STELIDOTA GEMINATA (COLEOPTERA: NITIDULIDAE): BIOLOGY AND MEANS OF CONTROL ON STRAWBERRIES IN MICHIGAN

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This is to certify that the

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ABSTRACT

STELIDOTA GEMINATA (COLEOPTERA:NITIDULIDAE):
BIOLOGY AND MEANS OF CONTROL ON
STRAWBERRIES IN MICHIGAN

By

Richard Franklyn Gertz

A new pest of strawberries--the strawberry sap beetle, *Stelidota geminata*--caused an estimated 2-3 million dollar loss to the Michigan economy in June 1966. Damage was caused by the feeding of adults and larvae.

Mass rearing in the laboratory for biology and control studies was carried out by culturing beetles in 2-quart, wide-mouth jars. Moist peaches were provided as a food source.

Life cycle studies showed that there are 3 larval instars and completion of development from egg to adult requires an average of 19 days at 75°F. Adult lifespan averaged 127 days; the oviposition period averaged 101 days; and the average number of eggs per day was 4.3 with a maximum of 16.

Adult beetles fed primarily on the underside of ripe and over-ripe fruit in contact with the ground. One to several feeding galleries were made in the strawberry fruit depending on the number of beetles present. The individual galleries coalesced into large cavities after several hours of feeding. Larvae also fed in the

interior of the fruit. Host crops of Stelidota geminata in Berrien Co. were sour and sweet cherry, dewberry, tomato, muskmelon, peach, pear and apple.

Fermenting molasses ground traps were employed to determine the site of overwintering and time of migration. Adults overwinter in the woodlots and thickets around the fruit plantings. When the mean temperature was above 65°F migration from the woodlots occurred. The odor of ripe, overripe or decaying strawberries attracted adults to the strawberry plantings. The peak of migration coincided with the peak of the strawberry harvest.

Application of spray chemicals on the strawberry foliage and fruit at rates up to twice the recommended gallonage per acre did not produce control. Bioassays of 24 chemical compounds showed that the following were toxic to S. geminata adults: mevinphos, malathion, azinphosmethyl, diazinon, naled, parathion, GC-6506, Lannate, Sumithion, GS-13005, Azodrin, Furadan, Imidan, and dieldrin. The other compounds tested were ineffective.

Outstanding response to a synthetic attractant, Duplicolor auto primer touch-up paint DP-GM 3 was demonstrated in July 1966. However, subsequent work in 1966 and 1967 in the laboratory and field failed to demonstrate exceptional attractant properties of this material.

Adult beetles showed significant response to the following natural attractants: bran, apple pomace, fermenting molasses, and fermenting grape juice. Fermenting grape juice and fermenting molasses were highly attractive. Two methods of control were developed that employed molasses as an attractant. The first method utilized a bait consisting of corncob-molasses-1.25% azinphosmethyl that was broadcast over the strawberry fields at a rate of 40 lb/acre. This bait was applied over a majority of the commercial strawberry acreage in southwestern Michigan in June 1967 and produced satisfactory control. The second method of control was the placement of liquid fermenting molasses-yeast-insecticide poison bait stations around the perimeter of the strawberry field to intercept the migration of adults.

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By

Richard Franklyn Gertz

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

Production of strawberries has been a major horticultural enterprise in Michigan for over 70 years. Michigan is currently exceeded only by California, Oregon and Washington in strawberry production. In the years 1959-63 Michigan growers produced an average of 37.2 million pounds of strawberries annually with a cash value of 6.3 million dollars. Almost two thirds of the crop is sold on the fresh fruit market. The strawberry industry is exceeded only by apples and cherries in dollar volume for fruit enterprises in the state. Strawberries are horticulturally adaptable for most sections of the state and are grown commercially in the following counties: Wayne, Kent, Ottawa, Berrien, Van Buren, Manistee, Leelanau, Alpena, and Houghton. Approximately 50% of the 9,440 acres devoted to commercial strawberry production is located in Berrien and Van Buren Counties in southwestern Michigan.

In late June 1966, the strawberry harvest in southwestern Michigan was abruptly terminated because of insect-contaminated fruit. An epizootic population of a nitidulid beetle, which was uniformly distributed throughout the area, was determined to be the causal agent. Approximately two thirds of the crop was not harvested during the 1966 season. The beetle was later identified by Dr. Melville H. Hatch of the University of Washington as *Stelidota* geminata (Say); family Nitidulidae. Stelidota geminata is commonly referred to as the strawberry sap beetle in Michigan.

The loss to the Michigan economy was estimated at 2-3 million dollars. In addition, particular hardship was felt by thousands of migrant harvest workers who were deprived of 2-3 weeks employment at a time when no other harvest work was available.

Surveys and reports from other strawberry producing areas of Michigan have shown that the beetle is restricted in distribution to southwestern Michigan. However, climatic conditions in Michigan are within those cited in the literature for S. geminata so that there is no guarantee that the insect cannot become established in other regions.

Control of S. geminata is complicated by the following factors: (1) The adult beetles start migrating into the strawberry plantings as the fruit begins to ripen. Operating ground spray or dust equipment through the planting at this time results in excessive damage to the crop. In addition, injured fruit attracts more beetles into the planting. (2) Plant foliage is at peak density which prevents proper coverage of the fruit with insecticides. (3) The harvest season is extended over a 3 week period which involves 5-6 separate pickings, each picking followed by 1-2 inches of irrigation. To be effective, pesticides would have to be applied after each irrigation. (4) Irrigation practices during the harvest season limit the use of ground pesticide application equipment. (5) The type and quantity of insecticide which can be applied close to or during harvest is restricted by the Food and Drug Administration regulations. As a result, many effective insecticides cannot be used within the "interval from last application to harvest" as published in the USDA Pesticide Summary.

