ACCELERATING DECOMPOSITION RATE OF FRESH FAECAL MATERIALS FROM A FARROW-TO-FINISH SWINE FARM WITH BLACK SOLDIER FLY LARVAE *(Hermetia illucens)*

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ABSTRACT

There is need to generate information required for the development of facilities for reducing environmental pollution caused by careless dumping of raw faecal materials from swine production facilities into streams, channels, ponds and other water bodies in developing countries. The objectives of this work were to:(1) use a simple bio-decomposer to study the decomposition rate and waste reduction index (or efficiency of decomposition) of fresh solid faecal materials obtained from a farrow- to- finish swine production unit when treated with Black Soldier Fly Larvae (BSFL) (2) fit a regression curve with acceptable R-squared value to the decomposition rate data generated in the study. With the use of the bio-decomposer, four batches of the Black Soldier Fly Larvae (BSFL) that developed from the hatched eggs were carefully collected and decanted from the faecal materials, after which they were weighed and mixed with four weighed samples of fresh solid swine faecal materials with three replications at an average inclusion rate of 94.3, 81.4, 61.4, and 59.04 gm of BSFL/kg of fresh solid swine faecal materials respectively in a Complete Randomized Design; the fifth sample of fresh solid faecal materials was used as the control. The average decomposition rates for the four samples treated at three treatment levels and control were 0.046, 0.041, 0.040, 0.040 and 0.0 kg/day, respectively translating to an average of 0.042 kg/day. These results depict a mean waste reduction index of 8.74 %/day indicating that high waste reduction efficiency has been obtained as attested to by the computed R-Squared value of 0.919. The fitted regression curve showed that the decomposition rate increased with increase in BSFL inclusion rate up to maximum limit of 42.85 g/day and inclusion rate of 63.27 g/kg for a 0.8 kg initial mass of fresh swine faecal materials. It was, therefore, concluded in the study that incorporation of BSFL is very effective for accelerated decomposition of fresh solid swine faecal materials from a farrow-to-finish production facility.

Keywords. Bio-decomposer, black soldier fly larvae, decomposition rate, environmental pollution, Swine faecal materials, waste reduction index.

Introduction

In most developing countries of the world, there is an increase in improper disposal and inadequate treatment of wastes in most of the villages and cities. This has led to unbearable unsanitary conditions in the environment. These Nations continue to battle with the issue of effective and sustainable waste management, especially in the wake of high rate of population growth due to rapid urbanization. In addition, it is obvious that as the waste and sanitation burdens grow heavier, the capacity of the states to effectively manage the situation becomes a challenge. In view of this, their governments are spending equivalent of millions of US dollars in tackling the problems of environmental sanitation annually although it seems as if management of agricultural wastes have been inadvertently left out in these endeavors.

Apart from the fact that improper disposal of solid organic wastes creates breeding places for disease pathogen-transmitting insects such as common flies, and other insects, they also constitute another form of serious health hazards through the generation of nauseating odors and noxious gases. According to Sheppard and Newton, (2000), organic material constitutes more than 50% of the total agricultural residues generated on a typical farm. Given such a large proportion of generated organic waste, a simple and efficient collection and treatment system may significantly mitigate these problems and enhance efficient recycling of organic matter and soil nutrients.

Conversion of Organic Refuse into manure by Saprophages (CORS) has become a new technology used in effective management of organic wastes (Elissen et al., 2006; Diener et al., 2009). The commonest example of CORS is vermicomposting, which is conversion of organic waste by worms (usually red wigglers, white worms, and earthworms) and micro organisms into black, earthy-smelling, nutrient-rich humus. This could also be used to create a heterogeneous mixture of decomposing vegetables or food wastes (excluding meat, dairy, fats, or soils), bedding materials from farm animals and vermicast/worm casting (utilization of various species of worms in the breakdown of organic matter). The worm casting, which is rich in calcium and other growth-promoting nutrients is sometimes used as organic fertilizer (vermicompost) and soil conditioner because it also contains microorganisms which return vital minerals and vitamins into the soil (Vermi Co., 2001).

