REPORT FOR MIKE WILLIAMS

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# USING THE BLACK SOLDIER FLY, *Hermetia illucens*, AS A VALUE-ADDED TOOL FOR THE MANAGEMENT OF SWINE MANURE


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## EXECUTIVE SUMMARY

Previously reported work has shown that black soldier flies (*Hermetia illuscens*) are effective in reducing the mass as well as the nutrient and moisture content of hen manure. Preliminary results from using the black soldier fly to digest swine manure solids suggested that the system could be even more effective for swine manure. A small scale system for digesting swine manure solids, harvested by a belt beneath a slatted floor holding pigs, was installed and tested. Manure mass was reduced 56% while the concentrations of most elements and nutrients were reduced 40 to 55 %. Nutrient analyses and feeding studies indicate that dried black soldier fly prepupae grown on swine manure solids have value as a feedstuff, particularly for aquaculture. In a pot study, plant growth was increased when the digested manure residue was added to either a clay soil or clean sand.

Key words: Manure digestion, Insects, Maggots, Feed, Amino acids, Soil amendment

## INTRODUCTION

Manure is the principal food of many insects in nature, especially the larva of the black soldier fly (*Hermetia illuscens*) (Figure 1). Insect utilization contributes to natural recycling of nutrients and the insects produced are food for many larger animals. Insects convert residual manure proteins and other nutrients into their biomass, which is a high quality animal protein feedstuff. Considerable research has been conducted to understand and exploit this activity for manure management. Scientists in China, USSR, United States, Mexico, Eastern Europe, Israel, Australia and Central and South America have studied manure digestion with insects to produce high quality feedstuff. Lately, the emphasis has shifted from feedstuff production to potentially using insects to solve the problems associated with the large amounts of manure produced on Concentrated Animal Feeding Operations (CAFO's). While incorporating and concentrating nutrients from manure into more valuable biomass (animal feedstuff), insect larvae reduce the nutrient concentration and bulk of the manure residue, thus reducing pollution potential 50-60% or more. Because of its' value ($0.50/kg or more), this feedstuff can be economically hauled significant distances (unlike manure) to relieve local nutrient overloads. Also, while occupying the manure they aerate and dry it, reducing odors. Maggots modify the microflora of manure, potentially reducing harmful bacteria (Erickson, et al., 2004). The high-value insect feedstuff, reduction of the manure mass, moisture content, offensive odor, and pollution potential are the returns for good management of such a system.

The black soldier fly (*Hermetia illucens*) is a native insect common to the southeastern United States. Adults live and mate and lay their eggs in cracks and crevices near larval habitat (Figure 1). The black soldier fly is not recognized as a pest because the adult is not attracted to human habitation or foods (Furman et al. 1959). Adults do not need to feed, surviving on the large fat body stored from the larval stage. The larva of the black soldier fly is a voracious consumer of decaying organic matter including kitchen waste, spoiled feed, and manure.

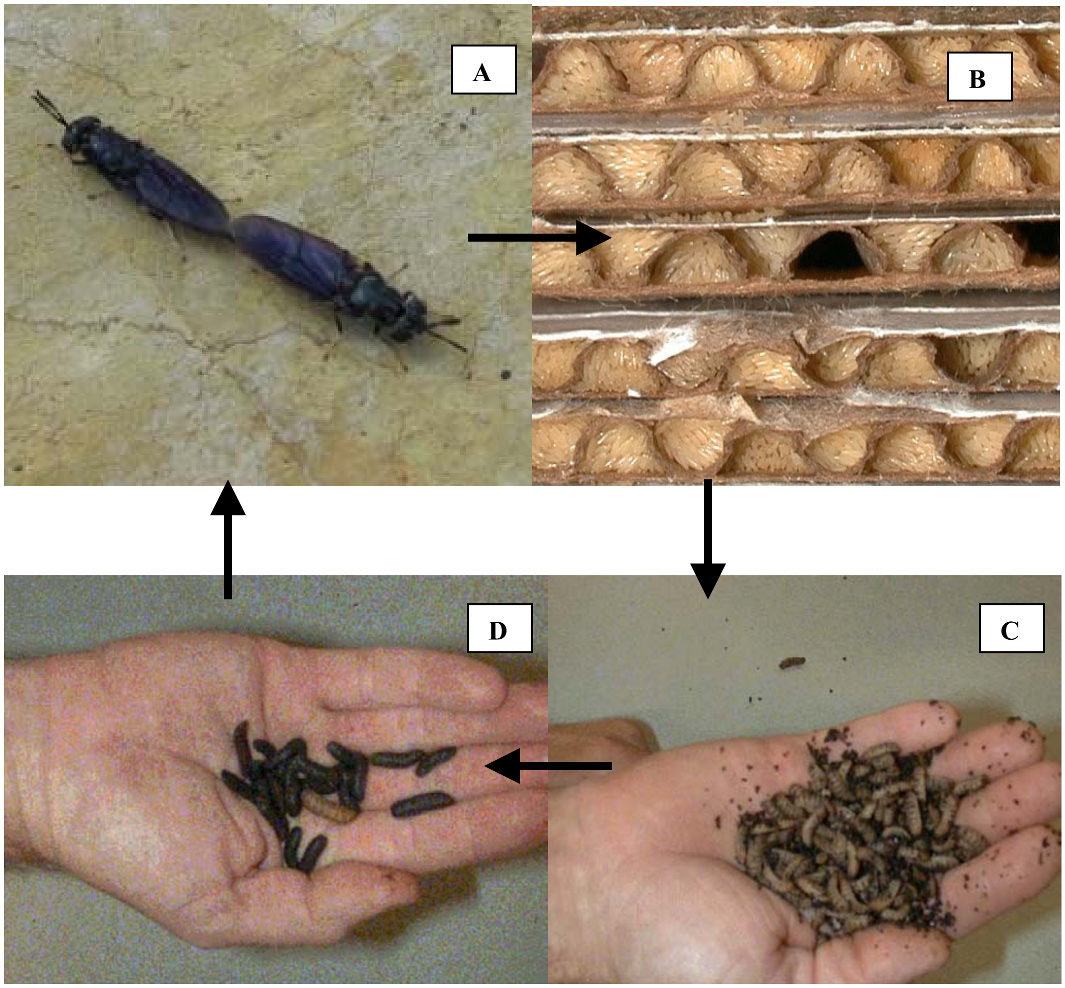



Figure 1. Life stages of the black soldier fly. The adult flies are not considered a pest (A. mating adults). Females are occasionally observed depositing their eggs in cracks and crevices near larval substrate. For rearing purposes eggs were collected in cardboard flutes (B). Larvae consume large quantities of organic wastes including spoiled animal feed or fresh manure (C. larvae), and the self-harvesting prepupae can be used as a feedstuff (D. prepupae and pupae).

