For:

Bioresource Technology

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A Value Added Manure Management System Using the Black Soldier Fly[1]

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ABSTRACT

A manure management system for laying hens using the black soldier fly, *Hermetia illucens* (L.) converted manure to a 42% protein, 35% fat feedstuff, reduced manure accumulation by at least 50% and eliminated house fly breeding. No extra facility or added energy was required. Mature larvae self-harvested producing a feedstuff as they attempted to pupate. Optimal feedstuff to manure dry matter yield was 7.8%. This insect occurs worldwide in tropical and warm-temperate regions and can digest many biological wastes.

INTRODUCTION

Manure is the principal food of many insects, especially larval flies. This insect utilization aids in the natural recycling of manure, and the insects produced are food for many larger animals. Several researchers have proposed using manure as a larval fly medium, thus producing high quality insect based feedstuff, while reducing manure residue (Booram. et al. 1977, Calvert et al. 1970, Chiou and Chen 1982, Eby and Dendy 1978, Miller et al. 1974, and Morgan and Eby 1975, and Sheppard 1983). Feeding studies and chemical analyses with various fly based feedstuffs have shown them to be generally equal to soybean meal in feed value to poultry (Calvert et al. 1969, Dahshefsky et al. 1976, Gawaad and Brune 1979, and Teotia and Miller 1974). Gawaad and Brune (1979) also conducted organoleptic tests with their insect fed broilers. They reported a typical smell and taste in both the standard and experimental groups, but noted that the meat from insect fed broilers had "a little more intensive taste". This may be valuable in certain markets, e.g. in Hong Kong local broilers are more expensive than U.S. imports because the U.S. broilers are judged to be lacking in flavor.

The proposed production and collection systems for house flies, face flies or blow flies noted above, involved moving manure from animal production facilities to insectaries. There, specialized equipment was utilized to produce and harvest the insects (Morgan and Eby 1975, Eby and Dendy 1978). These procedures increase the cost of operating these systems.

The system we report here utilizes wild populations of the black soldier fly, *Hermetia illucens* (L.), directly under caged layers. No separate facility or special equipment is needed for production or harvest. This is possible due to certain habits of this large wasp-like fly, i.e. it is not a significant pest (especially as managed in our system), and the migrations of the last immature stage facilitate a simple self-collection of the mature larvae (prepupae).

Soldier fly larvae have been fed experimentally to several animals, with larvae used to replace soybean or fish meal in a formulated diet. These feeding tests have utilized cockerels (Hale 1973), pigs (Newton et al. 1977) and catfish and tilapia (Bondari and Sheppard 1987). The general conclusion of each of these studies was that soldier fly larval meal was a suitable replacement for conventional protein and fat sources. Separation of the protein and fat in the larval meal would have allowed for more precise formulation.

The black soldier fly is an attractive manure management agent since it can; 1) eliminate house fly breeding, 2) reduce manure bulk by half or more when compared to similar unoccupied manure, and 3) produce economically attractive quantities of larval feedstuff. Soldier fly larvae tolerate a wide range of temperatures and are well adapted to the tropics and the warmer temperate regions (Callan 1974). It is native to the Americas and is widespread from Argentina to the central U.S. Transport by man has resulted in a worldwide distribution from about 45°N latitude to 40°S latitude (Leclerq 1969), including Australia and New Zealand (Callan 1974). They show an amazingly wide range of larval habitats and have been collected from manures, rotting fruits and vegetables, catsup and dead animals (James 1947). Little is known about the adult biology of this insect. Adults seen at animal housing, or other larval habitats, are newly emerged adults and older females returning to oviposit. Adults apparently live in a wild environment. Unlike house flies, they very rarely enter dwellings (Furman et al. 1959). Adults initiate mating on the wing. Females usually lay an egg mass of ca. 500 and prefer to oviposit in a dry crevice near the selected larval medium. Booth and Sheppard (1984) reported 99.6% of black soldier fly oviposition occurs between 27.5 to 37.5°C. General observations indicate that most oviposition occurs at 32°C and higher. Eggs hatch in 102-105 h at 24°C (Booth & Sheppard 1984). Under ideal conditions larvae can mature in 2 weeks, but limited food can extend the larval period to 4 months (Furman et al 1959). This ability to extend the larval interval in response to a food shortage is useful in managing wild populations for long-term production and for storing larvae to begin new populations. The last immature stage is the prepupa, a nonfeeding migratory stage. A prepupal soldier fly has emptied its gut of waste and developed a large fat body to provide energy for its migration and pupation to an adult. An empty gut and maximal stored energy make this the desired stage to collect for feedstuff. This nonfeeding prepupae has its mouth parts modified into a hook, enabling it to travel some distance from the larval habitat and dig into the soil to pupate (Schremmer 1986). Pupation usually lasts ca 2 weeks but is highly variable and may extend to 5 months (Furman et al 1959).