Naturally, animal faecal material is the principal food of many insects and larvae, especially the larva of the black soldier fly (*Hermetia illuscens*) (Figure 1).

Figure 1. Adult Black Soldier Fly

Considerable research has been conducted on manure digestion by insects to produce high quality feedstuff. Various fly larvae (maggot) readily feed on fresh manure, converting residual protein and other nutrients into their biomass, which can be a high quality animal feedstuff (Newton et al., 2004). Furthermore, the emphasis has in recent times 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) (Newton et al., 2005). Insect larvae (such as maggot) reduce the nutrient concentration and bulk of the manure residue, thus reducing pollution potential by 50 – 60 % or even more (Newton et al., 2005). In addition, while occupying the manure mass, they also aerate and dry it, thus reducing its odors. Erickson et al., (2004) reported in their research that maggots, for example, modify the micro flora of manure by potentially reducing the harmful bacteria content.

The use of black soldier fly larvae (*H. illucens*), is an interesting recycling technology and an ideal biological method of managing solid wastes. The method has been used to solve many of the problems (insects' pest, water pollution and odors) associated with large manure accumulation by 42-56 % and 94-100 % housefly control through larval competition and repelling oviposition of female house flies (Bradley and Sheppard, 1984). Graczyk et al., (2001) also stated in their research that, these house flies are serious disease vector especially in developing countries, where open defecation and inappropriate sanitation account for dangerous sources of pathogens (Figure 2).

Figure 2. Black Soldier Fly Larvae

The black soldier flies which are slender and about an inch (25 mm) long are often mistaken for wasps. The wasp has four wings and a sting unlike the black soldier fly which is stingless. Like the larvae of many other flies, the *H. illucens* feed on decaying organic matter, including manure, but unlike most insects that decompose faeces, the *H. illucens* is not considered a pest because the adult is neither attracted to human habitations nor foods (Furman et.al, 1959). Soldier fly larvae concentrate excess manure nutrients into valuable feedstuff and other product, which can be economically transported. This would relieve local nutrient overload (Sheppard and Newton, 2000). They quickly reduce the volume and weight of solid waste by breaking apart the food, churning it, and generating heat which increases the rate of compost evaporation.

Sheppard and Newton, (2000) reported in their research into the use of BSF in the management of poultry manure that, BSF are effective in reducing the mass and volume by about 50% as in addition to removable reduction in their nutrient and moisture contents. In another study on nutrient use efficiency by Newton et al., (2005), it was reported that plant growth rate was increased when the digested manure residue was added to either a clay soil or clean sand.

The benefits obtainable from good management of such systems are : production of high-value insect feedstuff; tremendous reduction in manure mass with a short period of time due to simultaneous reduction in moisture content and high rate of decomposition; rapid reduction or total elimination of offensive odors; reduction in ground water pollution potential.

The main objective of this study was to contribute to the reduction of environmental pollution caused by careless dumping of raw faecal materials from swine production facilities into streams, channels, ponds and other water bodies in developing countries of the world. The specific objective was to investigate the decomposition rate and waste reduction index of fresh solid swine faecal materials obtained from a farrow- to- finish swine production unit when treated with Black Soldier Fly Larvae (BSFL).

Methodology

The materials used for the study consists of: a bio-decomposing apparatus in form of a black soldier fly bucket composter version 2.1 ,which in itself, consists of a 22.50 liter plastic bucket with lid; filtering materials in form of palm nut fibers; eight smaller units of small capacity buckets; Biodegradable wastes (in form of fish offal) for use as bait; 15 units of small capacity plastic containers or bio-decomposers with lids (for use as air-tight containers when sealed with grease); 4 meter length of polyvinyl tube (high quality transparent plastic hose) cut into eight pieces of 2 meter length each; Weighing scale in form of beam balance (Camry type with 20 kilogram capacity and 50 g subdivisions); electronic balance (Model ADP 2100); white muslin cloth (cotton cloth with fine apertures); Spatula(for use as Stirrer); Rubber bands; colander (Plastic Sieve); glue (super glue); glass/plastic beakers; knife; small-sized nails; sawdust and thermometer (for use in the laboratory setup) . Others are protective equipment and clothing in form of disposable hand gloves; Anderson (or protective rubber) boots; nose masks; eye goggles and laboratory coat.