Historically, the black soldier fly flourished in open-sided caged layer houses common to the southern U.S. In these situations soldier fly larvae were present by the millions, but only a few ovipositing females were observed. These unmanaged populations eliminated house fly breeding through larval competition and female house flies avoided ovipositing where *Hermetia illuscens* larvae occurred. Although, the black soldier fly reduced manure residue in such poultry operations, utilizing black soldier fly as a feedstuff harvest was never attempted.

## BLACK SOLDIER FLY MANURE MANAGEMENT SYSTEMS

The simplest black soldier fly manure management system utilizes wild fly populations to digest the manure. The larvae occur in very dense populations on organic wastes as diverse as manures, coffee bean pulp, vegetables, catsup and carrion. Mature larvae (prepupae) can be harvested and used as a feedstuff. The black soldier fly system developed by Sheppard et al. (1994) converted poultry manure to a 42% protein, 35% fat feedstuff at an 8% dry matter conversion rate (Sheppard et al., 1994). This system also controlled house flies (Sheppard, 1983) and reduced manure volume by 50% (Sheppard 1983), including a 24% reduction in total nitrogen concentration (62% reduction of N mass) (Sheppard et al., 1998).

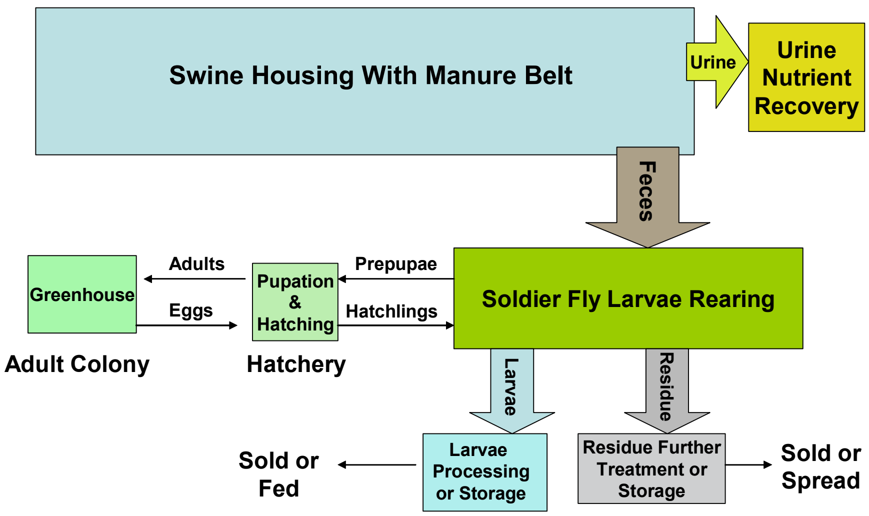
Black soldier fly are most easily managed in concrete basins directly under caged layers or swine. No separate facility or special equipment is needed for production or harvest. This is possible because of the migratory habits of the prepupae. This migration occurs because larvae need to leave the manure to successfully pupate to an adult. At this stage they are at their maximum size, with a large store of fat to sustain them through metamorphosis. Migrating prepupae have evacuated their digestive tract and no longer feed, but use their mouthparts to pull their body along in the quest for a safe pupation site. Pupation takes a minimum of 10 days so collections can be stockpiled prior to processing or utilization. Theoretically, in a 5-month season, when black soldier fly are most abundant, a 100,000 bird caged layer house could produce 53 t of prepupae suitable for feed.

## PROJECT DESIGN AND INFRASTRUCTURE

Recent developments in rearing this insect allow for waste management in fully contained situations (Figure 2). Swine waste collected by conveyor belt was separated into manure solids, and urine plus excess water; which drained off the sides of the belt into collection gutters (Baird et al. 2004). Collected manure solids were delivered to the larval culture basin (Figure 3). The larval culture basin contained 90,000 to 100,000 mixed aged larvae/$m^2$. A $35^o$ ramp along opposing walls of the manure pit directed the migrating prepupae to gutter at the top. This gutter directed prepupae to collection containers. A portion of the prepupae were saved and used to support the adult soldier fly colony. Eggs from the adult colony were used to maintain larval densities sufficient to digest the manure. The remaining prepupae were frozen until the composite was dried for feed preparation.

During 2003, 169 kg of fresh manure (67.8 kg dry wt) was delivered to the manure basin. A total of 45,000 live black soldier fly larvae were added to the basin. These larvae converted the manure into 41.6 kg dry weight of black soldier fly digest, resulting in 37,978 prepupae for harvest, weighing 26.2 kg.