The investigations reported in this thesis were designed to clarify certain aspects of the biology and control of the strawberry sap beetle with respect to the production of strawberries in Michigan. These investigations included studies of: (1) the life cycle, (2) the fecundity and longevity, (3) the host range, (4) the site and stage of overwintering, and (5) a method for control of the insect.

LITERATURE REVIEW

Very few papers have been published with direct reference to Stelidota geminata; consequently, much of this review will be devoted to the genus Stelidota and related genera.

Parsons (1943) stated that the genus Stelidota is comprised of approximately 40 species and is generally distributed throughout the world with the exception of continental Africa. Although considered a tropical genus the three North American species, S. strigosa, S. geminata and S. octomaculata, seem to have a neotropical origin (Parsons 1943).

Parsons characterized Stelidota geminata as follows:

Nitidula geminata Say, 1825, Journ. Acad. Philad., 5, 181.

> Oval, narrower posteriorly, moderately shining, sparsely punctate, testaceous to rufo-piceous, elytra with indistinct pale spots. Head coarsely, densely, shallowly punctate. Prothorax twice as wide as long, narrower in front, apex deeply emarginate, base bisinuate, sides regularly arcuate from base to apex, margin broad, deplanate, hind angles rectangular, disc moderately convex, surface coarsely, densely punctate. Elytra slightly broader than the pronotum. Each elytron with 9 costae each of which has a row of fine punctures, each puncture bearing a short pale hair. Between the costae are rows of large, shallow punctures. Beneath moderately densely, coarsely punctate. In the male the middle and posterior tibiae distinctly arcuate, the former suddenly dilated in its distal half, the latter in the distal third. Length 2-3 mm.
>
> This species occurs (Feb. 20-Oct. 23) chiefly in the spring from Massachusetts (Tyngsboro, Springfield) to Florida (Capron, Haulover, Edgewater, Miami, Paradise Key), west to Iowa (Mt. Pleasant), Missouri (St. Louis) and Texas (Columbus), south through Middle America to Colombia and Brazil.

Hosts from which S. geminata have been reported are summarized in Table 1. The majority of reported hosts indicate a preference for overripe or decomposing fruit.

Nitidulid beetles are primarily saprophytic and are not considered to be economically important. The genus Carpophilus, however, does have several species which are considered economic pests. Species of this genus invade corn, dates, pineapples and stored products (Connell 1956). Schmidt (1935) reported that of 6 species of nitidulids found in Hawaiian pineapple fields, C. humeralis (F.) and C. hemipterus (L.) were the most important. He stated that none of the species were capable of inflicting primary injury or of transmitting disease. Their primary economic importance was as a nuisance in canneries where they had to be prevented from getting into the cans. Both species had a high reproductive potential and a short immature period as compared to length of life of the adult. However, the numbers of C. hemipterus and humeralis adults present in the pineapple fields were a result of migration in response to the odors from decaying and freshly cut pineapple and not their reproductive potential (Schmidt 1935).

Lindgren and Vincent (1953) reported that 4 species of beetles, Carpophilus dimidatus (F.), C. hemipteries (L.), Urophorus humeralis (F.), and Haptoncus luteolus (Er.), infest dates in California. Adult beetles were primarily attracted to fermenting dates on the soil; these dates resulted from "June drop". Reproduction occurred at these sites and the adults later infested dates on the trees, being particularly attracted to any that were rotten. Fumigation of the dates

TABLE 1.--Reported hosts of Stelidota geminata

Stage	Host material	Time observed	Relative occurrence	Location	Reference
Adult	Tree sap	spring	frequent	throughout Indiana	Blatchley (1910)
	Beneath leaves	spring	frequent	"	"
	Decaying fruit & melons	autumn	frequent	"	"
	Rotten citrus fruit	year round	common	Florida	Vogt (1950-51)
	Oak sap flows	May-July September	common	Maryland	"
	Overripe strawberries, fermenting apples, rotten watermelon		common	Maryland	"
	Acer sp., flowers on ground	May 16	occasional	Maryland	Connell (1956)
	Apple, fallen fruit	July 21-Oct. 8	abundant	"	"
	Quercus sp., weevil-infested acorns	May 18	occasional	"	"
	Corn-ear refuse in soil	June 3-July 18	common	"	"
	Fermenting molasses	May 14-June 6	common	"	"
	Fungus, Polyporus sp.	July 16	rare	"	"
	Hibiscus sp., flowers	Aug. 17	occasional	"	"
	Podophyllum peltatum fruit	Aug. 11	common	"	"
	Maclura pomifera, fallen fruit	Sept. 25-Oct. 9	common	"	"

	Peach, fallen fruit	July 26-Aug. 17	abundant	"	"
	Strawberry (Fragaria sp.), ripe fruit	May 25-June 20	common	"	"
	Strawberry, rotting fruit	May 25-June 20	abundant	"	"
	Rotting melons	April 14-Sept. 21	abundant	"	"
	Grape (Vitis sp.), ripe fruit	Sept. 14	abundant	"	"
	Quercus sp., sap flow	June 9-Sept. 21	rare	"	"
	Quercus sp., oak stump, under chips	June 5	occasional	"	"
	Pea, under lodged vines	June 29	common	"	"
	Vaccinium sp., flowers	May 2	rare	"	"
Larvae	Apple (Pyrus malus), fallen fruit	Aug. 14-Sept. 25	common	"	"
	Peach (Prunus persica), fallen fruit	Aug. 14-Aug. 29	common	"	"
	Podphyllum peltatum, fruit	Aug. 14-Aug. 29	common	"	"
	Rotting melon	Aug. 8	occasional	"	"

prior to processing at the packing house was the primary means of control, but applications of a 5% malathion dust to the trees 1-6 weeks before harvest, greatly reduced adult beetle populations.

