INVESTIGATIONS OF THE DESTRUCTIVE BEHAVIOR, AND METHODS FOR CONTROL OF THE LESSER MEALWORM, *Alphitobius diaperinus* (Panzer) (COLEOPTERA: TENEBRIONIDAE)

by

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(ABSTRACT)

The relationship between the types of construction of high rise caged layer houses and insulation damage produced by the lesser mealworm was examined. Polyurethane insulation which had heavy-weight paper glued to its surface and was installed with tape to seal off the seam between the insulation boards had no infestations. Structures with concrete block pit walls had lower insulation infestations than those houses with wooden walls forming the pits. Houses with a support structure set on top of the concrete block pit wall had lower infestations than houses built with the support structure set directly into the earth. The insulation installed nearest the pit was the most severely infested, and infestation intensity was inversely proportional to insulation height above the manure pit. Damage in extruded polystyrene insulation resulted in a substantial loss of volume of material in the corner areas of the insulation panels, and caused a significant reduction in insulating quality.

Observations were made on the effect of manure moisture and poultry house construction materials on lesser mealworm dispersal behavior. Larvae and adults preferred manure habitats of 30 and 40% moisture, and dispersal from the manure significantly increased when manure moisture was increased to levels of 50 and 60%. Larvae climbed a significantly greater distance up a vertical wooden surface than up a vertical concrete block surface under field conditions. Results indicate that structures built with wood pit walls are predisposed to infestations, and that fluctuating manure moisture levels in these houses can indirectly contribute to accelerated infestation by driving the larvae from the manure pits into the insulation.

Insecticide sprays, plastic films, paint barriers applied to the surface of extruded polystyrene, and different types of insulation were evaluated for lesser mealworm resistance. In a laboratory study, tetrachlorvinphos and pirimiphos-methyl sprayed on extruded polystyrene produced greater than 90% mortality in larval and adult populations up to 71 weeks postapplication. Larvae were unable to penetrate either chlorpyrifos-impregnated or non-insecticidal polyethylene films. Infestation intensity was inversely proportional to insulation cell size. Effective treatments identified under field conditions were

permethrin and pirimiphos-methyl sprays, and two formulations of chlorpyrifos-impregnated latex paint. Insulation materials with a cell size of 1.5 mm were resistant to lesser mealworm field populations.

I dedicate this dissertation
to my dear grandfather, ,
and uncles, and ,
who passed away during my years at
Virginia Polytechnic Institute
and State University.

May their memory be for a blessing.

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CHAPTER I

STATEMENT OF THE PROBLEM

From a historical perspective, the major influence of the insect on the poultry industry was its ability to transmit pathogenic organisms (De las Casas *et al*. 1968, Harein and De las Casas 1969, Harein *et al*. 1970, Eugenio *et al*. 1970, and De las Casas *et al*. 1972). In addition, the lesser mealworm is an intermediate host for several helminth parasites of poultry (Alicata 1939, Case and Ackert 1940) Much research was conducted after 1965 when the lesser mealworm was implicated as a vector of Marek's disease (Eidson *et al*. 1965, Eidson *et al*. 1966). These studies focused on basic biology and chemical control of field populations in the litter of floor houses (MacCreary and Catts 1954, Simco *et al*. 1966, Lancaster and Simco 1967, Silbermann and Schmittle 1967, Preiss 1969, Barke and Davis 1969, Lancaster *et al*. 1969, Wilson and Miner 1969). When anti-Marek's vaccines were developed in the early 1970's, and inoculation against this major disease became a standard management procedure at the hatchery, interest in the lesser mealworm subsided.

In recent years, poultry producers have reported the ability of the lesser mealworm to burrow into all types of materials used as insulation in both broiler-roaster and high rise caged layer facilities. The infestations were of an insidious nature, and were not always noticed by the poultry house managers. The infestations were characterized as a maze of interconnected tunnels permeating throughout the insulation (Ichinose et al. 1980, Vaughan et al. 1984). In advanced stages of infestation, the insulation panels (in particular, extruded polystyrene) became friable, and broke away from the house support structure. Infestations reduced the ability of the insulation to perform as a barrier to heat flow, thus increasing the amount of heat lost through the walls of the structure (Vaughan et al. 1984).

The infestations in high rise caged layer houses in Virginia were considered to be an acute problem. Preliminary surveys of high rise structures showed damage ranging from very severe to imperceptible. Questions from the egg industry arose concerning the cause of this variable degree of inter-house infestation, and on how to control darkling beetles. Since there are no official recommendations on record concerning control or prevention of lesser mealworm infestation for Virginia, there clearly is a need for further research in the area.

The initial step in a pest management problem is to gather information about the factors which contribute to the problem situation. All too often, the only perceived method for controlling a problem such as this is to apply insecticidal sprays to the insulation. Chemical control is effective in protecting the insulation if used sparingly, and other noxious pests can also be controlled (e.g. adult house flies) by the same spray application. However, it can be an unsound (and uneconomical) management practice to rely on a temporary prophylactic method such as premise insecticide sprays in a severely infested house without first examining the possible factors which contribute to reduce infestation and damage levels in other high rise houses. With a basic understanding of the factors leading to the destructive behavior exhibited by the lesser mealworm, more effective methods of prevention and control can be addressed. Hence, the major objectives of this research project were:

1. to conduct an on-site examination of high rise caged layer houses in Virginia to ascertain the extent of damage to extruded polystyrene insulation, and, if possible, associate the damage with different high rise construction characteristics;

2. to observe the effect of manure moisture levels and poultry house construction materials on the dispersal and destructive behaviors exhibited by the lesser mealworm;

3. to evaluate methods of protecting extruded polystyrene *in situ* and evaluate alternative insulation materials for resistance to lesser mealworm infestations.

CHAPTER II

SELECTED REVIEW OF THE LITERATURE

An extensive and in-depth review of the literature published on the lesser mealworm was done by Vaughan (1982). In this introductory review, I will address the literature on the biology and habits of the insect. The literature which is directly associated with the research objectives and which has been published since 1982 will be discussed in those respective sections of the dissertation.

2.1 LIFE STAGE BIOLOGY AND HABITS

2.1.1 EGG STAGE

The lesser mealworm egg is elliptical in cross section, and measures 1.2-1.3 mm and 0.4-0.7 mm in width (Preiss 1969, Wilson and Miner 1969). The eggs are anchored to a substrate by a clear sticky secretion. The development of the embryo can readily be seen through the chorion (Wilson and Miner 1969).

Most of the research on the egg stage has concerned the study of the effects of temperature and humidity on development and survival (hatchability). Lancaster and Simco (1967) first observed the duration of the egg stage. Adult beetles were placed on wheat kernels which previously had been sterilized via an autoclave and allowed to ferment for several days. They found that the female lesser mealworms readily laid eggs in this medium, and observed the insect's habit of inserting their eggs into small crevices. An incubation period of 4.3 days was determined, but since the temperature was not reported, the data can not be of use in basic ecological studies. More quantitative studies were to follow with the efforts of Preiss and Davidson (1968), Wilson and Miner (1969) and Ichinose _et al_. (1980). Preiss and Davidson (1968) found that egg hatch did not occur below 21.1° C or above 37.8° C. They found the shortest incubation time was 3 days at 35.0° C and longest development time was 10 days at 21.1° C and 25% RH. These data were later corroborated by results obtained by Wilson and Miner (1969) and Ichinose _et al_. (1980). The highest percent hatch (95.5%) occurred at 26.7° C. Preiss and Davidson (1968) found that percent hatch was reduced by low relative humidity (7-11% RH), but as relative humidity was increased (ranges from 20-28% to 79-81% RH), percent hatch significantly increased from 64.5% (at 7-11% RH) to 83.6% (at 68-71% RH).

2.1.2 LARVAL STAGE

This stage is a typical elateriform - campodeiform larva, somewhat cylindrical in cross section, elongate, and a very active organism. The first instar is pearly white, and the larval instars become increasingly darker (yellowish to brown) with development (Wilson and Miner 1969). Of the three preimaginal stages, the larval stage is the longest in duration (Ichinose _et al_. 1980). Anywhere from six to 12 instars are found, with the number of instars inversely proportional to rearing temperature (Wilson and Miner 1969). First instars are 1.5 mm long, and late instar larvae (sixth to twelvth instar) measure between six mm to 10 mm (Wilson and Miner 1969). At the range of temperatures found in commercial poultry housing (21.1°-32.2°C) the lesser mealworm passes through eight to nine instars (Wilson and Miner 1969). The length of the larval stage ranged from 38 days to 68 days, according to the rearing temperature (Wilson and Miner 1969, Ichinose _et al_. 1980).

The larvae are omnivorous, having been reported infesting a wide range of stored products. Vaughan (1982) provided a list of stored products commodities, including animal feeds and products, grains, palm fruits, and rice. Infestations most frequently occurred in stored products which had become moist and subsequently moldy, hence giving rise to the common name used by German entomologists for the adult stage: _glanzendschwarzen_ _Getreideschimmelkafers_; literally translated, the shiny black moldy grain beetle. Larvae prefer wheat and cracked corn (Sarin and Saxena 1975, Wilson 1968), and increased larval survival inexplicably occurred in those grain cultures which had become moldy (Wilson and Miner 1969). If given the opportunity, larvae will switch food resources, and have been shown to feed on the flesh and internal organs of dead and moribund chicks (Harding and Bissel 1958) and on the breasts of incapacitated broiler chickens (W. D. Weaver, personal communication, Poultry Science Department, VPI&SU). Harris (1966) found as many as 5,762 beetles occurring on and inside a broiler carcass. The insects are quite voracious, and have been reported feeding on the flesh of pigeon squabs (Lewis 1958, Keifer 1935 as cited in Crook *et al*. 1980) and actually killed and completely consumed the soft tissues of a ten-inch rat snake (*Elaphe* sp.), a DeKay's snake (*Storeria dekayi*) and a salamander (Harris 1966).

Larval cannibalistic behavior was described by Vaughan (1982) where he found that both larvae and adults fed upon exposed pupae. Under normal conditions, the frequency of intraspecific predation is probably minimal, because most late instar larvae burrow into the soil or manure pad to construct pupal cells (Preiss 1969). Vaughan (1982) suggested that by removing themselves from the stratum of beetle activity, the larvae increase their chances of surviving through the pupal stage.

The habit of tunneling the rearing substrate begins early in the larval stage. Wilson and Miner (1969) reported such behavior in the second instar, and it persisted throughout the remainder of the larval stage. While in the tunnel, larvae ceased tunneling long enough to molt to the next stage. The tunneling activity commenced immediately after ecdysis.

2.1.3 ADULT STAGE

The adult is a small black beetle, ranging from 5.1 to 6.1 mm in length (Wilson and Miner 1969). The teneral adult is reddish brown, changing color over a 7-day period as the cuticle hardens (Preiss 1969, Wilson and Miner 1969, Preiss and Davidson 1971). Sexes may be separated by examining the shapes of the meso- or metathoracic tibial spines or the eighth sternite. Females have two straight meso- or metathoracic spines, while in the male, one spine is straight and the other is curved (Barke and Davis 1967). The posterior edge of the male's eighth sternite is deeply emarginate; the sternite is straight in the female (Barke and Davis 1967).

There have been several investigations on the reproductive biology of the adult stage. Lancaster and Simco (1967) reported that females had an average preoviposition period of 10.8 days when reared on fermented grain at 15.6° C ambient air temperature, while Preiss and Davidson (1971) reported an average preoviposition period of 12.7 days under ambient air temperatures ranging between 21.1° and 23.9° C.

The discrepancy between the reported figures was probably a result of the warmer (unrecorded) temperature of the fermenting rearing substrate in the experiment conducted by Lancaster and Simco (1967). Adults have an extremely long life span, living in excess of 400 days (Preiss and Davidson 1971). Females averaged 3.5 eggs per day when reared at room temperature (21.1° C), and one female deposited 2,674 apparently viable eggs during its lifetime (Preiss and Davidson 1971). Wilson and Miner (1969) found that fecundity increased with temperature, and the largest number of eggs were produced at 32.2° C. Oviposition did not occur at 10° C. The optimum temperature for development from egg to adult appeared to be 32.2° C, with an average developmental time of 45.6 days. Wilson and Miner (1969) found that of the three moisture levels (9%, 12%, 15%) and six temperatures (10°, 15.6°, 21.1°, 26.7°, 32.2°, 37.8° C), the environment most conducive for producing larvae was at 15% moisture and 32.2° C.

2.1.4 BEHAVIOR WITHIN HABITAT

Lancaster and Simco (1967) most commonly found adults and larvae under objects lying on or slightly buried in the litter of broiler houses (*e.g.*, dead birds, feeders, pieces of lumber). In houses free of carcasses and lumber, adults and larvae were found along the edges of caked manure and litter, under clods of manure, and in areas where moisture was available (Lancaster and Simco 1967, personal observation). Neither larvae nor adults were found in areas of excessive moisture, but some dampness was necessary for survival and reproduction (Lancaster and Simco 1967, Preiss 1969). Wilson (1968) observed an aggregated distribution for adults and larvae within poultry houses. He noted that the beetles congregated in confined areas, forming large aggregations.

CHAPTER III

CONSTRUCTION PROFILES OF HIGH RISE CAGED LAYER HOUSES IN ASSOCIATION WITH INSULATION DAMAGE

The controlled environment used in modern day intensive poultry production facilities is conducive to rapid development of lesser mealworm populations. The biological requirements necessary for optimum lesser mealworm reproduction, such as relatively constant manure temperature (Armitage 1985), abundant water, and foodstuffs, are readily available in the pits of most high rise (HR) poultry houses and in the litter of broiler houses (Ichinose et al. 1980).

Ichinose et al. (1980), and more recently, Vaughan et al. (1984) have described the habits of the lesser mealworm in relation to the infestation of insulation materials most commonly used in broiler chicken and HR egg houses. Late instar larvae were shown to bore into polyurethane and extruded polystyrene (Ichinose et al. 1980) and construct pupational cells. Vaughan et al. (1984) observed the succession of life stages appearing in the tunnels made in expanded bead polystyrene, and found that the initial invasion by late instar larvae was followed by the appearance of adult beetles. The adults were observed to expand the diameter of the holes and tunnels made by the larvae.

The larval stage has a remarkable ability to penetrate many types of poultry house insulation and construction materials. Ichinose et al. (1980) exposed polyurethane foam, fiberglass, extruded polystryrene, and expanded bead polystyrene to lesser mealworm colonies, and found that all of the materials were equally susceptible to intensive tunneling by the larvae. Vaughan et al. (1984) found that extruded polystyrene, fiberglass and polyurethane were invaded by late instar larval lesser mealworms, but that the larvae preferred polystyrene over the other materials in which to construct pupation cells. All life stages were present in the fiberglass insulation, but pupation was not successful in this material. The general effect of the tunneling activity is an increase in the width of the insulation (Ichinose et al. 1980) and loss in the structural integrity of the insulation. Vaughan et al. (1984) showed that infestations increased the insulation thermal conductivity by as much as 20% over that measured in uninfested insulation, as measured from samples of extruded polystyrene insulation obtained from HR houses in Virginia. Penetration of polyvinylchloride film has been reported by Swatonek (1970) in Germany. Wildey (1983) and Safrit and Axtell (1984) described the ability of the larvae to bore into wood, further emphasizing the significance of this insect as a structural insect pest in poultry production facilities.

High rise house construction profiles and damage

Early reports from egg producers and extension personnel revealed that a relationship might exist between certain construction profiles of HR houses and the intensity of lesser mealworm infestation. Therefore, an on-site examination of the HR houses was conducted to ascertain the extent of insulation damage caused by the lesser mealworm, and, if possible, associate this damage with different construction characteristics of HR houses.

For the purpose of this study, a HR house is one constructed entirely above the normal surface level of the soil. The manure holding pit is of a depth necessary to allow front loading equipment to enter and remove the manure (not less than 1.8 m (6 ft)).

3.1 MATERIALS AND METHODS

Before the actual field inspections of individual premises began, a questionnaire was distributed to the egg producers, their service personnel and managers. This questionnaire was designed to provide information about producer awareness of the presence of the lesser mealworm and insulation damage in their HR houses. Questions were asked about the construction of each HR house,such as type of insulation, pit wall and outer wall construction, and the year each house was built. Certain other management factors, such as manure cleanout schedules, watering system problems, and replacement of insulation due to lesser mealworm infestation or other problems were explored. Upon completion the questionnaires were tabulated.

The follow up field inspections consisted of an on-site examination of each HR house having exposed insulation in the walls. High rise houses insulated with fiberglass could not be included in the data analysis, as the insulation and any infestations were concealed from view by a sheet of plywood. Items included in the questionnaire were also examined on each inspection date. To quantify the extent of lesser mealworm damage in the poultry house insulation, 30 random samples were recorded; 15 on each long side of the house. A rectangle, 3.8 X 57.2 cm (217.4 cm^2) was marked on the insulation at the seam created between the insulation panels. The number of visible penetrations inside the rectangle was recorded and analyzed for infestations by calculating the average number of penetrations per cm^2 of surface area. Based on preliminary observations it was determined that it is at these locations that lesser mealworm larvae first invade the insulation and visible signs of infestation are most prevalent. Two rectangles were marked above the personnel walkway, and one was marked below the walkway. The rectangles were approximately 1.2 m below the walkway, and 1.2 m, and 2.4 m above the walkway, hereafter designated pit, lower and upper level, respectively. The samples coincided with the width of the insulation panels. However, some HR houses were installed with insulation of such a width that only one location could be sampled above the personnel walkway. The samples from these houses were designated as upper level, and used in comparison with that level from the rest of the HR houses. The rectangles were aligned vertically on the wall.

3.2 RESULTS AND DISCUSSION

The returned questionnaires provided preliminary information on 20 of the 29 HR houses currently in use in Virginia (raw data from questionnaires may be found in Appendix A). I found from these questionnaires that the egg producers were aware of the presence of lesser mealworms in 75% of the houses. The beetles, presumably in the adult stage, were said to have been located only in the pits and on the lower portions of the walls. Ten houses were insulated with extruded polystyrene and the remaining houses contained varying thicknesses of fiberglass insulation in the ceiling and side walls. Of those houses which were insulated with extruded polystyrene, 90% were reported to have infestations in the wall insulation. However, none of the producers had reported that the infestations were severe enough to warrant replacement of the damaged insulation.

The field inspection data revealed that the HR houses with insulation which could be readily examined (*i.e.*, those not insulated with fiberglass) were built between 1969 and 1979 (Table 1). While it could be hypothesized that a positive relationship should exist between the length of exposure time and the intensity of lesser mealworm infestations, I found that there was no clear relationship between house age (this factor is equivalent to insulation age) and insulation damage. Indeed, three of the five oldest houses were among the least infested egg facilities I visited.