A. Diagram of potential arrangement of a full scale black soldier fly manure digestion system




B. Using soldier flies to process swine manure solids into a feedstuff and a soil amendment

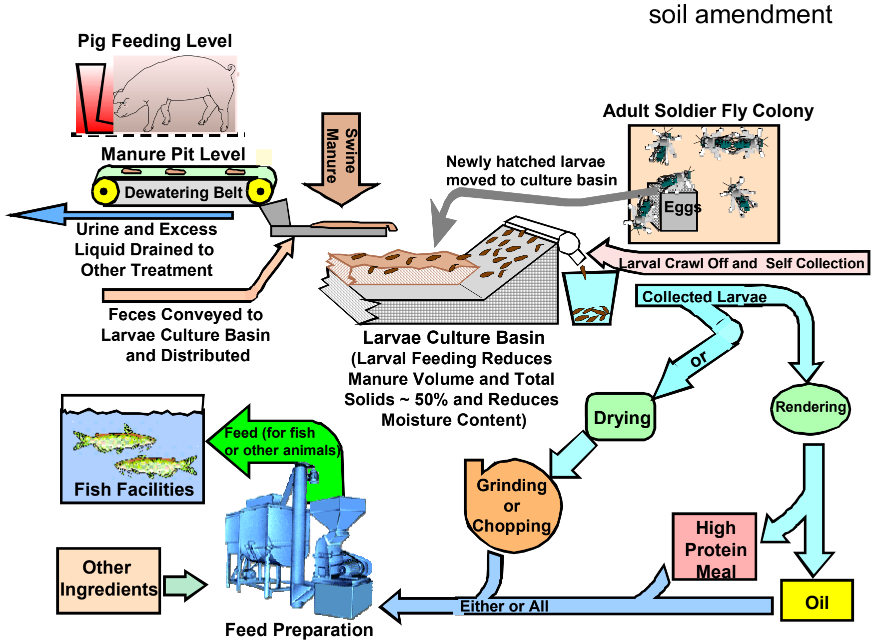



Figure 2. Schematic (A.) and detail (B.) of the black soldier fly production system

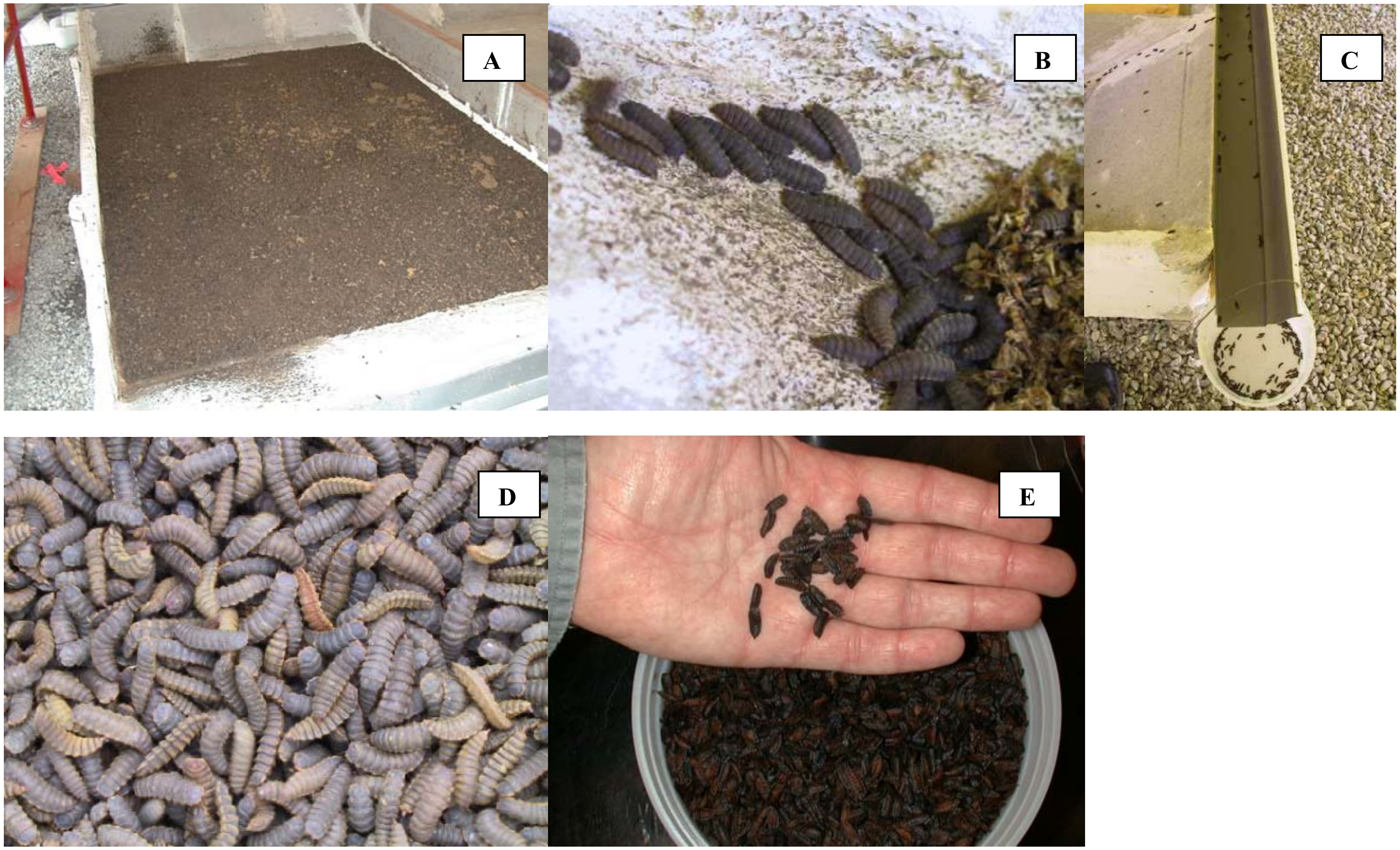



Figure 3. Harvesting process of black soldier fly: larvae consume the fresh manure in the deposited in the basin (A), the migrating larvae climb the 35$^o$ ramp (B), falling into a gutter and bucket collection system (C). The collected prepupae (D) were frozen and dried at 70$^o$C for storage (E).

To fit the project layout, a method to deliver manure solids to the basin was explored. A compressed air driven piston pump, capable of delivering fresh manure to the basin was developed in Georgia (Figure 4). The capacity of the manure receptacle was about 2 liters. As the piston slide was retracted, about 0.5 to 0.75 liters of manure dropped into a void anterior to the piston drive. Under pressure the manure was forced into a 7.5 mm flexible hose attached to a manure spreader. The manure spreader was suspended over the black soldier fly basin from a beam. Driven by an electric motor, the spreader traveled the length of the beam on a wheeled dolly. Trip mechanisms positioned at either end of the beam triggered a switch reversing the direction of the manure spreader. Shielded rotating fans distributed the manure across the basin.

