Ecology and Control of the Principal Flies Associated with a Compost Plant

By

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ECOLOGY AND CONTROL OF THE PRINCIPAL FLIES ASSOCIATED WITH A COMPOST PLANT

By

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March, 1971

Chairman: Dr. F. S. Blanton
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Seasonal fluctuations of Diptera indigenous to domestic solid waste were examined at the Gainesville, Florida, municipal compost plant during 1968-1969. Populations of both immature and mature forms were estimated and the efficiency of chemical and physical control procedures was tested. Adult dispersal studies were conducted during 1970 at the city landfill.

The major fly source at the compost plant was found to be from larvae-infested incoming refuse. The greenbottle blow fly, *Phaenicia cuprina* (Shannon), comprised more than 90 percent of the larvae which migrated into protected areas where they developed into adults. Approximately 450,000 adult flies per week were produced during the summer months. This figure could be reduced by more than 63 percent by procedural changes and good housekeeping.

The daily application of a dichlorvos sugar bait reduced the number of flies by 66.7 percent while a single application of dimethoate reduced the population by more than 90 percent for 1 week. Parathion, Dursban, naled, and diazinon were also effective as shown by laboratory tests.

The number of house flies captured on sticky tapes was shown to be proportional to the number present in a large outdoor cage. Sticky tapes were used to show seasonal fluctuations of house flies in the digester building.

House flies were the predominant insect breeding in compost. They were limited to the top 2.5 cm in the digesters because of temperature. The optimum moisture content for house fly breeding was 75 percent. One to 14 percent of the eggs placed in compost at 45-55 percent moisture (normal operating conditions) developed into pupae. Egg survival to pupae decreased significantly when placed in refuse after 5-10 days of composting.

P. cuprina males flew an average of 19,405.4 m and a maximum of 30,137 m when attached to a flight mill until death. Females flew an average of 25,235.2 m and a maximum of 45,030 m.

Wild *P. cuprina* and *M. domestica* were marked and released 1 mi from a landfill and later recaptured at the landfill. An average of 10.17 percent of the wild *P. cuprina* and 1.66 percent of wild *M. domestica* released at the landfill on days followed by 24 hr without rain were recaptured 24 hr after release. An average of 10.7 percent of the wild *P. cuprina* released at the compost plant were recaptured in the same area 24 hr later. An average of 11.3 percent of laboratory-reared *P. cuprina* released at the landfill were recaptured 24 hr later. Baited traps surrounding the landfill recaptured only 2 flies after a total release of 255,000 flies.

INTRODUCTION

The demands of our affluent society for more goods and convenience items such as no deposit and non-returnable materials, result in the generation of waste products in gigantic proportions. As the affluence and the population increase, the per capita and total amount of waste increase proportionally. The disposal of these tremendous quantities of wastes has primarily been an urban problem. Since the trend in the United States is toward urbanization the problems of refuse disposal become increasingly more important. This becomes evident when it is noted that in 1960 the estimated median waste per capita per year in urban areas was 1,430 pounds. This amounted to 180 billion pounds per year and the cost of collecting and disposing of this refuse was more than 1.5 billion dollars (1).

To combat the rising problem of refuse disposal the "Solid Waste Disposal Act" was enacted in 1965 to support a national program designed to implement and evaluate more efficient methods of coping with the solid waste problems. Under this act the Bureau of Solid Waste Management awarded a contract to the Gainesville Municipal Waste Conversion Authority for the construction and operation of a refuse composting facility. The purpose of this project was to "demonstrate the reliability, suitability, economic feasibility, and sanitary and nuisance-free operation of a recently developed high-rate, mechanical composting system for the disposal of municipal refuse. . . (11,.20).

The primary objective of composting is to dispose of refuse by biological degradation of the organic materials. Modern scientific composting procedures which are employed in municipal disposal systems involve the rapid partial decomposition of organic matter by the use of aerobic microorganisms under controlled conditions (1). Municipal composting is a fairly common practice in many European countries. It is rarely used in the United States because land for refuse disposal was available in close proximity to urban centers in the past. The increasing demand for land provided the stimulus for municipalities to seek a more acceptable form of refuse disposal. As late as 1950, there was little scientific information available on municipal composting in the United States. Since then several universities and the United States Public Health Service conducted studies that have as yet yielded only a limited amount of practical information. The capital and operating costs of composting are known to be higher than most other forms of refuse disposal but the specific economics involved in municipal composting in the United States are practically unknown. The feasibility of composting must be determined by the major advantage of composting, the recycling of waste products. The sale of marketable compost and salvageable goods would reduce the net cost and may result in a profit.

There are 2 general composting processes that appear to be the most efficient and economical under U.S. conditions. The first is mechanical digestion, a process in which refuse is sorted, ground, and mechanically manipulated in order to shorten the biological degradation process. The second method termed windrowing involves the sorting, grinding, and placing of refuse in windrows allowing the material to compost naturally. The compost plant constructed at Gainesville used the mechanical digestion process.

Statement of the Problem

As with other scientific information concerning composting in the U.S., little is known concerning insect problems that may arise in this type of operation. The original purpose of the present investigation was to search out these problems, determine their magnitude, and suggest possible solutions. Initial observations revealed that large numbers of fly larvae entered the compost plant within the refuse. These larvae seeking a suitable pupation site migrated from the refuse stored in the refuse receiving building. These insects were aesthetically unpleasant to the employees as the larvae were often crushed beneath their shoes and sometimes crawled into the clothing of a resting employee. Many of the immature insects eventually became adults and further tormented the employees at the site by their constant presence while others were reputed to invade the surrounding community. Thus, the primary areas of this investigation were as follows:

To identify the larvae entering the compost plant with the refuse and to determine their magnitude and seasonal fluctuations.

To search out possible processing procedures which may reduce the number of larvae migrating into the plant.

To evaluate mechanical and insecticidal control procedures to reduce the larval populations.

To screen several commercial insecticides for their effectiveness against the emerging adult flies.

To determine the density and seasonal fluctuations of the adult house flies at the compost plant.

To determine the extent and some of the limiting factors of house fly breeding in compost.

To determine the extent of fly dispersal from the compost plant into the surrounding community.

Laboratory studies were conducted at the USDA Insects Affecting Man and Animals Laboratory in Gainesville, Florida, and at the University of Florida Medical Entomology Laboratory. Field studies conducted at the compost plant were begun in June, 1968. Because of a lack of funds, this plant was closed on December 31, 1969, and some of the studies were not expanded as the author had intended. Most of the dispersal studies were performed at the City of Gainesville Sanitary Landfill during the summer of 1970.

Location of Compost Plant

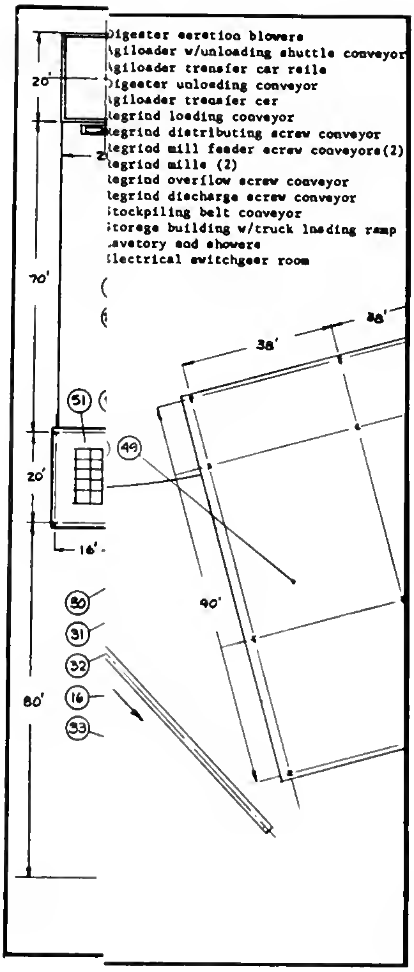
The compost plant was constructed on a 5-acre tract of land located in southeast Gainesville at the city's sewage treatment complex. This site was near a sewage treatment plant, an animal shelter, and an abandoned dump.

A densely populated region of middle-income apartment complexes inhabited primarily by University of Florida students and a low-income residential area were located in the immediate vicinity. A woodland area buffered a middle- and high-income residential area located one-half mile from the plant.

Operation of Compost Plant

The floor plan of the compost plant is presented in Fig. 1 and the general flow plan of the refuse is shown in Fig. 2. Refuse was brought by truck and dumped on the floor of the receiving building (Fig. 3). The refuse was then placed into a receiving hopper by a tractor modified with a front-end loader. The hopper (19.8 m long, 3.6 m wide, and 3.6 m deep) constituted the rear side of the building. An apron conveyor which consisted of a series of overlapping or interlocking apron pans was located at the bottom of this hopper. The refuse was transported along the conveyor onto an oscillating table. This table loosened the packed refuse in order to assure a uniform flow. A sorting conveyor carried the refuse from the oscillating table to a platform where 6 laborers manually removed salvageable paper, cardboard, and large bulky items (Fig. 4). The paper and cardboard were dropped into chutes which fed into a baler and the bulky items were placed in chutes that emptied into a dump truck which carried these materials to a landfill. The sorted refuse then proceeded directly into a crusher-disintegrator grinding mill. The ground refuse discharged from the crusher averaged 7.6 cm^2 but varied in size depending upon the type and amount of material fed into the machine (20).

Refuse passed from the first grinder into a second grinding unit which reduced the particle size to approximately 5 cm^2. It was then discharged from the bottom of the secondary grinder into mixing screws where 2 counter-rotating ribbon-type screws, placed side by side in a common trough, blended the material with water or sludge. A conveyor belt carried the moistened refuse under a magnetic separator which removed the ferrous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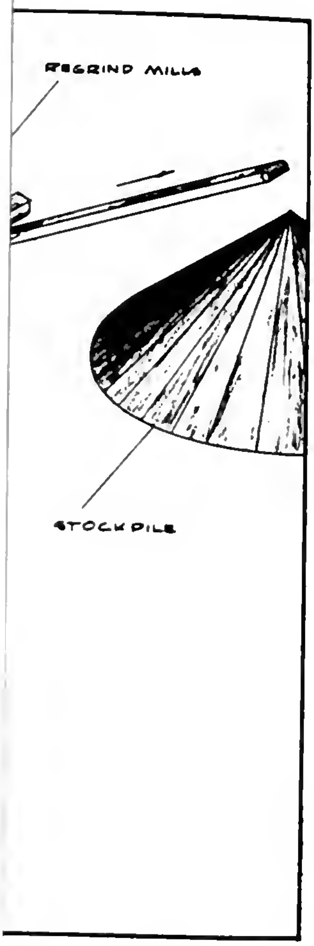
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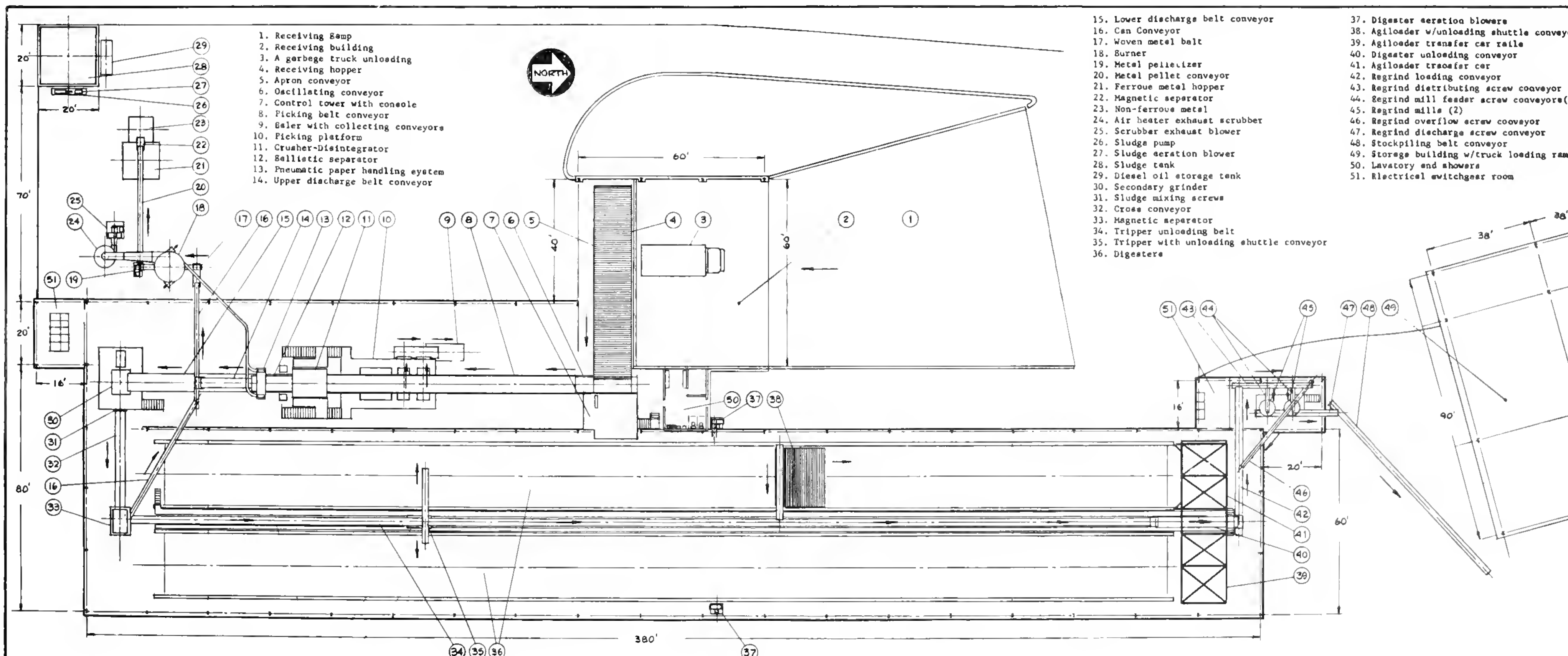


Fig. 1. Floor plan of Gainesville municipal compost plant (20),

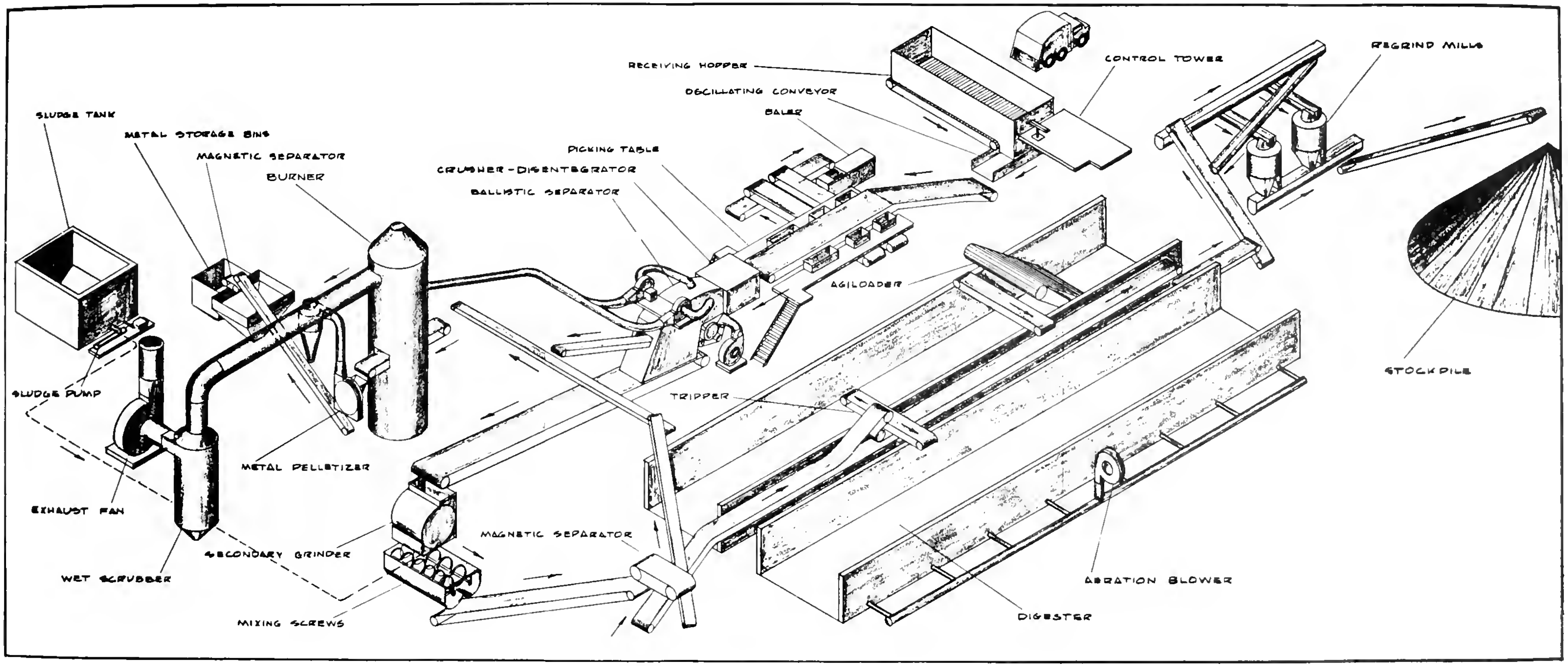


Fig. 2. Refuse flow plan of Gainesville compost plant (20).

Fig. 3. Receiving building filled with refuse.

Fig. 4. Sorting conveyor carries refuse to sorting platform.

metals and then dumped onto the tripper conveyor belt which extended the length of the digesters. A shuttle conveyor, which travelled on a pair of steel rails between the digesters discharged the refuse into these units.

The digesters or digesting tanks were 2 concrete troughs 99 m long, 6 m wide, and 2.7 m deep (Fig. 5). The digester walls were constructed of concrete blocks and the floor was converted with perforated galvanized steel plates. These plates were above an air plenum into which air was discharged by a centrifugal low pressure fan. River gravel approximately 0.6 cm in diameter covered the perforated plates to a depth of 7-10 cm. This enabled the air to diffuse evenly through the small slots over the entire floor of the tank. The refuse was placed in the digesters to a depth of 1.8-2.4 m and allowed to compost for approximately 6 days (20). (In this investigation "compost" refers to refuse that has remained in the digesters for a period greater than 24 hours.)