Two types of insulation, polyurethane and extruded polystyrene, were installed in the side walls, with the latter insulation being found in 88% of the houses. There was a wide range in insulation infestation in the polystyrene-insulated houses, from a low of 0.002 holes per cm^2 to a high of 0.204 holes per cm^2 (Table 1). The extruded polystyrene boards were fully exposed to lesser mealworm infestation pressure, save for one HR house, coded LG in Table 1. In the LG house, an aluminum skin covered the two broad faces but not the edges of the insulation. However, the aluminum skin was not effective as a barrier to invading lesser mealworm larvae, since this house was one of the most heavily infested. The insulation was not protected with any form of seal at the seam formed between the juxtaposed insulation boards. Two houses, DWR1 and DWR2, had no insulation infestations. The insulation in DWR1 and DWR2 had a covering of heavy-weight paper on the two broad faces of the insulation boards. The seam between the sheets of

Table 1. Construction profiles and associated damage to exposed extruded polystyrene insulation in HR houses in Virginia.

Site	Year Built	Insulation Type	Water System	Outer Wall Construction	Pit Wall Construction	Damage Mean[1]
DW93	1973	Polystyrene	Hart Cup	Pole	Wood	0.204 a
SB16	1973	Polystyrene	Hart Cup	Pole	Wood	0.110 b
LG	1977	Polystyrene[2]	Hart Cup	Pole	Block-wood	0.095 bc
SB21	1977	Polystyrene	Trough	Pole	Wood	0.086 bcd
SB15	1977	Polystyrene	Hart Cup	Pole	Wood	0.067 bcde
DW92	1972	Polystyrene	Hart Cup	Pole	Wood	0.060 cde
SB18	1975	Polystyrene	Hart Cup	Pole	Wood	0.055 cde
SB23	1977	Polystyrene	Trough	Pole	Wood	0.051 cde
SB22	1977	Polystyrene	Trough	Pole	Wood	0.047 def
SB19	1976	Polystyrene	Hart Cup	Pole	Wood	0.043 def
DW91	1972	Polystyrene	Hart Cup	Pole	Wood	0.033 ef
SB20	1976	Polystyrene	Hart Cup	Pole	Wood	0.030 ef
FW5	1977	Polystyrene	Hart Cup	Frame	Block-wood	0.029 ef
MR	1979	Polystyrene	Hart Cup	Pole	Wood	0.020 ef
FW4	1973	Polystyrene	Hart Cup	Frame	Block-wood	0.002 f
DWR1	1969	Polyurethane[3]	Hart Cup	Metal truss	Block	0
DWR2	1970	Polyurethane	Hart Cup	Metal truss	Block	0

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[1] Average number of holes per cm² surface area of insulation ($n = 60$). Values with different letters significantly different, Tukey's HSD test, $\alpha = 0.05$.

[2] Polystyrene had an aluminum skin surface.

[3] Polyurethane had a surface covered by heavy-weight paper, with the seams between the boards sealed with a paper tape. DWR1 and DWR2 not included in damage analysis.

insulation were sealed with a paper tape; this tape apparently provided an effective barrier to invasive larval lesser mealworms. Ichinose et al. (1980) previously found that a paper coating on the surface of polyurethane-foam, as well as on the surface of expanded polystyrene, extruded polystyrene and fiberglass, was effective in the protection of the insulation. Evidence of isolated infestations was present in houses DWR1 and DWR2 in those areas where the insulation was cut to form the service doors. The cut in the insulation exposed a bare surface of the inner polyurethane insulation, and the larval lesser mealworms were able to gain access. Therefore, the application of the paper sealing tape at all seams formed with the insulation boards would appear to be necessary to remove sites for initial infestations.

There was a vertical gradation of polystyrene insulation damage along the walls of the HR houses. In nearly every house where two or more locations could be sampled, I found the lower level of the polystyrene to be more infested than the upper level (Figure 1). While the infestations in the lower level were ca. 28% greater than those at the upper level, there were only two houses in which there was statistical significance between the two levels. It would have been desirable to inspect the insulation installed in the pits of the HR houses. However, the manure was very wet in most houses. In two exceptions, houses SB22 and SB23, I was able to walk onto the pit manure, and I found the

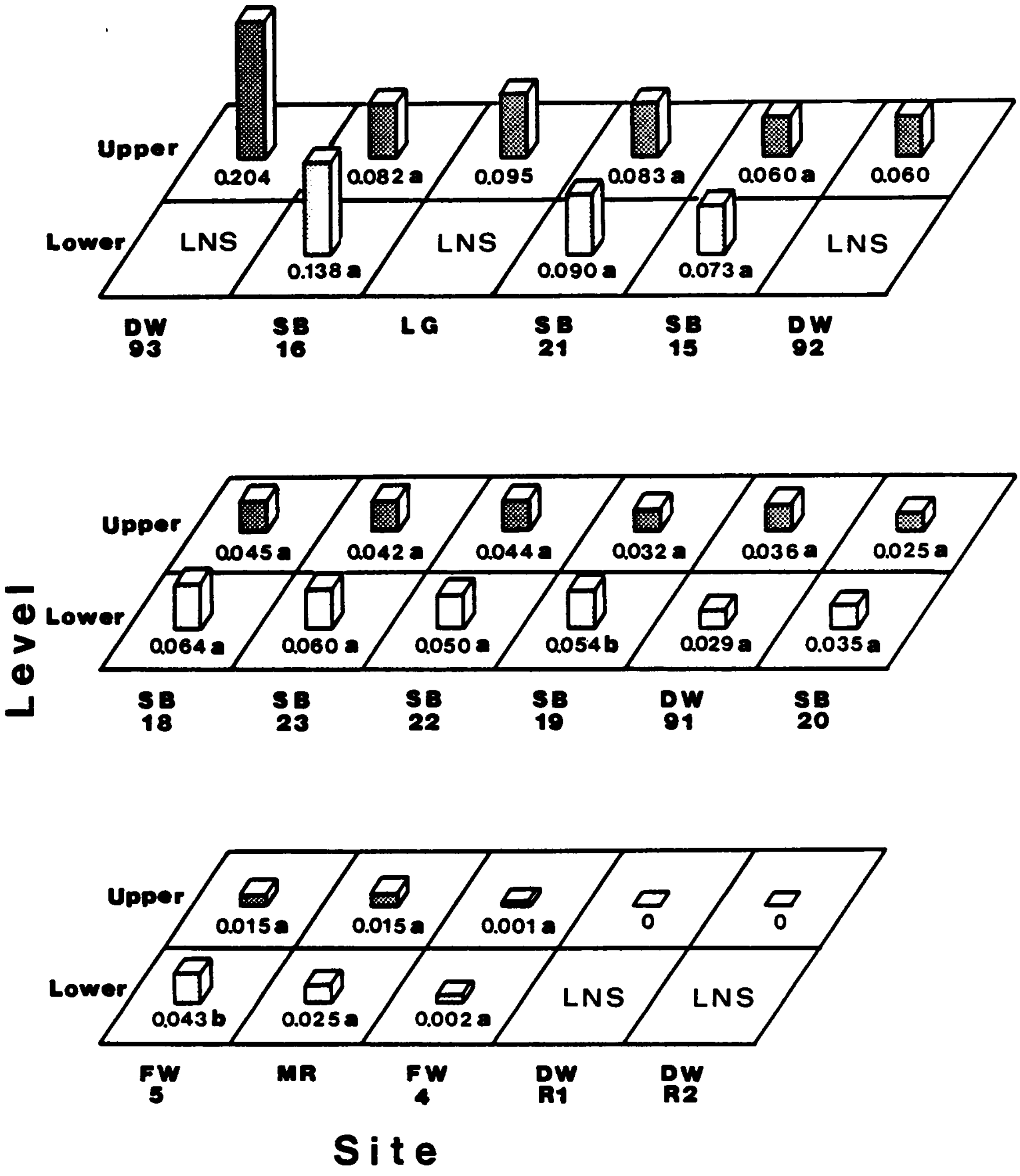

Figure 1. Vertical distribution of lesser mealworm infestation in HR caged layer houses; levels with same letter within site are not significantly different, t-test, alpha = 0.05. LNS = Level Not Sampled.

insulation to be severely damaged, with a decreasing gradation from the pit level to the upper wall level (Table 2). The upper and lower levels were not significantly different, but the pit level had the highest infestation of the 3 levels (Tukey's HSD test, $\alpha=0.001$).

These data indicate that larval lesser mealworms are entering the insulation as they encounter it on their upward movement from the pits. Since the infestations and damage are so extreme in the pit areas of a HR only 6 years old (the age of the house at the time of inspection), it may be economically prudent not to place insulation in the pit areas of HR houses constructed in the future, or else seal the insulation against mealworm damage.

House DW93 was the most heavily infested of all the houses examined. I found that much of the insulation in the pit and many of the panels above the walkway of the house were severely damaged. In some cases the insulation panels had actually fallen away from the supports. This phenomenon was most frequently observed in the pit insulation. Many of these fallen insulation panels were retrieved from the pit. Panels which had been loosened from the house support structure were removed and examined for physical defects due to lesser mealworm infestation.

Infestations were most often observed at the periphery of the insulation panels. An uninfested panel (183 X 122 cm) has a peripheral distance of 610 cm, and with a thickness of

Table 2. Vertical distribution of lesser mealworm damage in extruded polystyrene insulation in HR caged layer houses.

	Levels[1]		
High Rise House	Upper	Lower	Pit
SB 22	0.044a	0.050a	0.288b
SB 23	0.042a	0.060a	0.162b

[1] Holes/cm^2; Means within row with same letter are not significantly different, Tukey's HSD test, $\alpha = 0.05$.

3.8 cm has a volume of 84,838 cm^3. We found an 11.6% reduction in the peripheral distance in the samples, and only ca. 81% of the original insulation volume remained to provide a barrier to heat flow through the wall. Thus, the general result of the infestation was a loss of insulation at the corners and edges of the panels, due to the weakening of the material and subsequent falling away of pieces of the insulation.

Random samples of these infested insulation panels were evaluated for reduction in thermal conductivity by DOW Chemical U.S.A., Granville Research Center, Granville, OH. The samples were placed in a k-matic heat flow meter and analyzed for change in thermal conductivity according to ASTM C-158-76 at 23.9° C (75° F) mean temperature. Lesser mealworm infestations significantly reduced the R-value from 7.5 (advertised for the 3.81 cm extruded polystyrene product STYROFOAM) to an average of 6.1 (SD = 0.69; Student's t-test, $\alpha=0.001$, df = 7) (Table 3), with a concomitant increase in the thermal conductivity (k-value) of the insulation. These data indicate that there would be an increase in the overall loss of sensible heat from the HR house. Heat losses would result from an increase in the conductivity through the insulation and also from infiltration through the spaces around the insulation boards and from those boards that had actually fallen away from their original position on the wall.

Table 3. Effect of lesser mealworm infestations on the insulating properties of extruded polystyrene obtained from HR house DW93.

Sample	R-value	K-value[1]	
		w/m² · °C · cm	BTU/hr·ft² · °F · in
A - Least infested	6.57	3.20	0.252
A - Heavily infested	5.18	3.92	0.309
B - Least infested	6.53	3.14	0.247
B - Heavily infested	5.55	3.48	0.274
C - Lease infested	6.75	2.92	0.230
C - Heavily infested	5.23	3.75	0.295
D - Least infested	6.89	2.88	0.227
D - Heavily infested	6.09	3.28	0.258
Avg.	6.10	3.32	0.262

Data courtesy of Dow Chemical U.S.A., Granville Research Center,
P. O. Box 515, Granville, OH 43023.

[1] Measured in a heat flow meter (k-matic) for thermal conductivity (k-value) according to ASTM C-158-76 at 23.9°C (75°F) mean temperature. R-value and k-value for 3.81 cm Styrofoam is 7.5 and 2.54 w/m²·°C·cm, respectively.

One can calculate the heat flow through the wall by estimating the R-value for each of the materials of the wall, and including the surface air films and enclosed air spaces. Once the total R-value for the wall is determined, the number of BTU's moving through the wall can be calculated using the following formula:

$$\text{HEAT LOSS (BTU/24h)} = [(\text{Area (ft}^2\text{)} \times \Delta T)/\text{R-value}] \times 24$$

where ΔT (° F) is the difference between inside and outside air temperature. Given the following situation of a wall having uninfested extruded polystyrene (3.81 cm thick, R-value of 7.5), and 0.17, 0, 0.90, and 0.68 for the respective R-values of the outside surface air film, outside metal skin, 2.54 cm air space, and inside air surface film yields a total R-value of 9.25 for the wall. With a difference in temperature of 50° F, as could occur on a typical winter day, the heat loss would be 129,730 BTU's per 24 hours through a 1000 ft^2 area of surface. With the reduction in R-value to 6.1 (all else being equal) there would be 152,866 BTU's lost, representing a 15% increase in heat flow over that occurring in a wall with undamaged insulation.

The questionnaire results indicated that the egg producers had not replaced damaged insulation. However, much of the severely damaged extruded polystyrene insulation has now been replaced in the upper story of DW93, but none in the pit. The cost for replacement materials (100 polystyrene sheets) and 80 hours of labor (@ $4.00/hr) was ca. $1700.00 according to the producer. This cost allowed only for replacement of the heavily damaged panels in the upper story of one house. In order to calculate the amount of money which can be attributed to heat loss through damaged insulation, one must calculate the number of pounds of feed needed to replace the BTU's lost through the surface area represented by the 100 missing panels (which is 3200 ft^2 of surface area). In the hypothetical situation, 23136 BTU's were lost through 1000 ft^2. One pound of layer diet contains 5040 BTU. Dividing the number of BTU's lost by the number of BTU's in one pound of layer diet yields 4.59 lb. of feed. At $0.075 per pound of feed, the equivalent cost of this feed is 34 cents per day per 1000 ft^2. Extrapolating this cost figure to the number of square feet replaced in HR house DW9 (3200 ft^2) gives the cost per day ($1.10). Dividing the cost for replacement materials and labor ($1700) by this cost per day yields the length of time needed to pay back the investment (1545 days or 4.2 years represents the pay back period). The average R-value of the most heavily infested figures from Table 3 is 5.51, and using this figure in calculating the number of

BTU's lost in the hypothetical situation gives the value of 217786 BTU's lost per day and per 1000 ft². The pay back time period of this "worst case scenario" would be calculated as follows: 88056 BTU lost per 1000 ft² divided by 5040 BTU per pound of feed equals 17.5 lb. of feed per 1000 ft². The cost per day equals 17.5 lb. feed X $0.075 per lb. feed, which equals $1.31/1000 ft². Again, extrapolating to the amount of materials replaced in DW93, the cost per day would be $4.19, and the pay back period would be 406 days, or 1.1 years. These figures indicate that it would be economical to replace damaged insulation in houses which are relatively new (e.g, 5 years or newer) since the life of a HR house can be 10 or more years. In addition to the insidious losses realized through increased heat flow through the walls, the egg producers are also faced with the replacement of panels which have either fallen away or no longer serve their intended function as insulation.

The control of manure moisture by the degree of effective management of the watering systems and its effect upon lesser mealworm activity was also examined. The Hart Cup was the most common water system, and was used in 82% of the HR houses; the trough water system was used in the remainder of the houses (Table 1). There appeared to be no relationship between mealworm damage and type of watering system. However, a related factor which does affect the resident insect population in the pits is manure moisture. Excessive manure moisture is one of the most frequent problems encountered in HR houses, and in this study, wet pits were encountered in all but 2 of the 17 houses (SB22 and SB23). The ideal environment for growth of lesser mealworm populations results when the manure is accumulating in dry cones beneath the layer cages. Dry manure is the goal of the management, since it reduces noxious odors, facilitates manure cleanout and suppresses development of house fly populations (Axtell 1986). Under dry manure conditions, dense populations of beetles develop, and the action of the beetle population promotes further aeration and drying of the manure pad through tunneling activity. For the purposes of this study, the condition of the manure could not be used to explain variation in insulation damage as manure moisture conditions can be subject to considerable change over time, and are a function of the ability of the management personnel to maintain a water system with minimal leakage. However, houses which have a history of manure moisture problems (e.g., above 55-60% moisture) tend to be devoid of resident beetle populations in the pits. Such was the case for 2 of the houses in this study, DWR1 and DWR2, where the pits could be most easily described as lagoons, and this may explain, in part, the lack of infestations in these facilities.

One of the theoretical advantages of the HR house egg production system is that the manure can be stockpiled for up to a year or more, (providing manure is dry) before removal. This removal also evacuates the majority of the population of insects from a HR facility. However, the most common management practice in Virginia is to cleanout, or pump out the manure once every 6 months; thus this management practice does not appear to be of importance in the explanation of the variation of lesser mealworm damage between houses.

Two components which appeared to have an association with the insulation infestations are the construction of the walls of the pits, and the construction of the house support structure. HR houses which had pits constructed of concrete block, or a block foundation in combination with a wood frame set in or on top of the block (denoted block-wood in Table 1) had minimal insulation damage. DWR1 and DWR2 pits were built with ca. 2.75 m of cement block with a metal truss support structure. In FW4 and FW5, ca. 1.5 m of cement block formed the foundation of the pits, with a wood frame structure forming the rest of the wall. The support structure in FW4 and FW5 was built of 15 X 15 cm wood posts set on top of the concrete block foundation. In all of the other houses, the support structure consisted of wood posts set into the ground, with wood boards forming the walls of the pits. It would appear that some factor or factors associated with the concrete block (e.g., surface texture, temperature gradient) had an inhibitory effect on the upward movement of the late instar larval lesser mealworms from the pits, with the same factors either being absent or favorable to the dispersal behavior in those pits that had support structures constructed of wood. In those houses with pits built of concrete block, the support structure rested upon the block, and the lesser mealworm larvae would have to crawl up the concrete to gain access to the insulation. If the five most infested houses (excluding house LG) and the five least infested houses are compared, there is a significant difference between houses with respect to pit wall construction (Kruskal-Wallis K-sample test, $X^2 = 6.22$, df = 2, $\alpha = 0.05$). Houses with block wall construction in the pits had significantly less beetle activity in the insulation. However, a nonsignificant nonparametric test resulted if house LG is entered into the analysis. A possible explanation for the aberrant status of house LG could be that this house was built with 15 X 15 cm wood posts set directly into the ground, providing an avenue for the beetles to reach the insulation. In addition, it had been 2.5-3 years between manure cleanout, and the manure had accumulated up to the level of the polystyrene insulation which was in place in the pit, thus providing the lesser mealworms direct access to the insulation.

CHAPTER IV

EFFECTS OF POULTRY MANURE MOISTURE AND POULTRY HOUSE CONSTRUCTION MATERIALS ON LESSER MEALWORM DISPERSAL BEHAVIOR

Despins et al. (In Press) correlated certain manure pit wall construction materials with lesser mealworm damage in caged layer houses. Insulation in houses with wooden manure pit walls was more severely infested than in those houses with concrete block pit walls. Houses which had pit wall foundations built of both types of materials had intermediate lesser mealworm infestations. Despins et al. (In Press) suggested that there might be an effect on mealworm dispersal due to construction of the pit wall. These authors also indicated that fluctuating moisture levels in the manure might affect the dispersal behavior of the manure-inhabiting beetle populations. The automatic devices supplying egg layers with water are prone to leaking, and maintenance of dry manure requires constant attention from management personnel. Periodically, leaks remain undetected, and the water entering the manure pit can quickly create a catastrophic change in the manure habitat, and stimulate insect dispersal from this habitat.