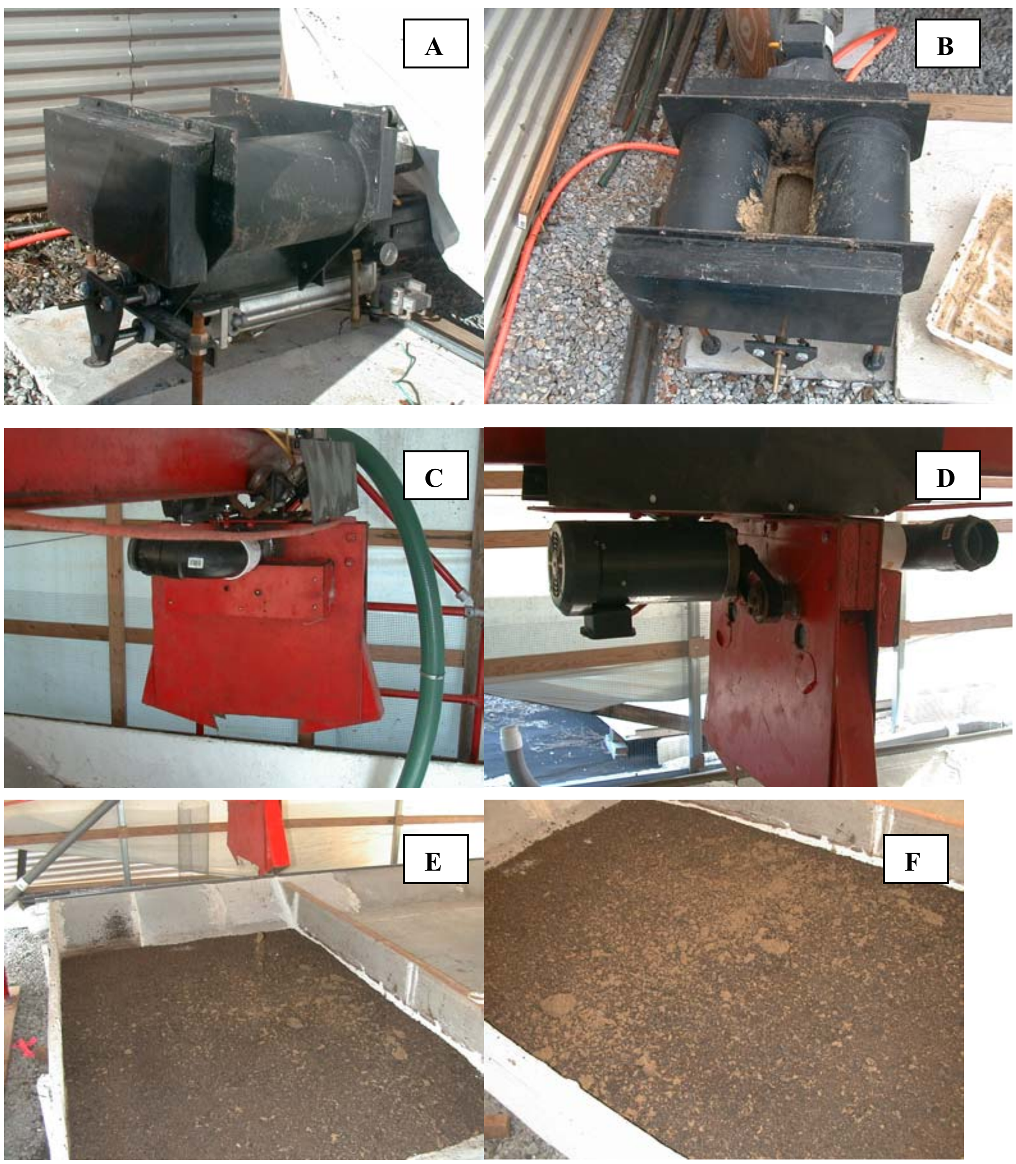



Figure 4. Compressed air driven piston pump (A and B) was used to deliver fresh manure to a manure spreader traveling a beam (C and D). Shielded rotating fans spread the manure across the larval basin (E and F).

## POTENTIAL FEED VALUE OF LARVAE

Soldier fly larvae have been fed experimentally to several animal species, with larvae or prepupae used to replace soybean or fish meal in formulated diets. These feeding tests have utilized cockerels (Hale, 1973), pigs (Newton et al., 1977) and catfish and tilapia (Bondari & Sheppard, 1981, Sheppard and Newton 2000). The soldier fly larval meal was a suitable replacement for conventional protein and fat sources. Amino acid profiles reported by Newton et al. (1977) for a mixed age larval population harvested from finishing steer manure, and that for self-harvested prepupae from swine manure during 2003 and analyzed by a commercial laboratory (Table 1). If rendered to obtain oil and protein meal, amino acids levels should be about 40% greater than those shown (Table 1). Essential amino acid levels for such a meal from larvae produced on swine manure should be similar to soybean meal in lysine, lucine, phenylanine, and threonine; higher in methionine, histidine, valine, and tryptophan; and lower in isoleucine and arginine. Additional fractionation of prepupae to remove the chitinous cuticle might also improve the amino acid profile.

Table 1. Percent amino acid content of dried soldier fly larvae fed either beef (Newton et al. 1977) or swine manure.

| Essential Amino Acids | | | Additional Amino Acids | | |
|---|---|---|---|---|---|
| | Beef | Swine | | Beef | Swine |
| Methionine | 0.9 | 0.83 | Tyrosine | 2.5 | 2.38 |
| Lysine | 3.4 | 2.21 | Aspartic acid | 4.6 | 3.04 |
| Leucine | 3.5 | 2.61 | Serine | 0.1 | 1.47 |
| Isoleucine | 2.0 | 1.51 | Glutamic acid | 3.8 | 3.99 |
| Histidine | 1.9 | 0.96 | Glycine | 2.9 | 2.07 |
| Phenylalanine | 2.2 | 1.49 | Alanine | 3.7 | 2.55 |
| Valine | 3.4 | 2.23 | Proline | 3.3 | 2.12 |
| l-Arginine | 2.2 | 1.77 | Cystine | 0.1 | 0.31 |
| Threonine | 0.6 | 1.41 | Ammonia | 1.3 | -- |
| Tryptophan | 0.2 | 0.59 | | | |