Attracting BSF

A 30cm long, 50 mm diameter transparent polyvinyl tube was connected to a 50 mm diameter hole drilled at the lowest side of the bio-decomposer to serve as drain for excess liquid from the compost into a vessel located at a level below the bio-decomposer. The design of the black soldier fly bucket composter version 2.1 was based on that of a large white plastic bucket. The bottom of the bio-decomposer was covered with a few layers of filter materials in form of palm nut fiber (which is a biodegradable material) to serve the purpose of starting up the decomposition process, increasing the bulkiness of the empty unit, absorb excess liquid in the faecal material (when filled with it) and allowed to drain into a containing vessel (in form of a small plastic bucket) placed underneath the setup while retaining the decomposing solid swine faecal materials. The bio-decomposer was filled with fresh solid faecal materials obtained from a farrow-to-finish swine production facility and baited with fish offal to serve as attractants to the BSF and covered with a lid with a "T" shaped inlet for ventilation. Four small pieces of corrugated cardboards (made out of a pair glued together) were cut and glued to the four 16 mm x 100 mm slits located on the upper part of the bucket composter to serve as the place where the attracted female BSF oviposited (they oviposited in the flute of the strips of the corrugated cardboard). The apparatus, ready for use, was set up in a cool quiet location underneath a shed on the Teaching and Research Farm of the University of Cape Coast, Ghana .In about 2-3 days, the oviposited larvae would have moved into the smaller bucket located on the sides of the bio-decomposer through another white polyvinyl chloride pipe located on the upper part of the wall of the vessel which served as the ramp (Figure 3). The palm nut fiber (which is a biodegradable material), was used as a starter for the unit by because it would allow the build of bulk of material in the new unit, as well as absorbing and retaining liquid without overloading the unit with waste. The system was set up to drain into another bucket which serves as liquid collection bucket. The bio-decomposer was filled with fresh solid swine faecal materials collected from a farrow-to-finish swine farm and baited with fish offal. It was later set up in a quiet place underneath an open-sided shed for 2 to 3 days in order to enable it attract female Black Soldier Flies (BSF).

Separating the larvae from the compost

Apart from the larvae which moved from the composter(or bio-decomposer) into the larvae collection bucket through the PVC ramp, those still feeding on the compost in bio-decomposer were separated it, weighed and transferred into each of the fifteen units of smaller capacity composting buckets. This was achieved, essentially, by making use of the decantation method. In this method, the decomposing compost in the large capacity composter in Figure 3 was soaked with water and stirred. This enabled virtually all its larvae content to stay afloat on the surface of the liquidized decomposing compost because lower density of the larvae compared to that of the compost.

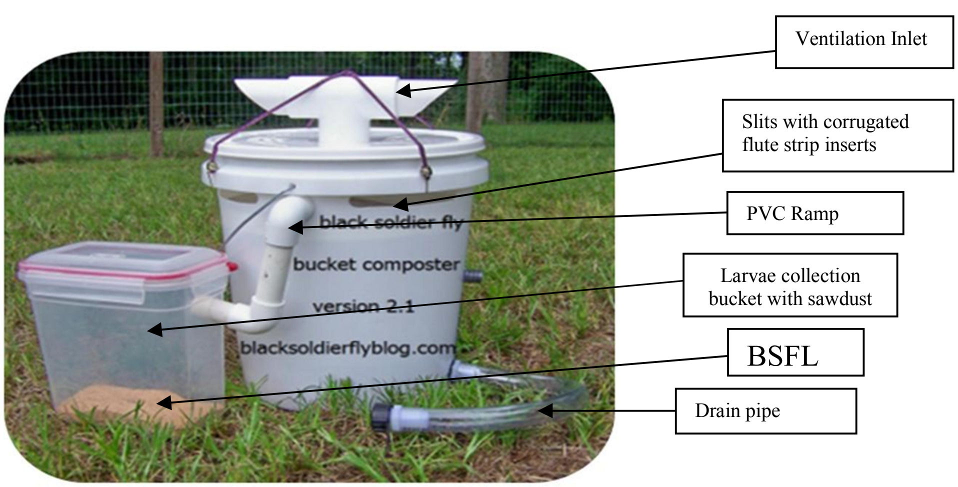

Figure 3. Large capacity Bio-decomposer

The floating larvae were later carefully separated from mass of the liquidized compost by pouring the water content through a sieve with aperture much smaller than the average size of the larvae.