The overall goal of this research is to provide the egg producer with recommendations on methods to prevent or reduce infestations in poultry house insulation. Thus studies were made to examine the conditions which bring about the destructive behavior of this insect. They were to: 1) observe the effect of manure moisture levels on adult and late instar larval dispersal, and 2) observe the climbing ability of adults and late instar larvae on wood and concrete block surfaces.

4.1 MATERIALS AND METHODS

4.1.1 EFFECT OF MANURE MOISTURE ON ADULT AND LARVAL DISPERSAL

The apparatus used in this experiment is shown in Figure 2. Fifty grams of air dried, semi-pulverized chicken manure were placed in the center cup, a plastic container (11 top dia. X 9 bottom dia. X 7.5 cm height). Ten grams of ground corn meal were placed on the manure surface. Based on the weight of the corn meal and manure, moisture levels of 30%, 40%, 50%, and 60% were prepared by adding a measured quantity of distilled water to the cup to condition the manure to a given percentage moisture. Preliminary studies showed that minimal evaporation occurred over the short time period of this experiment. Three population levels of adults and larvae (20, 60, 100) were established and observed at each manure moisture level. A mixture of late instar larvae and adults at each population level were placed in the center

Figure 2. Apparatus for manure moisture experiments.

of each treatment cup, and allowed to acclimate for 8 hours. The manure container was placed into the larger container (15.2 top dia. X 14.0 bottom dia. X 12.1 cm height) to trap the dispersed insects. After this acclimation period, a wedge-like piece of extruded polystyrene was fastened to the wall of the center cup by placing a piece of masking tape at the top of the polystyrene (Figure 2). The polystyrene provided an exit for the lesser mealworms. The number of insects climbing onto the extruded polystyrene and out of the treatment cup were counted 12 hours after the polystyrene was introduced. Each moisture level treatment and population level was replicated three times. All experimental setups were maintained in a walk-in controlled environment chamber in complete darkness at 23.3° C ambient air temperature. Experimental data were subjected to a standard X^2 analysis.

4.1.2 VERTICAL CLIMBING ABILITY OF LARVAE ON WOOD VS. CONCRETE SURFACES

Laboratory Studies: A wooden surface was made by connecting 15.2 X 5.1 cm plywood boards together end-to-end to form a 198.1 cm vertical surface on which the lesser mealworm larvae could crawl. Graduated markings (at 1 cm distances) were made on the board surface to measure the distance crawled by each larva. A 142.2 cm high vertical concrete block wall was built by stacking block to the given height. The blocks fit tightly together, and since there were no holes through which the larvae could crawl, no mortar was used between the blocks. The metered wooden board was also used to measure the distance crawled by the larvae on the block wall. Fifty grams of poultry manure were prepared to either 50% or 60% moisture in the manner described earlier and placed into a plastic container measuring 11 cm top diameter X 9 cm bottom diameter X 7.5 cm height. Ten late instar larvae were then placed on the manure surface. The lower end of the wooden board was placed into each manure cup, the assembly was secured with a clamp attached to a ring stand, and observations at each moisture level were made on the distance which larvae crawled. A vertical cut through the wall of one side of the plastic container was made so that the container would be flush against the concrete wall. The container was secured to the block wall by means of masking tape to prevent escape of the larvae.

The tests were done in complete darkness over three 45 minute periods using three sets of manure treatments and three replications of larvae in a walk-in controlled temperature room (23.3° C). A flashlight masked with red plastic provided enough illumination to observe movements of the larvae. The average distance crawled on wood and concrete block was tested for statistical significance using Student's t-test. Other data were also analyzed using a X^2 test.

Field Studies: The field studies on the climbing ability of late instar larvae were made in a HR Leghorn breeder house located in south central Virginia. This facility was built with a concrete block pit wall ca. 76.2 cm high above the manure surface at the time of these observations. The dry manure on the sides of the building under the overhead scratch areas (1.4 X 107 m) supported a dense population of lesser mealworms. Observations were made near ventilation fans because the insect population appeared to be most dense near these locations. For recording climbing ability on this substrate a portable wall built of wood (30.5 X 101.1 cm high) was placed in a vertical orientation against the concrete wall of the breeder house. The wood was representative of the material used to build many of the pit walls of high rise houses in Virginia. The distance crawled by larvae over a 30 minute period was recorded in three different locations in the high rise house for the two different substrates. As in the laboratory experiment, a flashlight shaded with red plastic film provided enough light to see the insect activity. Data from the manure moisture experiment were analyzed using a X^2 test, and the distances crawled by larvae on each substrate were compared using Student's t-test.

An additional field experiment was designed to record the number of insects at two heights on the block wall and on the wood house support beams for a longer period of time. A modified Ahrends trap (Safrit and Axtell 1984) consisting of halved sections of 3.8 cm PVC pipe (22.9 cm long) were fastened to the wall at 7.6 cm and 53.3 cm above the manure surface. The longitudinal axis of the trap was oriented perpendicular to the plane of the manure surface. Six 15.2 cm square sheets of wrinkled paper were loosely rolled in a circular fashion and slipped under the PVC pipe, providing a resting site for the insects. The pipe sections were placed in four locations in the breeder house, and were removed from the field after 2 weeks. Data were analyzed using a X^2 test.

4.2 RESULTS

4.2.1 EFFECT OF MANURE MOISTURE ON ADULT AND LARVAL DISPERSAL

A positive relationship was observed between lesser mealworm dispersal and manure moisture levels. Significantly greater numbers of adults and larvae at each insect population level were found crawling from the manure habitat with increases in percentage manure moisture (Figure 3, Figure 4 and Figure 5) with the exception of the low adult population level (Figure 3). Adults were more active than larvae in the 30% and 40% manure moisture treatments. Manure moisture of 50% and above greatly stimulated larval dispersal from their habitat, a phenomenon which was less evident for

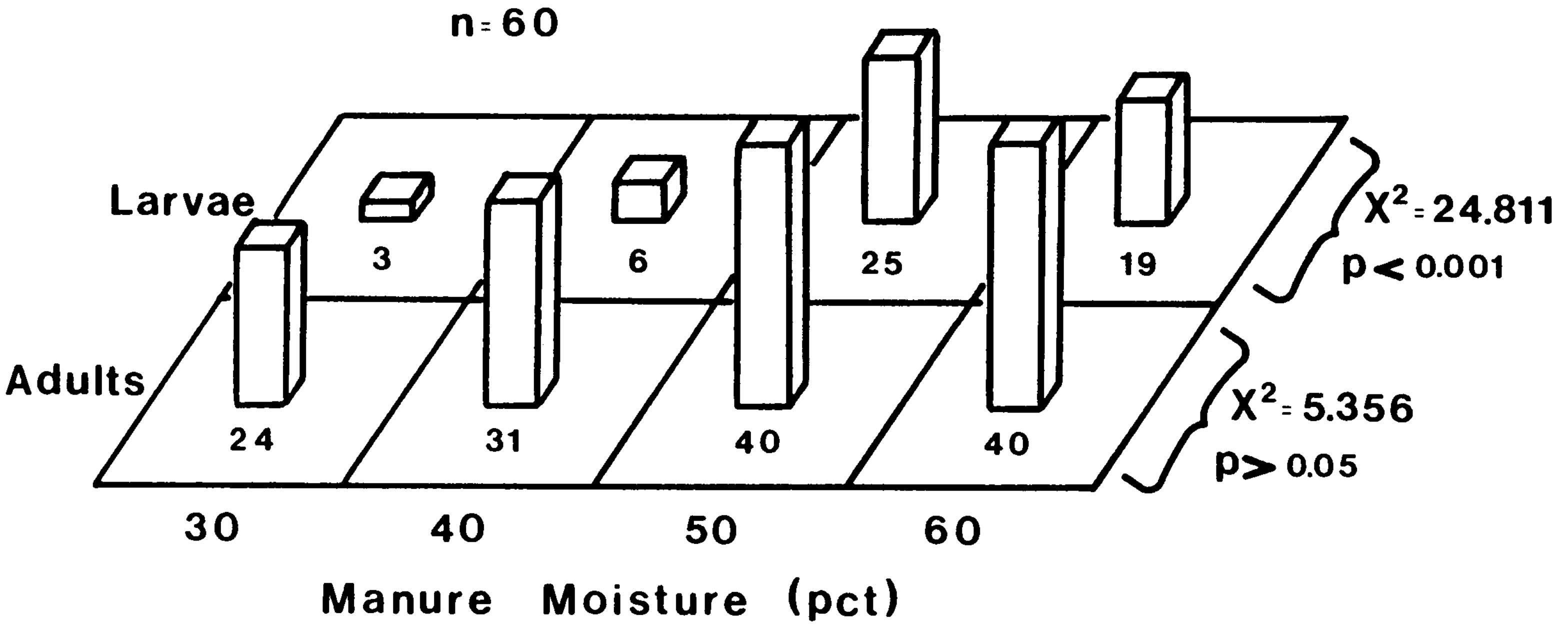

Figure 3. Effect of percentage manure moisture on lesser mealworm dispersal behavior (n = 20 per stage and moisture level X 3 replications).

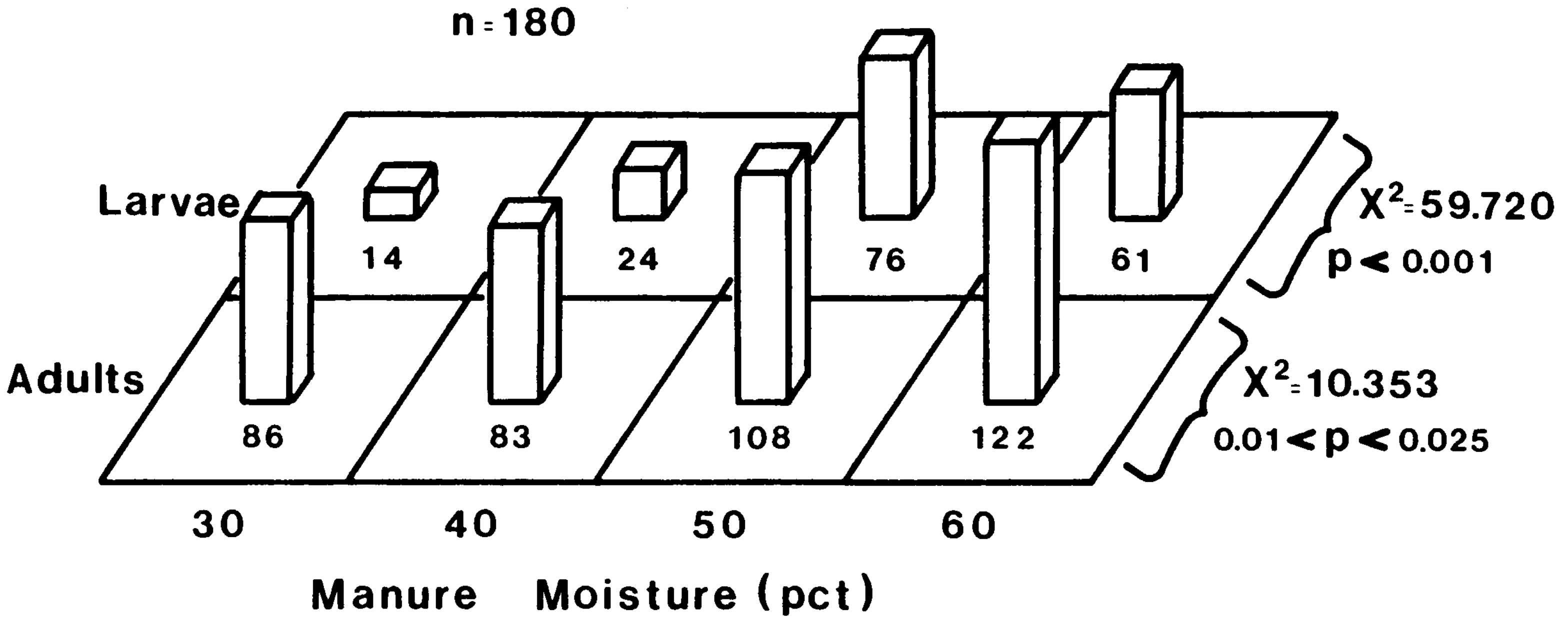

Figure 4. Effect of percentage manure moisture on lesser mealworm dispersal behavior (n = 60 per stage and moisture level X 3 replications).

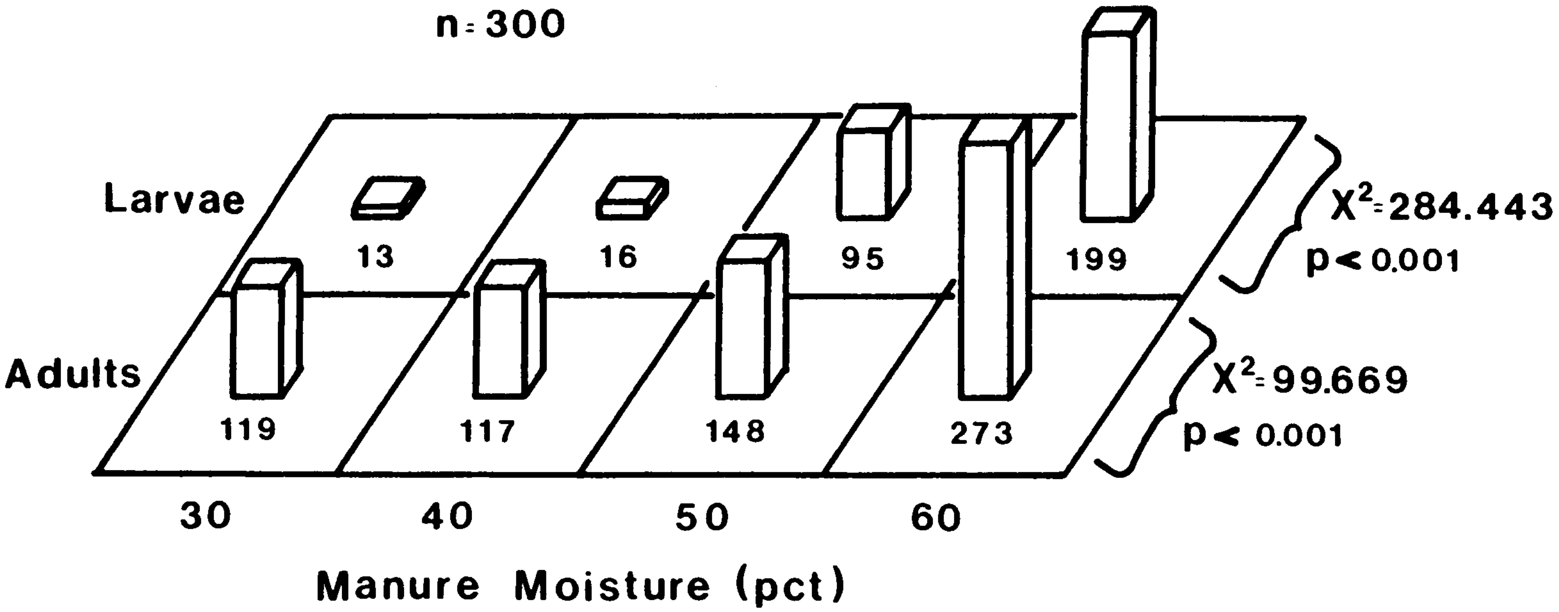

Figure 5. Effect of percentage manure moisture on lesser mealworm dispersal behavior (n = 100 per stage and moisture level X 3 replications).

adults at the 20 and 60 population levels (Figure 3 and Figure 4). No trend in dispersal due to increases in population density was observed.

4.2.2 VERTICAL CLIMBING ABILITY OF LARVAE ON WOOD VS. CONCRETE SURFACES

Laboratory observations revealed that larvae could climb a longer distance per unit time on a vertical surface of plywood than on a concrete block surface (Table 4). There was a three to four fold difference between the distances crawled on the two construction materials. The larvae were better able to cling to the wood surface, and they used their urogomphi to support themselves against the wood as they climbed up the plywood panel. Larvae were more successful in climbing the vertical wood substrate than on the concrete block wall over the 30 minute time period under field conditions (Table 5). After leaving the modified Ahrends traps in the breeder house for 2 weeks, I found that more larvae were found on the wood support beam than on the concrete block wall at 53.3 - 76.2 cm (Figure 6, $P<0.001$). Relatively similar numbers of larvae were found in the lower PVC traps for each building material. However, there was a six fold difference in the number of larvae in the higher level PVC traps which were on wood than in those which were on the concrete block wall, reflecting the inability of the

Table 4. Distance crawled by larval lesser mealworms on poultry house construction materials in the laboratory.

Percent Manure Moisture	$\bar{x}$ Length Crawled (cm)	
	Block	Wood
50	8.35 ± 5.28 (7)[1]	33.70 ± 39.16 (28)
60	13.49 ± 18.38 (88)	32.84 ± 41.41 (43)

[1] $\bar{x}$ ± SD (n). Means within row are significantly different, student's t-test, $0.01 < p < 0.05$.

Table 5. Distance crawled by larval lesser mealworms on poultry house construction materials under conditions found in a HR breeder house.

Construction Materials	n	$\bar{x}$ Length Crawled (cm)
Block	127	22.65 (± 1.88 SE)[1]
Wood	209	55.81 (± 1.95 SE)

[1] Means are significantly different, student's t-test, $p < 0.001$.