Connell (1956) in his comprehensive publication of the biology, taxonomy and control of *Carpophilus* species also included host materials where *S. geminata* adults and larvae were collected. He stated that *Carpophilus lugubris* Murr. was a primary pest of corn and was of particular concern to the sweet corn industry. He also reported that chemical control of adults was effective but costly.

Dorsey and Leach (1956) reported that *S. geminata* and *Glischrochilus fasciatus* (Oliver) were important vectors of oak wilt. This was the only reference to *S. geminata* as a economic pest.

METHODS AND MATERIALS

Collection of Adults

Projected laboratory investigation required large numbers of adult beetles. Approximately 1,000 beetles were collected from the cherry orchard and the muskmelon and tomato cull piles on the Dominion farm, Berrien Co. in August, 1966. Beetles were collected by transferring infested fruit to a 1-pint Plasti-Kan container. After the beetles left the fruit, the fruit was discarded and the same procedure was repeated until the desired number of beetles was collected. Wet paper towels were placed in each container to prevent desiccation in transit to the laboratory.

Culturing and Rearing Techniques

A modification of the technique reported by Connell (1956) was used in rearing and culturing adult beetles and larvae. Two-quart, wide mouth Kraft citrus jars one half filled with moist wood shavings were used to rear adult beetles. Moist sand was used in place of the wood shavings for larval and pupal studies. To provide ventilation and avoid desiccation, a problem experienced by Connell, 2 three-quarter inch holes were bored into each cover and the holes covered with 32-mesh Saran screen.

Several food sources, including apples, cherries, dried peaches and dried apricots, were investigated for suitability in rearing adults and larvae. Dried peaches and apricots moistened with water for several hours were the most satisfactory media tested. Dried peaches, which were less expensive than apricots, were used as the primary food source. One half of a moistened peach was placed on a 3X3 inch Saran screen in each adult culture jar, the screen was employed to prevent adherence of the shavings to the food. The food was exchanged weekly to transfer the larvae before pupation started and to prevent excessive wetting of the wood shavings. Each rearing jar contained approximately 300 adult beetles.

Several hundred larvae in different stages of development were observed on peaches after 1 week. Infested peaches were transferred to jars one half filled with sand, which simulated natural conditions for pupal development. Only 1 layer of fruit was placed on the sand because several layers of fruit retarded drying and caused excessive moisture in the sand.

Adult emergence was observed 10-12 days after the day of transfer and continued for approximately 1 week. To lure the adults from beneath the fruit and from the soil tunnels, an attractant trap, consisting of a moistened peach in a 1 pint Plasti-Kan, was used. The newly emerged beetles were then transferred to adult culture jars. When emergence terminated, the decayed remnants of the peaches were discarded and the jars were used for the next brood.

The culture jars were placed on a table in the laboratory where the temperature ranged from 60-80°F. and the relative humidity from 25-70%.

Life Cycle Study Techniques

Lindgren and Vincent (1953) reported that oviposition was obtained on moist strips of green blotting paper in petri dishes for *C. dimidatus*, *C. hemipterus*, *U. numeralis*, and *H. luteolus*. Eggs were transferred to petri dishes containing dates and moist sand to observe further development. Connell (1956) employed 2-quart battery jars one half filled with sand to investigate the life history, fecundity and longevity of *Carpophilus* sp.

Small baby food jars with 2 one-quarter inch holes bored in the top and covered with Saran screen were very satisfactory for the laboratory investigations of life cycle, fecundity and longevity of *S. geminata*.

In the life cycle study each egg was observed through the larval and pupal stages. Eggs were obtained by placing 50 beetles in a rearing jar with moist filter paper and a section of peach. The filter paper was observed 2-3 times daily for eggs. Eggs were separated by cutting the filter paper around each egg with a pair of scissors and were transferred to a jar containing moistened filter paper and a small portion of peach. Observations and records on developmental progress were made 2-3 times daily.

To determine the length of the stadia, head capsule measurements were made with an ocular micrometer in a binocular stereo microscope. The larvae were observed directly in their jars, hence disturbance was kept at a minimum. After the second molt, one-quarter inch of sand was added to each jar as a medium for pupation.

After the pupal cell was constructed in the soil, the top layer of soil was carefully picked away to allow observation of the pupa. Following observation the opening was covered with a small section of moist filter paper.

Fecundity and Longevity

Considerable difficulty was experienced in separating adult beetles on morphological characteristics without injuring the specimen. To determine the fecundity and longevity of S. geminata, 15 newly-emerged adults were placed in a rearing jar for an 8-10 day mating period. When the first eggs were observed, each adult was placed in a separate jar and egg counts were recorded daily. Jars in which eggs were observed were labeled, tabulated, and set aside. After 10 days, beetles in jars which contained no eggs were classified as males and put in with the females to make 5 pair.

Fecundity was determined by transferring the adults to a new culture jar every 3 days to circumvent egg hatch because larvae are more difficult to count than eggs. After transfer, the filter paper and bottom of the original jar were observed for eggs and the results recorded.

Longevity studies were conducted using the same beetles as observed for fecundity.

Overwintering Site Studies

Insect control is predicated on a thorough knowledge of the life cycle. Included in the life cycle is the stage that overwinters and the overwintering site. Several studies were made to determine these facts.