Weighing of the BSFL

The decanted larvae were combined with those collected from the larvae collection bucket of the large capacity bio-decomposer and weighed with the use of the model ADP 2100 electronic balance and transferred into a glass beaker. The BSFL in the beaker were divided into 12 portions, each of which were weighed and transferred into twelve glass/plastic beakers and weighed with the use of the electronic balance.

Mixing the weighed BSFL with weighed fresh solid swine faecal materials

Five samples of fresh solid faecal materials obtained from a farrow-to –finish swine production facility on the Teaching and Research Farm of the University of Cape Coast, Ghana were weighed with the use of the Weighing scale in form of beam balance (Camry type with 20 kilogram capacity and 50 g subdivisions) and placed in 5 units of small capacity plastic containers or bio-decomposers with lids (for use as air-tight containers when sealed with grease) and labeled A, B, C, D, and E. Four batches of the Black Soldier Fly Larvae (BSFL) that developed were collected from the collection containers and combined with those carefully decanted from the manure, weighed and mixed with four weighed samples of fresh solid swine faecal materials in three replications in a Complete Randomized Design; the fifth fresh faecal material sample was used as the control. The ambient temperature was constantly checked with a thermometer to make sure it ranged between 25 and 27^{o}C, throughout the experiment. This was with a view to ensure that the right temperature, as spelt out in literature was provided in the environment for the larvae to effectively decompose the faecal materials. A control for the experiment was also set up by having a container filled with fresh faecal material only (i.e. not mixed with BSFL).

One end of five (5), 16 mm diameter transparent vinyl tubes, 80 cm in length was connected to the drilled holes on the top part of the side of each of the five small capacity bio-decomposers with super glue while the other end was similarly connected to another set of five plastic smaller containers in such a way as to provide a 45^{o} incline plane for the larvae to climb from the bio-decomposer into the containers. This was designed to provide easy movement of the larvae back and forth from the smaller capacity bio-decomposers whenever a sudden increase in temperature during the decomposition process makes the mass of compost in the bio-decomposer uncomfortable for the BSFL. The entire experimental setup was placed on a wooden platform and left to decompose for 7 days (Figure 4).