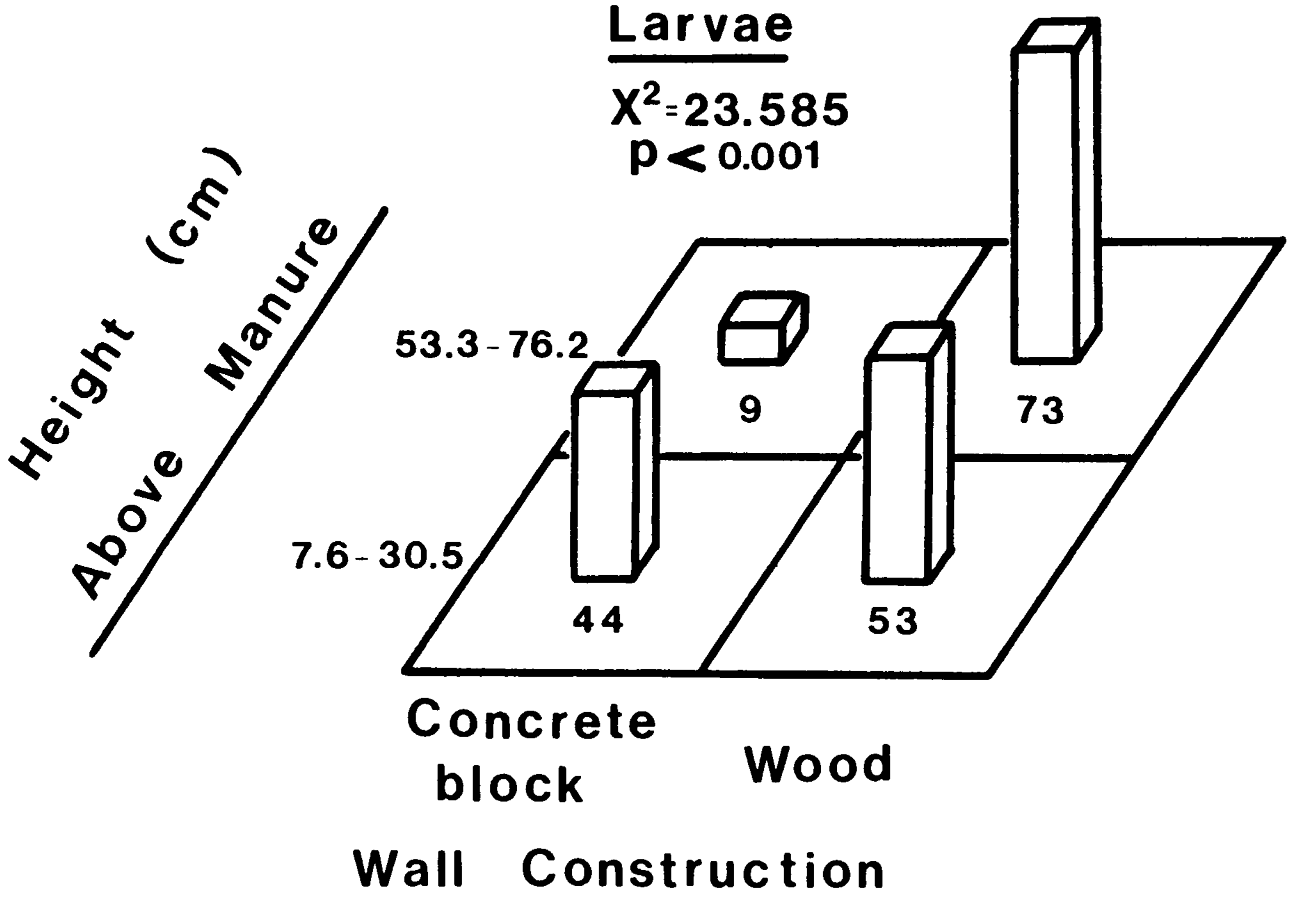

Figure 6. Effect of pit wall construction materials on the vertical distribution of larval lesser mealworms.

larvae to successfully crawl on a vertical surface of concrete block.

4.3 DISCUSSION

This study only deals with one environmental factor (changes in manure moisture levels) which might have an effect on larval lesser mealworm movements. Factors such as temperature, food availability, degree of maturation of the late instar larvae, etc., were not addressed in the present work, and their effects on lesser mealworm dispersal remain the subject for future experiments. However, changes in the level of manure moisture had a significant effect on the movements of larvae from the manure habitat. Larvae remained in the manure habitat under dry conditions (30 and 40% manure moisture). The moisture threshold which stimulated a larval dispersal response was at the 50% moisture level. Generally, adults were more active than larvae at the two lower manure moisture levels.

The laboratory and field data on the climbing ability of lesser mealworm larvae confirm our previous conclusions about the effect of manure pit wall construction and insulation damage (Despins *et al*. In Press). Since the larvae can climb a vertical wooden surface more easily than a concrete block surface, high rise houses built with wood pit walls are predisposed to greater levels of insulation damage. High rise houses built with wood support beams which are set directly into the ground would also be subject to greater infestations than houses with pits built entirely of concrete block. These findings indicate that future building recommendations of HR houses should include that at least three to four courses of block should form the foundation of the pit wall, and thereby creating a barrier to lesser mealworm larvae.

CHAPTER V

INVESTIGATIONS OF METHODS TO PROTECT POULTRY HOUSE INSULATION

The controlled environment of the HR house is conducive to the development of certain arthropod populations in the manure pit, with the lesser mealworm, Alphitobius diaperinus (Panzer) being the most common beetle species at some times of the year (Pfeiffer and Axtell 1980). The lesser mealworm develops in the accumulated manure in the lower story of the HR house, where foodstuffs and water are readily available and the temperature from the composting manure is favorable (Armitage 1985). The insect tunnels throughout the upper 15 cm of the manure pad (Green 1982), which promotes aeration of the waste and reduces the habitat for noxious fly development. Unfortunately, this beneficial behavior has been overshadowed by its status as a structural insect pest in poultry houses. The insulation is used by late instar larvae as material for the construction of pupation cells (Dale *et al*. 1976, Ichinose *et al*. 1980, and Vaughan *et al*. 1984). Before producing the pupation cell, the larvae burrow for distances ranging from 10 to 30 mm, in either a straight or sinuous fashion in the insulation (Ichinose *et al*. 1980). The tunneling activity reduces the structural integrity of the insulation, resulting in the physical disintegration of the material and increasing thermal conductivity (Dale *et* al. 1976, Ichinose et al. 1980, Vaughan et al. 1984, Despins et al. In Press). Dale et al. (1976) reported larval tunneling behavior in the polystyrene insulation in broiler houses in New Zealand. In one case, they found nearly a third of the insulation of a 3 year old house was destroyed, an observation which has been also been reported in North Carolina (Christopher J. Geden, Department of Entomology, N. C. State University, Personal Communication). Le Torc'h (1979) and Chaix (1980) reported lesser mealworm infestations in insulation of animal structures in France, and recommended sanitation and chemical control methods.

Insulation materials commonly used in broiler houses and HR egg houses have been examined for resistance to lesser mealworm infestations under laboratory conditions, with conflicting results (Ichinose et al. 1980, Le Torc'h and Letenneur 1983, Vaughan et al. 1984). Ichinose et al. (1980) compared polyurethane foam, expanded bead polystyrene, fiberglass, absorbent cotton, and extruded polystyrene. The latter material was found to be only slightly more resistant than the others to burrowing larvae. Vaughan et al. (1984) observed that expanded bead polystyrene was preferred by lesser mealworm larvae over polyurethane foam, and that fiberglass represented an inhospitable environment in which to construct pupation cells. Le Torc'h and Letenneur (1983) compared similar types of insulation (but presumably from different manufacturers) to that examined by Ichinose et al.

and Vaughan *et al*. (1984), and found that polyurethane foam and extruded polystyrene were consistently more resistant than fiberglass and expanded bead polystyrene, indicating that insect preference was for less compact materials.

Effectiveness of application of mechanical barriers to various forms of insulation has also been evaluated under laboratory conditions. Ichinose *et al*. (1980) applied sealing paper, paint ("blue" paint, "plasterlike" paint, and coaltar), aluminum foil, and "cementex" as separate treatments to the surface of polyurethane foam, expanded bead polystyrene, fiberglass, absorbent cotton, and extruded polystyrene. They found that the larvae were not able to penetrate any of these coatings when applied to polyurethane foam, and that sealing paper was the most resistant to larval penetration on the other insulation materials, with the exception of absorbent cotton. Le Torc'h and Letenneur (1983) examined coatings of either smooth aluminum foil or corrugated aluminum foil applied to polyurethane foam and compared uncoated expanded bead polystyrene with extruded polystyrene for lesser mealworm resistance. They found that the two aluminum sided polyurethane insulations were similar to extruded polystyrene in resistance to infestation, and these three treatments had significantly fewer surface penetrations than the expanded bead polystyrene. No material to date has been reported to be completely resistant to penetration by the lesser mealworm.

Insecticide barriers show promise in protecting insulation from lesser mealworm. Vaughan and Turner (1984) examined the residual effectiveness of an insecticide spray in killing adult and late instar lesser mealworm larvae under laboratory conditions. They found that tetrachlorvinphos WP (0.5% AI) and permethrin WP (0.1% AI), when sprayed on expanded bead polystyrene, provided greater than 90% mortality to adult beetles, while only the former insecticide and rate was effective against larvae (greater than 80% mortality) over ca. 20 weeks post-application. Both permethrin and carbaryl had a longer residual activity on expanded bead polystyrene than on unpainted plywood. Wettable powder formulations were more effective than the emulsifiable concentrates on expanded bead polystyrene than on unpainted plywood, and of the three insecticides, tetrachlorvinphos WP (0.5% AI) yielded the longest residual activity on unpainted wood or expanded bead polystyrene.

The laboratory is an environment which is free of organic contamination and from extremes in temperature. A HR caged layer house is often warmer than room temperature during summer months, and the dust particles and organic filth which cover everything inside the egg production facility may have an adverse effect on any insecticidal treatment applied to insulation. Therefore, the objectives of this study were 1) to conduct comparisons of various mechanical barriers, insecticide sprays and new types of insulation materials under laboratory conditions, for selecting the most resistant treatments, and 2) to evaluate the promising treatments for resistance to lesser mealworm infestations under the conditions existing in the pit of a HR egg house.

5.1 MATERIALS AND METHODS

A series of tests were set up to evaluate the protective effectiveness of insecticides and surface barrier treatments against lesser mealworm damage to standard insulation. Colonies of the insect were maintained in a controlled environment room at ca. 30° C and in complete darkness for each experimental period. The initial culture of experimental insects was obtained from field populations in HR houses in various locations in southwestern Virginia. This culture was periodically replenished with wild-type insects to maintain the genetic heterogeneity of the laboratory population.

5.1.1 INSECTICIDE RESIDUAL EXPERIMENT

The insecticide treatments used in this experiment were:
1) permethrin, 25 WP (0.05% AI at 0.0108 g AI/m^2),
2) permethrin, 5.7 EC (0.05% AI at 0.0107 g AI/m^2),
3) pirimiphos-methyl 7E, (0.25% AI at 0.0534 g AI/m^2),
4) pirimiphos-methyl 7E, (0.5% AI, at 0.1069 g AI/m^2),

5) tetrachlorvinphos 50 WP (0.5% AI at 0.1032 g AI/m^2) and 6) chlorpyrifos-impregnated latex paint (Insectaway™ Anti-Insect Flat Latex Paint, Universal Cooperatives, Inc.) (0.86% AI by weight, one coat application). Tetrachlorvinphos was used as a standard. The insecticides were applied to square foot panels (0.0929 m^2) of extruded polystyrene (Styrofoam® TG), an insulation material commonly used in HR caged layer houses in Virginia (Vaughan *et al*. 1984, Despins *et al*. In Press). The insecticide solutions were prepared by mixing the amount of commercial product to give the desired concentration in 473 ml of distilled water. From this stock solution, 2 ml were placed into a 5 ml glass test tube and sprayed evenly using a chromatography sprayer over one side of a polystyrene panel. Control panels were sprayed with distilled water. One coat of the chlorpyrifos paint was evenly applied to 1 side of the insulation panel, and, as with the other treatments, left to air dry for 24 h before evaluation. Treated and control panels were kept at room temperature (ca. 21° C) for the length of the 71 week experiment. Each treatment was arranged with three replications. Residual activity of the insecticides was evaluated using the method of Vaughan and Turner (1984). Ten adults and ten late instar larvae (ca. 6th - 8th instar) were isolated for one hour on each treated surface beneath an overturned 14 cm X 2 cm plastic Petri dish. Treated and untreated control insects were placed in 473 ml glass

recovery jars maintained at room temperature for 24 h and 48 h, at which time mortality observations was observed and recorded. Mortality was defined as the insect's inability to right itself or crawl after being prodded with a forceps. Natural mortality was accounted for by using Abbott's formula (Abbott 1925). The adjusted data were subjected to an analysis of variance by using the appropriate procedure (Proc ANOVA;) (SAS Institute, Inc. 1982).

5.1.2 LABORATORY EVALUATIONS OF BARRIERS, FILMS AND NEW TYPES OF INSULATIONS

Surface barrier treatments were evaluated in the laboratory for resistance to lesser mealworm penetration. They included a polyurethane varnish (Deft® Defthane® Polyurethane Finish) and a paint (Rustoleum® Silver Metallic 7715). Panels of extruded polystyrene were cut into 30.5 X 7.6 X 2.5 cm sections. A single coat of paint was applied to the polystyrene and allowed to air dry for 48 hours. Two panels of each treatment plus uncoated panels were nailed to a wooden block (15.2 X 10.2 X 7.6 cm) and placed on the surface of a mealworm colony. The experiment was arranged in three replicates, and evaluations of the treatments were made 73 days and 103 days after introduction.

A Dow Adhesive Film (DAF) impregnated with 1% chlorpyrifos by weight (0.065 g AI/ft^2) was evaluated for mealworm resistance. The DAF was a random copolymer consisting of ethylene and acrylic acid. Only one side (side A, Figure 7) of the extruded polystyrene panel was covered with DAF, the other side (side B, Figure 7) was left exposed. A second treatment consisted of a chlorpyrifos-DAF film which was overlaid with a polyethylene film facer and applied to side A; this extra covering was to retard release of chlorpyrifos insecticide from the DAF. As in the former chlorpyrifos-DAF treatment, side B was left unlaminated. A third film treatment involved covering sides A and B of extruded polystyrene panels with the unimpregnated polyethylene film facer. The sides C, D, E and F (Figure 7) of all film treatments were unlaminated. A panel (15.4 X 30.5 X 2.5 cm) of each treatment was nailed to the side of a wood block and placed on the litter surface of the colony. Treatments were exposed for 35 days.

Three Dow Chemical products, Styrofoam® IB, Styrofoam® BB, and Ethafoam® 220, were tested for resistance to lesser mealworm infestations. Styrofoam® IB was a low density (20.6 g/m^3) polystyrene foam board with a cell size of 0.6 mm. This product is primarily used as a plastering or stucco base. Styrofoam® BB was a polystyrene foam buoyancy billet, with a density of 25.7 g/m^3 and 1.5 mm cell size. Ethafoam® 220 was a polyethylene foam product typically used for cushion packaging. It was characterized as having a large cell size (1.5 mm) and had the highest density (29.5 g/m^3) of the three

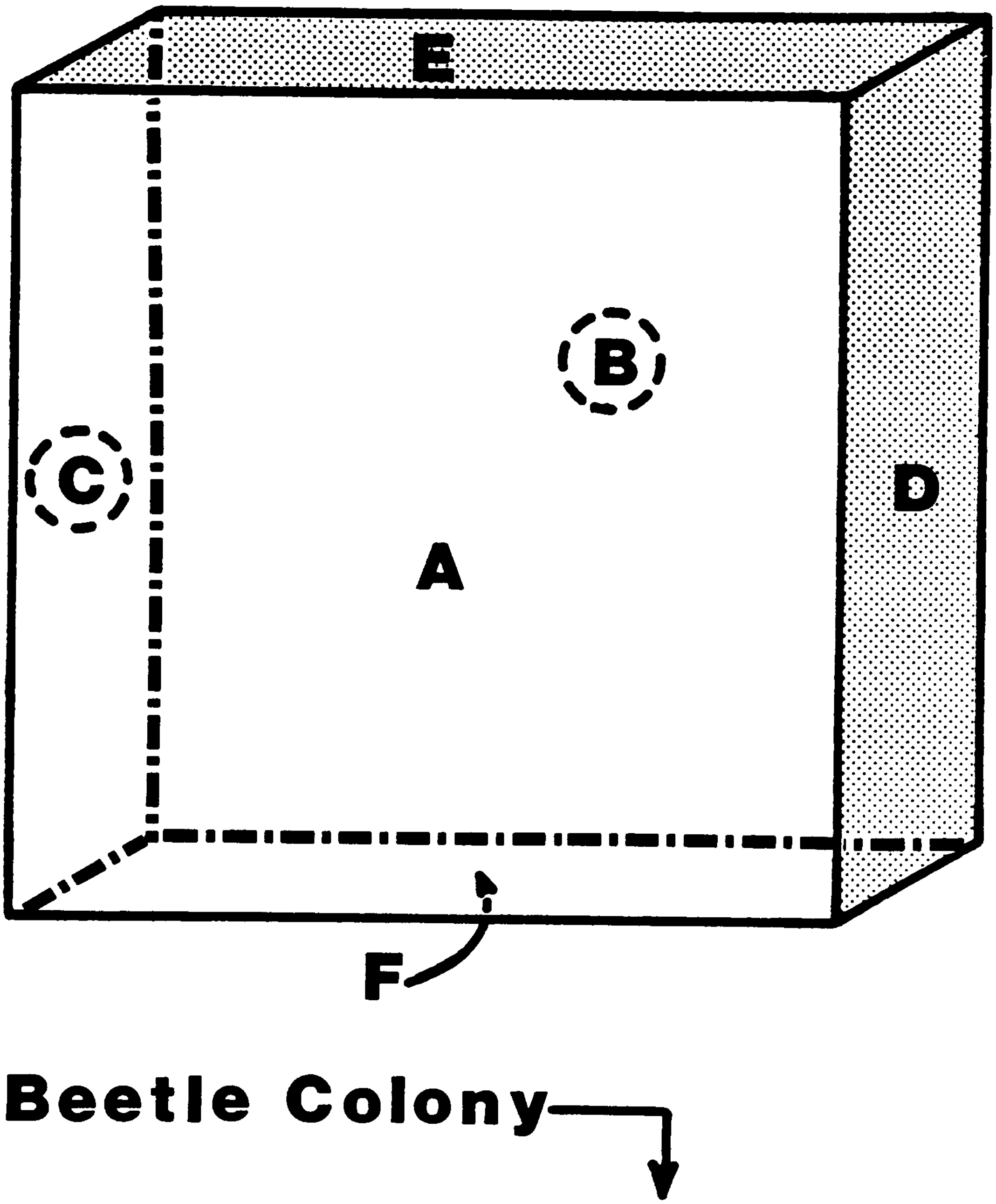

Figure 7. Reference diagram for Dow Adhesive Film experiment.

test materials. The uncut extrusion surface forming the broad sides of Ethafoam® 220 was very smooth, but the cut sides exposed the internal cell structure of the insulation. In comparison, the density and cell size of an extruded polystyrene insulation used in agricultural buildings (e.g., Styrofoam® TG) is 25.7 g/m^3 and 0.35 mm, respectively. Small panels of each insulation were hand cut from the stock supply of insulation. Each panel of Styrofoam® IB and Styrofoam® BB measured 10.2 X 10.2 X 2.5 cm, or a total surface area of 309.7 cm^2. Each Ethafoam® 220 panel was 10.2 X 10.2 X 3.8 cm or a total surface area of 361.3 cm^2. One panel of each insulation type was randomly selected and placed on the surface of each colony. The first experiment was designed with four replicates, and the second with 12 replications. Each experiment was evaluated after 14 days of exposure. As a final experiment, Dow insulations and paint and varnish treatments were compared for overall preference by the lesser mealworms. The insulation formulations were cut into sections small (7.6 X 7.6 X 2.5 cm) enough to allow enough room for inclusion of all treatments in a single replicate container housing a colony of beetles. There were 10 replicates in this final 21-day experiment.

