-5.07

* 1 ton extruded spent hen product yields 1715 lbs meal (85.75%) and 285 lbs oil (14.25%), thus = 0.8575b + 0.1425c
1 ton extruded swine mortality product yields 1899 lbs meal (94.95%) and 101 lbs oil (5.05%), thus = 0.9495b + 0.0505c

Table SF.9. Assumptions Associated with Production of Products (Middleton, et al.)

	Spent Hen Product		Swine Mortality Product	
	Extruded	**Expelled**	**Extruded**	**Expelled**
Daily vol. of raw material	14 tons	14 tons	14 tons	14 tons
Soyhull requirements				
Daily (lbs)	5,600	5,600	2,800	2,800
Annually (tons)	974	974	487	487
Finished meal production				
Hourly (lbs)	707	606	780	741
Daily (lbs)	11,319	9,707	12,480	11,856
Annually (tons)	1,969	1,689	2,173	2,064
Fat production				
Hourly (lbs)	N/A	100.7	N/A	39.4
Daily (lbs)	N/A	1,612	N/A	630
Annually (tons)	N/A	280	N/A	109
Finished meal value ($/ton)	$208.71	$194.13	$232.11	$222.62
Finished fat value ($/ton)	N/A	$240.00	N/A	$310.00
Hours/day of production	16	16	16	16
Yearly production days	348	348	348	348
Labor	2 shifts @ $13/man hour			
Plant size (sq. ft.)	3,600	3,600	3,600	3,600
Energy costs				
Electrical ($/kwh)	$0.075	$0.075	$0.075	$0.075
Propane fuel ($/gallon)	$0.900	$0.900	$0.900	$0.900
Maintenance costs ($/dry ton)	$2.00	$2.30	$2.75	$2.50
Capital cost of plant	$674,972	$749,967	$725,972	$800,967
Interest (70% financed)	7.5 % annual rate			
Depreciation				
Equipment	Eight (8) years straight-line			
Building	Ten (10) years straight-line			

Table SF.10. 2001 Capital Expenditures (Includes building and major equipment, excludes land) (Middleton et al.)

	Spent Hen Product		Swine Mortality Product	
	Extruded	**Expelled**	**Extruded**	**Expelled**
Drying, extruding, expelling				
ITS dryer(s)	$175,000	$175,000	$108,000	$108,000
1-Insta-Pro® Ext. (2000RC)	$48,213	$48,213	$48,213	$48,213
1-Insta-Pro® Cooler (#836)	$17,859	$17,859	$17,859	$17,859
1-Insta-Pro® Expeller	-	$55,495	-	$55,495
Total	$241,072	$296,567	$174,072	$229,567
Material Handling				
1-Grinders/prebreakers	$42,000	$42,000	$145,000	$145,000
1-Live bottom surge bin	$25,000	$25,000	$25,000	$25,000
1-Horizontal mixer	$56,000	$56,000	$56,000	$56,000
Misc. augers and inside bins	$33,900	$50,400	$33,900	$50,400
Total	$156,900	$173,400	$259,900	$276,400
Building, Wiring, and Scales				
3,600 sq. ft. building	$90,000	$90,000	$90,000	$90,000
Truck Scale	$42,000	$42,000	$42,000	$42,000
Wiring	$80,000	$82,000	$95,000	$98,000
Installation labor	$50,000	$51,000	$50,000	$50,000
Land preparation	$15,000	$15,000	$15,000	$15,000
Total	$277,000	$280,000	$292,000	$295,000
Grand Total Estimate	**$674,972**	**$749,967**	**$725,972**	**$800,967**

Table SF.11. 2001 Financial Pro Forma (Middleton et al.)

	Spent Hen Product		Swine Mortality Product	
	Extruded	**Expelled**	**Extruded**	**Expelled**
Meal sold	$410,949	$327,885	$504,136	$459,487
Oil sold	-	$67,200	-	$33,790
Cost of soyhulls ($60/ton)	($58,440)	($58,440)	($29,220)	($29,220)
Gross Profit (a)	**$352,509**	**$346,645**	**$474,916**	**$464,067**
Direct Costs				
Drying (fuel)	($23,490)	($23,490)	($70,877)	($70,877)
Drying (electrical)	($24,220)	($24,220)	($22,550)	($22,550)
Extrusion (electrical)	($23,490)	($23,490)	($23,490)	($23,490)
Expeller (electrical)	-	($9,604)	-	($9,604)
Other electric (50 kwh)	($1,305)	($1,305)	($33,408)	($33,408)
Labor	($144,768)	($144,768)	($144,768)	($144,768)
Maintenance	($3,938)	($3,884)	($5,975)	($5,160)
Total Direct Costs (b)	**($221,221)**	**($229,561)**	**($301,068)**	**($309,857)**
Operating Profit (a) – (b) = (c)	**$131,296**	**$117,084**	**$173,846**	**$154,210**
Fixed Costs				
Depreciation	($82,000)	($91,495)	($88,496)	($97,870)
Interest	($35,436)	($39,373)	($38,113)	($42,050)
Total Fixed Costs (d)	**($117,439)**	**($130,868)**	**($126,609)**	**($139,920)**
Net Annual Profit (c) – (d)	**$13,862**	**($13,784)**	**$47,239**	**$14,290**

Table SF.12: Nutrient Comparison of Black Soldier Fly Digested Swine Manure and Vermicomposted Swine Solids

Table SF.12. Nutrient comparison of Black Soldier Fly digested swine manure and vermicomposted swine solids. (Sheppard), (Atiyeh, et al.)

Nutrient	Digested SF Residue (% dry weight)	Vermicomposted Swine Solids (% dry weight)
N	4.15 %	2.36 %
C	42.33 %	43.8 %
P	3.78 %	4.5 %
K	1.69 %	0.4 %
C:N	10.21	18.56