Removal of the compost was accomplished by a machine called the Agi-Loader (Metro-Waste Patent No. 3,294,491). This machine removed the compost and deposited it back onto the tripper conveyor. A system of conveyor belts transported the compost to a final grinding mill. A finely ground material approximately 1 cm^2 was discharged from this grinder and was transported by conveyor to an outdoor storage area (Fig. 6).

Flies

The most numerous species of flies present at the compost plant were the common house fly, Musca domestica Linnaeus, (Muscidae, Diptera), and the greenbottle blow fly, Phaenicia cuprina (Shannon), (Calliphoridae, Diptera).

Fig. 5. Composting takes place in concrete digesters.

Fig. 6. The finished product is discharged to outdoor storage areas.

The house fly has been incriminated as a carrier of numerous diseases of man and animals including typhoid fever, cholera, and amoebic dysentary (27, 82); however, these claims have been supported only by circumstantial evidence. House fly associations with diseases need further clarification as experimental evidence is sparse and contamination of house flies between caged mates has been shown to be sporadic (24).

Greenbottle blow flies may be domestic nuisances or carry disease organisms, but in this capacity they are far less important than other flies. However, the damage and suffering which the larvae inflict upon domestic animals in some stock-raising areas is of tremendous consequence. In Australia, this fly is by far the most important species in fly strike or cutaneous myiasis of sheep (44, 69). Fly strike is a condition produced by the development of blow fly larvae on living sheep which may lead to death or a considerable loss of wool. This is a formidable problem in Australia and amounts to an annual loss of 4,000,000 pounds to sheep raisers (44, 69).

The common house fly is well established as *Musca domestica* Linnaeus but the systematics of the greenbottle blow fly are somewhat confused. Australian authors refer to this fly as *Lucilia cuprina* (Wiedemann). Hall (26) compared specimens from the United States and Australia and concluded they were not the same species. He described the American species as a new combination, *P. pallescenes* (Shannon). Waterhouse and Paramonov (80) later examined numerous specimens from Texas, New York, New Orleans, Washington, and Australia and concluded that there was no difference in species, but a definite pair of subspecies. James (28) concurred in this view. Hall later in Stone *et al.* (78) maintained his combination of *P.*

pallescenes (Shannon) but recognized the works of Waterhouse and Paramonov. The author uses the species name from Waterhouse and Paramonov since their work appeared to be more comprehensive than that of Hall.

SECTION I

FLY LARVAL MIGRATION FROM REFUSE

The major source of fly infestation appeared to be from introduction of larvae from the collected refuse and not from breeding at the compost plant. Fly larvae that were breeding in refuse containers throughout the city were brought to the compost plant with the refuse. This infested refuse was stored awaiting processing in the receiving area. Many of the larvae were mature and the added stimulus of the disruptive transfer to the plant caused them to actively seek a pupation site (Figs. 7 and 8). Some of these larvae migrated into the working areas where they annoyed the employees while others reached protective areas where they metamorphosed to adults. Such occurrences were not unique to the compost plant. Large numbers of larvae may escape to pupation sites during the handling, transferring, or processing of larvae-infested refuse. Green and Kane (23) found that 7200 larvae/hr/per car were escaping from railroad cars awaiting dispatch to a rural disposal area.

The infestation of refuse by larvae in the Gainesville area was anticipated because in a southern California city, with a climate similar to that of Gainesville, Ecke et al. (18) reported that residential refuse containers can have as many as 50,000 larvae per container over a 10-week period. These larvae crawled out of the refuse after a short feeding period

Fig. 7. Fly larvae and pupae under receiving hopper.

Fig. 8. Fly larvae migrating from refuse to pupation sites under wall of receiving building.

to pupate in the soil and later emerged as adults. During the hot summer months it was reported that the feeding period was completed in 4 days (79). This observation led to the recommendation and subsequent adoption of a twice-weekly refuse collection system for several California cities (17, 79).

The purpose of this investigation was to determine the species of the larvae escaping into pupation sites at the plant, to determine the magnitude and the seasonal fluctuations of this massive influx of insects, and to search out possible processing procedures which would reduce the total number of escaping insects.

Methods

Seasonal Fluctuations

Visual observations indicated that the majority of the larvae escaping from the refuse were confined to the partially enclosed area under the apron conveyor. The larvae reached this area either by crawling through the openings between the metal pans of the conveyor or by falling through the opening between the floor of the receiving building and the edge of the receiving hopper. To determine the species present and the seasonal fluctuations of the larvae entering the plant, a trap was placed in this area. This trap was similar in function to that described by Roth (58) and consisted of a 30.48 cm^2 plywood box.. It was abutted to the wall under the apron conveyor so that larvae falling through the opening between the hopper and the floor would be trapped in the box. The trap was operated from January 12 to December 31, 1969.

The trap was checked daily and the number of larvae recorded. A minimum of one sample catch per week was preserved in alcohol for identification.

Population Factor

It was desired that the larval population trapped in the seasonal fluctuation survey be used to estimate the total number of larvae escaping into the plant. To accomplish this it was necessary to determine the total number of larvae that entered the plant, the percentage of the larvae trapped, and the reliability of the trapping procedure.

The total number of larvae entering the plant would be a difficult figure to accurately define. Since the majority of the larvae migrated under the apron conveyor it was used to determine the total number of larvae in that area and to determine the reliability.

The larval population under the apron conveyor was determined by sweeping the area for a 10-day period beginning August 29, 1969. These sweepings, which included the debris and larvae that had fallen during the previous 24 hr, were placed into a 55-gallon (208 l) drum. The drum and its contents were weighed, sealed, and thoroughly mixed by rolling on the floor for several minutes. Immediately a volume of approximately 0.5 l was removed and weighed on a laboratory balance (Ohaus, Union, N.J.). The larvae in the sample were counted and the total number of larvae in the drum or under the apron conveyor was calculated.

To determine the precision of the above method, a sample of approximately 0.5 l was removed, weighed, counted, and replaced in the drum. The contents of the drum were again mixed and the procedure was replicated 5 times. The results indicated that the method was precise and are given in Appendix 1.

Effects of Clearing Receiving Building Daily of Refuse

It was standard operating procedure that a sufficient amount of refuse remain in the receiving building overnight so that operations could begin the following morning and proceed without interruption until the trucks began delivering refuse. To determine the number of larvae escaping into the compost plant as a direct result of this procedure, the area under the apron conveyor was swept twice daily; once at 7:00 am, before daily operations began, and again at 6:15 pm, immediately after the plant closed. This was repeated for 6 consecutive days during September, 1969. The larvae collected were enumerated as described previously.

Result and Discussion

Seasonal Fluctuations

The results of a larval sampling program to determine the species present and seasonal fluctuations of the larvae escaping into the compost plant are shown in Fig. 9 and Appendix 2. These data show that relatively few larvae were captured during January, February, and March. The catch increased in April while a consistently high number of larvae were trapped from June to mid-October. The number declined throughout November and larvae became relatively scarce in December.

Phaenicia cuprina was the predominant fly species collected in this survey. Table 1 shows that greater than 97 percent of the captured larvae were *P. cuprina*. One percent were *M. domestica* while the remainder were comprised of *Cochliomyia macellaria* (Fabricius), *Hermetia illucens* (Linnaeus), and *Sarcophaga* spp. This distribution of species was similar to those reported by other investigators. For example, *P. cuprina* comprised 96-99.95

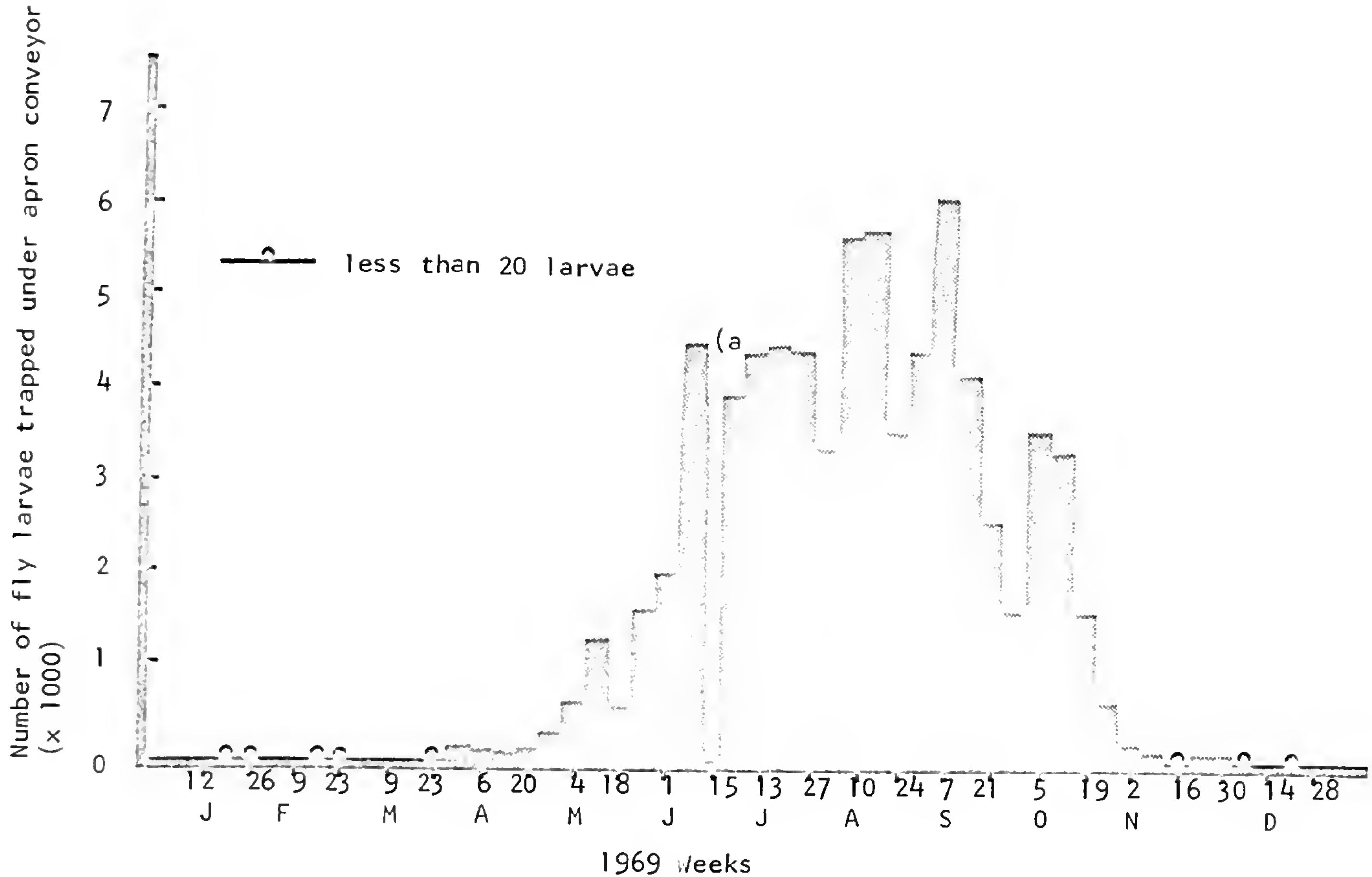


Fig. 9. Number of fly larvae caught under apron conveyor per week at Gainesville compost plant during 1969

(a Plant closed for repairs June 15-30.

Table 1. Percent abundance of species of fly larvae trapped under apron conveyor during 1969.

Species	Percent of total number of larvae examined per week		
	Maximum	Minimum	Average
Phaenicia cuprina	100	90.5	97.2
Musca domestica	6.4	0	1.0
Cochliomyia macellaria	6.0	0	.7
Sarcophaga spp.	4.7	0	.7
Hermetia illucens	4.7	0	.6
Others	<.01	0	-

percent of all larvae collected from residential refuse containers in southern California (28, 18, 79). It was also the principal blow fly found in garbage in Orlando, Florida (31). Green and Kane (23) reported *Phaenicia* was the predominant genus occurring in London during the summer.

Population Factor

Table 2 gives the calculated number of larvae collected per day under the apron conveyor and the percent trapped in the larval sampling program for that same day. These data indicate that an average of 0.99 or approximately 1 percent of the larvae under the conveyor were caught in the trap. The variance of 0.04 for these results indicates consistency.

Larval movement into the plant was not limited to the area under the apron conveyor as migration from a pile of refuse could be expected to occur randomly in all directions. Larvae migrating from the refuse in the receiving building in an easterly direction found harborage behind a wooden retaining wall. This was approximately 1 m from the outer wall of

Table 2. Total number of larvae collected under apron conveyor compared to number of larvae trapped the same day.

Sweepings (Kg)	Sample (Gm)	Larvae/ sample	No. larvae collected	No. larvae trapped	Percent trapped
19.0	976	1741	34,100	487	1.41
27.0	1894	2676	38,200	452	1.17
1.8	200	1500	13,500	114	.84
18.4	642	3842	109,500	986	.89
10.7	1076	6855	67,980	297	.44
14.5	1009	4873	70,250	602	.86
9.8	673	1993	29,100	238	.82
17.4	862	1758	35,731	411	1.15
16.3	611	1796	45,851	490	1.07
22.2	885	3979	97,600	1294	1.31
				Average	.99

the building and extended the length of the receiving area. It was difficult to sample this area and the larval population was an approximation based on visual observation. It was estimated that the number of larvae escaping behind the east wall was approximately one-third of those escaping under the apron conveyor for any given day.

The construction of the receiving area and the practice of handling the refuse greatly reduced larval survival in other directions. Refuse was deposited toward the east wall and as it was moved into the hopper from east to west by the front-end loader, those larvae migrating in a westerly direction were scraped into the receiving hopper. Northerly migration resulted in little survival since the ramp and paved areas provided no protected areas for pupation.

Combining the estimates that two-thirds of the larvae migrating into the plant enter the area under the apron conveyor and 1 percent of these are trapped results in a population factor of 133. This factor may be multiplied by the daily larval catch to give an approximation of the number of insects migrating from the refuse into the protected areas of the plant. For example, Appendix 2 shows that 6116 larvae were trapped the week of September 7, 1969. Multiplication by 133 gives an approximation of 813,428 larvae entering the plant during that one-week period.

Effect of Clearing Receiving Building Daily

Larvae collected under the apron conveyor during plant operation were compared to collections in the same area during off hours. The results are given in Table 3 and indicate that an average of 38.5 percent of the larvae escaping into the compost plant migrated from piles of refuse remaining in the receiving building after the plant was shut down for the

Table 3. Total number of larvae collected per day under apron conveyor compared to the number caught in the same area during the night.

Sweepings (Kg)	Sample (gm)	Larvae/ sample	Time[a]	No. larvae collected	Total daily catch	Night catch / Total catch
7.22	725	3400	D	36,180	67,980	46.8
2.95	351	3612	N	31,800		
11.35	666	2508	D	42,700	70,250	39.2
3.18	343	2971	N	27,550		
7.95	360	794	D	17,500	29,100	39.8
1.85	313	1961	N	11,600		
16.8	722	1318	D	30,700	45,320	32.2
.65	140	995	N	14,620		
16.3	611	1456	D	44,400	78,900	43.7
3.35	283	2914	N	34,500		
19.06	602	1992	D	63,200	88,900	29.1
2.57	282	2834	N	25,800		
					Average	38.5

[a]D = 7:00am - 6:15pm
N = 6:15pm - 7:00am

day. It is obvious from these results that not storing refuse overnight would reduce the number of larvae entering the plant by more than 35 percent and decrease the ensuing adult population.

The value of clearing the refuse from the receiving area daily was further demonstrated by observing the large numbers of larvae along the eastern edge of the approach ramp. When refuse remained on the approach ramp for several days numerous larvae migrated from the refuse and fell to the pavement below. On several occasions when this occurred fly larvae were so numerous that the pavement along the edge of the ramp appeared white. On one such occasion the pavement was swept clean and the larvae collected 12 hr later. Their number was estimated to be 30,000 or 60,000 per day migrating from the ramp (Fig. 10 and 11).

Adult Development from Larvae

The majority of the larvae that migrated from the refuse were mature and thus required only a suitable pupation site to develop into adults. This was demonstrated by placing 100 larvae collected under the apron conveyor into waxed paper cups (0.946 l). Twenty-five gm of refuse debris collected from the same area were added to one-half of the cups. The cups were covered with cloth, secured with a rubber band, and placed under the apron conveyor. Ten days later the number of adult flies that had emerged were counted. Nine replicates of each test gave an average of 65.3 percent adult emergence from the cups to which only larvae had been added, and an average of 88.8 percent adult emergence from the cups with debris added.

Generally there was a considerable amount of debris under the apron conveyor and behind the east retaining wall, the main areas of larval infestation. It was concluded that most of the escaping larvae reached

Fig. 10. Eastern edge of apporach ramp.

Fig. 11. Fly larvae along base of eastern wall of approach ramp.

adequate pupation sites and close to 88.8 percent adult emergence was expected. Extending the previous example given for the week of September 7, 1969, an approximation of 733,313 adult flies could be expected to emerge within 10 days as a result of larval migration from the refuse.

Survival of Larvae Through Grinding Mills

Approximately 10,000 mature house fly larvae were passed through the secondary grinder in May, 1969. The primary grinder was not in operation at that time because of equipment failure. Nine live larvae were recovered in the discharged refuse. In July, 1969, 10,000 mature house fly larvae were passed through the recently installed primary grinder. No surviving larvae were found in the discharged refuse.

SECTION II

CONTROL OF BLOW FLIES

Studies were initiated in June, 1969, to evaluate several procedures such as mechanical control and insecticide baits, fogs, and residues for the control of blow flies emerging from the incoming refuse. The effectiveness of a control measure was determined by the reduction of flies caught in two baited traps located behind the receiving building. These investigations were terminated in October with the advent of cooler weather.