Evaluation of all laboratory experiments was performed by counting the number of penetrations on the surface of the treated panels. The count data were divided by the total surface area of the respective treatments to yield a common measure for comparison purposes (i.e., average number of holes/cm^2). Data were analyzed using the Kruskal-Wallis test (Proc NPAR1WAY;) (SAS Institute, Inc. 1982).

5.1.3 FIELD EVALUATIONS OF CHEMICAL BARRIERS AND NEW TYPES OF INSULATION

Evaluation of insecticides, new types of Dow insulation and paint treatments was conducted in the pit of a HR caged layer house heavily infested with all stages of the lesser mealworm. The insecticide treatments were: pirimiphos-methyl 7E, 0.25% AI and 0.50% AI; tetrachlorvinphos 50 WP, 0.25% AI and 0.50% AI; permethrin 5.7 EC, 0.05% AI; and permethrin 25 WP, 0.05% AI. Two formulations of insecticide-impregnated paint included the product Insectaway™ Anti-Insect Flat Latex Paint (0.86% chlorpyrifos by weight) and Super IQ® Paint (0.90% chlorpyrifos by weight). An insecticide solution was applied to an extruded polystyrene panel (10.2 X 10.2 X 2.5 cm) by immersing each panel in a solution for 60 seconds. The panels were air dried for 24 hours. A single coat of the chlorpyrifos-impregnated latex paints was applied to the same size polystyrene panels and air dried for 24 hours. The experiment was arranged in a randomized block design, with 5 replications. Treatments were placed on 14.0 cm plastic Petri dish covers and set on the surface at the base of the manure cone accumulating beneath the hens. Petri dishes were used in an attempt to minimize manure contact with the treatments. Stake wire flags were placed near each treatment to facilitate treatment location at evaluation time. The experiment was evaluated ca. every 30 days by counting the number of surface penetrations in each exposed panel of insulation, and then computing the average number of penetrations per square centimeter of surface area. Data were analyzed using the appropriate SAS procedure (Proc ANOVA;); means were separated using the TUKEY option for Proc ANOVA, initiating Tukey's HSD (Honestly Significantly Difference) Test (SAS Institute, Inc. 1982).

5.2 RESULTS

5.2.1 INSECTICIDE RESIDUAL EXPERIMENT

Tetrachlorvinphos, and pirimiphos-methyl at both application rates, produced greater than 90% mortality in the larval and adult lesser mealworm test populations at 23, 61, and 71 weeks postapplication (Figure 8) and were significantly more effective in killing larvae and adults than permethrin WP or permethrin EC at the 61 and 71 week evaluation (ANOVA, $0.01<P<0.05$; Tukey's Honestly Significant Difference [HSD] test, $\alpha=0.05$) (Actual mortality figures and mean separation results are in Appendix B and C). Mortality

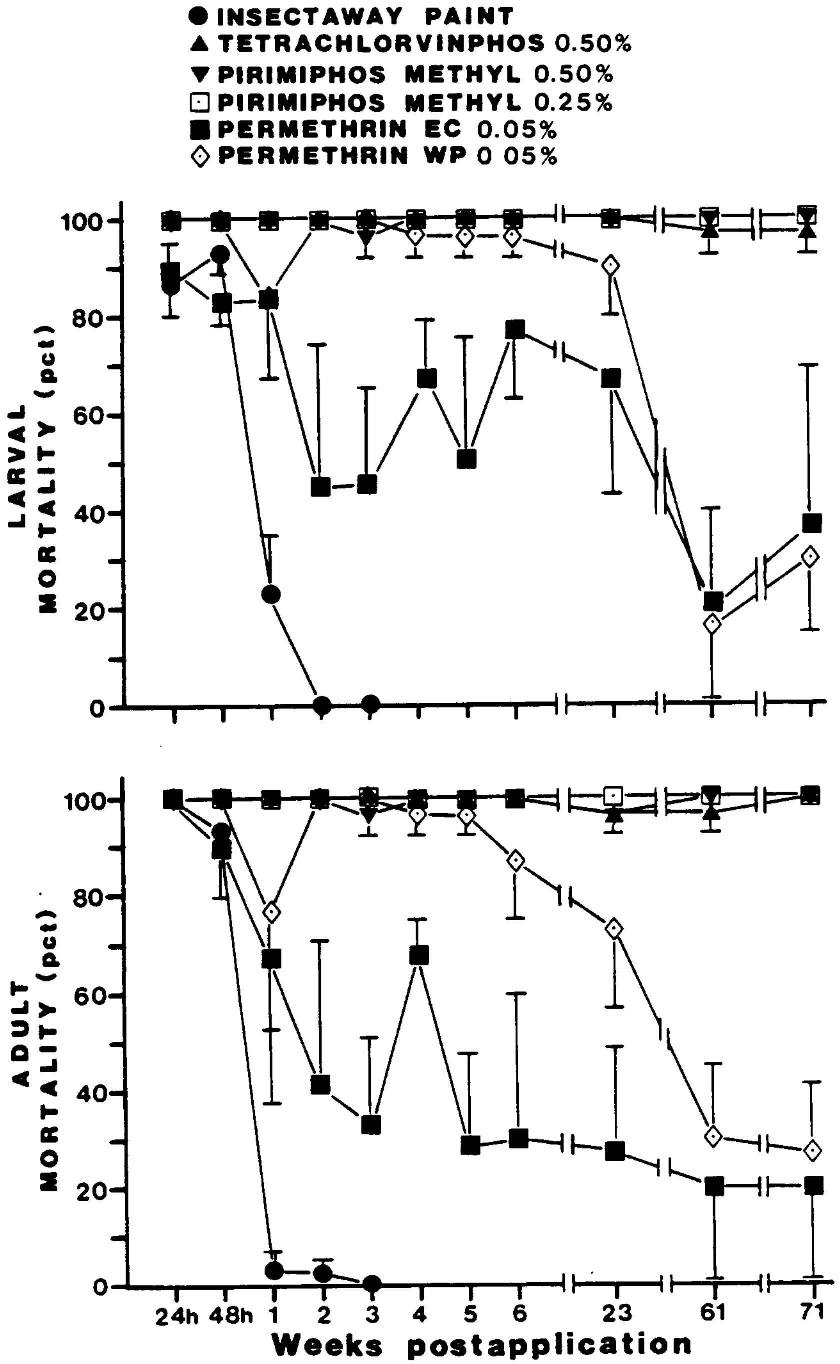

Figure 8. Residual toxicity of insecticide applied to the surface of extruded polystyrene against adult and larval lesser mealworms under laboratory conditions. Vertical bar = 1 standard error of the mean.

was significantly greater in the adult population placed on surfaces treated with permethrin WP than on those surfaces treated with permethrin EC from weeks 2 through 5 postapplication, (ANOVA, $0.001<P<0.005$; Tukey's HSD test, $\alpha=0.05$), after which there were no significant differences between the permethrin formulations. A similar trend was seen for larvae, although statistically significant differences were observed at only weeks 2 through 4 postapplication (ANOVA, $0.010<P<0.025$; Tukey's HSD test, $\alpha=0.05$), Insectaway™ Paint was toxic to larvae and adults at the 24 h and 48 h evaluation (mortality > 80%). Effective toxicity, however, dropped to unsatisfactory levels at 1 week postapplication (Figure 8). No mortality was observed in this treatment at week 3 postapplication, and the chlorpyrifos-impregnated paint was removed from the experiment.

5.2.2 LABORATORY EVALUATIONS OF BARRIERS, FILMS AND NEW TYPES OF INSULATIONS

Lesser mealworms were unable to penetrate side A (Figure 7) of the chlorpyrifos-DAF-film facer or the chlorpyrifos-DAF, and side A and side B of the polyethylene film facer (FF) treatment (Figure 9). However, mealworm larvae and adults extensively tunneled into those sides which were not sealed by film. Sides E and F were the most tunneled

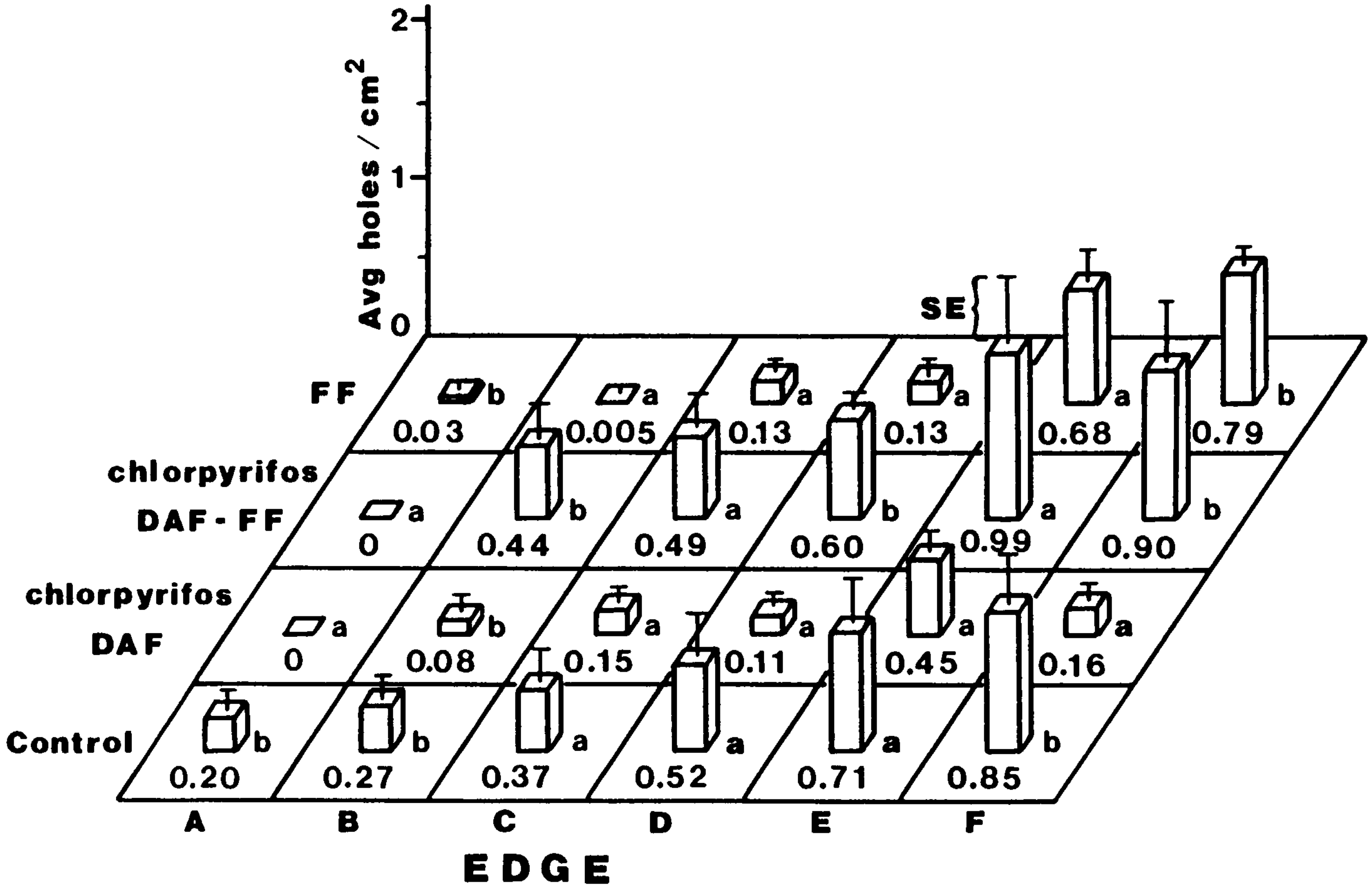

Figure 9. Evaluation of resistance of Dow Adhesive Film (DAF) treatments to lesser mealworm infestation (FF = Film Facer).

of the sides in all treatments; these sides corresponded to the upper- and lowermost sides of the vertical rectangle of polystyrene. Lesser mealworms were seen aggregating on these surfaces and these sides were most likely the first to be tunneled into by the insects. Sides C and D were the long sides of the polystyrene rectangle, and were also tunneled to a lesser extent. One might speculate on the reasons for the observed pattern of infestation. One such explanation might lie in the way larvae begin to make their tunnels in the polystyrene. When initiating a tunnel, a larva arched its body over the insulation surface, and chewed an indentation. The insect appeared to use its urogomphi as a means of leverage during the activity, and perhaps the tunneling activities were less easily accomplished on the sides of the insulation due to the effect of gravity on the larvae. Larvae also used their urogomphi to support their bodies against the wooden base when they began their tunnels on side F. Of the 3 film treatments, the single sheet of chlorpyrifos-DAF on one side of a polystyrene panel was the best overall film treatment, generally having the fewest number of holes per cm^2.

Both the Rustoleum® Paint and the Defthane® Polyurethane Finish formed a hard surface on the extruded polystyrene, which served as a barrier to lesser mealworm infestation (Table 6). At both the 73 day and 103 day evaluations, these treatments significantly reduced lesser mealworm infestations in the polystyrene by better than 70%. Adults were more commonly observed on the treated panels than larvae. Adult insects were observed at the top of the treatment panels, and there was evidence that these insects chewed away a layer of the aluminum paint and the polyurethane varnish. It has been shown, however, that the larvae initiate the tunneling damage, and are the major damaging stage (Ichinose *et al*. 1980, Vaughan *et al*. 1984). The adults apparently contributed to the initial stages of the sequence of infestation in the polystyrene by partially removing or weakening these types of paintlike barriers and thus exposing the polystyrene to the invading late instar lesser mealworm larvae.

All three of the Dow insulation materials were more resistant to lesser mealworm infestation than the standard (Table 7). The materials which had the largest cell size, Styrofoam® BB and Ethafoam® 220, resulted in significantly fewer surface penetrations than the materials with smaller cell sizes. Insulation density had no effect on lesser mealworm infestation. Infestations in Ethafoam® 220 always began along the cut side. Larvae apparently were unable to penetrate the smooth extrusion surface of the material, because there were no penetrations on these latter surfaces. No noticeable pattern of infestation was observed in the other two insulation types.

Table 6. Evaluation of paint-like barriers applied to the surface of extruded polystyrene for resistance to lesser mealworm infestation (n=6).

	Average number of holes per square centimeter of surface area			
	Day 73		Day 103	
Treatment	$\bar{x}$	SD	$\bar{x}$	SD
Rustoleum® Paint on Extruded Polystyrene	0.013 a[1]	0.008	0.028 a	0.011
Defthane® Finish on Extruded Polystyrene	0.013 a	0.007	0.026 a	0.012
Untreated Extruded Polystyrene	0.052 b	0.037	0.106 b	0.041

[1] Null hypothesis that the average number of holes per square centimeter is the same for all three treatments is rejected, Kruskal-Wallis test, $\alpha = 0.001$; Day 73: $x^2 = 21.27$; Day 103: $x^2 = 31.49$. Values within columns with different letters are significantly different, ($\alpha = 0.001$) using a nonparametric multiple comparison test analogous to the Newman-Keuls test (Zar, 1974).

Table 7. Laboratory evaluation of the resistance of insulation formulations to lesser mealworm infestation.

Insulation formulation	Cell size (mm)	Density (g/m^3)	Average number of holes per square centimeter of surface area					
			Experiment 1[1]			Experiment 2		
			$\bar{x}$	SD	n	$\bar{x}$	SD	n
Styrofoam® BB	1.5	25.7	0.035 a[2]	0.010	4	0.055 a	0.055	12
Ethafoam® 220	1.5	29.7	0.046 ab	0.048	4	0.139 b	0.119	12
Styrofoam® IB	0.6	20.6	0.101 b	0.055	4	0.378 c	0.285	12
Styrofoam® TG[3]	0.3	25.7	0.276 c	0.068	4	0.641	0.514	12

[1] Each experiment was fourteen days in duration.

[2] Null hypothesis that the average number of holes per square centimeter is the same for all four treatments is rejected, Kruska-Wallis test, $\alpha = 0.05$; Experiment 1: $x^2 = 11.74$; Experiment 2: $x^2 = 14.23$. Values within columns with different letters are significantly different ($\alpha = 0.05$) using a nonparametric multiple comparison test analogous to the Newman-Keuls test (Zar, 1974).

[3] Standard insulation formation.

A comprehensive preference evaluation of the chemical barriers and new types of insulation showed that Styrofoam® BB and Defthane® Polyurethane Finish had significantly fewer surface penetrations than the rest of the treatments (Table 8). Styrofoam® IB and the standard extruded polystyrene insulation, were heavily damaged, compared to the damage in Styrofoam® BB.

5.2.3 FIELD EVALUATIONS OF CHEMICAL BARRIERS AND NEW TYPES OF INSULATION

Sixty days elapsed before any noticeable infestations were observed in the treatments (Figure 10). At that time the pirimiphos-methyl (0.25% and 0.50% AI spray) and permethrin-WP treated panels continued to remain uninfested, and several treatments had very few numbers (<0.01 holes/cm^2) of surface penetrations. Extensively tunneled treatment panels (>0.10 holes/cm^2) were tetrachlorvinphos (0.25% and 0.50% AI spray), Rustoleum® paint, and Styrofoam® IB. It was not until after 90 days exposure time that a statistically significant separation of treatments was detected (ANOVA, $P=0.0022$). Styrofoam® BB and Ethafoam® 220 had very few surface penetrations, and were significantly less infested than the control treatment (Tukey's HSD test, $\alpha=0.05$) (Figure 10). Permethrin WP, the two levels of pirimiphos-methyl, and the chlorpyrifos-impregnated

Table 8. Laboratory evaluation of the resistance of paint-like barriers and types of insulations to lesser mealworm infestation (n=10, 21 day exposure to mealworm cultures).

	Holes per cm² surface area	
Treatment	$\bar{x}$	SD
Styrofoam® BB	0.006 a[1]	0.008
Defthane® Finish on Extruded Polystyrene	0.081 b	0.125
Ethafoam® 220	0.092 bc	0.082
Rustoleum® Paint on Extruded Polystyrene	0.168 bc	0.274
Styrofoam® IB	0.232 d	0.274
Untreated Extruded Polystyrene	0.418 e	0.355

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[1] Null hypothesis that the average number of holes per square centimeter is the same for all six treatments is rejected, Kruskal-Wallis test, $\alpha = 0.01$, $x^2 = 19.09$. Values with different letters are significantly different ($\alpha = 0.05$) using a nonparametric multiple comparisons test analogous to the Newman-Keuls test (Zar, 1974).