Soldier flies were found to compete with house flies for larval habitat. Female house flies did not lay eggs where soldier fly larvae were moderately abundant (Bradley & Sheppard 1984). Furman et al. (1959) in California, and Tingle et al. (1975) in Florida also reported house fly control where soldier fly larvae were abundant. Sheppard (1983) described a manure management system using the black soldier fly in small basins under caged layers. The results included 94-100% control of house flies, a 50% reduction in manure residue, and self-harvest of prepupae for use as feedstuff. A larger test of a similar system, reported here was conducted to test a soldier fly prepupal self-harvest system which would be practical in commercial caged layer houses and to determine if the larval digested manure residue could be handled with existing equipment. Some information on the biology of the black soldier fly, and potential rates of feedstuff production was also gathered.

MATERIALS AND METHODS

A 460 hen caged layer house was modified with 30 cm deep, 1.1m wide concrete manure basins under the cage batteries. The floor of the basin sloped at a gradient of ca. 200 cm per 100 m slope. Two-tier cage batteries on each side of the 12 m long walkway held 3 hens per 25 X 45 cm cage. The basin wall against the central walkway was vertical, and the wall towards the outside of the curtain sided house sloped up at ca. 40° to form a ramp for exiting prepupae. A 10 cm diam. plastic pipe was fixed parallel and along the top of this slope. A 1½ cm gap was cut along the length of this pipe and positioned at the top of the 40° sloped wall. This slit allowed migrating soldier fly prepupae to enter the pipe. Once in the pipe they travelled to down-spouts at each end of the basin-long pipe which directed prepupae into holding containers.

A 12hp Kuboto B4200, four-wheel-drive tractor was fitted with special steel box scrapers configured to the shape of the manure basins. This was used to push the residual larval-digested manure to the end of the house and into a sump. In the sump, water was added and the resultant slurry was taken into a vacuum tank manure spreader for distribution on pastures. Basins were cleaned out in February and August of 1991.

Two-year-old white leghorn hens from a commercial flock were used. Hens were house in August 1990. About 460 hens occupied the facility during this study. Each hen was provided with 105 gm of commercially prepared caged layer feed daily, and water continuously. A few days after all the hens were housed, about 15L of soldier fly larvae from a nearby beef facility were inoculated into the two manure basins to ensure development of a dense population.

Soldier fly prepupal collections from the self-harvest system were not carefully measured in 1990, since many of these were individuals that had been artificially introduced in early September. But prepupal collections in 1991 from the naturally regenerated population were collected and weighed regularly. Weight of collections were summed weekly and average weight of 100 prepupae was determined. This allowed a calculated estimate of the number of prepupae leaving the manure basins weekly. Ten percent, by weight, of each week's collection was released at the facility. These pupated naturally and transformed to adults to establish the next generation.

Percent dry matter of twenty self-collected prepupae was determined in November, 1990 by weighing, placing in a 59°c drying oven for five weeks, and then weighing again. An intermediate weighing indicated that drying was complete at 5 weeks. Percent dry matter was calculated by dividing the residual weight (1.81 gm) by the initial weight (4.24 gm) and multiplying by 100.

RESULTS AND DISCUSSION

The experimental caged layer manure management facility was fully operational at the end of August, 1990. The introduced soldier fly larvae established a resident population, and about 40 kg of prepupae were collected in September and October of 1990. Returning females established a robust larval population in 1991 and no new introductions were needed. Ovipositing females began appearing regularly by mid April in 1991. By late May a solid layer of soldier fly larvae, several deep, occupied the basins under the hens. Prepupal self-collections were irregular until late May, at which time we began recording collections on a weekly basis. Prepupal crawl-off on peak days during June 1991 blocked the slotted 10 cm diameter collection pipe. A replacement pipe with a 15.2 cm diameter performed well for the remainder of the study. Numbers of prepupae self-collected are illustrated in Figure 1. Also shown in Figure 1 are weekly average temperatures and monthly average weights of prepupae.

The pattern of prepupal crawl-off indicates that there are three generations each year (Figure 1). There are clear peaks of crawl-off from late May to late July, late July to early September and early September to mid-November. These peaks lasted 9 weeks, 6 weeks and 9 weeks, respectively. The last apparent peak on the graph in Figure 1 (mid-November to mid December) is probably an extension of the third peak caused by cooler weather. The zero collection on November 12 coincides with the lowest average temperature seen during the study (Figure 1). These apparent generation times agree well with the reported larval and pupal minimal residence times of two weeks for each stage. Allowing approximately one week for the unreported interval from adult emergence to oviposition results in a very good fit for the middle generation (August). The early and late generations may be extended by cooler temperatures. Sheppard (1983) did not determine numbers of prepupae collected per week, but graphing his data on weekly self-harvest weights gives very similar results. Three similar peaks result, with an average deviation in date of less than 7 days from the three major peaks given in Figure 1.