Minerals and proximate components are best characterized for black soldier fly reared on hen manure. Black soldier flies were reared on swine manure from the NCSU Lake Wheeler Swine Education Unit, Raleigh, NC. Approximately 180,000 larvae (occupying 1.7 $m^2$) were reared on fresh pig manure in a concrete basin. Prepupae were frozen, and dried at 70$^oC$. Mineral content and proximate analysis of these prepupae was performed at the University of Georgia (Table 2). Differences in black soldier flies reared on poultry and swine manure may reflect variation in the diet. Phosphorus was significantly higher in poultry reared black soldier flies and protein was slightly higher in those reared on swine manure. Other nutrients were similar regardless of the type of manure.

| Table 2. Mineral content and proximate analysis of dried black soldier fly prepupae raised on poultry and swine manure | | | | | |
|---|---|---|---|---|---|
| Mineral | Poultry | Swine | Proximate analysis | Poultry | Swine |
| P | 1.51% | 0.88% | Crude protein | 42.1% | 43.2 |
| K | 0.69% | 1.16% | Ether extract | 34.8 | 28.0 |
| Ca | 5.00% | 5.36% | Crude fiber | 7 | -- |
| Mg | 0.39% | 0.44% | Ash | 14.6 | 16.6 |
| Mn | 246 ppm | 348 ppm | | | |
| Fe | 1370 ppm | 776 ppm | | | |
| B | 0 ppm | -- | | | |
| Zn | 108 ppm | 271 ppm | | | |
| Sr | 53 ppm | -- | | | |
| Na | 1325 ppm | 1260 ppm | | | |
| Cu | 6 ppm | 26 ppm | | | |
| Al | 97 ppm | -- | | | |
| Ba | 33 ppm | -- | | | |

Chicks fed a diet containing dried black soldier fly larvae as the protein supplement (Hale, 1973) gained weight at a rate 96% (n.s.) of that of chicks fed soybean meal plus fat, but they only consumed 93% ($P<0.05$) as much feed. In pigs (Newton et al., 1977), dry matter and nitrogen (77.2 vs 76.0) digestibility were lower ($P<0.05$) for a dried larval diet than for a similar diet containing soybean meal plus fat. Palatability tests indicated that pigs preferred the black soldier fly diet to a soybean diet without added fat. For these chick and pig trials, both ash and fiber levels were higher for the black soldier fly diets (suggesting that the chitinous cuticle of the larvae was analyzed as fiber). Results of these trials suggested that the best use for black soldier flies might not be as a bulk protein supplement, due to high oil and ash concentrations.

Dried black soldier fly prepupae meal was fed to early weaned pigs as a replacement (0, 50, or 100%) for dried plasma (5% during phase 1, 2.5% during phase 2, and 0% during phase 3), with or without amino acid (AA) supplementation to balance the black soldier fly diets with the control. Without AA supplementation, the 50% diet gave slightly better performance during phase 1 (4% improved gain, 9% improved feed efficiency), however, the 100% diet, either diet with additional AA supplementation, or for the phase 2 diets, the black soldier fly diets did not perform as well as the control (overall performance reduced by 3 to 13%). It would appear that additional refinement (cuticle removal and rendering) may be necessary before black soldier fly prepupae have value above normal bulk protein supplements when used in early weaned pig diets.

## CATFISH FEEDING TRIAL WITH BLACK SOLDIER FLY PRE-PUPAE MEAL

The U.S. catfish industry produces over 600,000,000 pounds of catfish each year requiring 600,000 tons of feed. In Georgia, the feed potential, at current production levels, would be 18,000 tons per year. Potential soldier fly pre-pupae use in georgia would exceed 5,000 tons per year. This would replace over $ 1.3 million in catfish feed costs. Contribution per acre of catfish farm would be about $385 per year on farms using soldier fly pre-pupae as a supplement to a practical diet. Other opportunities for soldier fly use in the trout, salmon, tilapia and shrimp industries have feed potential of more than 10,000 tons per year in the U.S.

The objective studied under this part of the project was to determine the nutritional and economic replacement value of high quality insect based feedstuff for channel catfish compared to traditional feed ingredients (Table 3). The quantity of black soldier fly pre-pupae available allowed us to conduct a trial in tanks with channel catfish (*Ictalurus punctatus*) in order to estimate the value of pre-pupae meal as a feedstuff.

Table 3. Diet composition (% in diet). Diets were formulated with black soldier fly (SF) comprising 30, 22.5, 15, 7.5 and 0% of the composition.

| Item | 30% SF | 22.5% SF | 15% SF | 7.5% SF | 0% SF Reference |
|---|---|---|---|---|---|
| SBM, 48% | 32.0 | 37.0 | 43.0 | 48.6 | 43.0 |
| Fish meal | | | | | 8.0 |
| SF meal | 30.0 | 22.5 | 15.0 | 7.5 | 0.0 |
| Wheat mids | 13.8 | 13.8 | 14.0 | 13.7 | 16.8 |
| Corn | 21.0 | 23.5 | 22.0 | 22.5 | 27.0 |
| Soy Oil | 0.0 | 0.0 | 2.8 | 4.5 | 2.0 |
| Min mix | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vit mix | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vit C | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Choline | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Binder | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | | | | | |
| Analysis | | | | | |
| Protein | 32.15 | 32.05 | 32.06 | 32.01 | 32.18 |
| DE (kcal/kg) | 2977 | 2882 | 2985 | 3009 | 2820 |
| Fat | 12.07 | 9.60 | 9.80 | 8.90 | 4.85 |
| Calcium | 1.60 | 1.20 | 0.90 | 0.52 | 0.55 |
| Phosphorus | 0.83 | 0.76 | 0.68 | 0.60 | 0.72 |

Quadruplicate aquaria were utilized for each treatment and soldier fly pre-pupae meal was added to a practical diet formulation at 5 levels. The reference diet contained menhaden fish meal in order to compare the value of soldier fly pre-pupae meal to a known ingredient. Ingredients derived from plant materials were used to formulate diets with a uniform protein analysis. Digestible energy content was formulated to be approximately 2,900 kcal/kg.