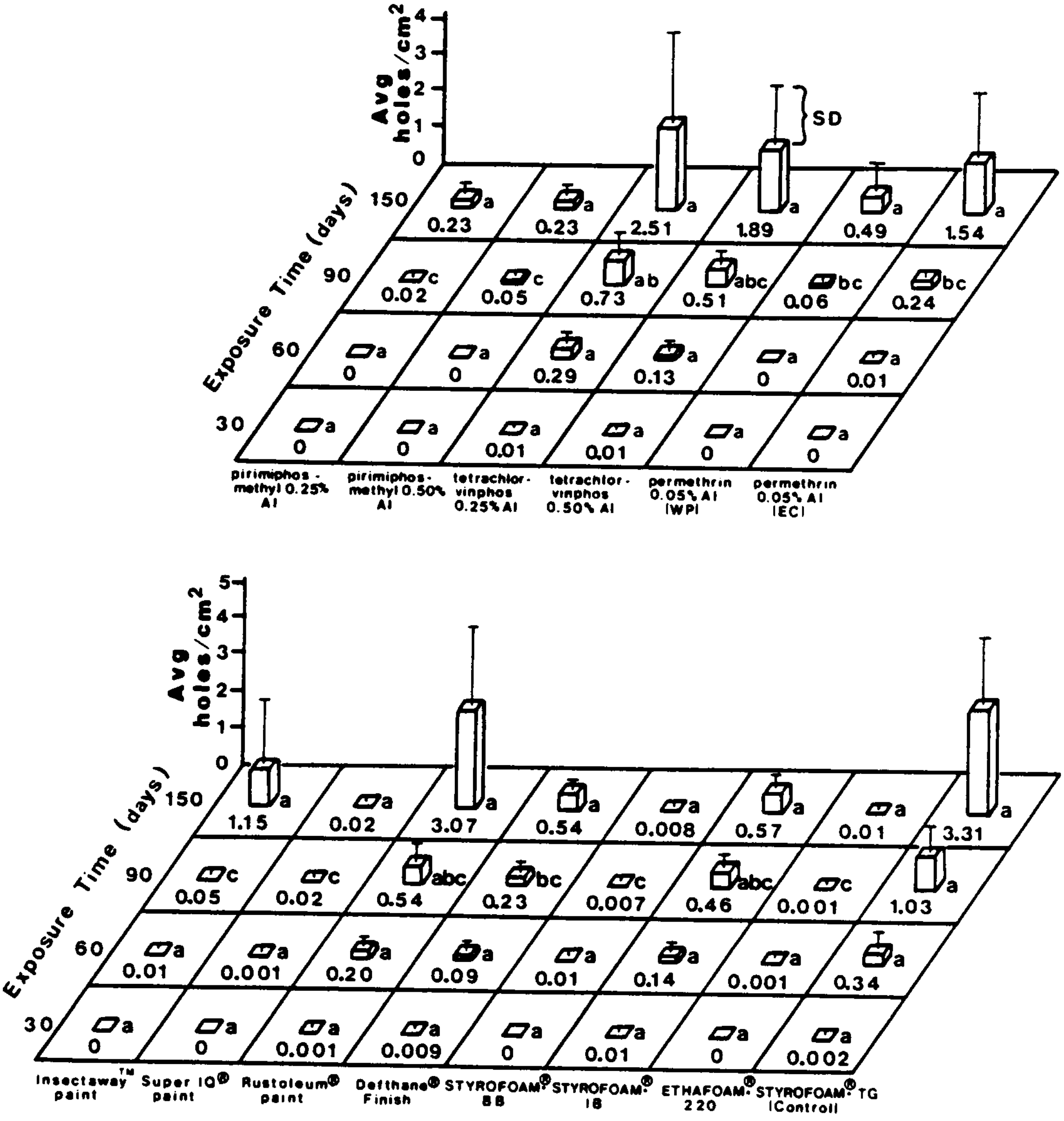

Figure 10. Field evaluation of insulation treatments. Different letters within exposure time indicate significant differences between treatments, Tukey's HSD test, alpha = 0.05.

Insectaway™ and Super IQ® latex paints were also very effective in preventing lesser mealworm infestations. Ineffective treatments were: the insecticide-free paint-like barriers, tetrachlorvinphos at both concentration levels, the emulsifiable concentrate formulation of permethrin, and the insulation Styrofoam® IB (Figure 10). Data from day 150 produced a nonsignificant ANOVA (P=0.1689). However, the best treatments, in terms of reduced numbers of surface penetrations, were the insulations Styrofoam® BB and Ethafoam® 220, both concentration levels of pirimiphos-methyl, and the chlorpyrifos-impregnated Super IQ® latex paint (Figure 10).

5.3 DISCUSSION

The application of a barrier to the exposed inside surface of an insulation material would be ideal for an egg producer who has insulation in situ. This type of treatment would eliminate the need to remove the external metal skin of the caged-layer house to gain access to the outside insulation surface. However, it is probable that lesser mealworms would have ready access to the outside surfaces of the insulation, and our findings with the DAF treatments (Figure 9) strongly suggest the need for treatment of every surface with the barrier of choice. Films would be an excellent choice for exclusion of lesser mealworms, if applied to new insulation being used to replace damaged materials, or on materials being placed in newly built caged-layer houses. Films in the form of heat-shrunk wraps have been used with success in packaging of stored products and commodities (Highland *et al*. 1984) and perhaps a similar method of sealing insulation could be developed. Ichinose *et al*. (1980) warned that such barriers would have to be free of tears to prevent access by lesser mealworms to the interior of the insulation.

The chlorpyrifos-impregnated latex paint barrier which was examined in this experiment provided excellent protection of extruded polystyrene insulation. The residual toxicity of these materials did not last very long under laboratory conditions, but painted insulation panels were well protected from the insect populations in the pit of a caged-layer house. The chlorpyrifos-impregnated paints were more effective barriers than either the polyurethane varnish and the aluminum paint. The insecticide impregnated latex paints were easy to apply, and with proper preparation of the insulation *in situ*, they would be viable mechanical barriers to beetle populations.

Pirimiphos-methyl at both 0.25% and 0.50% AI in final solution protected extruded polystyrene effectively, and was a better treatment than tetrachlorvinphos at the same concentrations through 90 days in the field. While the two insecticides had comparable residual activity in the laboratory, these materials had widely varying activity under the field conditions of the HR manure pit. Pirimiphos-methyl was very effective in preventing infestation in extruded polystyrene, and further toxicological studies should be undertaken to provide further registration data for use in poultry houses. The wettable powder formulation of permethrin, at 0.05% AI in final solution, was also effective in protecting poultry house insulation, and had residual activity comparable to the 0.50% AI level of pirimiphos-methyl under field conditions. The use of synthetic pyrethroids in combination with organophosphorous materials has been suggested to delay resistance in house fly populations (MacDonald et al. 1983) and application of permethrin WP would in turn contribute to insulation protection.

Many insulation materials have been examined for resistance to lesser mealworm infestations, yet no material has been found to be completely impervious to the insect (Le Torc'h and Letenneur 1983). Two insulation materials we examined, Styrofoam® BB and Ethafoam® 220, were very resistant to lesser mealworm infestation under the field conditions found in a caged layer house manure pit. It is apparent that resistance to lesser mealworm infestations has a direct relationship to the cell size of the insulation. Insulation materials should be selected which have a greater resistance to damage by this insect.

CHAPTER VI

LABORATORY STUDIES ON THE EFFECT OF VARIATIONS OF BARRIER TREATMENTS APPLIED TO EXTRUDED POLYSTYRENE ON LESSER MEALWORM INFESTATIONS

The behavior of lesser mealworm larvae tunneling into poultry house insulation materials has been described by many workers (Dale *et al*. 1976, Ichinose *et al*. 1980, Le Torc'h and Letenneur 1983, Vaughan *et al*. 1984, Despins *et al*. In Press). However, to date no observations have been reported on the larval infestation pattern in polystyrene insulation. Such information would be valuable in devising effective methods of protecting poultry house insulation. Therefore, the objectives of this study were to: 1) observe the location of the initial larval infestation sites, and 2) evaluate the application of simple non-insecticidal materials in various combinations to extruded polystyrene as barriers to lesser mealworm infestation.

6.1 MATERIALS AND METHODS

6.1.1 DETERMINATION OF INITIAL TUNNELING SITES

Two panels of extruded polystyrene (10.2 X 10.2 X 5.1 cm each piece) placed side by side, were nailed to the ends of two 15.2 X 5.1 cm plywood boards (Figure 11). A single polystyrene-plywood unit was thrust into the rearing medium of a thriving insect colony, with the polystyrene panels being held above the medium surface by the plywood; there were four replicates of this arrangement. Observations of tunnel initiation were made on a 7 day schedule over a 28 day period. Tunneling data were coded as being made either on the polystyrene edge (cut edge as well as inter-panel seam) or on the broad face of the polystyrene panel. On day 28, the panels were removed from the plywood boards to permit counting of holes on the cut edge surfaces comprising the inter-panel seam.

6.1.2 EVALUATION OF BARRIERS APPLIED TO SELECTED AREAS OF EXTRUDED POLYSTYRENE

This experiment was designed to evaluate the effectiveness of a barrier applied to the cut edge surface and to the inter-panel seam of extruded polystyrene insulation in reducing lesser mealworm infestations. The treatments were: 1) polyurethane varnish (Deft® Defthane® Polyurethane Finish) painted on the surface of the cut edges of extruded polystyrene insulation, with the inter-panel seams sealed with a commercially available bathroom caulking compound (Dow Corning® 100% Silicone Rubber Bathtub Caulk, Dow Corning Corp., Midland, Mich. 48640, USA); 2) same treatment as

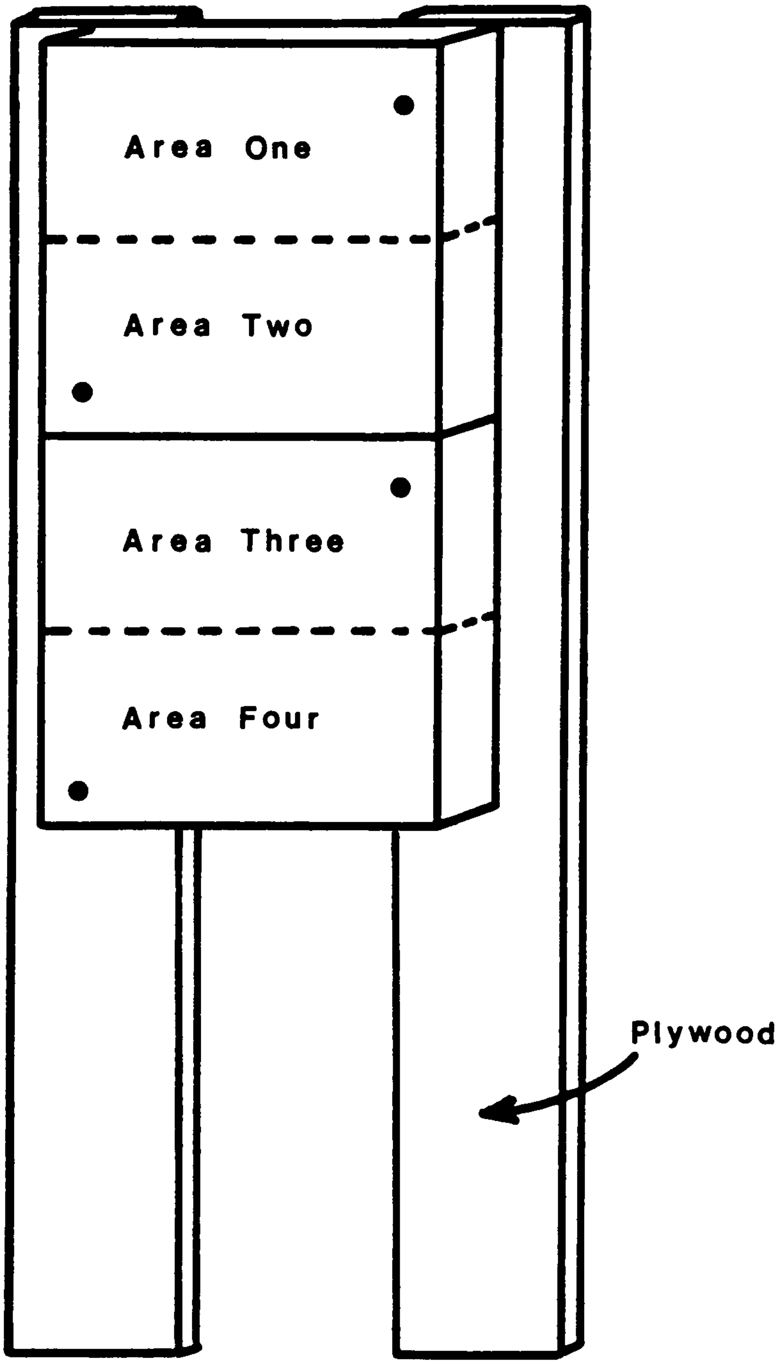

Figure 11. Arrangement of polystyrene panels to determine initial tunneling sites. Dashed lines indicate arbitrary demarcation points between the areas on the panels.

number 1 except without the sealed inter-panel seams; 3) inter-panel seams sealed with caulking compound, without polyurethane varnish on the cut edges; and 4) untreated extruded polystyrene. Four extruded polystyrene panels (7.6 X 7.6 X 2.5 cm, each panel) were glued to a plywood board, measuring 5.1 cm wide X 15.2 cm long X 0.6 cm thick (Figure 12). A plastic container (15.2 top dia. X 14.0 bottom dia. X 12.1 cm height) containing 250 g of air dried, semi-pulverized poultry manure was prepared as the larval habitat. The plywood board containing a treatment unit of 4 polystyrene panels was inserted into the manure, after which manure moisture levels of 40% and 60% were prepared and monitored as previously described in the methods section of Chapter IV. Each treatment/moisture level was replicated 3 times and maintained in darkness at 23.3° C ambient air temperature. At the beginning of the 9 day experiment, 50 late instar larvae were placed near the center of the manure surface, and 25 more larvae were added at 24 h, 96 h, and 168 h into each treatment replicate. Larvae were added in this manner to produce a population of insects in the treatments which would provide meaningful data for a X^2 analysis. Larval was the only stage used in these experiments since it produces the initial tunnels and is the major destructive stage (Ichinose et al. 1980, Vaughan et al. 1984). Treatments were evaluated by computing the average number of penetrations per cm^2, and by counting the resident insect

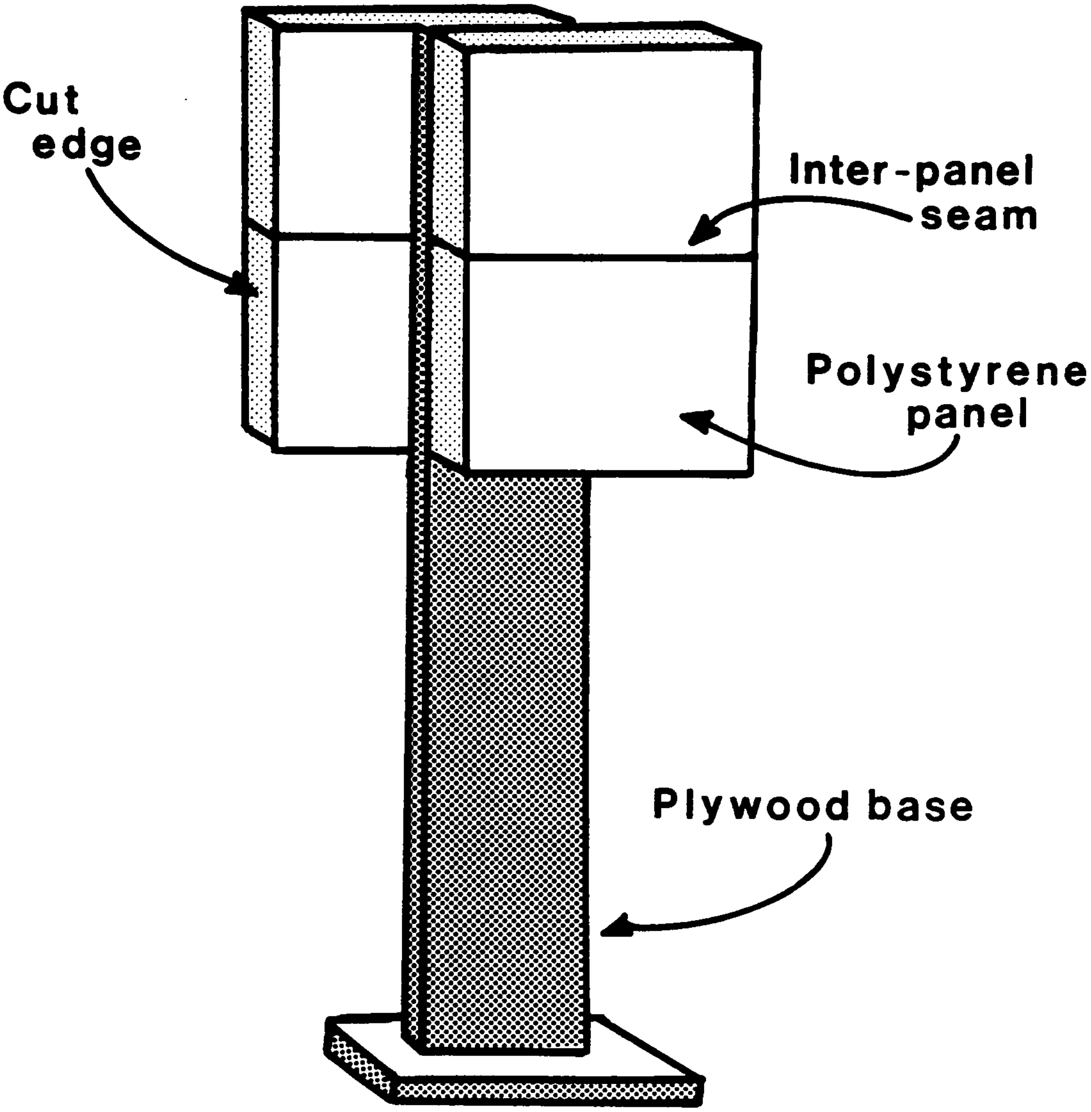

Figure 12. Diagram of apparatus used to evaluate the application of barriers to selected areas on extruded polystyrene.

population inside each polystyrene panel. Data were analyzed using either Student's t-test or X^2 test when appropriate.