Blow Fly Traps

A suitable method to estimate changes in the number of flies was needed to evaluate the various control procedures. Sticky tapes were ineffective because the large amount of dust created in the receiving area rapidly coated the adhesive material. Grill counting was ineffective because the counts varied with hourly density fluctuations and positive species identification was nearly impossible (42, 45).

Norris (45) reported that bait trapping was the only generally useful method available to study blow fly populations and that the bait employed was the most important variable. He reported that animal tissue was the best for blow flies, being more reliable than some of the more recently developed synthetic attractants (14, 45). However carrion is not a uniform bait. Its attractiveness varies with age, moisture, and decomposition (42). Kawai and Suenaga (30) found that fish 1-day-old was the most attractive to blow flies.

The traps selected for use at the compost plant were two 30 x 30 x 54 cm inverted cone traps. They were baited with 1-day-old fish heads acquired locally. The base of each trap was enclosed by 0.5 cm^2 screen wire to prevent small animals from stealing the bait. These traps are shown in Fig. 12.

The traps were placed on the pavement behind the receiving area, see Figs.1 and 13. The flies were collected from the traps daily by placing the trap and 10 ml of ethyl acetate into a plastic bag. After the flies were anesthetized, they were removed and placed into a small plastic bag. The catches were then transported to the laboratory for counting and identification.

Table 4 gives the identification of flies caught in 15 different daily catches. This shows that 89 percent of the flies trapped were *Phaenicia* spp., 6.8 percent were *Musca domestica*, 3.7 percent were *Cochliomyia macellaria*, and 0.5 percent *Sarcophaga* spp. These figures are close to those percentages recorded in Table 1 which gives the relative abundance of the various species of larvae entering the plant from the refuse. The differences that occur may be the result of the trapping method employed, different survival rates of the species involved, or immigration of adults from surrounding areas.

Fig. 12. Cone trap baited with 1-day-old fish heads to sample fly populations at compost plant.

Fig. 13. Rear view of receiving building showing receiving hopper and pavement behind building.

Table 4. Sex, species, and abundance (%) of flies caught in cone traps baited with 1-day old fish heads at Gainesville compost plant.

Species	Percent of total flies caught[a]	% Male	% Female
Phaenicia spp.	89.0	10.4	89.6
Musca domestica	6.8	1.7	98.3
Cochliomyia macellaria	3.7	55.2	44.8
Sarcophaga spp.	.5	0.0	100.0

[a]Mean of 15-day catches taken at random.

Field Tests

Methods

Several adult fly control procedures were evaluated to determine their effectiveness and cost of application during the summer of 1969. The effectiveness of the control procedures was determined by comparing the number of flies caught per day in baited traps during the treatment period to the number of flies caught during a prior period of no treatment. The duration of pre-treatment control sampling was 7 days and subsequent control periods were 3 days. Treatment and control periods were alternated and followed chronologically in the order presented in Table 5, beginning July 14, 1969. Four to 5 days elapsed between a treatment and the following control period.

The control procedures are described as follows:

Sugar bait. -- Keller *et al*. (31) in studies at dumps found that trichlorfon baits gave good control of blow flies. Bailey *et al*. (6) reported that dichlorvos in dry sugar baits controlled house flies.

Table 5. Number of flies caught per day in cone traps baited with fish heads as a monitor of procedures to control adult flies at the Gainesville compost plant.

Day	No. of flies caught per day: Control[a]	No. of flies caught per day: Sugar bait[b]	% Control	Day	No. of flies caught per day: Control	No. of flies caught per day: Sweeping[c]	% Control
1	2343			15-18	-		
2	2796			19	1197		
3	2268			20	2316		
4	979			21	1954		
5	1050			22	$\bar{X}$ = 1822	856	53.2
6	3456			23		1055	41.9
7	824			24		908	50.2
8	$\bar{X}$ = 1959[d]	1178	40.4	25		667	63.4
9		875	55.4	26		353	81.6
10		285	85.5	27		1061	41.6
11		596	69.7	28		1775	3.6
12		1041	47.1	29		1493	18.0
13		490	75.0	30		1437	21.1
14		107	95.5	31		1315	25.8
		$\bar{X}$ = 653	66.7	32		988	46.4
						$\bar{X}$ = 1083	40.6

[a]Number of flies caught per day when no control procedures were used.

[b]400 gm of 0.5% dichlorvos in sugar mixture applied daily as a bait.

[c]Area under apron conveyor swept daily.

[d]Mean values represent the mean number of flies caught per day for that given procedure (column).

Table 5 (Continued)

Day	No. of flies caught per day: Control	No. of flies caught per day: Malt bait[e]	% Control	Day	No. of flies caught per day: Control	No. of flies caught per day: Fog[f]	% Control
33-36	-			47-50	--		
37	1711			51	1967		
38	1397			52	1949		
39	1985			53	1826		
40	$\bar{X}$ = 1698	360	78.8	54	$\bar{X}$ = 1914	561	70.7
41		514	69.8	55		660	65.5
42		641	62.3	56		561	70.7
43		1245	26.7			$\bar{X}$ = 594	68.9
44		1467	13.8	57	627		67.3
45		597	64.9	58	1581		17.4
46		1017	40.1	59	1601		16.0
		$\bar{X}$ = 831	51.2	60	181[illegible]		5.2

[e] 200 ml of 1.0% dichlorvos in 25% malt solution, applied daily as a bait.

[f] 1 l of 5.0% fenthion in No. 2 fuel oil applied with a portable hot-air swing fogger on days 53, 54, and 55.

Table 5 (Continued)

Day	No. of flies caught per day		%	Day	No. of flies caught per day		%
	Control	Dimethoate[g]	Control		Control	Gardona[h]	Control
61	1437			76-80	-		
62	1719			81	1677		
63	2241			82	1170		
64	$\bar{X}$ = 1799	28	98.5	83	1410		
65		13	99.3	84	$\bar{X}$ = 1419	1056	25.6
66		37	97.9	85		653	54.1
67		18	99.0	86		1251	12.0
68		64	96.5	87		734	48.4
69		49	97.3	88		949	34.4
70		112	93.3	89		781	45.0
71		287	84.9	90		1090	23.3
72		170	90.6				
73		393	78.3				
74		811	55.0				
75		1256	30.1				

[g] 10% dimethoate solution applied at a rate of 2 gm (AI)/m^2 to grassy areas adjacent to receiving building, one application on day 63.

[h] 10% Gardona solution applied on day 83 at a rate of 2 gm(AI)/m^2.

Fly Bait, a 0.5 percent dichlorvos sugar bait obtained commercially from the Fasco Chemical Co., was used prior to this investigation to control the flies at the compost plant. This bait was evaluated when applied at a rate of 400 gm per day. The bait was distributed along the conveyor belt system for a 7-day period beginning on day 8 of Table 5.

Sweeping to remove larvae. -- The area under the apron conveyor has previously been shown to contain the majority of the larvae migrating into the compost plant. To determine the effect of collecting and removing these larvae on the total number of adult flies, this area was swept daily for 15 days.

Malt bait. -- Malathion, diazinon, chlorthion, and dichlorvos in malt or molasses were reported to be highly effective liquid baits for blow fly control around dumps (76, 31, 34). A dichlorvos and malt solution was used to determine the value of liquid baits for the control of flies at the compost plant. Blue Ribbon malt was diluted with distilled water to form a 25 percent malt solution. Technical grade dichlorvos was added to produce a 1 percent dichlorvos solution which was stored at 4°C until used. Fifty ml of this solution were applied daily to each of 4 locations along the conveyor belt system for a 7-day period beginning on day 40.

Fogging. -- Fogging is not a highly recommended procedure for effective control of flies since fogging leaves no residue and a high concentration is necessary to kill flies. However, the effectiveness of fogging was evaluated since it was used to control flies at the Tennessee Valley Authority compost plant in Johnson City, Tennessee (61).

It was observed that the adult blow flies, predominantly *Phaenicia* (Table 6), left the building at dusk and roosted in the grass immediately

Table 6. Sex, species, and abundance (%) of flies caught by sweep net[a] in grass adjacent to receiving area of Gainesville compost plant.

Species	Percent of total flies caught	% Male	% Female
	a. Caught during day		
Phaenicia spp.	95.2	43.1	56.9
Musca domestica	4.8	32.8	67.2
	b. Caught at night		
Phaenicia spp.	99.7	48.7	51.3
Musca domestica	.3	98.7	1.3

[a]Mean of ten samples taken by five sweeps of net.

surrounding the plant. These areas were fogged at 9:00 pm on day 53, 54, and 55 (Table 5) with a 5 percent fenthion in No. 2 fuel oil solution distributed by a portable hot-air swing fogger. This insecticide was selected because of availability and because a 5 percent fenthion solution killed 97 percent of the caged house flies 50 m from a moving fogger (4).

Residual sprays. -- Contact and residual sprays are the most often recommended methods of controlling flies. These sprays are most effective when applied to feeding areas and night-time resting places such as shrubs and plants in the surrounding area (34, 76).

Dimethoate gave the best control of house flies in Florida dairy barns when applied at a rate of 2 gm (AI)/m^2 (5, 9, 10). A 10 percent dimethoate in water solution was applied once on day 63 by a 2-gallon (7.57 l) compressed-air hand sprayer at a rate of 2 gm (AI)/m^2 to the grassy areas surrounding the plant.

Gardona, (2-chloro-1-2[2,4,5-trichlorophenyl] vinyl dimethyl phosphate), a house fly larvicide, was provided by Dr. G. C. LaBrecque, USDA Gainesville laboratory. A 10 percent Gardona in water solution was applied on day 83 in the same manner as described for dimethoate.

Results

The results of the field tests are presented in Table 5.

Sugar bait. -- Daily application of a 0.5 percent dichlorvos sugar bait reduced the number of flies trapped by an average of 66.7 percent when compared to a previous 7-day period of no treatment. This control procedure cost about $3.00 plus 0.5 man-hr per 6-day work week.

Sweeping to remove larvae. -- The area under the apron conveyor was swept daily to remove the larvae before they developed into adults. An average of 40.6 percent reduction in the number of flies was noted when compared to a previous 3-day control period. This reduction is considered to be a minimal value. It was significantly lower than expected since previous estimates indicated that 67 percent of the larvae that migrated into the plant escaped under the apron conveyor. The difference between the observed and predicted reduction may have been influenced by the short test period. Since the larvae entering the plant required 8-10 days to become adults the 15-day study period may not have been long enough to ascertain the true results of cleaning the area. Regular cleaning over a longer period should reduce the adult flies by a factor approaching the percentage of larvae escaping into the area.

A second factor influencing these results was the operation of the plant during the test period. Mechanical problems prevented regular operation of the plant and refuse remained in the receiving area for several days. This resulted in larval migration patterns differing from those encountered under normal conditions.

Since the larvae entering the plant required 8-10 days to become adults it is reasonable to assume that cleaning the area once a week would produce the same results as daily cleaning at a reduced cost. The effects of cleaning over a long period were not investigated.

The area under the apron conveyor could be cleaned once a week at a cost of about 4 man-hr.

Malt bait. -- A 51.2 percent reduction in the number of flies was observed over a 7-day period with the application of a dichlorvos malt solution. This bait was found to have several disadvantages; (1) it is not available commercially, (2) it must be stored under refrigeration, (3) it costs more and was less effective than dry sugar bait, and (4) its syrupy consistency made it inconvenient to use.

Fogging. -- The grassy areas of the compost were fogged for 3 consecutive nights producing an average reduction of 68.9 percent of the number of flies trapped on the following 3 days. The effects of fogging were minimal after 1 day as shown by the post treatment counts in Table 5. Thus, an effective control program would include a minimum of 3 foggings per week. This would cost $15.00 plus 3 man-hr per week.

To determine if this fogging procedure was effective on *P. cuprina*, 100 adults were caught at night by a sweep net at the compost plant and placed in a gauze cage. The cage was placed in the center of the grass hill during the fogging operation. After the area was treated the flies were transferred to a clean cage provided with fly food and water and held for 24 hr. A control cage was set up and the fly mortality observed in each. This procedure was duplicated for each treatment. An average of 97.2 percent of the treated flies were dead after 24 hr while 6.1 percent mortality was observed in the control cages.

Residual sprays. -- A single application of dimethoate gave better than 90 percent control of the flies for 1 week and remained effective for 10 days as shown in Table 5. The cost of one application was approximately $7.00 plus 0.5 man-hr.

Gardona was ineffective as a residual spray for the control of blow flies as shown in Table 5.

Larvicides. -- Green (22) demonstrated that 99.1 percent of the larvae escaping from standing refuse trains could be controlled by dusting the area twice weekly with DDT. However, the application of a larvicide under the apron conveyor to control blow flies was not attempted because of the large amount of debris falling daily into this area. The effects of the larvicide would be short-lived since incoming larvae probably would not be exposed after 24 hr.

Rearing Blow Flies

Methods

To screen insecticides in the laboratory for their effectiveness against *P. cuprina* it was first necessary to find a suitable rearing medium so large numbers would be available. *P. cuprina* are easily reared in the laboratory on a diet of decaying meat but this medium is odoriferous and also expensive when large numbers of flies are required.

When *P. cuprina* breeding was observed in spilled dog food an investigation was started to determine if this or some other material might be substituted for meat. Two series of tests were carried out which varied the amount and kinds of test media used. In the first series the test medium was placed in waxed paper cups (88.8 ml) with 200 P. cuprina eggs collected from wild flies captured at the Gainesville landfill. Each cup was then placed in a waxed paper cup (0.946 l) containing approximately 20 gm of dry builders sand. The larger cup was then covered with a black cloth and secured with rubber bands. Eight days later the mature larvae had pupated in the sand and the pupae were removed from the medium by sifting the sand through an 18-mesh sieve. The pupae were counted and the number recorded. One hundred of these pupae were randomly selected, washed, dried on paper towels, and weighed on a laboratory balance (Mettler, Evanston, Illinois) to determine differences in the size of the pupae reared on the various test media. Six replicates were prepared for each medium.

The media tested included the following: lean ground beef; Alpo, an all meat dog food; Chunx, a dry dog food; Strongheart, a canned grain base dog food; and Chemical Specialist Manufactures Association house fly rearing medium (CSMA). Various amounts and combinations of these media were used as shown in Table 7. Meat was added to several test media because P. serricata was reared on CSMA fly rearing medium when provided with sufficient meat for the larvae to develop to second instars (35).

In the second series of tests 1 ml or approximately 6,500 P. cuprina eggs collected from wild flies were placed with the test medium into 4 x 19 x 30 cm enamel trays. Each tray was placed on approximately 5 l of dry builders sand in a 40 x 55 x 25 cm plastic tub. A piece of one-fourth

Table 7. Analysis of several rearing media to determine the most suitable method of rearing *Phaenicia cuprina*.

Test medium	Pupae developed %	Pupae developed No.	Mean weight 100 pupae (gm)
a. 200 *P. cuprina* eggs + test medium placed in 88.8 ml paper cup			
10 gm lean ground beef	81.55	163.1	1.513
25 gm lean ground beef	83.05	166.1	2.154
25 gm Alpo	82.4	164.8	2.067
15 gm Chunx + 15 ml water + 1 gm Alpo	80.1	160.2	1.501
15 gm Chunx + 15 ml water + 1 gm beef	86.4	172.8	1.514
10 gm CSMA + 20 gm water + 1 gm beef	73.5	147.0	1.217
15 gm Chunx + 15 ml water	63.05	126.1	1.311
10 gm CSMA + 20 ml water	0	0	--
5 gm CSMA + 7.5 gm CHunx + 17.5 ml water + 1 gm beef	80.4	160.8	1.533
Strongheart	59.8	119.6	1.201
b. 1 ml (c.a. 6500) *P. cuprina* eggs + test medium placed in 19x30 cm enamel trays			
250 gm lean ground beef	26.5	1723	2.308
454 gm Alpo	34.8	2266	2.226
400 gm Chunx + 400 ml water + 50 gm Alpo	48.6	3160	1.689
400 gm Chunx + 400 ml water + 50 gm beef	62.1	4040	1.719
250 gm CSMA + 500 ml water + 50 gm beef	47.6	3092	1.078
400 gm Chunx + 400 ml water	17.0	1108	1.787
200 gm Chunx + 125 gm CSMA + 450 ml water + 50 gm beef	52.1	3391	1.416

inch plywood with a 25 cm diameter circle cut in the center and covered with muslin cloth for ventilation was placed over the tub and secured by 4 bricks. Eight days after egging the medium the pupae were removed by sifting them from the sand and the total number recorded. One hundred pupae were then randomly selected, washed, dried, and weighed. Six replicates were prepared for each test medium.

The test media included lean ground beef, Alpo, Chunx plus Alpo, Chunx plus ground beef, CSMA plus ground beef, Chunx, and Chunx plus CSMA and ground beef.

Rearing tests were conducted on the screened porch of University of Florida building number 618 which is located northwest of the medical entomology laboratory. The porch was screened on 3 sides and covered with a roof with 1 m eaves. Light, temperature, and humidity were ambient. These tests were conducted during May and June of 1970.

Results

The results of the rearing tests are presented in Table 7. These data show that immature *P. cuprina* reared on a diet consisting only of meat were larger than those reared on the other diets. When large numbers of larvae were reared, as in the second test series, 4 of the diets produced more flies than did the all meat diets.

The diet of the dry dog food, Chunx, plus water and 50 gm of ground beef was chosen to rear the flies used in the laboratory chemical screening tests. This diet was superior to all other diets tested in the numbers of pupae produced and cost less than the all meat diets without producing offensive odors. Although the pupae were not as large as those reared entirely on meat, these size differences were not considered great enough to adversely affect the tests or offset the advantages of the dog food diet.