Random soil samples were collected in October 1966 to ascertain the presence of S. *geminata* in the Dominion strawberry plot and adjacent pear orchard. Each sample consisted of 1 spadeful of soil taken to a depth of 8 inches. Twelve samples were obtained from beneath the dry remains of strawberry clusters, and 10 samples were collected from beneath pears. The soil samples were sifted through a coarse sieve in the laboratory to reveal the various stages of the insect.

On October 8, 1966, adults and larvae were placed in containers in the strawberry plot to determine the stage or stages that overwinter. The containers were 1 quart Plasti-Kan cartons three fourths filled with sand. A 1 inch layer of straw and one half of an apple were placed on the sand. Drainage holes were punched in the bottom of each carton. Adults and larvae were placed in containers as follows: Two cartons with 25 newly-emerged adults from laboratory cultures; 1 carton with 25 adults freshly-collected from beneath pears; 2 cartons of 25 adults 2 months or more in age from laboratory cultures; 1 carton with larvae collected from the field; and 2 cartons with approximately 50 larvae each from laboratory cultures. It was anticipated that a portion of the larvae would mature and pupate in the soil and could be used in the study. The cartons were covered with nylon cloth and sunk in the soil so that the tops of the cartons were even with the surface of the ground. On March 28, 1967, the containers were removed from the soil and taken to the laboratory where the sand was sifted, the trash sorted and the life stages data recorded.

In laboratory and field tests, discussed in the control section, several bait mixtures and compounds were found to have attractant properties for adult beetles. Effective attractant baits and traps were set out on April 12, 1967 in the vicinity of woodlots, pear orchards, peach orchards and strawberry plantings located on the Dominion, St. John and Swisher farms to determine the overwintering sites of the adult beetles. Attractants used were moist-bran, Duplicolor DP-GM3 auto paint primer, mixtures of bran and grape juice, bran plus 50% raw molasses and liquid molasses plus yeast.

Bran baits were prepared by wetting the bran with liquid until saturated and adding azinphosmethyl (25% WP) to make a 1% active azinphosmethyl mixture. The containers for the bran baits were 8 inch square boxes constructed of 1X2 inch boards, with a bottom of fine mesh screen and a removable top of coarse mesh screen. The containers were placed on the soil and partially covered with leaves to reduce the loss of water.

The raw molasses liquid bait was prepared by combining 1 part by volume raw molasses with 1 part water and yeast suspension (1 package of dry yeast in 1 gal of water). Sufficient azinphosmethyl (25% WP) was included to make a 1% active azinphosmethyl suspension. One eighth of a pint of this mixture was put into a 1 pint Plasti-Kan. A 2 inch hole was cut in the cover and the container was placed on the ground at a 45^{o} angle. Liquid molasses traps were exchanged every 2 weeks.

Paint primer attractant lures were prepared by filling 35 mm film cans with paint primer and attaching the screw cap cover. Each cover had 2 one-quarter inch holes. A 3 inch length of one-quarter inch cord was inserted into one of the holes to serve as a wick. The cans were fastened 3 ft above the ground on a yellow card that was attached to a wooden stake. Both sides of the yellow card were covered with Tanglefoot. The paint was replenished every 5 days.

Bait station performance records were taken at 2 week intervals, during the spring migration period.

Migration Study Methods

Fermenting molasses bait stations, as previously described, were employed to determine the dates of migration for *S. geminata*. The specific location for each trap in the study area is given in Table 6. The liquid traps were replaced on a weekly schedule during May and biweekly during June, at which time insect counts were made for each station.

DESCRIPTION OF STAGES

The Egg

Eggs of S. geminata are milky-white in color and average 0.71 mm in length by 0.27 mm in width. They are elongate and cylindrical in shape with rounded ends. The surface of the egg is smooth and is covered with a moist, adhesive substance. Eggs may be deposited singly or in clusters of 2-15. See Plate I.

The Larva

The mesothorax, metathorax and the 10 abdominal segments of the larva are white. The tergum of the prothorax is gray and the head is light tan with brown mandibles. The body is translucent with the gut appearing as a dark longitudinal band. There are 3 instars. The average head capsule width and body length of each instar are given in Table 2.

TABLE 2.--The average head capsule width and body length of the larval instars of Stelidota geminata

Instar	Head capsule width	Body length
First	0.30 mm	1.0 mm
Second	0.48	3.0
Third	0.60	4.5

Boving and Rozen (1962) described the distinquishing characteristics for the mature larvae of S. geminata as follows: The mandibles are not markedly swollen at the base, the apex is bidentate and only dorsal subapical teeth are present. Lateral spiracular tubes with spiracles situated at the apex extend from the abdominal segments. The length of the spiracular tubes on the 8th segment is approximately equal to their base diameter. Urogomphi are prominent and rise above the 9th abdominal tergum. They are curved upward, sharp pointed, apically simple and lack ventral accessory spines. The pregomphi rise sharply from the 9th abdominal tergum and are moderately long, their length being more than one-third that of the urogomphi. See Plate II.

The Pupa

Pupae of S. geminata average 2.2 mm in length. At first the pupae are white but become light-brown in the later stages of development. They are of the exarate type and are not covered by a shell. Transformation occurs within pupal cells formed at depths of 1-4 inches in the soil. See Plate III.