Fingerling size (10 g) channel catfish, obtained from the breeding stock at Tifton, GA, were stocked 20 per 55 liter aquaria in an aerated system with 28$^{o}$ C water flowing at 2 lpm. The diets were offered in a manner to satiate the fish and the trial was continued until the fish have at least doubled their initial weight, eight weeks.

Results of the trial indicate that channel catfish fingerlings grew well on all diets and the feed appeared to be palatable. No significant mortalities were observed during the trial period. Weight gain per fish (Table 4) remained similar among treatments up to the 30% addition level ($p < .05$). Variation within treatments occurred primarily due to slightly lower performance by one replicate tank in each treatment, however, variation was least when 7.5% or 15% of the diet was soldier fly pre-pupae meal. Protein efficiency and feed/gain reflected the gain per fish in this study, showing no significant differences ($p < .05$).

Table 4. Channel catfish performance[a] when fed diets containing soldier fly pre-pupae meal. Means within rows were not different from the reference containing menhaden fish meal, $P < 0.05$.

| | Percent black soldier fly in diet | | | | |
|---|---|---|---|---|---|
| Criterion | 30% | 22.5% | 15% | 7.5% | 0% Reference |
| Gain/Fish, g (SD) | 15.9 (4.7) | 13.7 (3.6) | 17.3 (2.5) | 18.0 (1.9) | 15.9 (3.6) |
| Feed/Gain (g/g) | 2.31 | 2.55 | 1.96 | 1.87 | 2.2 |
| Feed Intake (g/fish) | 33.79 | 33.36 | 33.36 | 33.36 | 33.36 |
| Survival (%) | 19.5 | 19.75 | 19.75 | 19.75 | 19.75 |
| Protein Efficiency Ratio | 1.46 | 1.28 | 1.62 | 1.68 | 1.48 |
| Value[b] as % of Reference | 113 | 95 | 114 | 112 | 100 |

[a]Data represent means of four tanks of fish per treatment held 20 fish per tank.
[b]Based on total diet cost times ratio of PER diet to PER reference with menhaden fish meal at $355/ton.

The use of black soldier fly pre-pupae in catfish diets appears to be advantageous especially as a replacement for menhaden fish meal in this study. The absence of negative observations during this study are remarkable due to the high chitin content and high fat content of the soldier fly pre-pupae meal.

Although digestible energy in the diets was formulated to be approximately the same in all treatments, crude fat content increased as the amount of soldier fly pre-pupae meal increased. Also, calcium and phosphorus content increased with increasing amounts of the soldier fly pre-pupae meal. However, from practical considerations of the addition of the new ingredient, addition of more than 7.5% soldier fly pre-pupae meal seems unnecessary. The possibility of eliminating fish meal from catfish diets without a decline in performance is encouraging.

Soldier fly pre-pupae meal should have a value similar to that of menhaden fish meal. However, the actual cost of the production and harvesting of pre-pupae is confounded by the associated benefit to livestock or poultry producers gain in manure management. Since menhaden fishing requires labor, fuel, and equipment, one could assume that the equipment used to collect manure, produce and harvest soldier fly pre-pupae might cost a similar amount. As such, using a value of $355 per ton of menhaden fish meal and $355 per ton of soldier fly pre-pupae meal seems appropriate in the absence of definitive economic analyses.

Comparison of diet formulations in this study would show an increase in cost as the amount of soldier fly pre-pupae meal was increased. Since no significant improvement in catfish weight gain results from additions beyond 7.5%, the relative value (Table 4) of that least expensive diet could represent the value of soldier fly pre-pupae meal versus menhaden fish meal. Therefore, at 112% of the value of menhaden fish meal, soldier fly pre-pupae utilization would be appealing if the necessary volume needed to service the catfish industry were available and no unusual costs were needed to produce the meal.

From ASAE Standard D384.1 (2003), swine are expected to produce 11 pounds of manure total solids (dry matter) per 1,000 pounds of animal weight per day. For 1,000 grow-finish pigs from 50 to 260 pounds over 110 days, the manure dry matter yield would be expected to be about 187,550 pounds. In several tests, black soldier fly larvae have converted swine manure dry matter to prepupae dry matter at rates of from 12 to 16%. If 12% of 187,550 pounds of manure is converted, it would yield 22,500 pounds, or 11.25 tons, of dried prepupae. If dried black soldier fly prepupae have a value equal to fish meal, 11.25 tons would have a value of $3,993; if it has a value equal to soybean meal ($310/ton; Fayetteville, NC, May 31, 2004) 11.25 tons would have a value of $3,485. At a 16% conversion rate, these values would be $8,175 and $4,650.

## POTENTIAL VALUE OF RESIDUE AS A SOIL AMENDMENT

Black Soldier fly larvae reduced 55 kg of fresh manure dry matter to 24 kg of digested manure dry matter within 14 days (a 56% reduction). No objectionable odor could be detected from the end product of black soldier fly digested manure. Black Soldier fly larvae reduced the concentrations of nutrients of fresh manure, generally, from 40 to 55% (Table 5). (This reduction does not take into account the 56% reduction in manure mass.) These data suggest black soldier fly could be used to produce a valuable soil amendment, possibly somewhat similar to compost.

A majority of soils in the piedmont region of North Carolina are characterized as Cecil red clays. These soils characteristically are easily compacted and are easily water saturated. In contrast commercially available play sand is essentially devoid of nutrient value. To test the nutrient value of black soldier fly digested swine manure, digest was added to sand or clay soil at ratios of 0, 5, 10, 20, 30, 40 and 50%, with the growth response of basil (*Ocimum basilcum*) compared to growth on commercially formulated potting soil. Soil, sand and digest mixtures were prepared and added to 250 ml containers and planted with basil seed. Plants were watered every 2 days for 30 days. Basil plants were harvested and wet weight/dry weights measured. Basil dry weight growth response to black soldier fly digest was greatest at 5 and 10% mixtures for clay soil and at 10 and 20% for sand (Table 6). Basil did not grow in clay and was stunted in sand at digest mixtures of 40 and 50%. Basil growth response was best on commercial potting soil, which is formulated to promote plant growth. A similar growth response might be achievable with a more completely formulated product using black soldier fly digested manure as a component.