Adult blow flies used in the chemical screening tests were reared from eggs collected from wild flies caught at the city landfill. These flies were reared to the F_1 generation on the larval diet consisting of 400 gm Chunx, 400 ml tap water, and 50 gm lean ground beef in the manner described above for the second test series. Adult flies were held in 15 x 24 x 50 cm gauze-covered cages and provided with fresh water and fly food daily. The fly food consisted of 6 parts granulated sugar, 6 parts non-fat dry milk, and 1 part dried egg yolk. The cages were held in the University of Florida medical entomology laboratory environmental control chamber with 16 hr of artificial day light provided by incandescent lights. Temperature and humidity were maintained at 26°C and 70 percent RH.

Laboratory Screening of Insecticides for Control of *P. cuprina*

Methods

Five-day-old female *P. cuprina* adults were exposed to space sprays of 12 commercially available insecticides in the wind tunnel described by Davis and Gahan (15). The insecticide solutions were prepared by dissolving each chemical in acetone to attain the desired concentrations (w/v). The original range of concentrations for each chemical was based on the LC_{50} values obtained for an insecticide susceptible strain of house flies at the USDA Laboratory, Gainesville.

The tests followed the procedures outlined by Bailey *et al*. (7, 8). Twenty adult females were confined in test cages made of metal sleeves closed with screen wire at each end. These cages were placed in the wind tunnel. One-fourth ml of the insecticide solution was atomized at 1 psi into the mouth of the machine, and drawn through the cages by a 4 mph air current. Duplicate cages of flies were treated with each concentration. Immediately after treatment the flies were transferred to clean holding cages and a cotton pad saturated with a 10 percent sugar water solution was placed on top of each cage as a source of food and water. The treated flies were held under constant light at 25°C and at 70 percent RH for 24 hr when mortality was recorded. If the concentrations of the chemical tested produced greater than 90 or less than 10 percent mortality these data were discarded and other concentrations selected until a minimum of 4 concentrations were used that produced mortalities within the acceptable range. These data were used to calculate LC_{50}'s by the probit analysis technique described by Finney (19).

Twelve compounds were evaluated in 13 tests, each of which included from 4-7 insecticides, acetone, a dimethoate standard, and an untreated check. The chemicals tested were as follows: dimethoate, parathion, naled, diazinon, fenthion, ronnel, propoxur, carbaryl, malathion, Dursban [*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pryidyl) phosphorothioate], Gardona [2-chloro-1-(2,4,5-trichlorophenyl) vinyl dimethyl phosphate], and Bayer 41831 [Sumithion] [*O*,*O*-dimethyl O-(4-nitro-*m*-tolyl) phosphorothioate].

Results

The insecticides tested as space sprays are listed in Table 8 in ascending order of the LC_{50} values obtained by probit analysis. The fiducial limits (P=0.05) are also listed. Dimethoate was the most effective

Table 8. LC_{50} of 5-day old *Phaenicia cuprina* females to insecticides in a wind tunnel.

Insecticide	LC_{50} (%)	Fiducidal limits P=0.05	LC_{50} susceptible house fly (%)[a]
dimethoate	0.0259	± 0.0064	0.04
parathion	.0532	.0068	.05
Dursban	.0567	.0063	.74
naled	.0648	.0065	.018
diazinon	.0857	.0063	.062
Gardona	.126	.0063	.06
fenthion	.133	.0065	.15
Sumithion	.183	.063	.074
ronnel	.246	.065	.13
propoxur	.264	.092	.95
carbaryl	8.42	.67	>2.5
malthion	>50.	-	.81

[a]Data obtained from the U.S.D.A. Gainesville laboratory.

chemical tested and along with parathion, Dursban, naled, and diazinon demonstrated potential for use as a chemical control of *P. cuprina*. Gardona, fenthion, Sumithion, ronnel, and propoxur were less effective. Carbaryl and malathion were ineffective with 50 percent malathion failing to kill 87 percent of the exposed flies. Appendix 3 shows the concentrations and percent mortalities used in the probit analysis to calculate the LC_{50}'s. The Chi square tests for chance variation of a homogeneous population were acceptable at the 5 percent confidence level for all tests and are listed in Appendix 3.

The LC_{50} values obtained by the USDA Gainesville Laboratory with the Orlando susceptible strain of house flies for the insecticides tested are listed in Table 8. These values when compared to the LC_{50}'s obtained with the wild blow flies show a reasonable correlation. Seven of the chemicals tested demonstrated LC_{50} values for house flies and blow flies within a factor of 2. The tolerance of _P. cuprina_ to these insecticides appeared to be about the same as those of the susceptible house fly strain colonized over 25 years ago. This is understandable since the blow fly has not been generally exposed to insecticidal pressures over a widespread area in the United States.

The ineffectiveness of malthion to kill _P. cuprina_ was unexpected as malathion residual sprays have been recommended to control blow flies at Florida dumps (34, 79). This becomes less startling, however, when one considers that malathion did not control _P. cuprina_ on sheep in Australia (57) and that malathion has induced a very specific resistance in the house fly, in _Culex tarsalis_ Coq., and in the blow fly, _Chrysomyia putoria_ Wiec. (11). In the case of the blow fly, complete resistance was induced within 6 months.

P. cuprina are controlled in Australia and widespread dieldrin resistance has been reported. Wild flies were 100 times more resistant to dieldrin than a susceptible strain and resistance was also observed to aldrin, endrin, isodrin, chlordane,, other cyclodienes, and BHC (32, 67, 63). Since the general use of chlorinated hydrocarbons is illegal in Florida these chemicals were not tested in this study.

A shift in the control of blow flies to organic phosphates was made in Australia in the late 1950's. Diazinon was the primary insecticide used and according to Shanahan (70, 71, 72, 73) no resistance was found after 6-8 years of use. He terms a 3-5-fold increase in the LD_{50} values of wild flies as tolerance. Schuntner and Roulston (65) found resistance to diazinon in blow flies and identified it as the breakdown of the *in vivo* pool of free diaoxon. A perusal of the literature revealed that resistance to any insecticide by *P. cuprina* has not been reported in the United States.

SECTION III

DENSITY AND SEASONAL FLUCTUATIONS OF HOUSE FLIES AT THE COMPOST PLANT

Observations conducted during 1968 revealed that blow flies and house flies were present in large numbers in the receiving area and around the sorting platform, while house flies predominated in the digester building. These flies annoyed the workers and posed a possible public nuisance if the plant proved to be a source of flies to the surrounding community.

A house fly sampling program was begun in January, 1969, to determine the density and seasonal fluctuations of the house fly population at the compost plant. The purpose of this survey was to determine the magnitude of the house fly population, the necessity of a fly control program, and seasonal changes that may affect such a program.

Rearing House Flies

All stages of house flies used in this and the following section were obtained from the insecticide susceptible or Orlando strain maintained by the USDA Gainesville Laboratory. These flies were reared in a 10 l plastic tub in a mixture of 1 part CSMA fly rearing medium and 2 parts water. A 6.5 x 6.5 x 10 cm sponge saturated with water was placed in the bottom of the tub to maintain proper moisture. The tub was covered with a black cloth secured with rubber bands. Pupae were collected 7 days after egging the medium and placed in 15 x 24 x 50 cm gauze cages. The adults were provided with fresh water and fly food which consisted of 6 parts granulated sugar, 6 parts non-fat dry milk, and 1 part dried egg yolk.

The flies were reared at the USDA laboratory in rooms with 16 hr of artificial light provided by fluorescent lamps. Temperature and humidity were maintained at approximately 26°C and 70 percent RH.

Seasonal Fluctuations of House Flies

Trapping

The digesters were selected as the primary sampling area for adult house flies at the compost plant for 2 reasons: (1) initial observations showed that adult house flies were usually more abundant near the digesters, and (2) equipment operation in the receiving and sorting areas made sampling procedures difficult.

The grill method of sampling house flies, developed by Scudder (66), was initially selected for use in the seasonal fluctuation study. This sampling procedure results in an index of the population and not an actual measure of population density (43). The reliability of grill sampling is debatable. Murvosh and Thaggard (43) reported a high correlation between grill counts and the total number of house flies in kitchens on the Island of Mayaguana, while Schoof (62) found that grill counts did not increase linearly with the population sampled. Welch and Schoof (81) reported that grill counting was subject to individual error and was no more accurate than visual estimates.

Grill counting was ineffective at the compost plant because of the large volume of attractive materials present.

One-foot-square (32.4 cm^2) masonite boards covered by a thin layer of Stickem (Michal and Pelton Co., Emryv.ile, California) were evaluated for trapping flies in the digester. These boards were attached to stakes 1 m in length which were then driven into the compost in the digesters. This procedure was discarded because such large numbers of flies were trapped that the boards became ineffective before 24 hr had passed. Also, more than 1000 flies per board were trapped and a population reduction this great may have significantly reduced the total population.

Fly sticky tapes (Aeroxon Products Inc., New York, N.Y.) measuring 5 x 85 cm were tested after the sticky boards were shown to be unacceptable for trapping the flies. Raybould (54, 55, 56) reported that sticky tapes were more accurate than grill counts in sampling house fly populations in Africa because they were less dependent on human judgment, took into account temporary fluctuations in densities, and allowed for the identification of the flies. Sticky tapes have also been shown to be more accurate than vacuum collections and visual counts at poultry farms (2), and baits at dairy barns (51). Tests during December, 1968, revealed that sticky tapes were acceptable for trapping house flies at the compost plant.

House flies were sampled in the digesters from January 12 to December 31, 1969, using sticky tapes suspended from 1.2 m wooden stakes driven into the compost. Five stakes were employed daily and each stake was placed in a different age of compost varying from 1-5 days of age. Sticky tapes were replaced daily and the number of house flies caught on each tape and the age of the compost in which it was suspended were recorded.

The mean number of flies caught per sticky tape per week was calculated by dividing the number of flies caught per week by the number of sticky tapes. These data are shown in Fig. 14.

Effects of Temperature

The maximum and minimum ambient air temperatures were recorded daily at the sewage treatment facility which was located immediately adjacent to the compost plant. These data were made available through the courtesy of Mr. C. R. Bennet, manager of the treatment facility. The weekly means of the maximum daily air temperatures were calculated and are shown in Fig. 14.

A comparison of the mean weekly catch of flies in the digesters and the mean weekly maximum air temperatures shows an apparent correlation between these data from January to June. The compost plant was closed to replace the primary grinding mill on June 15, 1969. When operations resumed on July 6, a definite drop in numbers of trapped flies was observed. A check with the plant foreman revealed that the operating procedures were the same as those before the plant closed for repairs. The only observable difference was that the refuse discharged into the digesters was slightly smaller in size. There was no reason to believe that this would greatly affect the number of flies in the area.

It was observed that temperatures in the digester building were higher than the ambient air temperatures because of the heat generated in the composting process and the construction of the metal digesting building. A hygrothermograph was placed on a platform 15 cm above the compost in the digester and the temperatures were recorded for several 1-week periods. These results given in Table 9 show that the mean daily

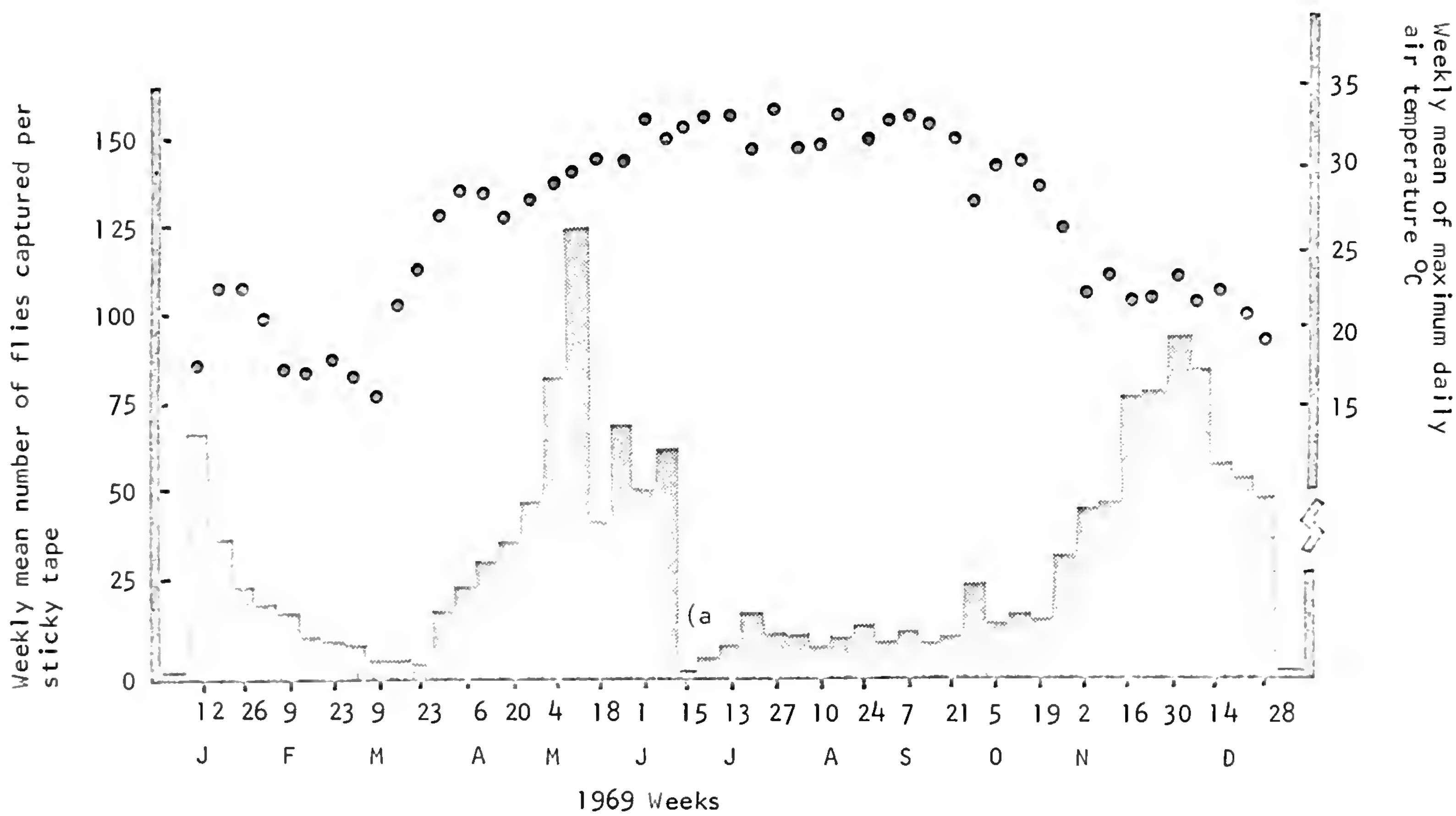


Fig. 14. Mean number of adult flies captured per sticky tape per week during 1969, in digesters at Gainesville compost plant.

(a Plant closed for repairs June 15-30.

Table 9. Air temperatures recorded[a] 15 cm above compost in digesters at Gainesville compost plant.

1969 Week of	Mean daily high	Mean daily low	Mean hourly temperature	No. flies caught per sticky tape[b]
Aug. 17	41.6	34.1	37.1	9.0
Sept. 21	37.5	32.4	34.9	9.9
Oct. 19	37.3	31.6	34.5	13.0
Nov. 16	33.7	24.2	28.5	77.3
Dec. 21	33.3	20.1	24.0	54.2

[a]Degrees Farenheit recorded on a hydrothermograph converted to degrees Centigrade.

[b]See Fig. 14.

maximum air temperature in the digester building could be expected to exceed 37°C during the summer months. Apparently these temperatures discouraged the flies from entering the building, resulting in a lower number of flies trapped on the sticky tapes.

The number of flies trapped increased in late October while a decrease was observed in the ambient air temperature and the temperature in the building. These observations lend credence to the opinion that the flies were repelled because of the higher temperatures.

A decrease in the number of flies and the ambient air temperature was observed in December.

This investigation was originally designed to determine the seasonal fluctuations of house flies at the compost plant. The temperatures in the digester building where the traps were located affected the number of flies caught during the summer months and this study failed in its original goal. However, these data do show a general trend during the cooler months and demonstrated that the building design reduced the number of flies present in the digester building during the period when fly numbers were potentially the greatest.

The number of flies caught on sticky tapes placed in the different ages of compost are shown in Table 10. These data demonstrate that flies prefer the freshly ground refuse. Greater than 50 percent of the flies in the digesters normally congregated in the area of the 1- and 2-day-old compost.

Table 10. Number of adult house flies caught on sticky tapes in different ages of compost.

	Days compost in digesters					Percent of total flies caught in	
1969 Week of:	1	2	3	4	5	1-Day old compost	1+2-Day old compost
Jan. 12	629	417	434	360	367	28.5	47.4
Jan. 26	266	182	173	91	119	30.8	52.1
Feb. 9	241	150	121	94	105	33.9	55.0
Feb. 23	74	65	44	46	51	26.4	49.6
Mar. 9	28	27	21	36	20	21.1	41.7
Mar. 30	154	130	45	51	42	36.5	67.4
Apr. 20	553	321	123	105	52	47.5	74.9
May 4	1413	501	193	197	179	56.0	76.9
May 18	501	365	193	154	162	40.4	65.3
June 1	790	347	228	151	198	46.1	66.3
Jul. 13	99	55	40	26	37	38.5	60.0
Jul. 27	85	106	17	46	32	29.7	66.8
Aug. 10	83	46	45	56	16	34.2	51.8
Aug. 24	176	128	44	51	37	36.3	62.6
Sept. 7	123	116	41	49	79	30.2	58.5
Sept. 21	105	81	69	40	51	30.4	53.8
Oct. 5	86	134	75	59	88	19.5	50.0
Oct. 19	188	92	91	58	61	38.4	57.2
Nov. 2	407	369	226	201	321	26.7	50.9
Nov. 16	677	533	675	424	297	26.0	46.5
Nov. 30	971	714	542	407	469	31.4	54.4
Dec. 14	680	461	437	374	217	31.6	53.1

Evaluation of Fly Sticky Tapes

Methods

A known number of house flies were released in a large outdoor screen cage with sticky tapes to determine if the number of flies caught could be correlated with the total number of flies present. The cage was located in a partially shaded lot behind the main building of the USDA Gainesville laboratory. The cage had a 5 x 5 m base with a gothic arch roof 3.5 m high. The floor consisted of soil and was kept cleaned of weeds and grasses during the tests. Two 1.2 m stakes were driven into the ground on the center line of the cage 1 m from each end. A sticky tape was hung on each stake and replaced daily. A 30 x 120 x 120 cm 3-shelf metal stand was placed in the center of the cage to hold the food and water supplied daily and to provide shelter for the flies. Tests were conducted during June, July, and August of 1969.