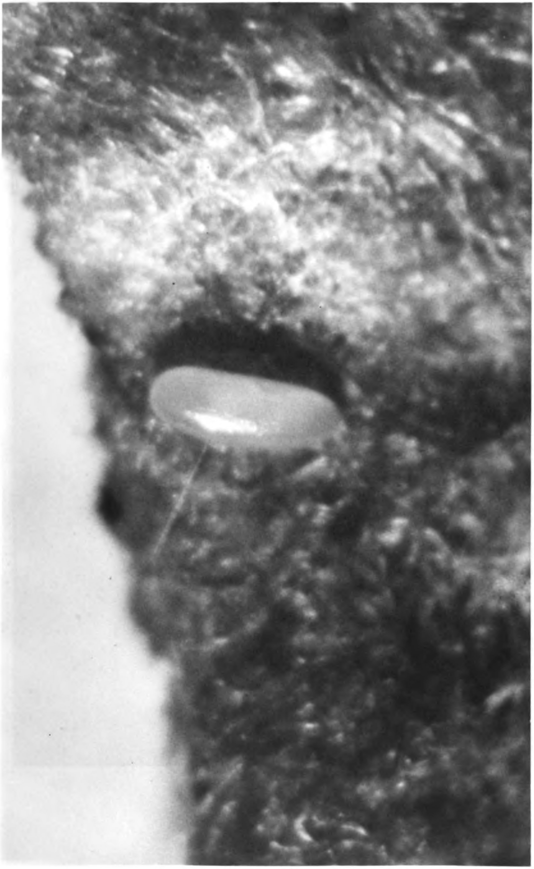


Plate I.--Egg of _Stelidota geminata._

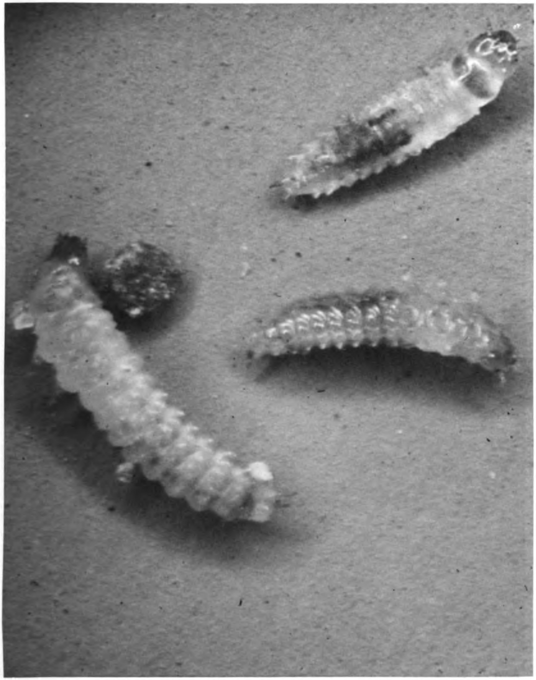


Plate II.--Larvae of *Stelidota geminata*.

Plate III.--Pupae of *Stelidota geminata.*

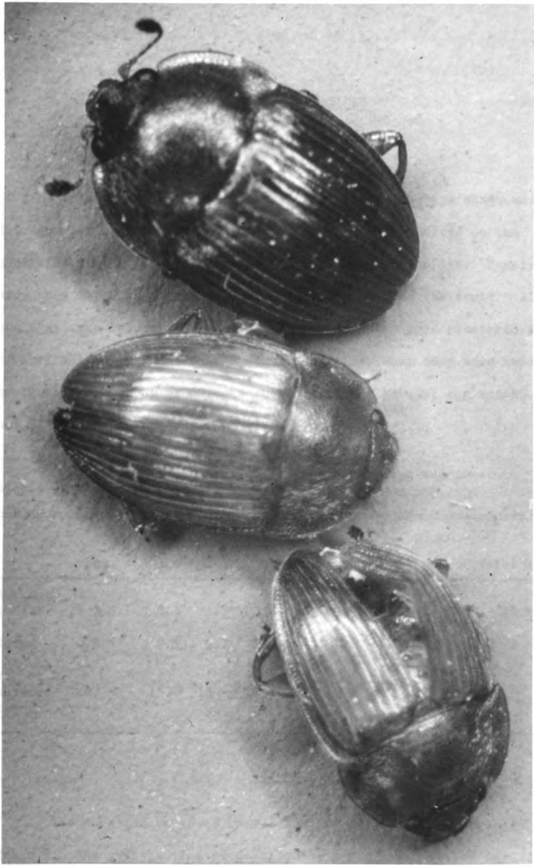


Plate IV.--Adults of *Stelidota geminata*.

LIFE HISTORY OBSERVATIONS

Egg

As shown in Table 3, the average length of the egg stage was 2.5 days for 27 eggs. The majority of eggs were deposited on the underside of the filter paper and on the bottom of the jar. Rarely were they found on the lid and none were observed on the fruit. All the eggs were laid on their sides and the majority were clustered in rows of 3-15. Egg desiccation occurred rapidly when they were exposed to the air. A study of 50 eggs showed that the percent egg hatch was 93% under humid conditions.

TABLE 3.--The duration in days of the egg and immature stages of *Stelidota geminata* at 75°F

		Instar					
	Egg	1	2	3	Prepupal	Pupal	Total time
Average length	2.5	2.3	1.3	3.6	3.1	6.3	19.1
Range	0.4	0.9	0.7	2.1	1.9	2.5	8.5
No. of observations	27	15	13	12	12	11	

Larvae

The duration of the 3 larval instars at 75°F is shown in Table 3. The average time of development for the 1st-instar was 2.3

days for 15 larvae. The duration of the 2nd-instar was the shortest, averaging 1.3 days for 13 larvae. The 3rd-instar had the longest time of development with an average of 3.6 days for 12 larvae. The 3rd-instar larvae, upon reaching maturity, were observed to wander about the jar for approximately 12 hr all the while exhibiting a curious searching behavior. Connell (1956) also reported this phenomenon for *Carpophilus lugubris*. After the searching period, the larvae burrowed into the soil and constructed a cell for pupation.