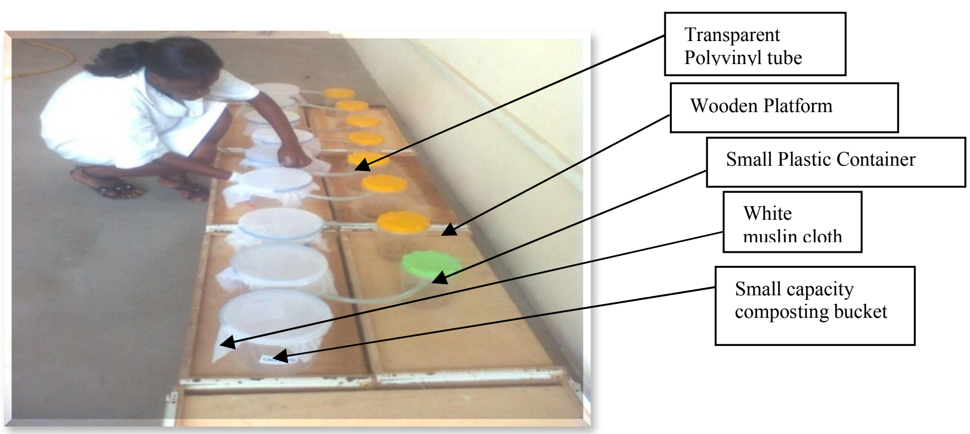

Figure 4. Laboratory Experimental Setup

Determination of the mass of decomposed Swine Faecal Materials

The mass of BSFL were weighed by carefully tarring the balance in such a way that the measurements were taken directly without the need to weight the containing vessels (i.e. the beakers). In order words the mass M_1 was taken as the mass of the BSFL in grams. Since the mass of the BSFL mixed with the mass of the solid fresh swine faecal materials was relatively infinitesimal compared to the mass of the faecal materials, the mass of the BSFL were ignored in determining the mass of the fresh and decomposed solid swine faecal materials in the material analysis (Equation 2).

The mass of decomposed faecal materials was determined after 7 days of decomposition by weighing each of the four treated samples and the control with the use of the weighing scale.

Mass of fresh solid swine faecal materials, M_4 , was determined as :

$$M_4 = M_3 - M_2 \qquad (1)$$

Where:

M_2 = Mass of empty small capacity bio-decomposer, kg.

M_3 = Mass of empty small capacity bio-decomposer + Mass of fresh solid swine faecal materials, kg.

Mass of decomposed swine faecal materials, M_6, was determined as:

$$M_6 = M_5 - M_1 \quad (2)$$

M_5 = Mass of empty small capacity bio-decomposer + Mass of Decomposed swine faecal materials, kg. (3)

Determination of the Rate of Decomposition

The decomposition rates, DR, of the fresh samples of solid fresh swine faecal materials were determined as:

$$DR = \frac{M_4 - M_6}{t} \quad (4)$$

Where;

t = time taken for decomposition, days.

Determination of Waste Reduction Index

The waste reduction index, WRI, was calculated by dividing the overall degradation, D, by the number of days for which the BSFL fed on the fresh solid swine faecal materials and multiplying the value of the quotient by 100. It is a measure of the efficiency with which the residue reduction process took place.

It was expressed mathematically as:

$$WRI = \frac{D}{t} x\, 100 \quad (5)$$

$$\text{Where: } D = \frac{M_4 - M_6}{M_4} \quad (6)$$

Data Collection and Analysis

Data were collected on the quantity (or mass) of BSFL introduced, time interval in days over which decomposition process took place, and mass of faecal materials before and after decomposition. The efficiency of decomposition process was measured by computing the Waste Reduction Index (WRI) from the generated data. The experiment was replicated three times with five treatments including the control. Data collected were subjected to regression analysis using the window 7 version of the MICROSOFT Statistical Software Package.

The results are presented in the form of bar charts, and other appropriate forms that could elicit trends and facts at a glance in form of fitted curves, their equations and R-squared values to facilitate meaningful discussions and drawing of logical and appropriate conclusions .

Results and Discussion

Mass of Fresh and decomposed Swine Faecal Materials

The relative mass of fresh and decomposed swine faecal material after 7 days are as shown in Figure 5. The four samples A, B, C, D and their three replicates had average waste reduction of 0.57, 0.42, 0.37 and 0.26 kg, respectively when weighed after 7 days with the control not exhibiting any change in mass. Sample B had the highest waste reduction in spite of the fact that it was treated with the least amount of BSFL (41.33 g). This was followed by samples C, A and which had the least mass reduction. The control (not treated with BSFL at all) did not exhibit any mass reduction implying that fresh solid swine faecal materials will take much longer time to decompose when not treated with BSFL.

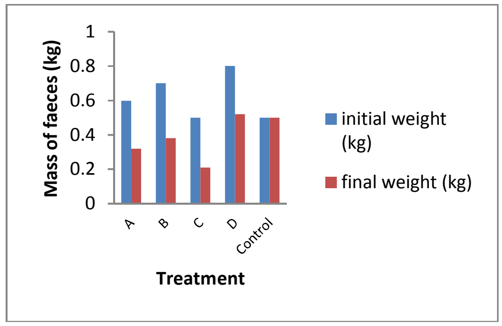

Figure 5: Mass of Fresh Solid Swine Faecal material before and after decomposition in 7 days

This corroborates the findings of Myers et al., 2008; Newton et al., 1995; Sheppard, 1983.