Test insects were obtained as pupae from the USDA's insecticide susceptible house fly colony and were held in cages until adult files were beginning to emerge. At the onset of eclosion approximately 200 pupae were placed in a 15 x 24 x 27 cm gauze cage. After 24 hr the remaining pupae were removed. The cages were provided daily with fresh fly food and water and were held in a room provided with 16 hr of artificial daylight by fluorescent lamps. Temperature and humidity were maintained at 26°C and 70 percent RH.

Flies used in the test were removed from the cages, anesthetized with carbon dioxide and counted. A 1:1 ratio of males to females was selected and the flies were then released into the large outdoor cage. Sticky tapes were placed in the outdoor cage immediately after releasing the flies. Twenty-four hr later the tapes were collected and the numbers of flies counted. All flies remaining in the cage following a test run were killed using a fly swatter. Pupae, 1-, 3-, and 5-day old house flies were released in the cage in numbers of 100, 250, 500, 1000, and 2000. Duplicate tests were conducted for all ages and numbers of flies tested.

One-day old flies were released in the outdoor cage 24 hr after placing the emerging adults in the small cages. This procedure provided flies which were 1/2 - 24 hr old at the start of each test. Three-day old flies had emerged 48-72 hr prior to release and 5-day old flies had emerged 96-120 hr prior to release.

In one series of tests, mature pupae were counted and placed in the large outdoor cage. Sticky tapes were hung on the stakes and 24 hr later the number of adult flies which had emerged during the test was determined by counting the number of remaining pupae.

Results

The number of flies caught on sticky tapes was linearly correlated to the total number of flies present in an outdoor cage as shown in Fig. 15. A high degree of correlation was noted for flies of the same age while there was a smaller though acceptable linear relationship in the combined values of all ages between number caught and number present. The slope of the correlation was calculated following the procedures outlined in Dixon and Massey (16).

The percentage of flies released as pupae, 1-, 3-, and 5-day old flies caught on the sticky tapes were 11.9, 24.8, 17.1, and 19.2, respectively (Fig. 15).

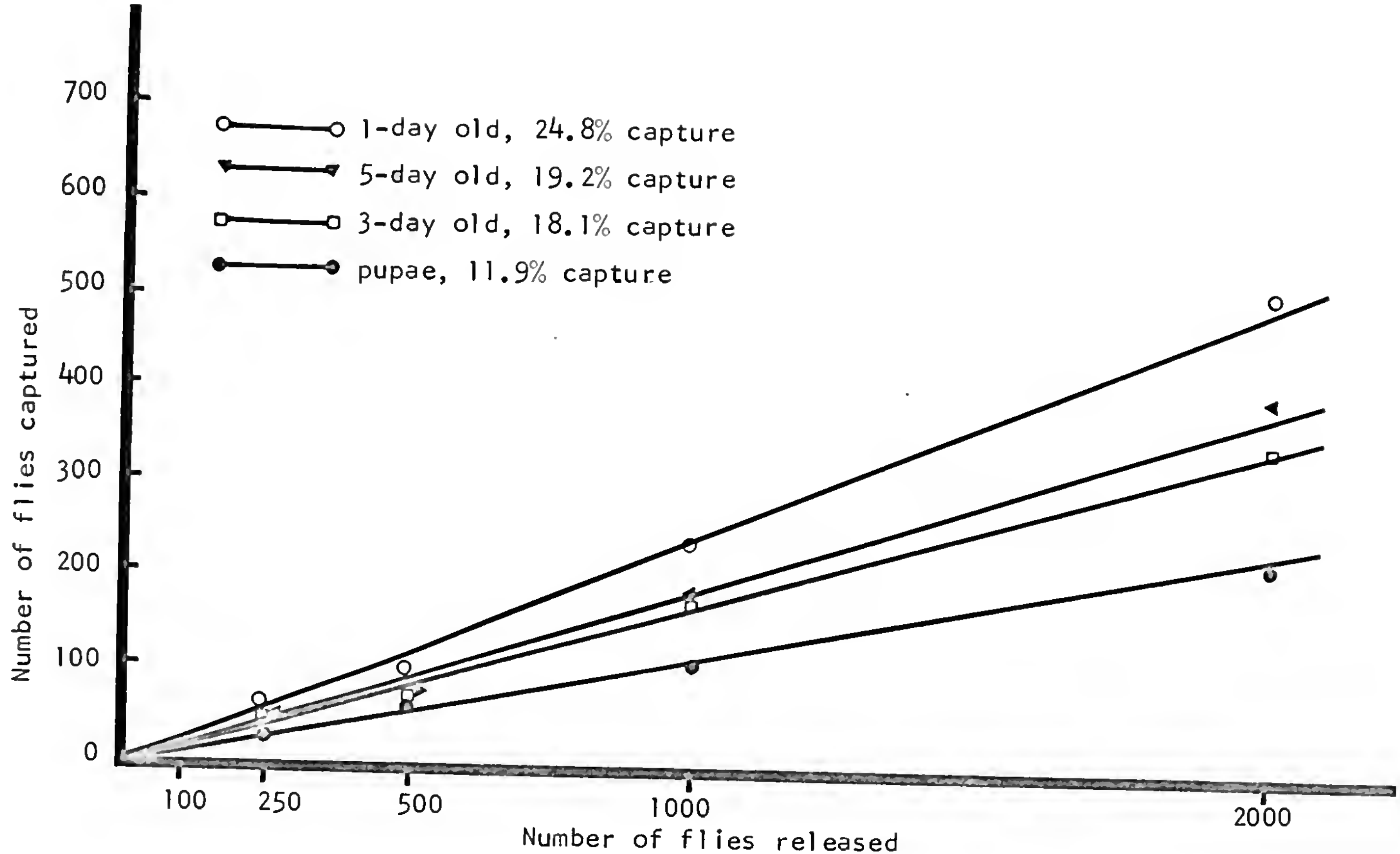


Fig. 15. Number of house flies captured on sticky tapes within 24 hr after release in a large outdoor cage.

The smaller number of flies trapped when pupae was allowed to emerge in the outdoor cage were not surprising since a higher mortality rate was expected.

Determination of the Magnitude of the House Fly Population

Methods

The total number of house flies in the digester building was estimated by determining the percentage of marked flies captured on sticky tapes that were released in that area. Three-day old house flies from the USDA susceptible colony were anesthetized by carbon dioxide and placed into small screen holding cages. These flies were marked by adding one-half teaspoon of DayGlo (Switzer Brothers Inc., Cleveland, Ohio) fluorescent dust to approximately 800 flies and gently rotating the cages. The flies were then transferred to 15 x 24 x 27 gauze cages. Following a 1-hr period to allow the flies to recover, the flies were transported to the compost plant and released in the digester building. All releases were made between 10:00 - 11:00 am on a Saturday or a Sunday when the plant was not in operation. Although all the doors in the building were closed, flies were not confined to the digester building because the siding did not fit flush to the base of the building leaving a 25 cm opening.

The flies were captured by 5 sticky tapes suspended from stakes in the digesters and were the same as described previously for the seasonal fluctuation survey. The sticky tapes were collected 24 hr after each release and the marked flies identified by use of a battery powered ultraviolet light. Four releases were made involving 1500 flies each and 3 were made with 5000 flies each.

Results

An average of 1.8 percent of the laboratory-reared house flies released in the digesters were captured on sticky tapes (Table 11). The capture of house flies on sticky tapes in a large outdoor cage was shown previously to be proportional to the number of flies present. Whether the percentage captured is 17 percent as shown for 3-day old flies released in an outdoor cage as shown in Fig. 15 or 1.8 percent as shown in Table 11, would depend on the circumstances. Admittedly, any value assigned would be questionable due to death, dispersal, and environmental factors. However, in the present case the value 1.8 percent is given credence since Murvosh and Thaggard (43) counted 1.25 percent of the house flies present in a similar partially open situation.

This figure (1.8 percent) can be used to estimate the total number of house flies present in the digesters based on the numbers caught on the sticky tapes. For example, Fig. 15 shows that 48.9 flies per stake per day were caught the week of April 27, 1969. An estimate of the total number of flies present can be calculated by 100 percent ÷ 1.8 percent x 5 stakes per day x 48.9 flies per stake and is equal to 13,569 house flies per day present in the digester building during the week of April 27, 1969.

Table 11. Recapture of 3-day old marked[a] laboratory reared house flies by sticky tapes hung in digesters for 24 hr following release of flies in the same area at the Gainesville compost plant during 1969.

Date	No. marked flies released	No. marked flies recaptured	Percent recaptured	No. unmarked flies trapped on sticky tapes
Oct. 5	1500	60	4.0	42
Oct. 12	1500	27	1.8	30
Oct. 18	1500	15	1.0	33
Nov. 16	1500	37	2.5	396
May 10	5000	83	1.7	1058
May 17	5000	41	.8	696
Dec. 13	5000	63	1.3	450
		Average	1.8	

[a]DayGlo fluorescent dust.

SECTION IV

HOUSE FLY BREEDING IN COMPOST

Observations conducted during 1968 and early 1969 revealed that house fly larvae were present in the compost in the digesters and along the conveyor belts where spillage had occurred. The ability of house flies to breed in compost presented the possibility of great numbers of flies reproducing in the enormous amounts of compost available.

An investigation began in April, 1969, to determine the extent and some of the limiting factors of house fly breeding in compost in order to devise procedures that may be used to prevent or hamper house fly breeding.

Moisture and Age of Compost

Methods

Composts of various ages and moisture (%) were evaluated to determine their effects on house fly breeding. Compost 0, 1, 3, 5, and 10 days of age was tested at 30, 45, 60, 75, and 90 percent moisture. The age of the compost was determined by the length of time the compost had been in the digester. The 0 days of age compost was freshly ground refuse taken off the conveyor belt just prior to discharge into the digester. Compost 10 days of age was tested prior to and after it had passed through the final grinders.

The samples taken from the digesters were removed from a depth of 30-60 cm and placed into a plastic bag. A minimum of 5 areas were sampled for each bag. The bag was then sealed and the contents thoroughly mixed. A 10 gm sample was removed from the bag and the moisture content determined with a moisture determination balance. The moisture content of the compost in the digesters usually varied from 35 to 55 percent moisture. Since this was greater than the lowest moisture content tested, a portion was removed from the bag and placed into a plastic screen mesh bag. The mesh bag was then placed in an oven maintained at 80°C. After a short drying period, the compost was transferred to a separate plastic bag. A 10 gm sample was taken to determine the remaining percent moisture.

The desired moisture content was obtained by adding tap water. The amount of water added was calculated by the following equation:

$$x = \frac{(y)\ (100-z)}{(100-y)} - z$$

x = ml of water added per 100 gm of compost
y = moisture content desired (%)
z = moisture content of sample (%).

After the amount of water needed for each desired moisture content was calculated, the compost was divided into 100 gm portions and each portion placed into a separate plastic bag. Tap water was added in the amounts calculated and the bags were sealed and the contents mixed. Fifty gm dry weight samples were removed from the bags and placed into waxed paper cups (0.946 l) which were marked for identification. Either 100 eggs or 100 48-hr old larvae of _M. domestica_ were added to each cup. The cups were then covered with black cloth and secured with rubber bands. Temperature and humidity were maintained at 26°C and 70 percent RH. Seven days after egging or 5 days after placing the larvae in the compost, the cups were emptied into a pan of water and the floating pupae were collected and counted. Each test was replicated 6 times. CSMA fly rearing medium containing 66 percent moisture was used as a control.

Results

Moisture content and the age of the compost had little effect on the maturation of 48-hr old house fly larvae (Table 12). However, these factors did influence the development of house flies from eggs. All ages of compost tested containing 60 and 75 percent moisture supported house fly development to some extent. Ninety percent moisture inhibited house fly development while 45 percent moisture was insufficient to rear house flies. Forty-five percent moisture in freshly ground refuse resulted in less than 1 percent survival to pupae. It should be noted that these tests were subjected to ambient RH (70%) and moisture fluctuations during the test period were not measured.

The age of the compost affected house fly development but this was secondary to moisture as shown in Table 12. There was a significant reduction in the number of eggs that developed to pupae in 3-day old compost at 60 percent moisture but no significant reduction occurred in the ages of compost tested at 75 percent moisture.

The effects of moisture on house fly development from eggs was extended to define more closely the optimum moisture of compost for fly breeding. In this test series 100 *M. domestica* eggs were placed in 3-day old compost containing 55, 60, 65, 70, 75, and 80 percent moisture, and tested in the same manner as described above. Each moisture content was replicated

Table 12. Influence of moisture and age of compost on maturation of immature house flies reared in compost.

Time composted[b] (days)	Percent moisture 30	45	60	75	90	Control[c]
	No. of pupae collected per 100 larvae (48 hr old)[a]					
0	82.5	78.0	84.8	81.6	67.0	94.1
1	54.3	81.3	58.6	33.5	50.3	92.5
3	84.3	74.3	80.3	88.3	80.1	90.1
5	76.0	80.6	84.6	91.6	70.1	92.6
10	81.6	79.6	86.6	90.3	58.5	92.6
10[d]	82.8	86.6	89.0	90.5	80.3	92.6
	No. of pupae collected per 100 eggs[a]					
0	0	0.8	16.5	43.3	5.6	80.6
1	0	0	11.3	33.8	.4	87.6
3	0	0	21.2	40.8	.8	78.6
5	0	0	3.1	39.0	.6	64.8
10	0	0	3.1	25.1	.3	80.5
10[d]	0	0	.3	8.5	0	88.3

[a]Mean of 6 replicates.
[b]Length of time in digesters.
[c]CSMA fly rearing medium containing 66 percent moisture.
[d]Passed through final grind (finished product).

10 times. CSMA fly rearing medium containing 66 percent moisture was used as a control. The optimum moisture content for house fly development was 75 percent (Table 13).

Sludge and Grinding

Methods

A test similar to the preceding experiments was conducted to determine what effects the addition of raw sewage sludge and the grinding of refuse had on house fly development. In these tests either tap water or sludge (approximately 98 percent moisture) was added to various grinds of refuse to obtain the desired moisture content. The sludge was obtained from the storage tank at the compost plant which was maintained by the city sewage treatment facility. Sixty and 75 percent moisture contents were chosen to be tested with the various grinds. The amounts of water and sludge added to achieve these moistures were calculated as in the previous study.

Four sizes of refuse particles were evaluated in this study. These were obtained from refuse taken immediately after primary grinding, refuse taken after secondary grinding, a 1:1 mixture of refuse from the primary and secondary grinders, and refuse that had passed through a small laboratory mill with a 0.63 cm grid. These samples were placed in plastic bags and mixed with water or sludge in the same manner as described for the previous experiment.

One hundred *M. domestica* eggs were added to 50 gm dry weight of the test materials and placed in waxed paper cups (0.946 l). The cups were covered and the pupae collected by flotation 7 days later. CSMA fly

Table 13. Influence of moisture on maturation of immature house flies reared in 3-day old compost.

Percent moisture	No. of pupae collected per 100 eggs
55	14.0
60	21.7
65	23.7
70	30.2
75	39.4
80	21.6
Control[b]	80.3

[a]Mean of 10 replicates.

[b]CSMA fly rearing medium containing 66 percent moisture.

rearing medium brought to 66 percent moisture by adding either water or sludge was used as a control. Six replicates were prepared for each test.

Results

The addition of raw sewage to compost of all size ranges produced a higher yield of house fly pupae than the addition of an equal amount of water as shown in Table 14. Such an increase is not surprising since the total organic content was increased and since Olson and Dahms (49) found sewage sludge an ideal breeding medium for house flies.

The effects of grinding compost were not clearly demonstrated. The results shown in Tables 12 and 14 indicate that the larger particles were more conducive to house fly survival. However, the size of the refuse

Table 14. Influence of sludge and grinding[a] of refuse on maturation of immature house flies reared in compost.

Percent Moisture	Refuse after primary grinding ca. 8" x 8"	50:50 Mixture of refuse from primary and secondary mills	Refuse after secondary grinding ca. 4" x 4"	Refuse passed through 1/4" grid[b]
a. Water added for desired moisture (control[c] = 85.2).				
60	26.3	20.5	19.0	0
75	33.6	29.1	30.0	0
b. Sludge added for desired moisture (control[c] = 88.5).				
60	31.9	26.3	28.0	2.8
75	47.0	39.5	35.3	19.8

[a]Grinding samples taken from grinding mills at the Gainesville compost plant operating under normal conditions.

[b]Refuse from secondary grinding mill passed through a small laboratory mill.

[c]CSMA fly rearing medium containing 66 percent moisture.

particles varied with the daily wear of the grinding mills and the exact size range was difficult to ascertain.

Temperature

The temperatures occurring in house fly rearing containers were investigated to determine the temperature range preferred by immature house flies. Nine probes of an Atkins H 51-X semiconductor thermometer (Atkins Inc., Gainesville, Florida) were placed in a 10 l plastic rearing tub containing CSMA housefly rearing medium at 66 percent moisture. The probes were placed in the positions and depths shown in Fig. 16. The temperatures were recorded every 24 hr for 6 days. This procedure was replicated 3 times.

The mean temperature recorded in the rearing tubs at each position are presented in Table 15. The blocked data in Table 15 represent those probes in areas occupied by larvae. The maximum temperature observed in the larval region was 46.1°C. These data indicate that larvae develop in a temperature range of 28 - 46.1°C.

The maximum temperature in which immature house flies can develop is not known. There are many references dealing with temperature studies on house flies but little definite information was found concerning this particular area. West (82) stated that house fly eggs cannot survive a temperature above 46.1°C while Roubaud (59) reported that larvae died in 3 minutes when exposed to 50°C.