In laboratory studies the larvae preferred to feed on the bottom and in the interior of the peach rather than on the top. All of the instars fed voraciously until just before the molting period, then they became quiescent.

In the field, larvae were observed to feed within overripe and decayed strawberries. Large numbers also were observed under the berries in the juice-soaked trash and soil. In addition, larvae were observed in other host crops (Table 4).

Prepupa

The prepupal stage has morphological characteristics similar to the larva with the exceptions that the body color is milky-white, not translucent, and is more cylindrical. Initiation of this period started when the 3rd instar ceased feeding and wandered about the jar. The criterion used for termination of the period was the appearance of transformation to the adult. As shown in Table 3 the mean number of days for 12 prepupae was 3.1.

Pupa

The length of the pupal period, as indicated in Table 3, was found to average 6.3 days for 11 pupae. Pupation usually occurred in the soil at depths of 1-4 inches; however, it also was observed on top of the soil under moist trash and to depths of 7 inches in loose soil. The majority of pupae were found within a 12 inch radius of the cluster on which the larvae were feeding, indicating a restricted dispersal range for the mature larva.

Adult

Newly-emerged adults are light brown and 2.5 mm in length. Sexes are not readily distinguishable on the basis of morphological characteristics. Mating occurs soon after emergence but a preoviposition period of from 8 to 10 days is required before eggs are laid. Mating is apparently required for continuous oviposition because females that were isolated from males stopped laying eggs after several days. These observations support those of Connell (1956) who reported that mating was frequent and apparently necessary to initiate and sustain oviposition in *C. humeralis*. Adults are shown in Plate IV.

The fecundity study, based on observations of 5 females, showed the average total number of eggs laid per female to be 437, with a range of 239. The maximum oviposition period was 125 days with an average of 101 days. The average number of eggs deposited per day was 4.3; the maximum was 16 eggs per day. The average lifespan of 10 adults was 127 days with a range of 147 days. The oviposition period was found to last through most of the adult life.

Adult Feeding Habits

Stelidota geminata adults were observed to be strongly attracted to overripe and partially decayed strawberries. They prefer to feed on berries that touch or are in contact with the ground. However, when this food supply is depleted they will feed on berries that do not make contact with the soil. After flying to new food sources and alighting on the berry, they immediately move to the underside of the fruit and commence feeding by chewing into the soft flesh. The typical feeding tunnels made in the fruit are shown on Plate V. Each injured berry may contain from 1 to 50 beetles. The number and size of the holes and feeding tunnels is determined by the number of beetles present in the fruit.

The adults will leave infested berries to crawl under the moist trash where they construct tunnels in the soil. When infested fruits are disturbed the beetles will disappear into the soil tunnels. Beetles with no chance of escape will remain motionless and feign death.

Host Plants

After feeding on strawberries, the beetles feed on a succession of ripening fruits. The host plants, as determined by observations of infested fruit, are summarized in Table 4. *Stelidota geminata* was found in approximately 50% of the overripe and decayed tart

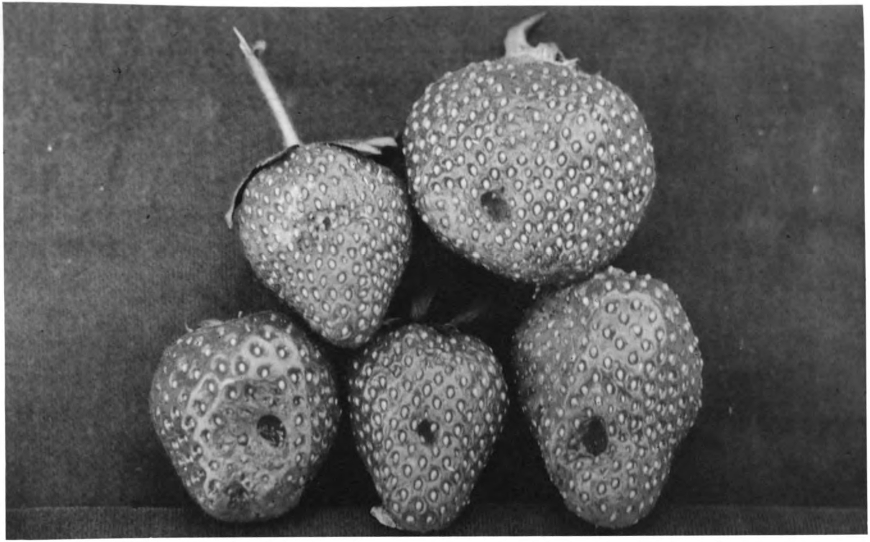


Plate V.--Damage to strawberries caused by the feeding of Stelidota geminata adults.

TABLE 4.--The host plants of <u>Stelidota geminata</u> in Berrien Co. Mich., 1966 and 1967

Decaying fruit	Stages present	Date observed	Relative occurrence
Sour & sweet cherry	adult	July 25-Aug. 9, 1966	abundant
	larva	" "	occasional
	pupa	Aug. 9	occasional
Dewberry	adult	July 26	common
Tomatoes in field	adult	Aug. 1-Aug. 9	occasional
Tomatoes in cull piles	adult	Aug. 9-Aug. 18	abundant
Muskmelon	adult	Aug. 18-Aug. 29	abundant
Peach	adult	Aug. 29-Sept. 30	common
	larva	Aug. 29-Sept. 13	common
	pupa	Aug. 29-Sept. 23	occasional
Pear	adult	Aug. 29-Oct. 31	common
	larva	Aug. 29-Sept. 30	common
Apple	adult	June 5-June 30, 1967	abundant
Strawberry	adult	June 5-July 15	abundant
	larva	June 12-July 15	abundant
	pupa	June 20-Aug. 1	abundant

cherries on the ground in the Dominion orchard on July 25, 1966. Beetles were not observed on the fruit in the trees. All stages of the insect were found, but the immature stages were not as abundant as they were in the strawberries. Adults and immature stages were still present on August 9.