6.2 RESULTS

6.2.1 DETERMINATION OF INITIAL TUNNELING SITES

There was a 14 day time period in which little tunneling activity was observed (Figure 13). At 14 days, and for the next two observations, the insects produced a significantly greater number of tunnels in the edge areas than on the broad faces of the extruded polystyrene (Student's t-test, $P<0.001$, $df=79$). Many of the tunnels in the edge area were made at the polystyrene-plywood interface, and at the inter-panel seam. Areas one and two, corresponding to the upper panel of the apparatus (Figure 11), were more tunneled than areas three and four on day 28 post-introduction (Tukey's HSD test, $\alpha=0.05$, Table 9). These data present an puzzling relationship in light of the results of the high rise house inspection survey. The inspection survey indicated that the lowermost insulation was the most severely damaged, and that infestations became less with insulation height above the manure. However, the findings from present experiment were completely reversed from those of the field inspection survey. This phenomenon was probably an artifact of the small size of the apparatus used in the laboratory

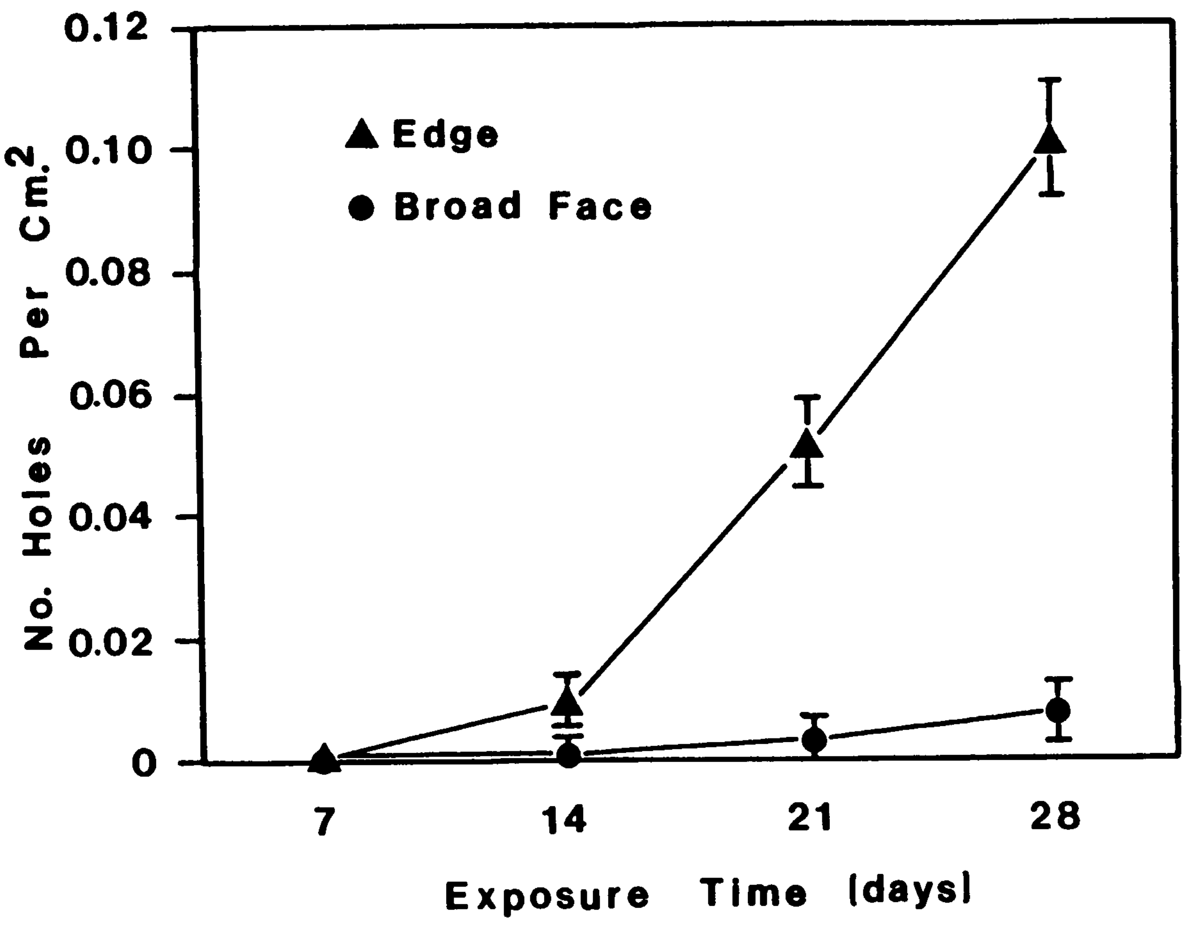

Figure 13. Pattern of lesser mealworm infestation in extruded polystyrene (vertical bar indicates ± 1 standard error of the mean [n = 4]. Means on day 14, 21, and 28 are significantly different, Student's t-test, P<0.001).

Table 9. Observations of the initial lesser mealworm tunneling sites in extruded polystyrene insulation.

Exposure Time (days)	Holes per cm² surface area			
	Area on Extruded Polystyrene			
	One	Two	Three	Four
7	0	0	0	0
14	0.007 a[1]	0.006 a	0.007 a	0.002 a
21	0.030 a	0.054 a	0.012 ab	0.006 b
28	0.106 a	0.082 a	0.022 b	0.009 b

[1] Values with different letters within a row are significantly different ($\alpha = 0.05$), Tukey's HSD test.

experiment, and therefore, the relative vertical distribution of damage in the two studies should not be compared.

6.2.2 EVALUATION OF BARRIERS APPLIED TO SELECTED AREAS OF EXTRUDED POLYSTYRENE

There were significantly fewer larvae in the barrier treatments than in the untreated polystyrene (Figure 14, X^2 test, $P<0.001$). Under the 40% manure moisture treatment, the treatment composed of varnished cut edges and sealed inter-panel seam was completely free of infestation. Under the infestation pressure induced by the wet manure conditions (60% manure moisture), only three larvae were found in the polystyrene insulation. Treatments consisting of either varnished cut edges or sealed inter-panel seams contained intermediate numbers of larvae and provided less protection of polystyrene insulation than was observed in the treatments which were used in combination with each other.

6.3 DISCUSSION

Results from the laboratory experiment indicated that larvae initially made their tunnels in the inter-panel seam and on the cut insulation surfaces. Similarly, the tongue-and-groove seam between major insulation panels, and the junction between insulation and the wood posts of the

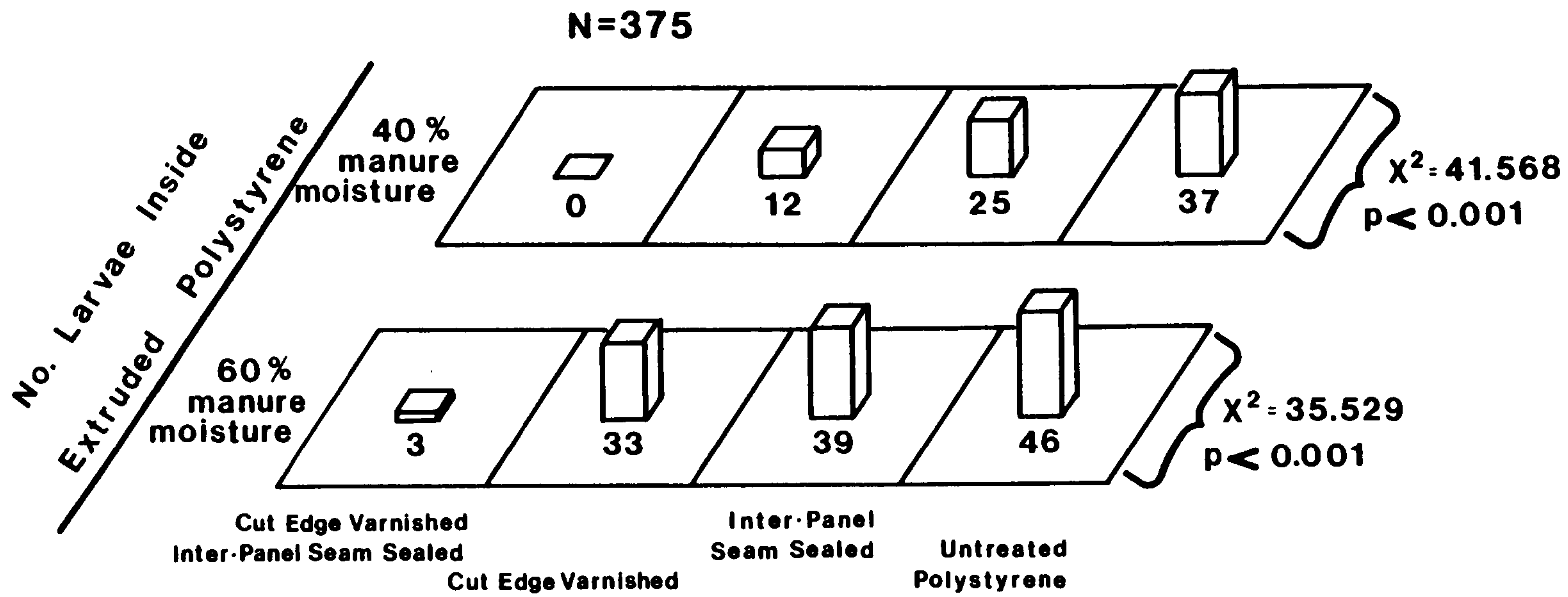

Figure 14. Effect of barriers placed on selected areas of extruded polystyrene on lesser mealworm infestations.

poultry house support structure are areas where infestations commonly occur in high rise houses.

Knowledge of the site of initial infestation is important when planning the efficacious application of mechanical/chemical barriers to extruded polystyrene insulation. Experimental results indicate that one should apply these barriers to areas where the insulation abuts other insulation or house support structures, and also along the exposed insulation edges. Thus, time and monetary resources spent in applying these barriers should be considerably reduced.

Larval movements up the pit walls can occur as the result of rising manure moisture conditions. This change in larval behavior has serious economic implications, because the results in this chapter have shown that such increased larval dispersion led to increased infestation rates in extruded polystyrene. The application of a coating of polyurethane varnish on the cut surface of extruded polystyrene, in combination with caulking the inter-panel seam, was an effective barrier to infestations. The barrier even withstood increased infestation pressure induced by a 60% manure moisture environment over a 28 day period in the laboratory.

Any material which would function in larval exclusion could be used. The chlorpyrifos-impregnated latex paints evaluated in Chapter V would be a viable candidate for such a barrier. Latex paint with the low concentration of chlorpyrifos had a long residual activity under poultry house conditions, and this material should be relatively easy to apply to a precise area on the polystyrene insulation. However, before this control technique may be recommended to egg producers, further studies should be conducted under the conditions found in a high rise house to obtain data on long term effectiveness of the method.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS FOR PRODUCERS

There were three major objectives which formed the basis of the present research. I will first state the objective and provide a summary of the results and discussion thereafter.

Objective Number One: was to conduct on-site examinations of high rise caged layer houses to ascertain the extent of damage to extruded polystyrene insulation, and, if possible, associate the damage with different high rise construction characteristics.

Summary: Polyurethane insulation which had heavy-weight paper glued to the surface of the insulation and which was installed with tape to seal off the seam between the insulation boards had no infestations. High rise houses with pit walls constructed of concrete block had lower insulation infestations than those houses with wooden walls forming the pits. Those houses which had pit wall foundations built of both types of materials had intermediate lesser mealworm infestations. Houses with their support structure set on top of the concrete block pit wall had lower infestations than those houses where the support structure was set directly into the earth.

There was a reduced gradient of damage with height of the insulation above the pit, with the insulation installed in the pit being the most severely infested. Extruded polystyrene insulation exposed to 10 years or more of lesser mealworm infestation was subject to a substantial loss of volume in the corner area of the insulation panels, ranging from 9.1% to 30.8% reduction from an original volume of 84,838 cm^3. Additionally, there was a significant reduction in the R-value of insulation in the infested areas.

<u>Objective Number Two</u>: was to observe the effect of manure moisture levels and poultry house construction materials on the dispersal behaviors exhibited by the lesser mealworm.

<u>Summary</u>: Larvae preferred to remain in manure habitats of 30 and 40% moisture, and dispersal from the manure significantly increased when manure moisture was increased to 50 and 60% levels. Adults were more active than larvae in the 30 and 40% manure moisture treatments, and the adult dispersal rate also increased significantly with raised manure moisture levels. Larvae could climb a significantly greater distance up a vertical wooden surface than up a vertical concrete block surface. These data suggest that high rise houses built with wood pit walls and support beams

which are set directly into the ground are predisposed to greater levels of insulation damage.

Objective Number Three: was to evaluate methods of protecting extruded polystyrene in situ and to evaluate alternative insulation materials for resistance to lesser mealworm infestations.

Summary: Insecticide sprays, plastic films, paint barriers applied to the surface of extruded polystyrene, and different types of insulation were evaluated for resistance to lesser mealworm infestations in the laboratory and under the field conditions in a high rise caged layer manure pit.

In the laboratory study, tetrachlorvinphos 50 WP (0.50% AI, at 0.1032 g AI/m^2), and pirimiphos-methyl 7E (0.25% AI, at 0.0534 g AI/m^2, and 0.50% AI, at 0.1069 g AI/m^2) sprayed on extruded polystyrene produced greater than 90% mortality in larval and adult lesser mealworm populations after 71 weeks postapplication. In a separate laboratory experiment, larvae were unable to penetrate either chlorpyrifos-impregnated or non-insecticidal polyethylene films. However, insects initiated tunnels on polystyrene surfaces which did not receive the film lamination. Infestation intensity was inversely proportional to insulation cell size, and insulation density had no effect on infestations.

Treatments which best protected extruded polystyrene when exposed to lesser mealworm populations in a high rise manure pit were permethrin WP (0.05% AI spray), pirimiphos-methyl 7E (0.25 and 0.50% AI spray), and 2 commercially available formulations of chlorpyrifos-impregnated latex paint (0.86 to 0.90% AI by weight). Insulation materials with a cell size of 1.5 mm were very resistant to lesser mealworm field populations.

Larvae first made their tunnels in the interpanel tongue-and-groove seam found between polystyrene panels and on the cut edges of the insulation. Very few tunnels were initiated on the broad flat insulation faces. Placing a barrier in the form of caulking at the interpanel seam and painting polyurethane varnish on the cut panel edges was effective in preventing infestations over a 28-day period of exposure.

Recommendations for Producers

Egg production in the high rise caged layer house system requires constant attention from management personnel on several levels. Management aspects which should not be neglected are proper waterer maintenance and manure moisture management (*i.e.* maintainance of relatively dry manure conditions). Research results indicate that larvae prefer to remain in manure at 30 to 40% moisture, and that movements from the manure greatly increased with rising manure moisture. These data indicate that the egg house manager should ensure that moisture conditions are not allowed to fluctuate after dense beetle populations have developed in the manure pit. This management tactic serves as a form of source reduction for house fly breeding habitat, and would fit well into a house fly integrated management program. Dry manure is also easier to handle than wet manure when it comes time to remove it from the house, a fact which is desirable to most people involved with the removal operation.

It is highly recommended to egg producers who are planning to build new high rise houses to place the structures on foundations built of concrete block. This is due to relative inability of lesser mealworm larvae to crawl up this building material. Use of Styrofoam® BB or Ethafoam® 220 instead of the standard insulation, Styrofoam® TG, might also be suggested, owing to the highly resistant nature of the former insulations to infestations. Styrofoam® BB and Ethafoam® 220 have similar insulating properties to the standard insulation, but they are also more expensive. A cost analysis would be necessary before any recommendations of these new insulation products could be made to egg producers. The literature has shown that fiberglass is also a resistant insulation, and the relative prices for these insulation materials will most likely be the deciding factor.

The choice of using insecticides for noxious arthropod control should fit well into a program which integrates other control methods such as cultural and biological control techniques. The chlorpyrifos-impregnated latex paints evaluated in Chapter V would be the suggested material for use in protecting extruded polystyrene _in situ_ in high rise houses. Latex paint with the low concentration of chlorpyrifos had a long residual activity under poultry house conditions, and this material should be relatively easy to apply to a precise area on the polystyrene insulation. Results show that an application of the paint material need only be applied to the tongue-and-groove seam between insulation panels, because very few tunnels are initiated in any other area on the insulation. The caulking technique discussed in Chapter V could also be used in combination with chlorpyrifos paint for insulation protection. Insecticide sprays of wettable powder formulation of permethrin, sprayed onto insulation for control of house fly populations, would also serve to protect the insulation from lesser mealworm damage. This method is probably the least labor intensive of those discussed in this summary section, and for this reason it will be the most attractive to egg producers.

LITERATURE CITED

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18:265-267.

Alicata, J. E. 1939. Preliminary note on the life history of Subulura brumpti, a common cecal nematode of poultry in Hawaii. J. Parasit. 25:179-180.

Armitage, D. M. 1985. Environment of deep-pit poultry houses: survey of air and manure temperatures in British houses. Br. Poultry Sci. 26:275-280.

Axtell, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. PSA symposium on arthropods of economic importance to the poultry industry. Poultry Sci. 65:657-667.

Barke, H. E., and R. Davis. 1967. Sexual dimorphism in the lesser mealworm, Alphitobius diaperinus (Panz.) (Coleoptera: Tenebrionidae). J. Ga. Entomol. Soc. 2:119-121.

Barke, H. E., and R. Davis. 1969. Notes on the biology of the lesser mealworm, Alphitobius diaperinus (Panz.) (Coleoptera: Tenebrionidae). J. Ga. Entomol. Soc. 4:46-50.

Case, A. A., and J. E. Ackert. 1940. New intermediate hosts of fowl cestodes. Trans. Kansas Acad. Sci. 43:393-396.

Chaix, M. O. 1980. The extermination of infested breeding places. Phytoma 3/4:18-20 (in French).

Crook, P. G., J. A. Novak, and T. J. Spilman. 1980. The lesser mealworm, Alphitobius diaperinus, in the scrotum of Rattus norvegicus, with notes on other vertebrate associations (Coleoptera, Tenebrionidae; Rodentia, Muridae). Coleopts. Bull. 34:393-396.

Dale, P. S., J. C. Hayes, and J. Johannesson. 1976. New records of plant pests in New Zealand. N. Z. J. Agric. Res. 19:265-269.

De las Casas, E., B. S. Pomeroy, and P. K. Harein. 1968. Infection and quantitative recovery of Salmonella typhimurium and Escherichia coli from within the lesser mealworm, *Alphitobius diaperinus* (Panzer). Poultry Sci. 47:1871-1875.

De las Casas, E., P. K. Harein, and B. S. Pomeroy. 1972. Bacteria and fungi within the lesser mealworm collected from poultry brooder houses. Environ. Entomol. 1:27-30.

Despins, J. L., E. C. Turner, Jr. and P. L. Ruszler. 1987. Construction profiles of high rise caged layer houses in association with insulation damage caused by the lesser mealworm, *Alphitobius diaperinus* (Panzer) in Virginia. Poultry Sci. (In Press).

Eidson, C. S., S. C. Schmittle, R. B. Goode, and J. B. Lal. 1965. The role of the darkling beetle, *Alphitobius diaperinus*, in the transmission of acute leukosis in chickens. Poultry Sci. 44:1366-1367.

Eidson, C. S., S. C. Schmittle, R. B. Goode, and J. B. Lal. 1966. Induction of leukosis tumors with the beetle *Alphitobius diaperinus*. Amer. J. Vet. Res. 27:1053-1057.

Eugenio, C., E. De las Casas, P. K. Harein, and C. J. Mirocha. 1970. Detection of the mycotoxin F-2 in the confused flour beetle and the lesser mealworm. J. Econ. Entomol. 63:412-415.

Green, D. B. 1982. The fauna and environment of two Lancashire deep-pit poultry houses. Ministry of Agriculture, Fisheries and Food Poultry Sect. A Quarterly Journal March (140):15-32.

Harding, W. C., and T. L. Bissell. 1958. Lesser mealworms in a brooder house. J. Econ. Entomol. 51:112.