To determine if the temperatures attained in the digesters may prevent house fly development in the compost an Atkins H 51-X semiconductor thermometer was used to measure these temperatures. The probes were

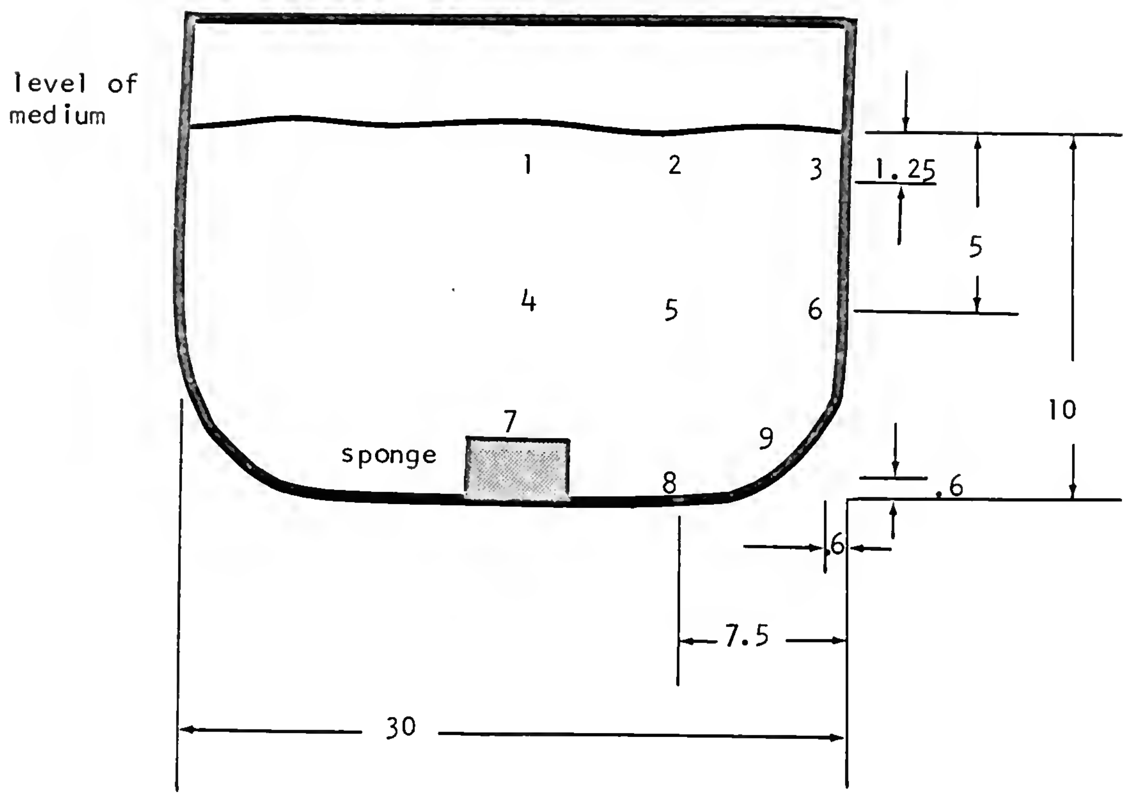


Fig. 16. Position of temperature probes in house fly rearing containers (distances in cm).

Table 15. Temperatures observed in house fly rearing containers.

Position Number[a]	Degrees Centigrade recorded[b] days after preparing and egging media					
	1	2	3	4	5	6
1	34.9	35.7	33.9	30.3	31.1	28.0
2	40.7	41.9	37.8	33.6	33.3	29.4
3	40.3	42.7	37.2	32.4	31.8	28.1
4	45.8	49.4	43.7	37.4	34.9	31.0
5	43.2	45.9	41.7	36.7	35.5	32.4
6	36.4	38.2	34.8	31.8	33.3	29.1
7	45.8	49.9	44.1	38.0	36.3	31.5
8	37.1	39.2	39.2	37.0	36.1	33.2
9	34.7	36.1	36.8	34.7	34.2	31.8

[a]See Fig. 12.

[b]Mean of 3 replicates recorded by an Atkin's semiconductor thermometer.

[c]Blocked data indicate area occupied by larvae.

placed in 4-day old compost at depths ranging from 1.27 - 15.24 cm and allowed 10 minutes to equilibrate. The temperatures were then read and recorded. Twenty-five readings were made at each depth over a period of several weeks. The temperatures ranged from a mean of 38.2°C at a depth of 1.27 cm to a mean of 59.4°C at 15.24 cm (Table 16). Information on the temperature in the digesters at greater depths was supplied to the author by Dr. D. T. Knuth, Environmental Engineering, Inc., Gainesville, Florida, and is presented in Appendix 4. From these data it can be concluded that temperature would prevent house fly breeding in the digester except in the top 2.5 cm of the compost.

Table 16. Temperatures observed in 4-day old compost in digesters.[a]

Depth (cm)	Degrees Centigrade		
	Minimum	Maximum	Mean of 25 Observations
15.24	56.2	61.5	59.4
12.70	54.3	62.5	58.5
10.16	54.7	59.9	57.2
7.62	48.4	59.7	53.9
5.08	43.0	55.5	49.7
2.54	40.0	66.0	44.9
1.27	35.8	62.5	38.2

[a]Sewage sludge added to achieve 50-55% moisture content in compost and ca. 4.6 ft^3 per hour of air per ft^3 of refuse supplied for aeration.

SECTION V

MIGRATION AND DISPERSAL

Compost plants and other similar types of refuse handling systems are centrally located to lower the transportation costs. These facilities are optimally designed to operate in these central locations without causing a nuisance to the surrounding community. The Gainesville compost plant has previously been shown to produce approximately one-half million adult flies per week during the summer months. These flies may disperse into the surrounding community, thus discounting the value of central location. An investigation to determine the extent of fly dispersal from the compost plant was begun in 1969. When the plant closed in December, 1969, these dispersal studies were completed at the city landfill.

Literature Review

House Flies

There is an undue prominence often attached to the maximum distance of dispersal of flies (63). Flies released from a central location and recaptured later at some distance in very limited numbers imply that the area covered is subject to infestation from the release point. Although this may be true, it should be noted that those one or two flies recovered at some great distance were among the exceptional few that, by some element of chance, managed to achieve this distance. The dispersal of the mass of the fly population rather than that of a few individuals is the significant criterion of concern in regard to the effects on man (63). The dispersal capacity of the mass population is expected to be expended within 1/2 - 2 miles because of the meandering character of house fly movement (13, 48, 50, 53, 63, 64, 75). The fly moves from one field of a stimulus causing a tropic reaction to that of another (33). A fly may travel 15 miles to reach a distance 1 mile from its origin (63).

The attractiveness of the release site may greatly influence dispersal. Pickens et al. (51) recaptured 13 percent of the liberated house flies at the release site when the site was an attractive barn. When they released flies in an open area located at the center of a 1/2 mile circle of 4 barns only 4.1 percent of these flies were recaptured. Schoof (63) found that in many instances flies dispersed from a location despite the presence of an apparent excess of feeding and breeding areas.

There are conflicting reports of the effects of wind on fly dispersal (25, 40, 52). However, the more comprehensive studies of Schoof and Silverly (64) found that house fly movement was not equal in magnitude in all directions and Pickens et al. (51) revealed that fly dispersal was random when the wind was variable and upwind when the wind blew predominantly from 1 quarter.

Ogata et al. (48) demonstrated that house fly dispersal was not influenced by highways, rice fields, or mountains. Dispersal is influenced by the age and sex of the fly. However, there was no significant difference observed in the flight of male or female, 1, 2, and 3-day old flies (51).

Schoof and Silverly (64) concluded that the common characteristic of fly dispersal was a basic randomness of movement influenced by 5 conditions: (1) population pressure, (2) differentially attractive sites, (3) geographical barriers, (4) preferential movement, and (5) inherent tendency of flies to disperse.

The maximum flight range of flies recorded in most studies was usually the maximum distance of trapping. The maximum recorded flight of house flies is 20 miles (83).

Blow Flies

Gilmore *et al.* (21) found that *P. cuprina* released at a central point were distributed randomly after 2 days in open sheep country. MacLeod and Donnely (38, 39) concluded that blow fly dispersal was random but that aggregations were formed producing a clumped distribution. These aggregations were due to different degrees of attraction offered to those individuals in their random movement across the activity areas. These authors later decided on two types of blow fly flight: a sustained dispersal flight, independent of the environment, and an interspersal flight which may involve no net displacement (40).

Gurney and Woodhill (25) found that *P. cuprina* tended to fly down or across a prevailing wind, while MacLeod and Donnelly (40) found no evidence of wind affecting blow fly flight. *Phaenicia* spp. has demonstrated a seasonal migration in autumn from the forest to the cities in Finland (47) and from the forest to open terrain in Great Britain (36). *Phaenicia* spp. was unaffected by steep slopes of a valley in upland sheep country of Great Britain (37) and crossed a 200-yard-wide river and a 90-yard-wide deciduous woodbelt (38). Norris (46) showed that blow flies did not fly during heavy continuous rain and that *P. cuprina* was unimodal in daily activity in Australia. *P. cuprina* was bimodal in Japan, being most numerous in the afternoon peak (74). *P. cuprina* was recorded 4.7 miles from their liberation site within 30 hr (21).

Comprehensive reviews of references on blow fly dispersal and migration are presented by Johnson (29) and Norris (45).

Flight Mills

Flight mills provide a convenient means of observing characteristics of insect flight under controlled environmental conditions. Since *P. cuprina* was the dominant fly species at the compost plant, laboratory-reared specimens were attached to a flight mill to determine the maximum distance they may travel in dispersal flights.

A simply constructed flight mill was used by Atkins (3) with the scolytid, *Dendroctonus pseudotsugae* Hopk. This device was improved by Smith and Furniss (77) and Rowley *et al.* (60) by automatically recording the revolutions of the mills by means of photoelectric cells and electric counters. Chambers and O'Connel (12) further improved this technique by reducing the friction of the mills by supporting the pivot between 2 magnets.

Methods

The flight mills used in this study were generously provided by Dr. D. L. Bailey, USDA, Gainesville. The rotor arms of these mills were constructed from 0.52 mm chromium-steel wire 33 cm in length. One end of this wire was bent into 2 right angles as shown in Fig. 17, so that the terminal 1.5 mm of the wire was perpendicular to the plane of the rotor arm. A 3 cm length of wire was bent in the same manner and adhered to the end of the rotor arm to produce the double end shown in Fig. 17. A pivot was fastened 16 cm from the end of the arm so that the circle it described had a circumfrence of 1 m. The pivot was a No. 0 insect pin with its head removed which was glued, point upward, to the rotor arm between two 6 cm circles of paper. The pivot was suspended between two 6 x 25 mm magnets (stirring bars) so that the pin was in contact with the upper of the 2 magnets and was stabilized by the lower magnet. The magnets were supported by 2 wooden dowels connected to a steel rod frame.

The revolutions of the arm were counted and recorded by a method similar to that described by Smith and Furniss (77). A 6 volt lamp was attached to the wooden dowel holding the lower magnet as shown in Fig. 17. A photoelectric cell was positioned above the lamp so that a 2.54 cm black paper disc glued on the rotor arm would interupt the beam of light with each revolution of the arm. This paper disc was 7 cm from the pivot on the short end of the rotor arm and also functioned as a counterbalance. The photoelectric cell was connected to a power unit which operated an electric counter.

Flies used in this study were reared on a diet of lean ground beef in the method described previously. The flies were anesthetized in a cold room maintained at 2-4°C. These flies were then attached to the radius of the mill with a drop of rubber cement on their pronotum. The rotors were then immediately mounted on the mills. In one series of tests, P. cuprina of various ages were placed in constant light provided by fluorescent lamps for 24 hr and the distances flown recorded. Ten male and 10 female flies were used for each test.

A second test involved 10 male and 10 female P. cuprina which were attached to the rotor arm approximately 4 hr after they emerged as adults.

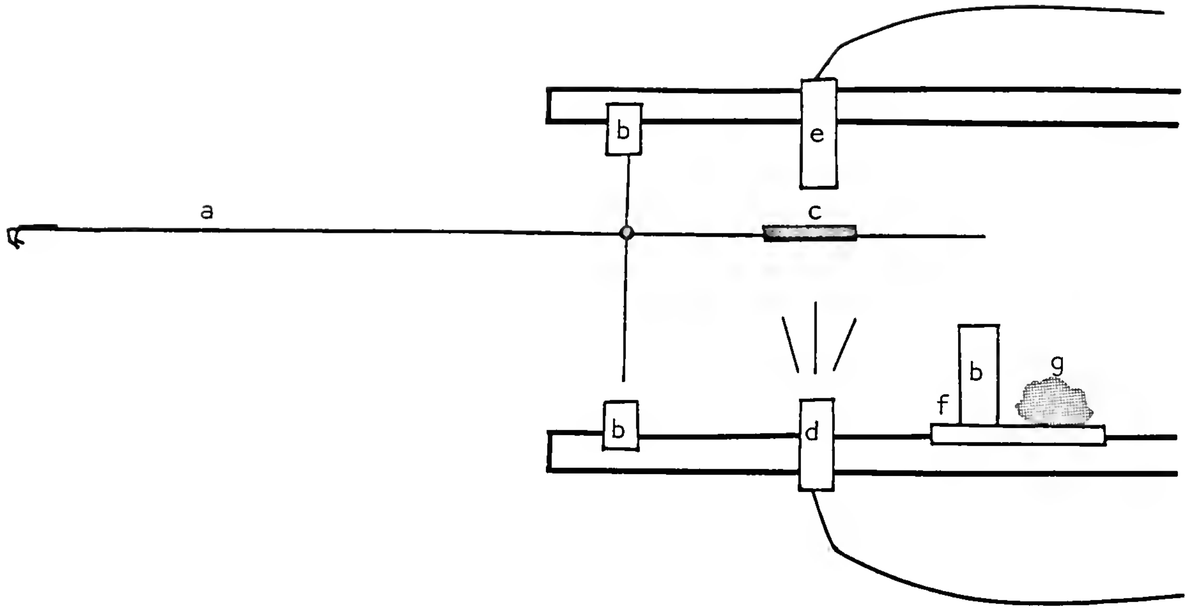


Fig. 17. Diagram of insect flight mill. a-rotor arm; b-magnet; c-counter-balance; d-light source; 3-photoelectric cell; f-metal plate; g-cotton ball.

These insects were allowed to fly until death. The flies were allowed to fly from 8:00 am to 6:00 pm each day under constant light. In the evening, the rotor arm was fastened to a magnet placed on the metal plate as shown in Fig. 17, and the flies were allowed to feed on a cotton ball saturated with a 10 percent sugar solution. The lights were turned off and the flies remained in this position overnight. All tests were conducted at the USDA laboratory in a room where temperature and humidity were maintained at 26°C and 70 percent RH.

Results

The mean distances flown by various ages of *P. cuprina* attached to a flight mill for 24 hr are presented in Table 17. The greatest distance travelled by an individual male was accomplished by a 5-day old fly that flew 24,129 m. The greatest distance travelled by an individual female was 19,603 m by a 3-day old fly.

Male and female *P. cuprina* flew an average of 19,405.4 m and 25,235.2 m and a maximum of 30,127 m and 45,030 m respectively, when attached to a flight mill until death, as shown in Table 18. Assuming these were less than ideal conditions, flies in the field could be expected to travel these distances and further, especially when taking advantage of the winds.

Blow Flies Released at Compost Plant

Methods

Four releases of wild flies were conducted at the compost plant during September, 1969, to determine their dispersal patterns in this

Table 17. Mean distances[a] flown in 24 hr by adult *Phaenicia cuprina* attached to an insect flight mill.

Age of fly (Days)	Males		Females	
	Meters	(Miles)	Meters	(Miles)
1/2	3,671	(2.28)	2,914	(1.81)
1	8,356	(5.19)	7,725	(4.82)
2	11,335	(7.04)	10,168	(6.32)
3	6,341	(3.94)	8,289	(5.15)
4	5,559	(3.45)	10,776	(6.70)
5	10,273	(6.38)	11,438	(7.11)
6	5,556	(3.45)	7,785	(4.84)
7	5,476	(3.40)	7,849	(4.88)

[a]Mean of 10 replicates.

area. The wild flies were captured by sweep net from the grassy areas surrounding the compost plant and placed into a large plastic bag. They were immediately anesthetized by carbon dioxide supplied from a portable lecture bottle. One teaspoon of DayGlo fluorescent dust was placed in the bag and the flies were marked by gently rotating the bag. The flies were volumetrically counted by pouring them into a 50 ml beaker. This volume represented approximately 500 flies. The flies were then placed into gauze cages, allowed 1 hr to recover, and then transported to the release site. Two releases of 1000 flies each were made at the compost plant, and 2 releases involving 1500 flies each were liberated at the city animal shelter. The flies were captured around 9:30 pm and releases were made about 11:00 pm that same night.

Table 18. Distance flown until death by adult Phaenicia cuprina attached to an insect flight mill.

Females			Males		
Meters	(Miles)	Age of Insect At Death (Days)	Meters	(Miles)	Age of Insect At Death (Days)
26,651	(16.6)	5	29,546	(18.4)	3
16,931	(10.5)	3	19,892	(12.4)	5
13,283	(8.3)	3	16,601	(10.3)	4
15,445	(9.6)	4	6,477	(4.0)	3
45,030	(28.0)	6	23,658	(14.7)	5
23,386	(14.8)	8	30,127	(18.7)	3
26,195	(16.3)	9	21,698	(13.5)	5
18,994	(11.8)	9	14,361	(8.9)	5
25,599	(15.9)	7	9,126	(5.6)	3
40,838	(25.4)	7	22,568	(14.0)	4
$\overline{X}$ = 25,235.2	(15.7)	$\overline{X}$ = 6.1	$\overline{X}$ = 19,405.4	(12.1)	$\overline{X}$ = 4.0

A sample of approximately 200 marked flies was taken from each release and identified. Greater than 99 percent of these flies were *P. cuprina*.