Table 5. Concentration of selected elements and other factors in the dry matter of black soldier fly digested and fresh swine manure.

| | Pig manure | | Black soldier fly residue | | Change |
|---|---|---|---|---|---|
| Element | ppm | SEM | ppm | SEM | % |
| N | 923.7 | 44.4 | 414.52 | 6.17 | -55.1 |
| P | 676.2 | 37.9 | 378 | 13.1 | -44.1 |
| K | 358.7 | 19.8 | 169.34 | 7.07 | -52.8 |
| Ca | 969.3 | 62.5 | 425 | 19.4 | -56.2 |
| Mg | 299.3 | 16.9 | 175.96 | 7.08 | -41.2 |
| S | 80.31 | 4.33 | 44.44 | 1.38 | -44.7 |
| Fe | 6.63 | 0.31 | 6.8 | 0.54 | +2.6 |
| Mn | 12.8 | 0.75 | 6.02 | 0.23 | -53.0 |
| Zn | 23.53 | 1.09 | 12.91 | 0.39 | -45.1 |
| Cu | 14.85 | 1.45 | 8.05 | 0.32 | -45.8 |
| B | 0.32 | 0.02 | 0.16 | 0 | -50.0 |
| C | 11,248 | 497 | 4,232.6 | 36.8 | -62.4 |
| Na | 99.93 | 5.59 | 48.15 | 2.04 | -51.8 |
| | | | | | |
| pH (units) | 6.24 | 0.05 | 7 | 0.04 | +12.2 |
| C:N (ratio) | 12.2 | 0.3 | 10.22 | 0.18 | -16.2 |

Sudan grass (*Sorgham sudanense*) is a common annual forage grass. Similar to the Basil growth experiment described above, we planted sudan grass seed in Cecil red clay and play sand mixed with and without black soldier fly digested manure. Percentages of digest were 0, 5, 10 and 20 percent and compared to commercial potting soil formulated to promote plant growth (Figure 5). Pots were watered daily for 30 days and the growth response recorded. Plants were harvested, weighed, dried and a final dry weight determined.

| Table 6. Growth response (weight) of basil (*Ocimum basilcum*) to Cecil red clay and sand amended with black soldier fly digested swine manure or commercial potting soil | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Percent black soldier fly digest added to soil | | | | | | | |
| | 0 | 5 | 10 | 20 | 30 | 40 | 50 | Control |
| Clay | | | | | | | | |
| Mean wet, g | 0.02 | 0.50 | 0.58 | 0.05 | 0.02 | None | None | 0.52 |
| Mean dry, g | 0.00 | 0.06 | 0.05 | 0.00 | 0.00 | None | None | 0.06 |
| | | | | | | | | |
| Sand | | | | | | | | |
| Mean wet, g | 0.03 | 0.20 | 0.32 | 0.32 | 0.38 | 0.19 | 0.05 | 0.52 |
| Mean dry, g | 0.00 | 0.03 | 0.05 | 0.04 | 0.03 | 0.02 | 0.00 | 0.06 |

Figure 5. Growth response of sudan grass (*Sorgham sudanense*) to black soldier fly digested manure mixed with sand and clay at (from left to right) 20, 10, 5, and 0% concentrations, respectively, and compared to commercial potting soil standard.

Sudan grass survival was greatest in the commercial potting soil mix (Table 7). Sudan grass growth response indicated by dry weight was best for 5% black soldier fly digest in both sand and clay soils. Although sudan grass grown in 20% digest was very similar in growth response to 5% results, sudan grass did not grow well in 10% digest. Sudan grass shoot formation accounted for 81% and 82% of the plant weight in the 5% digest in clay and commercial potting soil, respectively. In contrast, 53% of the plant weight in 5% digest mixed with sand was shoot compared to 55% in the potting soil mix. Root growth was more extensive in the sand pots than the clay. Interestingly, the roots formed knots around the digest particles mixed in the sand. This was not apparent in the clay pots, presumably because the nutrients were readily available in clay soils.

| Table 7. Growth response (weight) of sorgham-sudan grass (*Sorgham sudanense*) to Cecil red clay and sand amended with black soldier fly digested swine manure or commercial potting soil | | | | | |
|---|---|---|---|---|---|
| | Percent black soldier fly digest added to soil | | | | |
| | 0 | 5 | 10 | 20 | Control |
| Clay | | | | | |
| Mean wet, g | 0.05 | 0.38 | 0.13 | 0.25 | 0.53 |
| Mean dry, g | 0.02 | 0.07 | 0.03 | 0.06 | 0.14 |
| Mean shoot, dry, g | 0.01 | 0.04 | 0.02 | 0.04 | 0.09 |
| Mean root, dry, g | 0.01 | 0.02 | 0.01 | 0.02 | 0.04 |
| % plant survival | 89.4 | 31.5 | 52.6 | 42.1 | 94.7 |
| | | | | | |
| Sand | | | | | |
| Mean wet, g | 0.05 | 1.08 | 0.44 | 0.58 | 0.65 |
| Mean dry, g | 0.02 | 0.15 | 0.10 | 0.14 | 0.18 |
| Mean shoot, dry, g | 0.01 | 0.08 | 0.05 | 0.09 | 0.10 |
| Mean root, dry, g | 0.01 | 0.07 | 0.04 | 0.04 | 0.08 |
| % plant survival | 42.1 | 52.6 | 15.7 | 47.3 | 68.4 |

Even if the treated manure is not used in specialty soil products, since the volume and nutrient content of the feces is reduced, the area required for nutrient management plans (CNMP) will be reduced. Ribaudo et al. (2003) estimated the additional cost of complying with nitrogen standard CNMPs in the Mid-Atlantic region (with a 50% willingness of neighboring farms to accept the application of swine manure to their land) to be $11 per animal unit (AU) for farms with fewer than 300 AU, $2.25 per AU for farms with between 300 and 1,000 AU, and $3.80 per AU for farms with greater than 1,000 AU. Additional costs for complying with a phosphorus standard CNMP were estimated to be $12.35, $5.70, and $7.10 per AU for these same farm sizes, respectively. When the percentage reductions for the elements listed in Table 4 are combined with the 56% reduction in mass of the manure, the average overall reduction for these elements is 76% (including 80% for N, 75% for P, and 79% for K). The additional costs for complying with a CNMP would therefore be reduced significantly if black soldier fly manure processing were used (at least 75% for the solid fraction). Since urine contributes nitrogen and very little phosphorus, the overall products of such a system would have an N:P ratio more nearly reflecting the needs of crop plants. Additional costs would be eliminated completely in many cases, since many farms would have adequate land area for utilizing the treated manure, without hauling it to other farms.