Monthly average prepupal weights seemed to be influenced by numbers of larvae present and temperature. Only one weeks collection was made in May. This collection averaged 0.20 gm per prepupae (Figure 1). As numbers increased in June and July crowding (less food per larva) probably reduced weights from 0.20 g in May to 0.15 and 0.16 g, respectively. A decrease in numbers (permitting more food per larva) in late July and August while temperatures still averaged ca. 26° C increased average prepupal weights to 0.22 g. Weights dropped slightly in September, perhaps in response to somewhat cooler temperatures late in the month. Weights in October, November and December were distinctly lower, probably because of lower temperature (Figure 1).

The total weight of self-collected prepupae for each month is shown in Table 1. The calculated weight produced per hen and the metric tons expected from a commercial facility housing 100,000 laying hens are also shown. The prepupal dry matter determined in November 1990 was 43%. Subsequent to this study dry matter of a 33kg batch of prepupae "cooked" at a commercial rendering plant in April 1993, was determined to be 44%. Calculations that follow are based on the 43% dry matter determination.

Sheppard (1983) reported summer prepupal black soldier fly self-collections which amounted to 0.90 g per hen per day. At 43%

dry matter (d.m.) this is 0.39 gm prepupal d.m. per hen per day. The Midwest Plan Service (1975) reports 95 g manure with 25% d.m. produced per laying hen per day. Calculations with these values yields 23.84 gm manure d.m. per day. From the data given by Sheppard (1983), dividing 0.39 g prepupal d.m. by 23.84 g manure d.m. gives an estimated 1.6% prepupae:available-hen-manure yield. Similar calculations with the data in Table 1 gives a yield of 4.2% for May through December and 7.8% for May through August 1991. Prepupae:available-hen-manure yield was highest in the May-August period because of favorable temperatures for this heat-loving insect, and because the larval population had not yet been reduced by the late August manure clean-out (Figure 1).

Sheppard (1983) reported 56 and 42% reductions in manure accumulation (depth) concurrent with the 1.6% prepupae: manure yield. The present study did not have a check treatment without soldier fly larvae, so manure reduction attributed to these larvae could not be measured. However, the much higher prepupae: manure yield ratio in this study suggests that manure reductions may have been greater than 50%.

The dense soldier fly larval population prevented house flies from reproducing from May through January. A very few adult house flies were present more or less continuously and were assumed to have migrated from other nearby animal production facilities. Routine inspections did not reveal any house fly larvae during the summer and fall when soldier flies were abundant. Nearly all adult soldier flies seen at the facility were ovipositing females, which did not cause problems.

A February clean-out time was selected so that accumulated manure would not interfere with basin flooding for early season house fly control. The late August clean-out time was selected to allow time for re-establishment of soldier flies, before cooler weather, to assure a significant overwintering population. Examination of the data (Figure 1, Table 1) suggests that larvae production (and thereby manure reduction) could be maximized by a basin capacity allowing one annual clean-out. The late summer clean-out probably reduced prepupal production (Fig. 1).

Manure accumulations were easily scraped from the basins with the small tractor and specially designed steel box scrapers. The manure was scraped into a sump at the end of the basins, water was added to make a slurry, and the slurry was drawn into a vacuum tank manure spreader, and applied onto pastures. The soldier fly-digested manure did not handle differently than more conventional animal manures and no problems were encountered. The larvae which were removed and spread with the manure caused no apparent problems.

Soldier fly larvae yield was 7.8% of hen manure excretion, on a dry matter basis. Larval production and self-collection was accomplished easily with no external insectary or input of energy. House fly production was *eliminated* from May to January. Manure residue was estimated to be reduced 50% or more and this residue was easily handled with conventional equipment.

The economics of this manure management system are attractive.

There will be savings in the cost of fly control and in manure removal. Sale of the prepupal feedstuff could result in significant income.

Large scale commercial use of this system seems feasible and economically attractive. Many commercial caged layer farms in Georgia and Florida are heavily populated with wild soldier fly larvae each year. Increasing research scale from 11 hens per basin to 230 increased efficiency of manure to feedstuff conversion from 1.6 to 7.8%; increased scale seems to favor this insect. Low value manure can be converted to high quality feedstuff, while concurrently reducing manure residue 50% or more and eliminating house fly breeding.