The marked flies were recaptured by sweep net after they were identified by examining the blow fly roosting areas surrounding the compost plant with a portable battery powered ultraviolet light. Baited cone traps, described previously, were placed behind the receiving building, at the city animal shelter, and in the backyard of an apartment 200 m east of the plant. These traps were checked every 24 hr for 4 days after each release. The trap at the animal shelter was removed for those releases at that location.

Results

An average of 10.7 percent of the blow flies released at the compost plant were recaptured in the same area 24 hr after liberation as shown in Table 19. Traps baited with 1-day old fish heads at the city animal shelter and behind the apartment failed to capture any marked flies for these 2 releases. Flies released at the city animal shelter were recaptured at the compost plant at an average of 5.65 percent. The trap behind the apartment failed to trap any marked flies in these releases.

Fly Releases at the City Landfill

The compost plant closed December, 1969, forcing the completion of the dispersal studies to be conducted at the city landfill. The landfill presented a situation different from the compost plant but similar in the large amounts of attractive materials present and the generation of a large number of flies. It was concluded that dispersal patterns observed in this area may be interpolated as to general trends which may be applied to the compost plant.

Location of City Landfill

The landfill was located on a 30-acre tract of land north of the Gainesville Municipal Airport. This area was surrounded by pine flatwoods and the closest residence was located 1.2 mi south of the landfill. The Gainesville Industrial Park was located 1 mi west of the landfill and the airport runways began 1/2 mile southwest of the landfill. Three residences were located 1.5 mi north of the landfill while woodlands extended for several miles to the east.

Table 19. Recapture of wild marked[a] flies[b] by sweep net and baited traps 24 hr after release.

Date	Release site	No. marked flies released	No. recaptured at compost plant	Percent recaptured
9/11/69	Compost plant	1000	121	12.1
9/14/69	Compost plant	1000	93	9.3
9/17/69	City animal shelter	1500	102	6.8
9/21/69	City animal shelter	1500	67	4.5

[a] DayGlo fluorescent dust.

[b] $>$99 percent _P. cuprina_.

Operation of the Landfill

The refuse was brought to the landfill by truck and dumped into trenches 15 m wide and 5 m deep. A bulldozer was supposed to crush and pack the refuse into the trenches and then cover it with soil at the end of the day. Such an operation would be in compliance with the standards of the American Public Works Association for the operation of a sanitary landfill (1). Unfortunately these procedures were seldom complied with because of equipment failures. Refuse was observed to remain uncovered for several days on many occasions.

A separate area of the landfill was used to dispose of dead animals and the maintenance of this area was poor. Too frequently animals were not completely covered with soil or else not covered at all for several days. This resulted in large numbers of flies developing in this area (Fig. 18).

Fly Behavior Patterns Observed at the Landfill

Before a general discussion of the releases can be undertaken some observations concerning fly behavior at the landfill should be reported.

Blow flies and house flies were inactive at night, roosting on the refuse or on vegetation surrounding the refuse until sunrise (Fig. 19 and 20). As the roosting sites were exposed to the sun the flies crawled about the plant or refuse to position themselves in direct light where they groomed themselves for 15-90 minutes. The flies then left the roosting sites, flying as it seemed, an orientation flight. These flights occurred in all directions, with the majority of the flies finally appearing at a sunny, sandy area, absent of vegetation. The sunny sides of the mounds of sand used to cover the refuse were preferred sites. The flies

Fig. 18. Fly larvae in animal disposal area of city landfill.

Fig. 19. _P. cuprina_ roosting on grass tassel at night at city landfill.

Fig. 20. Predominantly M. domestica roosting on weed at night at city landfill.

Fig. 21. Predominantly C. macellaria with some M. domestica roosting on dead brush in refuse at night at city landfill.

remained in these areas 45-60 minutes and mating was widespread during this period. The activity diminished and flies began appearing on the refuse where they remained until dusk when they returned to the roosting sites. House flies and *P. cuprina* were both observed to follow this pattern and both occurred in the same mating area simultaneously.

The roosting sites were centered around the most recently dumped refuse. *M. domestica* rested on the refuse, especially brush in the refuse, and on the surrounding vegetation immediately adjacent to the refuse. There appeared to be little selection of plant species chosen as resting sites but there was a preference of height. House flies appeared most often on plants 1/2 - 1 m in height. House flies have previously been reported to roost preferably on ceilings, trees, and shrubs in rural areas (2, 33, 41).

Cochliomyia macellaria were observed to roost on leafless or dead branches 1-3 m in height. Brush in the refuse and plants immediately next to the refuse were preferred (Fig. 21).

P. cuprina was seldom observed roosting on the refuse and rested almost exclusively in grasses and weeds up to 1 m in height. Green (22) and Maier *et al*. (41) observed similar behavior at a slaughterhouse as well as in urban areas. These flies roosted at a greater distance from the refuse than did the house flies. If one walked from the refuse through the surrounding vegetation, he would first pass through a belt 2-5 m wide of plants containing roosting house flies. This zone would give way to a mixture of house flies and blow flies and finally to an area where the blow flies were in the majority. The number of flies decreased rapidly with increasing distance from the refuse. Flies became relatively scarce after about 20 m.

Mortality

The determination of the natural rate of fly mortality in field populations is almost impossible since flies are such mobile insects. The determination of mortality rates of marked flies released in the field is even more difficult. Some observations on the effects of environmental factors and predation of marked and wild flies which may provide some information for the estimation of fly mortality are given in this section.

Flies at the landfill were preyed upon extensively by toads, spiders, ants, beetles, earwigs, dragonflies, and birds. Flocks of cattle egrets were observed feeding on adult flies and blackbirds were often seen feeding on the larvae in the refuse. Numerous toads inhabited the area and appeared to have little difficulty in acquiring a meal of flies in the grass and weeds at night. Earwigs hunted the fly roosting sites at night. These insects would grasp a resting fly with its pinchers and then feed on its struggling prey. Numerous spiders and ants patrolled the weeds and attacked the roosting flies. Ants were especially numerous in the early morning hours. Dragonflies hunted the area catching flies in flight during the day. It appeared that different species hunted at different hours of the day with tremendous numbers of dragonflies appearing at dusk.

To determine the effects the marking procedure had on the flies samples of approximately 500 flies from several releases were taken to the laboratory. The flies were anesthetized in a cold room (2-4°C) and 50 male and 50 female *P. cuprina* and *M. domestica* were placed into a gauze cage. Fresh fly food and water were supplied each day. The dead flies were removed daily and the number and species recorded. A control cage was also set up which contained wild flies that had not been marked. The marked flies suffered mortalities of 10-15 percent within the first 24 hr, 15-25 percent within 48 hr, and 33-40 percent within 7 days. The control mortalities were 2-4 percent, 4-6 percent, and 10-25 percent respectively. These results were similar to those of Murvosh and Thaggard (43) where 25-30 percent mortality was recorded for marking flies by shaking anesthetized flies with a dust.

The above data show that the largest percentage of flies were killed within the first 48 hr, indicating that the marking procedure killed or mortally injured 15-25 percent of the flies marked. It should be noted that these results were under laboratory conditions and a greater loss could be expected in the field. This becomes more apparent since it was observed that the marked flies released at the landfill often groomed themselves approximately 2 hr longer than the unmarked flies in the area. These marked flies were physically weakened and more subject to predation. Ants were particularly injurious at this time as they were observed to attack roosting flies by grasping their legs and the weakened flies were less likely to shake free.

The physical operation of the landfill also contributed to fly deaths. Flies in their search for food and breeding sites in the refuse would crawl into every available opening in the refuse. The crushing of the refuse by the bulldozer and the covering of the refuse with soil trapped and killed numerous flies.

Flies Released Around the City Landfill

Methods. -- Four releases were made at sites 1 mi or more from the center of the landfill. The purpose of these releases was to determine if flies would travel that distance to the landfill.

Flies were captured by sweep net at night on the vegetation surrounding the landfill. These flies were placed in 15 x 24 x 27 cm gauze cages with approximately 3,000 flies in each cage. After a sufficient number of flies were captured, they were transferred to a large plastic bag by placing the sleeve of the cage in the bag and rapping sharply on the aluminum bottom of the cage. Because of the large number of flies in the cage and dampness of their wings, the flies tumbled into the bag. DayGlo fluorescent dust was placed in the bag at a rate of approximately 1 teaspoon per 2,000 flies, and the bag gently agitated. These marked flies then were counted by volumetric approximation in which a waxed paper cup (0.946 l) filled with flies was equal to 12,000 flies and a 50 ml beaker was equal to 500 flies. Approximately 8,000 flies were then placed in one of several 45 x 45 x 50 cm release cages. These cages were designed for fly release studies as the rear panel of the cage was hinged to facilitate removal of the flies. These cages were transported to the release sites and the flies released. Capture usually began around 9:30 pm and the releases were made about 1:00 am the following morning.

A sample of approximately 500 marked specimens was removed from the release cages and taken to the laboratory for identification. The percentage of each species in that sample was taken as representative of all the flies in that release and was used in conjunction with the total number of flies released to calculate the number of each species released.

The marked flies were recaptured at the landfill by sweep net after they were located by systematically examining the refuse and the surrounding vegetation with a portable battery powered ultraviolet light. These areas were examined for 7 nights following the release.

Each release employed a different colored marking dust. The sites, dates of release, and numbers and species of flies released are given in Table 20.

Results. -- Flies were recaptured at the landfill from 3 of the 4 release sites as shown in Table 20. These data show that an average of 0.097 percent of the *P. cuprina* and 0.07 percent of the *M. domestica* released at the last 3 sites were recaptured. The flies released at the 39th Avenue location were subjected to several attractive loci and this may explain why no flies were recaptured from this area. A cow pasture was located immediately across the road from the release point and 10-15 residences were in the area as well as a hog farm. A direct line of flight from this release point to the landfill would require a fly to pass 3 residences, the hog farm, and 1.1 mi of woodland. The remaining release points were at least 0.1 mi from any residences and a direct line of flight passed only through woodlands.

The results of these tests agree with other published reports that these 2 fly species can travel and infest areas over 1 mi from the release or breeding site. Releases at greater distances were not attempted.

Flies Released at Landfill

Methods. -- Wild flies were captured, marked, and released at the center of the landfill in the manner described previously. Baited traps

Table 20. Recapture of marked[a] wild flies at Gainesville sanitary landfill by sweep net after release.

Date	Release Site	Number & Species of Marked Flies Released		Number of Marked Flies Recaptured at Landfill Hours After Release: 24 ♂	24 ♀	48 ♂	48 ♀	72 ♂	72 ♀	Total	% Recaptured
7/23/70	1.2 mi S. of landfill on N.W. 39 Ave.	*P. cuprina*	5,400	0	0	0	0	0	0	0	
		M. domestica	4,600	0	0	0	0	0	0	0	
7/23/70	1.2 mi N. of landfill at St. John Church	*P. cuprina*	9,300	2	3	2	4	0	1	12	.13
		M. domestica	5,500	1	0	0	0	1	0	2	.04
		C. macellaria	200	0	0	0	0	0	0	0	
7/26/70	1.0 mi NW of landfill at Sperry Rand Ball Park	*P. cuprina*	15,400	0	4	3	3	0	0	10	.07
		M. domestica	9,400	2	5	1	2	0	0	10	.11
		C. macellaria	200	0	0	0	0	1	0	1	.05
7/26/70	1.0 mi S. of landfill	*P. cuprina*	10,000	0	4	2	3	0	0	9	.09
		M. domestica	14,600	4	1	1	3	0	0	9	.06
		C. macellaria	400	0	0	0	0	0	0	0	

[a]Day-Glo fluorescent dust on flies caught at landfill.

were used in addition to the sweep net capture method described above to recapture the marked flies. The traps were modified cone traps consisting of two 1 quart (0.946 l) plastic freezer jars taped together at the mouths. The bottoms were removed and replaced by an inverted screen cone. A putrified fish head was placed inside each trap as an attractant. The traps were placed at the 4 points of the compass in concentric circles 1.5, 1.0, and 0.5 mi from the center of the landfill for the first 2 releases. The outer circle was moved to 0.25 mi from the center for the remaining 5 releases. Captured flies were removed and fresh bait added daily.

Results. -- The results of the marked flies released at the landfill and later recaptured in the same area are given in Tables 21 and 22. An average of 8.26 percent of the *P. cuprina* and 1.89 percent of the *M. domestica* released were observed at the landfill 24 hr after liberation and these numbers decreased with each suceeding observation. In Table 23 these data are divided into the average percentages of flies observed for releases followed within 24 hr by rainfall and those where no rainfall was recorded (Table 24). These data show that releases followed by dry days resulted in 10.17 percent recapture of *P. cuprina* and this number decreased significantly with each suceeding observation. Those releases followed by rain resulted in an average of 6.84 percent recapture of *P. cuprina* and this number had a significantly lower rate of decrease. Norris (43) reported that rainfall inhibits dispersal of *P. cuprina* and these data support that observation.

The majority of the flies released were not recovered. This was because of recovery error, mortality, and dispersal. The method of locating and counting the marked flies was exhaustive but it could not

Table 21. Observations of marked wild *P. cuprina* remaining at Gainesville landfill after release.

No.	Release Date	No. released	Number of marked flies observed at landfill days after release (percent) 1	2	3	4	5	6	7
1	7/27/70	13,100	1255(9.6)	461(3.5)	89(.68)	6(.04)	0	1	0
2	8/8/70	5,700	219(3.85)	840(14.7)	649(11.4)	278(4.9)	35(.06)	1	0
3	8/13/70	2,700	392(14.5)	150(5.5)	77(2.9)	11(.4)	1(.03)	0	0
4	8/17/70	8,800	1261(14.3)	498(5.7)	11(.12)	2(.02)	0	0	0
5	8/21/70	16,000	561(3.5)	479(3.0)	17(.73)	42(2.6)	0	0	0
6	8/26/70	31,200	1711(5.5)	677(2.3)	209(.67)	18(.06)	0	0	0
7	8/31/70	11,100	736(6.6)	141(1.2)	31(.28)	6(.05)	3(.03)	0	0
		Average	(8.26)	(5.27)	(2.39)	(1.15)	(.09)		

Table 22. Observations of marked wild *M. domestica* remaining at Gainesville landfill after release.

No.	Release date	No. Released	Number of marked flies observed at landfill days after release (percent)						
			1	2	3	4	5	6	7
1	7/27/70	6,900	62(.9)	23(.33)	7(.01)	0	0	0	0
2	8/8/70	12,300	149(1.25)	561(4.5)	592(4.8)	261(2.2)	23(.2)	0	0
3	8/13/70	7,300	309(4.2)	156(2.1)	43(.59)	0	0	0	0
4	8/17/70	8,200	175(2.2)	10(.12)	0	0	0	0	0
5	8/21/70	31,000	439(1.4)	595(1.9)	91(.29)	2(.006)	0	0	0
6	8/26/70	12,800	191(1.5)	39(.3)	2(.01)	0	0	0	0
7	8/31/70	5,900	111(1.88)	4(.07)	6(.1)	0	0	0	0
		Average	(1.89)	(1.50)	(.83)	(.31)			

Table 23. Average percentage of flies remaining at city landfill under different weather conditions.

Species		Average (%) of flies observed at landfill days after release			
		1	2	3	4
Phaenicia cuprina	wet[a]	6.84	6.46	3.29	1.99
	dry[b]	10.17	3.46	.36	.03
Musca domestica	wet[a]	2.07	2.49	1.42	.55
	dry[b]	1.66	.17	.04	0

[a]Average of releases followed by rainfall within 24 hr (releases 2, 3, 5, and 6 from Tables 21 and 22).

[b]Average of releases not followed by rainfall within 24 hr (releases 1, 4, and 7 from Tables 21 and 22).

Table 24. Rainfall[a] recorded at Gainesville Municipal Airport during release studies at city landfill.

Date[b]	Rainfall in inches days after release						
	1	2	3	4	5	6	7
7/23/70	0	0	.75	.17	0	0	0
7/26/70	.17	0	0	.7	0	0	0
7/27/70	0	0	.7	0	0	0	0
8/ 8/70	.97	.69	.87	1.18	.61	.31	.35
8/13/70	.31	.35	.11	0	0	0	0
8/17/60	0	0	.92	..29	.39	.29	.37
8/21/70	.29	.39	.29	.42	0	1.09	1.49
8/26/70	1.09	1.49	0	0	0	0	0
8/31/70	0	0	.02	.13	.06	.01	0
9/17/70	0	0	0	0	0	0	.17
9/22/70	0	.17	0	0	0	.45	0
9/26/70	0	.45	0	0	0	0	0

[a]Courtesy of Federal Aviation Association.

[b]Dates of releases (Tables 20, 21, 22, and 25).

be expected to identify all of the flies present. Marked flies resting on the underside of leaves were difficult to locate and isolated patches of vegetation used as roosting sites may have been overlooked. Marked house flies roosting on the refuse were particularly difficult to find because of the tremendous quantities of refuse present. Mortality from marking was previously discussed and could be expected to amount to 15-25 percent of the released flies. Mortality from predatation and the natural death rate of the flies and dispersal accounted for the remaining flies. The assignment of any figure to each of these factors would be conjecture.

Information concerning dispersal patterns was minimal. Only 2 marked flies were captured in the traps surrounding the landfill. These were both *P. cuprina* females captured in the same trap on the same day 1/2 mi from the release site.

Release of Laboratory Reared *P. cuprina*

Wild *P. cuprina* caught at the landfill were reared to the F_2 generation in the laboratory on a diet consisting of Chunx and ground beef in a manner described previously. Two-day old adult flies were anesthetized in a cold room maintained at 2-4°C and marked with DayGlo fluorescent dust as described previously. The flies were counted volumetrically and placed into 45 x 45 x 50 cm release cages supplied with fly food and water and allowed to recover about 8 hr. The flies were transported to the landfill and released about 10:00 pm. Flies were recaptured with sweep nets and baited traps as described previously.