## OTHER POTENTIAL PRODUCTS

Preliminary tests suggest that black soldier fly residue from processing swine manure is a suitable medium for vermiculture. Processing the residue with earthworms would produce an additional product (earthworms) and convert the residue into a product with known economic value to the horticultural industry, i.e., earthworm castings.

There is a potential to recover energy from the processing of swine manure with black soldier fly. Since the prepupae have a high fat or oil content (Table 2), this oil might be used as an energy source. If swine manure were converted to black soldier fly prepupae at 16% of the manure dry matter, as shown above, and they contained 30% or more oil, separation of the oil followed by conversion to biodiesel would yield as much energy as methane fermentation of that same manure (Tom Richard, personal communication). After oil recovery (using an expeller process), the remaining high protein meal would likely have greater value as a feed than the whole dried prepupae. This would be especially true if black soldier fly were used as a bulk protein supplement, since high levels of inclusion of dried prepupae result in higher than optimum levels of fat in diets.

As noted, the cuticle or skin of the prepupae, like that of all arthropods, contains chitin. If black soldier fly were processed to recover oil, it might also be possible to add additional steps for recovery of chitin and chitosan. Such products have uses of significant value in several industries (http://members.tripod.com/~Dalwoo/use.htm, for examples). A refined animal protein, as would be produced by removal of the oil and chitin from black soldier fly, would likely have significantly greater feeding and economic value than the original dried insect larvae.

## CONCLUSION

Economic and environmental impacts of widespread adoption of this manure digestion system would be significant. Value of larval feedstuff produced would be a strong incentive to manage this system well (Sheppard and Newton, 2000). The potential added value from converting confined livestock manure to a high value feedstuff is many millions of dollars in the southeastern United States alone. If the prepupae were marketed as specialty feeds, or further processed for biodiesel, chitin, essential fatty acids and/or other products, then the value could be much higher. Environmental benefits from manure and plant nutrient reductions and house fly control would also be significant.

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## REFERENCES CITED


ASAE. 2003. Manure production and characteristics, Standard D384.1. ASAE, St Joseph, MI. 4pp.

Baird, C., F. Humenik, M. Rice, J. Classen, S. Liehr, K. Zering, and E. van Heugten. 2004. Belt System for Manure Removal. Project Report for the Attorney General Agreements Initiative. Waste Management Programs, CALS. Animal and Poultry Waste Management Center. North Carolina State University. Raleigh, NC. http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase1report04/A.5Belt%20cb.pdf

Erickson, M.C., M. Islam, C. Sheppard, J. Liao, and M.P. Doyle. 2004. Reduction of *Escherichia coli* O157:H7 and *Salmonella enterica* serovar Enteritidis in chicken manure by larvae of the black soldier fly. J. Food Protection. 67:685-690.

Furman, D. P., R. D. Young. and E. P. Catts. 1959. *Hermetia illucens* as a factor in the natural control of *Musca domestica* Linnaeus. J. Econ. Entomol. 52: 917-921.

Hale, O. M. 1973. Dried *Hermetia illucens* larvae (Stratiomyidae) as a feed additive for poultry. J. Ga. Entomol. Soc. 8: 16-20.

Newton, G. L., C. V. Booram, R. W. Barker, and O. M. Hale. 1977. Dried *Hermetia illucens* larvae meal as a supplement for swine. J. Anim. Sci. 44: 395-399.

Newton, G. L., D. C. Sheppard, S. A. Thompson, and S. I. Savage. 1995. The soldier fly, a beneficial insect: house fly control, manure volume reduction and nutrient recycling. Pages 106-116 in Proceedings nuisance concerns in animal manure management: Odors and flies conference. Gainesville FL, University of Florida. PRO107.

Newton, G. L., D. C. Sheppard. D. W. Watson, G. J. Burtle, C. R. Dove, J. K. Tomberlin, and E. E. Thelen. 2005. The Black Soldier Fly, Hermetia illucens, as a Manure Management/Resource Recovery Tool. State of the Science, Animal Manure and Waste Managmenent. Jan. 5-7, San Antonio, TX.

Ribaudo, M., N. Gollehon, M. Aillery, J. Kaplan, R. Johansson, J. Agapoff, L. Christensen, V. Breneman, and M. Peters. 2003. Manure management for water quality: Costs to animal feeding operations of applying manure nutrients to land. USDA-ERS Report No. AER824. 99 pp.

Sheppard, C. 1983. House fly and lesser house fly control utilizing the black soldier fly in manure management systems for caged laying hens. Environ. Entomol. 12: 1439-1442.

Sheppard, D. C., G. L. Newton, S. A. Thompson, and S. Savage. 1994. A value added manure management system using the black soldier fly. Biores. Tech. 50: 275-279.

Sheppard, D. C., G. L. Newton, J. Davis, G. Gascho, S. Thompson, S. Savage and K. Bramwell. 1998. Using soldier flies as a manure management tool for volume reduction, house fly control and feedstuff production (AS 93-9 and LS 93-5). Southern Regional SARE Program.

Sheppard, D.C. and G.L. Newton. 2000. Valuable by-products of a manure management system using the black soldier fly. Pages. 35-39 in Animal, Agricultural and Food Processing Wastes, Proceedings of the 8th International Symposium. ASAE, St Joseph, MO.