On the same date adults, but not larvae, were observed on fallen dewberries. Beetles were not observed in adjacent raspberry or blackberry plantings.

A survey of the tomato fields on the Dominion farm made on August 1, 1966 revealed the presence of adults in tomatoes which had cracked. Five to seven beetles per tomato were found in 25% of the tomatoes in the cull piles. By August 9, the infestation was reduced to 5% of the rotten tomatoes. Although tomato harvesting had been in progress for 2 weeks, only adults could be found in the cull piles, usually restricted to feeding in tomatoes on the perimeter of the piles. By August 18, only a few beetles were found in tomato fields or cull piles.

Beetles, but no larvae, were observed infesting melons in the field and in cull piles but the population remained small during the survey period (August 19, August 29, and September 13).

Peach and pear orchards surrounding the study area were surveyed during August, September and October for the presence of life stages of _S. geminata_. The results are summarized by date:

August 19.

Adults and larvae were abundant on fallen peaches.

Adults and larvae were abundant on pears which had fallen prematurely during pruning for fireblight control.

September 23.

No adults or larvae found in peaches. A few pupae were found in the soil under rotten peaches.

An average of 2-3 adults were found per pear. Larvae were common in fallen fruit.

September 30.

Newly-emerged adults were found under approximately 10% of the peaches.

No adults were observed in the pears.

October 12.

An average of 2 adults per pear, based on a 10-pear sample.

October 31.

One adult found on 34 randomly sampled fruits.

The host range of *S. geminata*, as reported by other workers, is summarized in Table 1.

Reproduction was not observed under field conditions in muskmelon and tomato. Laboratory experiments were designed to test the suitability of tomato, muskmelon, pear and apple as media for the production of larvae. Numerous larvae were produced in tomato, pear, peach and muskmelon; apple produced the fewest larvae. Although larvae were produced on food hosts in the laboratory, field observations indicate that tomato and muskmelons may not be preferred hosts for increasing beetle populations.

Overwintering

Soil samples taken in the fall from strawberry plantings with large spring populations failed to produce any significant numbers of overwintering life stages. One sample, adjacent to the pear orchard, contained 2 adults.

Cartons, which contained various life stages placed in the soil on October 8, 1966 were examined on March 28 for insect survival. None of the larvae survived; furthermore, no pupae were found in the sand in cartons which originally contained larvae. Live adults were found in 3 of the 5 cartons containing adults. Both newly-emerged adults and field-collected adults survived. In each case, the beetles were observed on the surface of the soil under the trash. Further laboratory culture of 5 overwintering adults showed that they were able to produce eggs.

The data from the attractant traps are shown in Table 5. In Investigation 1 initiated April 12, adults were trapped only in the woodlots and only in the fermenting molasses traps. An explanation for the low number of beetles collected can be deduced from the low mean daily temperature of 50°F during the test period. Stelidota geminata adults did not show migratory activity until the temperature reached 60-65°F. Large numbers of picnic beetles, Glischrochilus sp. were collected in the bran molasses and grape juice mixtures in all habitats.

TABLE 5.--The average number of Stelidota geminata adults collected per attractant trap. Berrien Co., Mich., 1967.

Material	Location					
	Dominion woodlot	St. John woodlot	Swisher woodlot	Strawberry plot	Dominion pear orch.	St. John peach orch.
			Investigation # 1 April 12-May 3			
Moist bran	--	0	--	0	0	0
Bran & grape juice	--	0	--	0	0	0
Bran & molasses	--	0.3	--	0	0	0
Liquid molasses & yeast	10	12	--	0	0	0
Paint primer elevated 3 ft	0	0	0	0	0	0
			Investigation # 2 May 3-May 18			
Liquid molasses + yeast	27	46	26	0.7	0	0
Paint primer elevated 3 ft	0	0	0	0	0	0

Since difficulty was encountered in separating the adults from the bran baits the results are not summarized for Investigation 2. As indicated in Table 5, under Investigation 2, 26-46 adults were collected in the fermenting molasses traps placed in the woodlots. Traps placed in the fruit plantings were essentially negative. Beetles were not attracted to the paint primer card traps.

To verify the identification as S. geminata, 10 specimens were forwarded to Dr. Melville H. Hatch of the University of Washington who confirmed the identification.

Migration

Data obtained to determine date of first migration, peak of migration, duration of migration, and distance of migration in relation to these factors are summarized in Table 6. The first adult emergence, as recorded by trap captures, occurred during May 19-24. Activity was highest in the overwintering woodlot sites. Migration increased gradually, and reached a peak during June 14-19 (Fig. 1). The population remained at relatively high levels in the woodlots throughout the remainder of the study period (Fig. 2). Beetles exhibit little activity below 60°F but show increased response to rising temperatures.