Laboratory reared releases were followed by 24 hr periods of no rainfall (Table 24). The results of these releases are shown in Table 25

Table 25. Observations of 2-day old marked laboratory reared *Phaenicia cuprina* remaining at Gainesville landfill after release.

Date	No. released	Number of flies observed at landfill days after release (percent)						
		1	2	3	4	5	6	7
9/17/70	13,000	2258(17.1)	872(6.7)	236(1.8)	63(.4)	8(.06)	0	0
9/22/70	45,000	3931(8.75)	518(1.2)	114(.2)	11(.02)	3(.01)	0	0
9/26/70	24,000	1931(8.05)	337(1.4)	61(.2)	1(.01)	0	0	0
	Average	(11.3)	(3.1)	(.73)	(.14)			

and are similar to those recorded for wild *P. cuprina* liberated during a dry period (Table 23). No laboratory reared flies were captured in the baited traps.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Investigations revealed that fly breeding at the compost plant was minimal under normal operating conditions. The major fly source was from larvae migrating from the refuse in the receiving building to protected areas where they developed into adults. This situation is not unique to composting facilities. Other disposal systems as central incineration or refuse transfer stations have similar problems. Any time refuse is centralized, transferred, or remains standing for any length of time, insects in the refuse may escape into the holding area. Thus, the results of the present investigation could be applied to other similar refuse handling operations.

The number of insects escaping from the larvae-infested refuse stored in the receiving building often exceeded 500,000 larvae per week during the summer months. As high as 88.8 percent of these larvae may become adults resulting in approximately 450,000 adult flies per week released into the environs. These flies were predominantly the green-bottle blow fly, *Phaenicia cuprina*.

The reduction of these large numbers of flies can be accomplished by procedural changes in the handling of refuse and application of the axiom that good sanitation is the most effective method of fly control.

Greater than 35 percent of the larvae escaping into the compost plant could be eliminated by not storing refuse overnight in the receiving building. Such a procedure may involve increasing the capacity of the equipment at the Gainesville plant. Although impractical in this case, this should be considered in the construction of new facilities. The problem of having insufficient refuse to begin operations in the morning could be eliminated by starting the working day at a later time.

The construction of the receiving building greatly influences larval survival. Refuse falls behind the wooden retaining walls and provides food and harborage to rodents, roaches, and fly larvae. The construction of a solid retaining wall that would prevent the accumulation of such wastes or one that provides access for easy cleaning would be more desirable.

The construction of a fly larvae trap behind the retaining wall would reduce the number of escaping larvae. Such a trap could be made by the construction of a sunken trough in the floor between the retaining wall and the building wall. This trough filled with water would drown migrating larvae. The trough could be cleaned by flushing.

The concrete floor of the receiving building has been chipped by the loading tractor at the edge of the receiving hopper producing an opening between the hopper and the floor. The construction of a lip over the edge of the hopper would reduce the debris and number of larvae escaping into this area. This lip could be either metal or several inches of re-enforced concrete.

It was shown that a 40.6 percent reduction in the number of adult flies occurred when the area under the apron conveyor was cleaned and a possible reduction of 67 percent was predicted. This demonstrates the value of good housekeeping. Not only are the number of flies reduced by cleaning but the dangers of working with poisons and the potential problem of insect resistance and pollution are eliminated.

A combination of cleaning the area under the apron conveyor and eliminating the practice of overnight storage of refuse in the receiving building would reduce the number of escaping larvae and the ensuing adult population of flies by 63.5 percent. The application of an insecticide would reduce the number of the remaining flies.

The daily application of a dichlorvos sugar bait reduced the number of flies caught in baited traps at the compost plant by 66.7 percent. Malt bait and fogging were less effective and not recommended. The application of a residual insecticide to the night-time roosting sites reduced the number of flies at the plant by more than 99 percent. Dimethoate gave better than 90 percent control for one week. Gardona was ineffective as a residual.

The laboratory screening of 12 commercial insecticides revealed that dimethoate, parathion, Dursban, naled, and diazinon were effective against female _P. cuprina_ adults exposed in a wind tunnel. These results indicate that parathion, Dursban, naled, and diazinon may also be effective in field tests for the control of _P. cuprina_.

A diet consisting of Chunx, a dry dog food, and ground beef was found superior to the all meat diet which had previously been used to rear _P. cuprina_. The dog food diet produced a higher yield in total number of flies, it cost less, and it produced less offensive odors than the all meat diet.

The number of house flies captured on sticky tapes was shown to be proportional to the number of flies present in a large outdoor cage. This indicates that the fly population may be estimated by the number trapped. When a known number of marked house flies was released in the digester building an average of 1.8 percent were recaptured on sticky tapes. Thus, the total number of flies present in the digester building may be estimated by the multiplication of 1.8 percent times the number of flies trapped.

A one-year study of house flies in the digesters revealed that the number of house flies fluctuated seasonally and that high temperatures in the digester building during the summer months discouraged flies from entering that area.

The ability of compost to support the reproduction of insects presents the potential problem that a great number of insects may result from this method of refuse disposal. Observations revealed that house flies were the predominant insect capable of breeding in compost and they were limited by several factors. Temperature was the primary factor limiting house fly breeding in compost. Temperatures in the digesters prevented house fly development except in the top 2.5 cm of compost.

The moisture content of the compost was a major factor affecting adult development from eggs in compost. Seventy-five percent moisture was the optimum moisture content. It should be noted that compost at moistures above 65 percent could not be processed because of equipment limitations. The moisture content of the compost in normal operations ranged from 45-55 percent which gave 1-14 percent survival of eggs to pupae in laboratory tests.

The length of time the refuse composted affected house fly development. Survival decreased significantly after 5-10 days, depending on the moisture content.

The addition of raw sewage sludge to the ground refuse increases the ability of compost to support house flies. The effects of the size of the refuse particles on survival was not clearly demonstrated but there were indications that the smaller the refuse particles, the fewer the adults produced.

The moisture and age of the compost had no adverse effects on the maturation of 48-hr old house fly larvae in compost. Thus, those larvae in the refuse that survived the grinding process and were able to migrate to areas where temperatures were not lethal might develop to adults. However, it was demonstrated that larvae could not survive normal grinding.

Fly larvae were observed in the compost in the digesters during April, May, June, October, November, and December of 1969, and more than 99 percent of those insects identified were _M. domestica_. These flies may be controlled by removing and grinding the compost before the house fly can complete its life cycle. They can also be controlled by mixing the compost in the digester by the Agi-Loader so that the larvae are exposed to lethal temperatures.

Flight and dispersal studies were conducted to determine flight ranges and patterns from an attractive site. _P. cuprina_ males flew an average of 19,405.4 m (12.1 mi) and a maximum of 30,127 m (18.7 mi) when attached to a flight mill until death. Females flew an average of 25,235.2 m (15.7 mi) and a maximum of 45,030 m (28.0 mi). These data represent maximum flight distances of the greenbottle blow fly under laboratory conditions. Wild flies may travel these total distances but their net displacement may not be this great because of the meandering character of their movement. It is possible, however, that the net displacement may exceed the laboratory distances when flies are blown with the winds.

Wild *P. cuprina* and *M. domestica* released 1 mi or more from the city landfill were recaptured at the landfill. An average of 5.65 percent of wild blow flies, *P. cuprina*, released at the city animal shelter were recaptured at the compost plant. These data indicate that flies are attracted from the surrounding areas.

An average of 10.7 percent of the wild *P. cuprina* released at the compost plant were recaptured in that area 24 hr later. An average of 10.17 percent of the wild *P. cuprina* and 1.66 percent of wild *M. domestica* released at the landfill on days followed by 24 hr without rain were recaptured 24 hr after release. An average of 11.5 percent of laboratory-reared *P. cuprina* released at the landfill were recaptured 24 hr after release.

Baited traps located at an apartment 200 m east of the compost plant and at the city animal shelter failed to capture any marked flies released at the compost plant. Baited traps surrounding the city landfill captured only 2 flies after the release of 255,000 marked specimens. Both were *P. cuprina* females captured 1/2 mi from the landfill on the same day in the same trap. These data appear to indicate that the flies do not disperse greatly from these very attractive loci.

The following are recommendations for composting:

1. Refuse must be processed the same day it is delivered.

2. The refuse receiving area must be constructed to preclude the migration of larvae from the refuse to protected pupation sites.

3. The plant must be cleaned regularly, especially the area around

the refuse receiving hopper which should be cleaned a minimum of once per week.

4. The daily application of a dry dichlorvos sugar bait and/or the weekly application of a dimethoate solution to the night-time roosting sites of the flies should be conducted when adult flies become a nuisance.

5. The moisture level selected for a composting process should be influenced by the breeding of house flies in compost which increases as the moisture approaches 75 percent.

6. The grinding of the refuse must be thorough to insure the death of larvae in the incoming refuse.

7. Larval breeding in the digesters should be destroyed by either re-grinding or turning the compost in the digesters.

8. The plant should be centrally located to lower trucking costs but preferably in an area at least one-half mile from residences to reduce the nuisance caused by flies migrating into the surrounding area.

9. Further research studies in the areas of fly dispersal from a composting plant and fly breeding in compost should be conducted.

APPENDIX

Appendix 1. -- Test for the precision of the counting technique used to determine total number of larvae collected under the apron conveyor.

Weight of sample (gm)	Number of larvae	Larvae per gram
514	3064	5.96
566	3279	5.79
708	4217	5.95
430	2720	6.33
642	3842	5.98
		$\overline{X} = 6.00 \pm .2$

Appendix 2. -- Fly larvae trapped under apron conveyor during 1969, at the Gainesville compost plant.

Week of		Number caught	Species present (%)				
			Phaenicia cuprina	Hermetia illucens	Cochliomyia macellaria	Musca domestica	Sarcophaga spp.
Jan.	12	0					
	19	4	100				
	26	2	100				
Feb.	2	0					
	9	0					
	16	1	100				
	23	1	100				
Mar.	2	0					
	9	0					
	16	0					
	23	12	100				
	30	130	91.5	4.2		4.2	
Apr.	6	102	90.5	4.7		4.7	
	13	78	96.5	1.8		1.8	
	20	131	100				
	27	285	91.0			6.4	3.2
May	4	614	95.0	1.0		3.0	1.0
	11	1297	97.5	.4			2.2
	18	592	94.5		2.0	2.0	1.5
	25	1629	96.0	.1	1.2	1.8	.9
Jun.	1	2004	96.5	.9	.6	1.5	.6
	8	4554	97.0	.1	1.0	1.5	.3
	15,22,29[a]						
Jul.	6	3945	96.4	.4	.7	1.2	.3
	13	4387	93.5	.1	6.0	.2	.1
	20	4500	96.5		1.6	1.8	
	27	4482	96.6	.8	1.9	1.5	
Aug.	3	3366	96.4	1.2	1.2	.8	.4
	10	5669	98.4	.1	.7	.2	.4
	17	5749	99.2	.1	.1	.1	.5
	24	3534	98.7		.7		.7
	31	4350	98.3	.2	.5	.2	.8

Appendix 2 (Continued)

Week of	Number caught	Species present (%)				
		Phaenicia cuprina	Hermetia illucens	Cochliomyia macellaria	Musca domestica	Sarcophaga spp.
Sept. 7	6116	97.8	.1		.8	1.3
14	4156	94.0	1.3	1.3	1.3	2.0
21	2621	98.8	.2	.3	.2	.3
28	1611	92.5		4.7	.4	1.7
Oct. 5	3597	99.0			.5	.5
12	3371	97.5	.7		.7	.7
19	1638	94.7	.4	2.8	1.6	.4
26	639	97.8	1.1			1.1
Nov. 2	212	93.0	2.3			4.7
9	173	100				
16	18	100				
23	78	100				
30	77	100				
Dec. 7	2	100				
14	0					
21	2	100				
28	0					

[a]Plant closed for repairs.

Appendix 3. Percent mortality of 5-day old *Phaenicia cuprina* females 24 hr after exposure to insecticides in a wind tunnel.

Chemical	Dimethoate		Parathion		Dursban		Naled	
No. flies/ point	220		140		160		140	
LD_{50} (mg/Kg)[a]	155-500		3-30		97-276		430	
X^2	.001		.02		.43		.11	
	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort.
	0.05	80.68	0.10	89.28	0.10	89.38	0.10	76.82
	.0375	78.64	.075	60.83	.075	82.50	.075	65.00
	.025	47.66	.05	37.85	.0625	63.33	.0625	45.00
	.0175	24.55	.0375	21.66	.05	39.38	.05	33.75
	.01	7.33	.025	5.71	.0375	10.00		

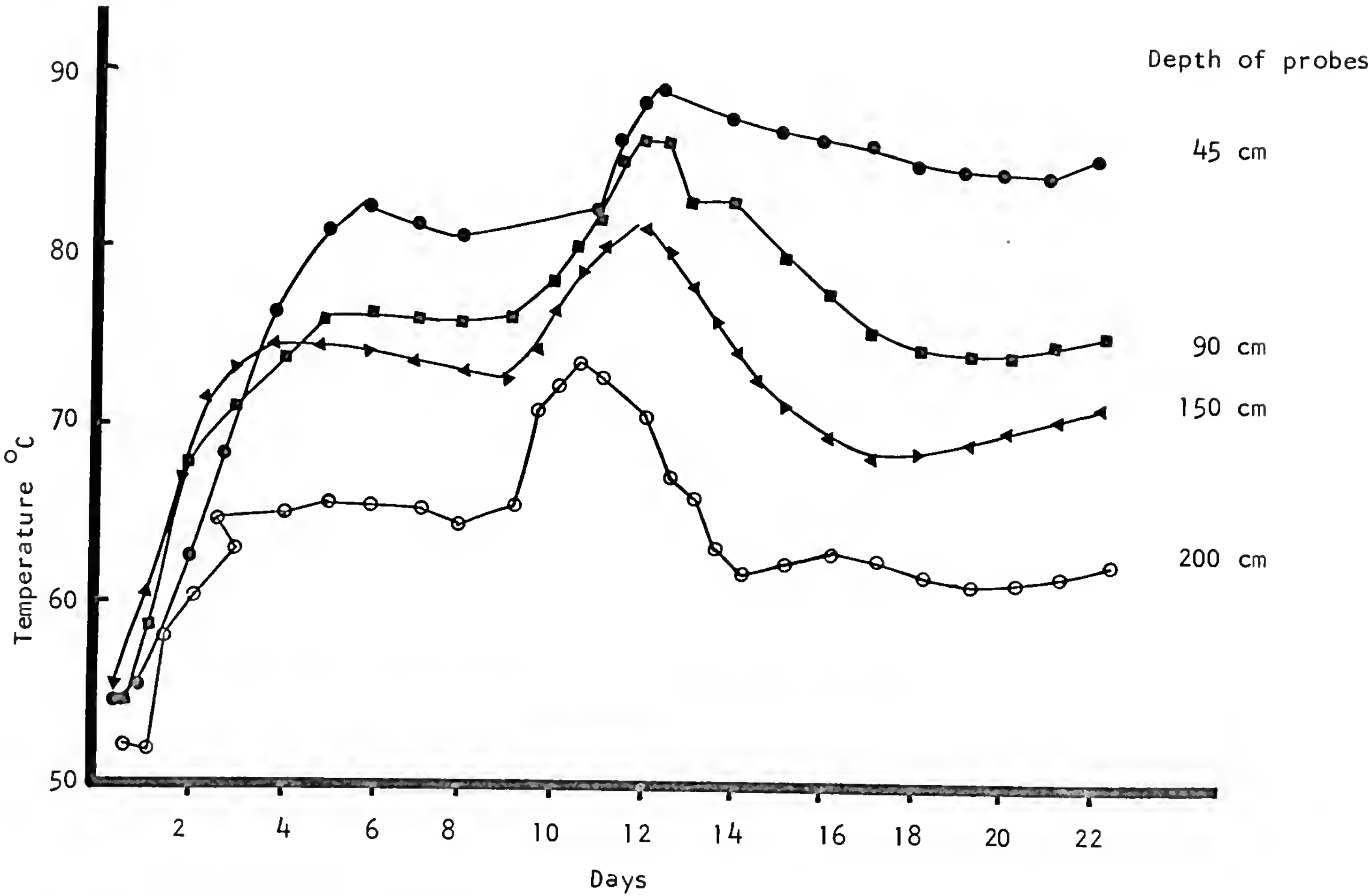
Appendix 3. (Continued)

Chemical	Diazinon		Gardona		Fenthion		Sumithion	
No. flies/ point	160		120		120		140	
LD_{50} (mg/Kg)	66-600		4000-5000		178-310		250-670	
X^2	.16		.01		.002		.09	
	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort.
	.175	89.16	.25	88.00	.25	95.00	.375	90.00
	.10	65.50	.175	75.83	.175	70.00	.25	70.00
	.075	37.50	.10	33.00	.10	30.63	.175	47.50
	.05	16.25	.075	15.00	.0875	18.75	.10	12.50
					.075	13.33		

Appendix 3 (Continued)

Chemical	Ronnel		Propoxur		Carbaryl		Malathion	
No. flies/ point	160		120		120		120	
LD_{50} (mg/Kg)[a]	906-3025		95-175		307-986		885-2800	
X^2	.23		.96		5.34		-	
	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort.	Conc.	% Mort
	.50	85.00	.50	85.62	10.0	52.20	50.0	13.1
	.375	77.50	.375	69.17	5.0	40.83	25.0	2.6
	.25	48.33	.25	46.66	2.5	30.83	10.0	1.0
	.175	30.00	.175	26.66	1.0	18.33	5.0	0
	.10	9.16						

[a] LD_{50} on white rats (acute oral).



Appendix 4. Temperature in digesters.[a,b]

[a]July 7, 1969; Initial compost height - 215 cm; No sewage sludge added.

[b]Courtesy of Dr. David T. Knuth, Environmental Engineering Inc., Gainesville, Fla.

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BIOGRAPHICAL SKETCH

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March, 1971

Dean, College of Agriculture

Dean, Graduate School