Decomposition Rate

The mean rate of decomposition of the fresh swine faecal materials for each of the four samples and their control is depicted in Figure 6. Decomposition rates of 0.040, 0.046, 0.041 and 0.040kg/day were obtained for samples A, B, C, and D were treated with BSFL at an inclusion rates of 81.40, 59.04, 94.26, and 61.40 g of BSFL/kg fresh solid swine faecal material respectively.

Sample B had the highest rate of decomposition as compared to the other samples which infers that within the 7days decomposition, it was able to decompose 0.046 kg of the fresh piggery faeces each day. Sample D and B had the lowest

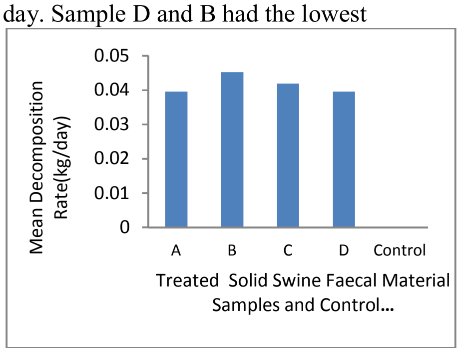

Figure 6. Mean Decomposition Rate of the Treated four samples of Swine Faecal Materials and Control

rate of decomposition of 0.040 kg/day which was even lower than the mean rate of decomposition of 0.042kg/day.

The disparity in the rate of decomposition among the samples may be due to factors such as BSFL inclusion rate, temperature (very dry conditions) and moisture differences within the containers. These affect larval growth and digestion, and may also help in creating conducive environments for the propagation of other micro organisms that aid in decomposition (NC State University, 2006).

Waste Reduction Index

The Waste Reduction Index (WRI) was calculated with the use of Equation 5 . Sample A, B, C, and D, had a mean waste reduction index of 6.67%/day, 6.53%/day, 8.28%/day, and 5.00%/day respectively, with a mean of 6.62%/day for the four samples. Sample C had the highest waste reduction index of 8.28%/day, indicating a good reduction efficiency as compared to the other samples. Diener et al.,(2009), reported in their experiment that a high Waste Reduction Index (WRI) value indicates good reduction efficiency. The mean waste reduction index of 6.62 %/day confirms the statement in literature, thus indicating good reduction efficiency was achieved with the use of BSFL in the experiment in this study (Figure 7). After larval digestion, the residual material can be used as a soil amendment or vermiculture media (Olivier, 2007).

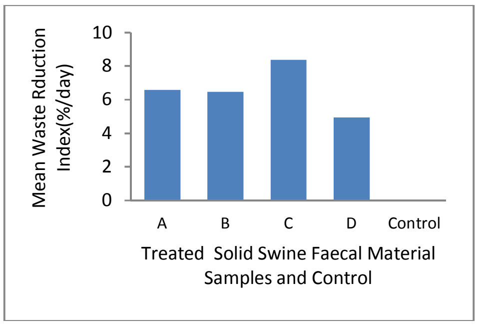

Figure 7. The mean waste reduction index of the treated samples and control

Developed Model of the Mean Decomposition Rate

The mean decomposition rate and BSFL inclusion rate data generated from the experiment did not exhibit an acceptable linear model when subjected to regression analysis. However when fitted with a polynomial curve of the second order (a quadratic curve), the model shown in Figure 8 was obtained.

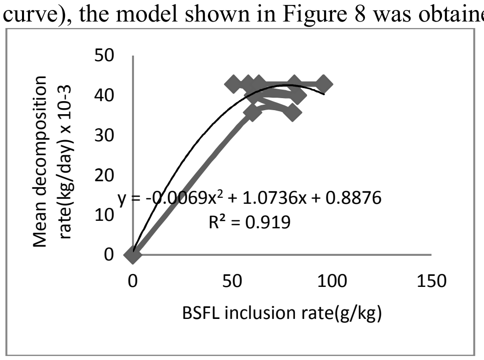

Figure 8. Fitted Model of Mean Decomposition Rate as a function of BSFL inclusion rate

The generated data on the decomposition rate of the fresh swine faecal materials resulted in a complicated curve when plotted against those generated from the BSFL inclusion rate. When fitted with a quadratic curve, a curve with mathematical model shown in equation (6) and R-Sq = 91.9 % emerged with the use of MICROSOFT statistical software package.

$$y = -0.0069x^2 + 1.0736x + 0.8876 \qquad (6)$$

where:

y is the decomposition rate of the treated swine faecal materials (g per day).