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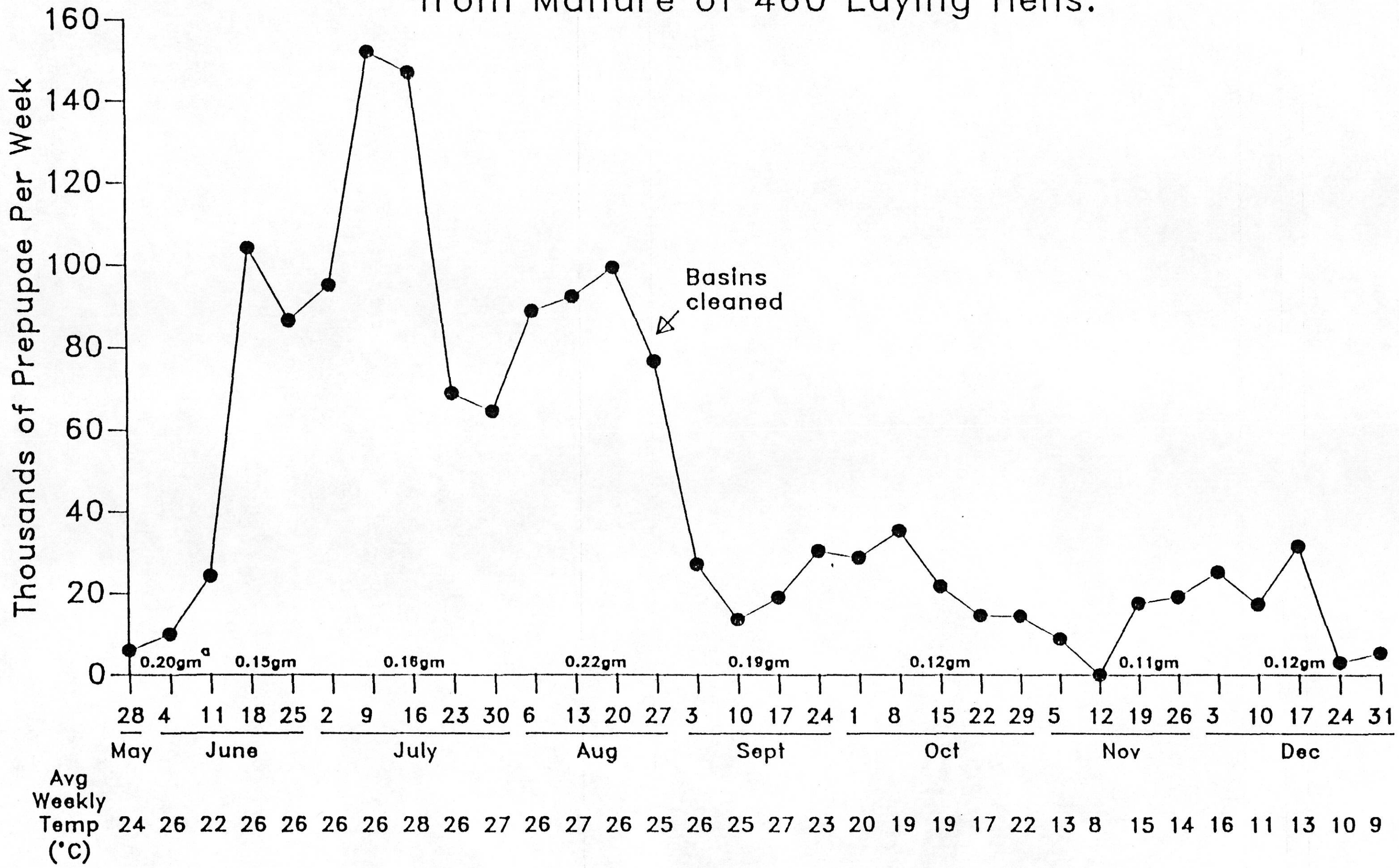
Table 1. Live Weight of Soldier Fly Prepupae Self-Collection in 1991 from Manure of 460 Laying Hens

	kg per 460 Hens	g per Hen	Metric Tons per 100,000 Hens
May	1.2	2.60	0.26
June	47.0	102.24	10.22
July	69.1	150.24	15.02
August	78.3	170.24	17.02
Manure basins cleaned out August 26, Larval population reduced.			
September	22.0	47.89	4.79
October	10.8	23.48	2.35
November	7.8	17.04	1.70
December	6.6	14.35	1.44
Annual Total	242.8kg	528.08g	52.80tons

Figure 1. Thousands of Prepupae Self—Harvested Per Week from Manure of 460 Laying Hens.



[a] Monthly average weight of one prepupae