Harein, P. K., and E. De las Casas. 1969. Microorganisms isolated from lesser mealworm collected in turkey brooder houses. Proc. North Central Branch, Entomol. Soc. Amer. 24:48.

Harein, P. K., E. De las Casas, B. S. Pomeroy, and M. D. York. 1970. *Salmonella* spp. and serotypes of *Escherichia coli* isolated from the lesser mealworm collected in poultry brooder houses. J. Econ. Entomol. 63:80-82.

Harris, F. 1966. Observations on the lesser mealworm, *Alphitobius diaperinus* (Panz.). J. Ga. Entomol. Soc. 1:17-18.

Highland, H. A., R. A. Simonaitis, and R. Boatright. 1984. Insecticide-treated film wrap to protect small packages from insulation. J. Econ. Entomol. 77:1269-1274.

Ichinose, T., S. Shibazaki, and M. Ohta. 1980. Studies on the biology and mode of infestation of the tenebrionid beetle, Alphitobius diaperinus Panzer, harmful to broiler-chicken houses. Jpn. J. Appl. Entomol. Zool. 24:167-174 (in Japanese with English abstract).

Keifer, H. H. 1935. The black fungus beetle and lesser meal worm. Calif. Dept. Agric. Bull. 24:316.

Lancaster, J. L., and J. S. Simco. 1967. Biology of the lesser mealworm, a suspected reservoir of avian leucosis. Univ. Ark. Agric. Exp. Stn. Rep. Ser. 159.

Lancaster, J. L., Jr., J. S. Simco, N. R. Gyles, and L. Lankford. 1969. Faunal survey of insects and mites in poultry litter in Arkansas. Univ. Ark. Agric. Exp. Stn. Rep. Ser. 182.

Le Torc'h, J. M. 1979. A new pest in breeding establishments, Alphitobius diaperinus. Phytoma 308:31-33 (in French, with English abstract).

Le Torc'h, J. M., and R. Letenneur. 1983. Laboratory tests of resistance of different thermic insulators to the boring of the tenebrionid Alphitobius diaperinus Panzer, (Col. Tenebrionidae). Comptes Rendus des Seances de l'Academie d'Agriculture de France 69:188-200 (in French, with English abstract).

Lewis, D. J. 1958. Coleoptera of medical interest in the Sudan Republic. Proc. Entomol. Soc. London, Ser. A 33:37-42.

MacDonald, R. S., G. A. Surgeoner, K. R. Solomon, and C. R. Harris. 1983. Development of resistance to permethrin and dichlorvos by the house fly (Diptera: Muscidae) following continuous and alternating insecticide use on four farms. Can. Entomol. 115:1555-1561.

MacCreary, D., and E. P. Catts. 1954. Ectoparasites of Delaware poultry including a study of litter fauna. Univ. Del. Agric. Exp. Stn. Bull. No. 307.

Matthews, R. W., and J. R. Matthews. 1978. Insect Behavior. John Wiley & Sons, Inc. New York.

Pfeiffer, D. G. and R. C. Axtell. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. Environ. Entomol. 9:21-28.

Preiss, F. J. 1969. The bionomics of the lesser mealworm, Alphitobius diaperinus (Coleoptera: Tenebrionidae). Ph.D. dissertation, University of Maryland, College Park.

Preiss, F. J., and J. A. Davidson. 1968. The effect of temperature and humidity on egg hatch of the lesser mealworm. University of Maryland Agric. Exp. Stn. Misc. Pub. No. 660.

Preiss, F. J., and J. A. Davidson. 1971. Adult longevity, preoviposition period and fecundity of Alphitobius diaperinus in the laboratory (Coleoptera: Tenebrionidae). J. Ga. Entomol. Soc. 6:105-109.

Safrit, R. D. and R. C. Axtell. 1984. Evaluation of sampling methods for darkling beetles (Alphitobius diaperinus) in the litter of turkey and broiler houses. Poultry Sci. 63:2368-2375.

Sarin, K., and S. C. Saxena. 1975. Food preference and site of damage to preferred products by Alphitobius diaperinus (Panz.) Bull. Grain Tech. 13:50-51 [as cited in Vaughan, 1982.] .

SAS Institute, Inc. 1982. SAS User's Guide: Statistics, 1982 Edition. Cary, North Carolina.

Silberman, M. S., and S. C. Schmittle. 1967. Chemical control of the lesser mealworm, Alphitobius diaperinus (Panz.) (Coleoptera: Tenebrionidae). J. Ga. Entomol. Soc. 2:1-8.

Simco, J. S., R. Everett, and J. L. Lancaster. 1966. Preliminary studies on control of the lesser mealworm in broiler houses. Ark. Farm Res. 15:8.

Swatonek, F. V. 1970. Zur Biologie des glanzendschwarzen Getreideschimmelkafers (Alphitobius diaperinus Panz. = A. piceus Oliv.). [On the biology of the lesser mealworm beetle (Alphitobius diaperinus Panz. = A. piceus Oliv.).] Anzeiger fur Schadlingskunde und Pflanzenschutz 43:101-104. (in German).

Vaughan, J. A. 1982. Biology and control of the lesser mealworm: Alphitobius diaperinus a structural pest in poultry houses. M.S. thesis, Va. Polytech. Inst. and State Univ., Blacksburg.

Vaughan, J. A., and E. C. Turner, Jr. 1984. Residual and topical toxicity of various insecticides to the lesser mealworm (Coleoptera: Tenebrionidae). J. Econ. Entomol. 77:216-220.

Vaughan, J. A., E. C. Turner, Jr., and P. L. Ruszler. 1984. Infestation and damage of poultry house insulation by the lesser mealworm, *Alphitobius diaperinus* (Panzer). Poultry Sci. 63:1094-1100.

Wildey, K. B. 1983. Insect pests in animal houses - current control developments. Proceedings, Sixth British Pest Control Conference, Robinson College, Cambridge, September 7th-10th 1983. P. L. G. Bateman, ed., British Pest Control Association. London.

Wilson, T. H. 1968. Some effects of temperature on biology of the lesser mealworm, *Alphitobius diaperinus* (Panzer). M.S. thesis. Univ. of Ark., Fayetteville.

Wilson, T. H., and F. D. Miner. 1969. Influence of temperature on development of the lesser mealworm, *Alphitobius diaperinus* (Coleoptera: Tenebrionidae). J. Kan. Entomol. Soc. 42:294-303.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey.

Zar, J. H. 1984. Biostatistical analysis. 2nd ed., Prentice-Hall, Englewood Cliffs, New Jersey.

APPENDIX A

HIGH RISE CAGED LAYER QUESTIONNAIRE

DARKLING BEETLE SURVEY
conducted by:
E. C. Turner, Jr. and Joseph L. Despins
Entomology Department
VPI&SU
Blacksburg, VA 24061
{Phone: (703) 961-5871}

Your name: Response Number 1

Name of facility:

Facility address:

Facility phone number:

Your phone number:

We would like some information about the types of buildings in which the darkling beetle has been a pest. Please fill out this questionnaire and return it to either of us at the end of the session. If more time is needed to complete the survey, please take it with you and mail it to us when you have completed it. Thank you very much!

Please indicate the number of houses at your facility:

A) Deep-pit house 2   B) Shallow-pit house 2

C) Floor 0   D) Other (please describe briefly):

DEEP-PIT HOUSE

House identification number or name: House #5

1) Have you noticed darkling beetles in this house?

Yes X No______

If yes, where have you seen them?

In the basement and along walls.

2) Have you noticed the damage that darkling beetles can do to styrofoam in this house? Yes X No____

3) What are the approximate dimensions of this house?

Length 530 Width 48 Wall Height 8 ft.

4) What is the age of this house? 4 yrs.

5) Is this house insulated? Yes X No____

If yes, what type of insulation is installed?

Styrofoam on walls, blown fiberglass in ceilings

6) Have you ever had to replace insulation due to darkling beetle damage? Yes____ No X

If so, approximately how many board feet have been replaced? _________

7) Does the outer wall have a frame construction X or pole construction ____?

8) Does the outer wall have a wooden siding ____ or a metal skin X?

9) What is the wall construction of the pit?

WOOD ____ BLOCK ____ BOTH X

If of block construction or both, how many courses of block are in the wall? 4 ft. heights block, then wood

10) What is the approximate manure removal schedule for this house? Once a year

11) Have you had water problems in this house?

Yes X No____

12) How would you describe the manure in the pit?

DRY ____ MOIST ____ WET X "SOUPY" ____

13) Are there problems with spilled or wasted feed?

if so, please explain. ______________________________

DARKLING BEETLE SURVEY

conducted by:

E. C. Turner, Jr. and Joseph L. Despins

Entomology Department

VPI&SU

Blacksburg, VA 24061

{Phone: (703) 961-5871}

Your name: Response Number 2

Name of facility:

Facility address:

Facility phone number:

Your phone number:

We would like some information about the types of buildings in which the darkling beetle has been a pest. Please fill out this questionnaire and return it to either of us at the end of the session. If more time is needed to complete the survey, please take it with you and mail it to us when you have completed it. Thank you very much!

Please indicate the number of houses at your facility:

A) Deep-pit house X B) Shallow-pit house ____

C) Floor ____ D) Other (please describe briefly):

DEEP-PIT HOUSE

House identification number or name: A-5 & A-6

1) Have you noticed darkling beetles in this house?

Yes X No____

If yes, where have you seen them?

Only in the pit

2) Have you noticed the damage that darkling beetles can do to styrofoam in this house? Yes____ No X

3) What are the approximate dimensions of this house?

Length 530 Width 40 Wall Height 18 ft

4) What is the age of this house? 4 yrs.

5) Is this house insulated? Yes X No____

If yes, what type of insulation is installed?

Fiberglass batts in ceiling, fiberglass batts in walls

6) Have you ever had to replace insulation due to darkling beetle damage? Yes____ No X

If so, approximately how many board feet have been replaced? __________

7) Does the outer wall have a frame construction X or pole construction ____?

8) Does the outer wall have a wooden siding ____ or a metal skin X?

9) What is the wall construction of the pit?

WOOD ____ BLOCK X BOTH ____

If of block construction or both, how many courses of block are in the wall? 6

10) What is the approximate manure removal schedule for this

house? Heavily in spring & fall for fertilizer.

11) Have you had water problems in this house? Yes____ No X

12) How would you describe the manure in the pit?

DRY X MOIST ____ WET ____ "SOUPY" ____

13) Are there problems with spilled or wasted feed?

If so, please explain. Some feed leaks but not significant (additional comment) Where the lumber in the house is exposed on the edge we have also noticed "wormed out" areas which structurally weakens the wood.

DARKLING BEETLE SURVEY

conducted by:

E. C. Turner, Jr. and Joseph L. Despins

Entomology Department

VPI&SU

Blacksburg, VA 24061

{Phone: (703) 961-5871}

Your name: Response Number 3

Name of facility:

Facility address:

Facility phone number:

Your phone number:

We would like some information about the types of buildings in which the darkling beetle has been a pest. Please fill out this questionnaire and return it to either of us at the end of the session. If more time is needed to complete the survey, please take it with you and mail it to us when you have completed it. Thank you very much!

Please indicate the number of houses at your facility:

A) Deep-pit house 11 B) Shallow-pit house 6

C) Floor ____ D) Other (please describe briefly):

DEEP-PIT HOUSE

House identification number or name: #8, 11, 12, 15, 16, 18, 19, 20, 21, 22, 23

1) Have you noticed darkling beetles in this house?

Yes X No____

If yes, where have you seen them?

Lower sides and end walls

2) Have you noticed the damage that darkling beetles can do to styrofoam in this house? Yes X No____

3) What are the approximate dimensions of this house?

Length 300 Width 50 Wall Height 8 ft.

4) What is the age of this house? From 8 to 15 yrs

5) Is this house insulated? Yes X No____

If yes, what type of insulation is installed?

Styrofoam

6) Have you ever had to replace insulation due to darkling beetle damage? Yes____ No X

If so, approximately how many board feet have been replaced? __________

7) Does the outer wall have a frame construction ____ or pole construction X?

8) Does the outer wall have a wooden siding ____ or a metal skin X?

9) What is the wall construction of the pit?

WOOD X BLOCK ____ BOTH ____

If of block construction or both, how many courses of block are in the wall? __________

10) What is the approximate manure removal schedule for this house? 8 houses pump regular, 3 houses 1 year

11) Have you had water problems in this house? Yes X No____

12) How would you describe the manure in the pit?

DRY ____ MOIST ____ WET ____ "SOUPY" X

13) Are there problems with spilled or wasted feed?

If so, please explain. ____________________________

DARKLING BEETLE SURVEY

conducted by:

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Entomology Department

VPI&SU

Blacksburg, VA 24061

{Phone: (703) 961-5871}

Your name: Response Number 4

Name of facility:

Facility address:

Facility phone number:

Your phone number:

We would like some information about the types of buildings in which the darkling beetle has been a pest. Please fill out this questionnaire and return it to either of us at the end of the session. If more time is needed to complete the survey, please take it with you and mail it to us when you have completed it. Thank you very much!

Please indicate the number of houses at your facility:

A) Deep-pit house _X__ B) Shallow-pit house ____

C) Floor ____ D) Other (please describe briefly):

DEEP-PIT HOUSE

House identification number or name: Farm 1

1) Have you noticed darkling beetles in this house?

Yes____ No X

If yes, where have you seen them? __________

2) Have you noticed the damage that darkling beetles can do to styrofoam in this house? Yes____ No X

3) What are the approximate dimensions of this house?

Length 530 Width 47 Wall Height 16 ft

4) What is the age of this house? 4 yrs.

5) Is this house insulated? Yes X No____

If yes, what type of insulation is installed?

Styrofoam

6) Have you ever had to replace insulation due to darkling beetle damage? Yes____ No X

If so, approximately how many board feet have been replaced? _________

7) Does the outer wall have a frame construction ____ or pole construction X?

8) Does the outer wall have a wooden siding ____ or a metal skin X?

9) What is the wall construction of the pit?

WOOD X BLOCK ____ BOTH ____

If of block construction or both, how many courses of block are in the wall? __________

10) What is the approximate manure removal schedule for this

house? <u>Spring & fall</u>

11) Have you had water problems in this house? Yes <u>X</u> No____

12) How would you describe the manure in the pit?

DRY ____ MOIST ____ WET <u>X</u> "SOUPY" ____

13) Are there problems with spilled or wasted feed?

If so, please explain. ____________________________

DARKLING BEETLE SURVEY

conducted by:

E. C. Turner, Jr. and Joseph L. Despins

Entomology Department

VPI&SU

Blacksburg, VA 24061

{Phone: (703) 961-5871}

Your name: Response Number 5

Name of facility:

Facility address:

Facility phone number:

Your phone number:

We would like some information about the types of buildings in which the darkling beetle has been a pest. Please fill out this questionnaire and return it to either of us at the end of the session. If more time is needed to complete the survey, please take it with you and mail it to us when you have completed it. Thank you very much!

Please indicate the number of houses at your facility:

A) Deep-pit house 4 B) Shallow-pit house ____

C) Floor ____ D) Other (please describe briefly):

DEEP-PIT HOUSE

House identification number or name: 1, 2, 3, 4

1) Have you noticed darkling beetles in this house?

Yes____ No X

If yes, where have you seen them? __________

2) Have you noticed the damage that darkling beetles can do to styrofoam in this house? Yes____ No X

3) What are the approximate dimensions of this house?

Length 380 Width 40 Wall Height 14 ft

4) What is the age of this house? 2 yrs

5) Is this house insulated? YesX No____

If yes, what type of insulation is installed?

6" fiberglass ceiling, 3.5" fiberglass side wall

6) Have you ever had to replace insulation due to darkling beetle damage? Yes____ No X

If so, approximately how many board feet have been replaced? _________

7) Does the outer wall have a frame construction X or pole construction ____?

8) Does the outer wall have a wooden siding ____ or a metal skin ____? (other) asphalt siding

9) What is the wall construction of the pit?

WOOD ____ BLOCK ____ BOTH X

If of block construction or both, how many courses of block are in the wall? 4

10) What is the approximate manure removal schedule for this

house? Yearly

11) Have you had water problems in this house? Yes____ No X

12) How would you describe the manure in the pit?

DRY X MOIST ____ WET ____ "SOUPY" ____

13) Are there problems with spilled or wasted feed?

If so, please explain. No

APPENDIX B

Mortality of adult lesser mealworms following a 1 hour exposure to insecticides.

Treatment	% AI	Average corrected percentage mortality										
		24h	48h	1wk[1]	2wk	3wk	4wk	5wk	6wk	23wk	61wk	71wk
Permethrin 25WP	0.05	100 a[2]	100 a	76.7 ab	100 a	100 a	96.6 a	96.4 a	86.7 ab	73.3 ab	30.0 b	26.7 b
Permethrin 5.7EC	0.05	100 a	90.0a	66.7 ab	41.4b	33.3b	67.0 b	28.5 b	30.0 b	26.7 b	20.0 b	20.0 b
Pirimiphos-methyl 7E	0.25	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Pirimiphos-methyl 7E	0.50	100 a	100 a	100 a	100 a	96.7a	100 a	100 a	100 a	96.7 a	100 a	100 a
Tetrachlorvinphos 50WP	0.50	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	96.7 a	96.7 a	100 a
Chlorpyrifos paint	0.86	100 a	93.3a	3.3 b	2.3 b	0 b	-[3]	-	-	-	-	-

---

[1] Number of weeks after treatment of the extruded polystyrene; date of treatment = 15 February 1984.

[2] Values within columns followed by the same letter are not different (Tukey's HSD test, $\alpha = 0.05$).

[3] Treatment removed from evaluation.

APPENDIX C

Mortality of late instar lesser mealworms following a 1 hour exposure to insecticides.

Treatment	% AI	Average corrected percentage mortality										
		24h	48h	1wk[1]	2wk	3wk	4wk	5wk	6wk	23wk	61wk	71wk
Permethrin 25WP	0.05	100 a[2]	100 a	83.3 a	100 a	100 a	96.7 a	96.7 a	96.7 a	90.0 a	16.7 b	30.0 a
Permethrin 5.7EC	0.05	90.0a	82.8b	83.3 a	46.7ab	46.7b	66.7 b	50.0 a	76.7 a	66.7 a	20.0 b	36.7 a
Pirimiphos-methyl 7E	0.25	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Pirimiphos-methyl 7E	0.50	100 a	100 a	100 a	100 a	96.7a	100 a	100 a	100 a	100 a	100 a	100 a
Tetrachlorvinphos 50WP	0.50	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	96.7 a	96.7 a
Chlorpyrifos paint	0.86	86.7a	93.1ab	23.3b	0 b	0 b	-[3]	-	-	-	-	-

---

[1] Number of weeks after treatment of the extruded polystyrene; date of treatment = 15 February 1984.

[2] Values within columns followed by the same letter are not different (Tukey's HSD test, $\alpha = 0.05$).

[3] Treatment removed from evaluation.

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