X is the Black Soldier Fly Larvae inclusion Rate (g/kg fresh solid swine faecal material).

Although very infinitesimal, this model predicts that there will be some amount of decomposition during the 7-day period (at the rate of 0.8876 g per day) even when no BSFL was included in the fresh solid swine faecal material.

When the BSFL quickly assimilate the nutrients in solid fresh swine faecal materials into biomass, the nutrients will no longer be available to the bacteria population that grow naturally in the faecal materials, thereby reducing the production of bad odors to the barest minimum (Diener et al., 2010). This because bacteria growing in faecal materials produce extremely noxious gases such as butyric and caproic acids. During competition with bacteria, the larvae will either reduce or eliminate odors by fast decomposition due to high larval densities and voracious appetite of the larvae. According to Diener et al., (2010), BSFL eliminates 97-100 % of the five most offensive gases during the larval digestion of swine faecal materials. The regressed model developed in this work can be used to determine the population of the BSFL that will optimize the decomposition rate of the swine faecal material which will, in turn, optimize the odor elimination rates.

Conclusion and Recommendations

Conclusion

The decomposition rate of fresh solid swine faecal material was accelerated in this study from 0.887 g/day, when no BSFL was incorporated, to 46.0 g/day when incorporated with BSFL at an inclusion rate of 59.04 g /kg of fresh solid swine faecal materials. The maximum waste reduction index achieved was 8.38 % per day when the faecal material was incorporated with BSFL at an inclusion rate of 94.26 g/kg of fresh solid swine faecal materials. The study confirms the application of the black soldier fly in solid waste management because it can reduce the decomposion rate by more than 5000 times the natural decomposition rate (i.e. without the application of BSFL).

Maximum decomposition rate was achieved with minimum BSFL inclusion rate whereas maximum waste reduction index was achieved with maximum BSFL inclusion rate.

Although a straight least square line did not fit into the data for decomposition rate of solid swine faecal materials and those for BSFL inclusion rate when subjected to regression analysis, a quadratic line fitted into them with a very good R-squared value. The R-squared value of this polynomial of the second order is 91.9 %. Also, the BSFL had a positive effect on the rate decomposition of the fresh solid swine faecal materials. The value, 0.919 attained indicated that BSFL significantly affected the decomposition rate of faecal materials obtained from a farrow-to-finish swine production facility. Combining waste treatment capacity demonstrated in the study with the inherent generation of a valuable by-product (i.e. the residue), makes the waste decomposition technology that makes use of Black Soldier Fly Larvae, a highly promising technique for organic waste management in low and middle-income countries.

Recommendations

Further investigation should be carried out on the effect of tropical temperatures on the lifecycle and decomposition ability of the black soldier fly larvae on swine faecal materials from farrow-to-finish and other types of production systems.

The use of BSFL in the treatment of organic residues from farms, industries and homesteads should be encouraged.

Further research should be carried out on the nutrient composition of the BSFL on Swine and poultry faecal materials and the possibility of use animal protein substitute in poultry, swine and fish feed formulations.

Investigation should be carried out on how BSFL culture could be used to maximize reduction of some excessive amount of some soil nutrients(such as phosphorus) in soils of organic manure dump sites intended for use in the production of some crops intolerant to excessive phosphorous .

Studies should be carried out on how some of the gases produced (e.g. methane, carbon dioxide, etc.) during decomposition of animal and perhaps human faecal materials with BSFL could be harnessed for use as bio fuel for heating, cooking, power generation, etc because of its odorless nature.

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