Adult captures in traps placed 80 ft from the overwintering sites occurred approximately 6-10 days earlier than traps placed 600-800 ft away from the woodlots. This would indicate that adult beetles do not fly great distances in one flight, but rather move in

TABLE 6.--The migration of *Stelidota geminata* adults to fermenting molasses, ground traps. Berrien Co., 1967

Location	No. of traps	Number collected during specified period									
		May 19-24	May 24-31	May31 June6	June 6-10	June 10-14	June 14-19	June 19-22	June 22-26	June 26-30	June30-July 7
St. John cherry orchard	1	0	0	2	51	118	300	73	70	61	95
80 ft N. of woodlot	2	0	0	10	110	125	315	130	50	55	77
Dominion pear orchard	1	0	3	3	50	102	24[a]	50	29	43	127
80 ft S. of woodlot	2	1	7	10	85	75	35[a]	60	30	26	76
Swisher apple orchard	1	0	0	1	26	99	159	171	61	40	135
80 ft W. of woodlot	2	0	0	2	35	--[b]	141	230	65	160	--[b]
St. John peach orchard 800 ft N. of woodlot	1	0	0	0	2	27	120	3	15	50	--[b]
Dominion pear orchard	1	--[c]	0	3	23	33	13	5	8	25	37
600 ft S. of woodlot	2	--[c]	--[c]	--[c]	40	124	25	37	11	7	31
Dominion woodlot	1	6	41	95	200	320	160	210	123	125	170
St. John woodlot	1	11	26	100	70	201	125	30	90	95	150
Swisher woodlot	1	--[c]	--[c]	--[b]	100	370	150	--[b]	38	105	--[b]
Mean temperature[d]		55°	61°	66°	76°	76°	71°	68°	65°	68°	65°

[a]Grover placed other traps near these.

[b]Destroyed in the field, presumably by animals.

[c]Not included in the initial phase of this study.

[d]Average of mean daily temperatures (°F) of period.

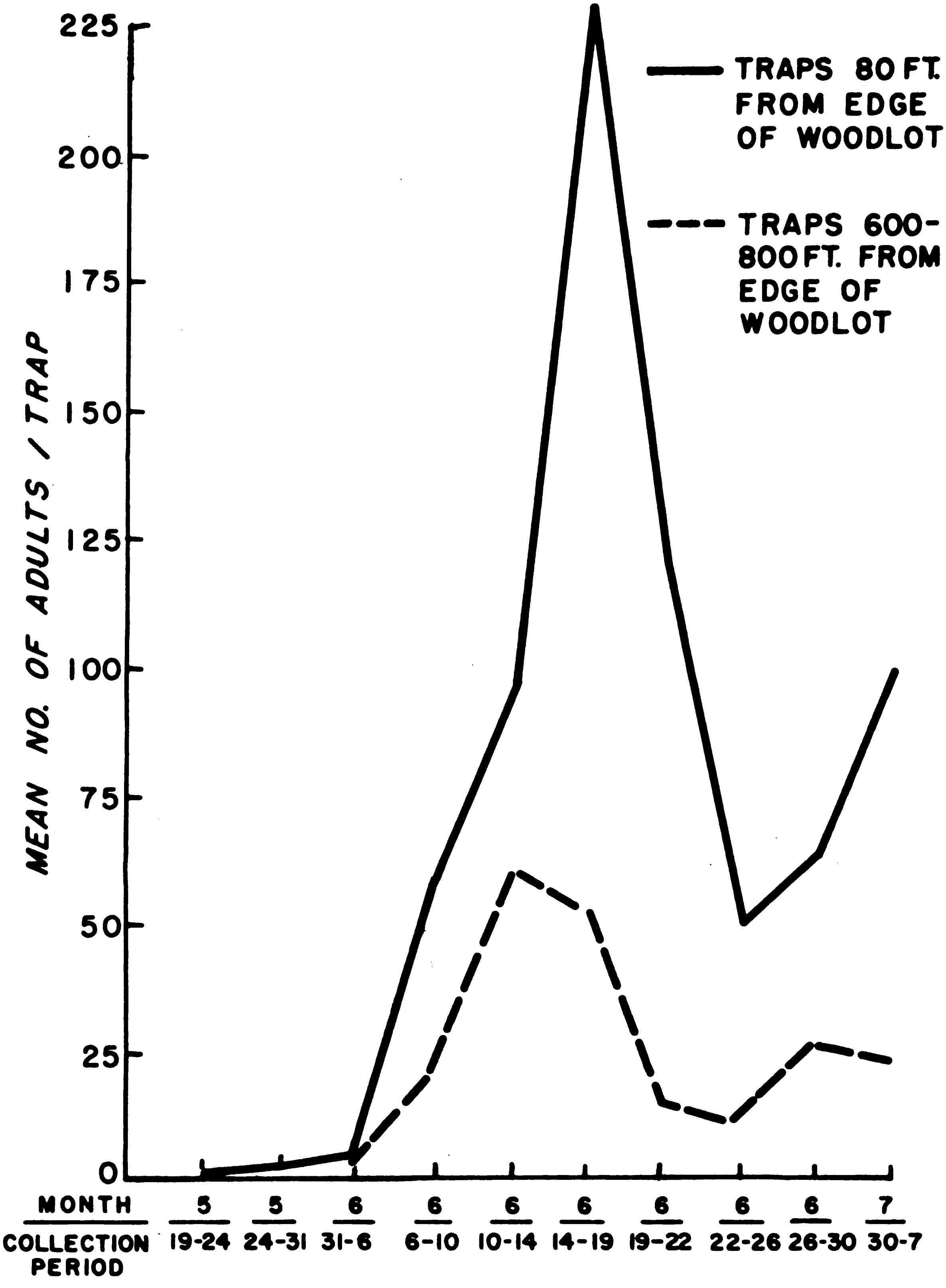


Figure 1. Migration of Stelidota geminata adults to fermenting molasses ground traps. Berrien Co. Mich., 1967.

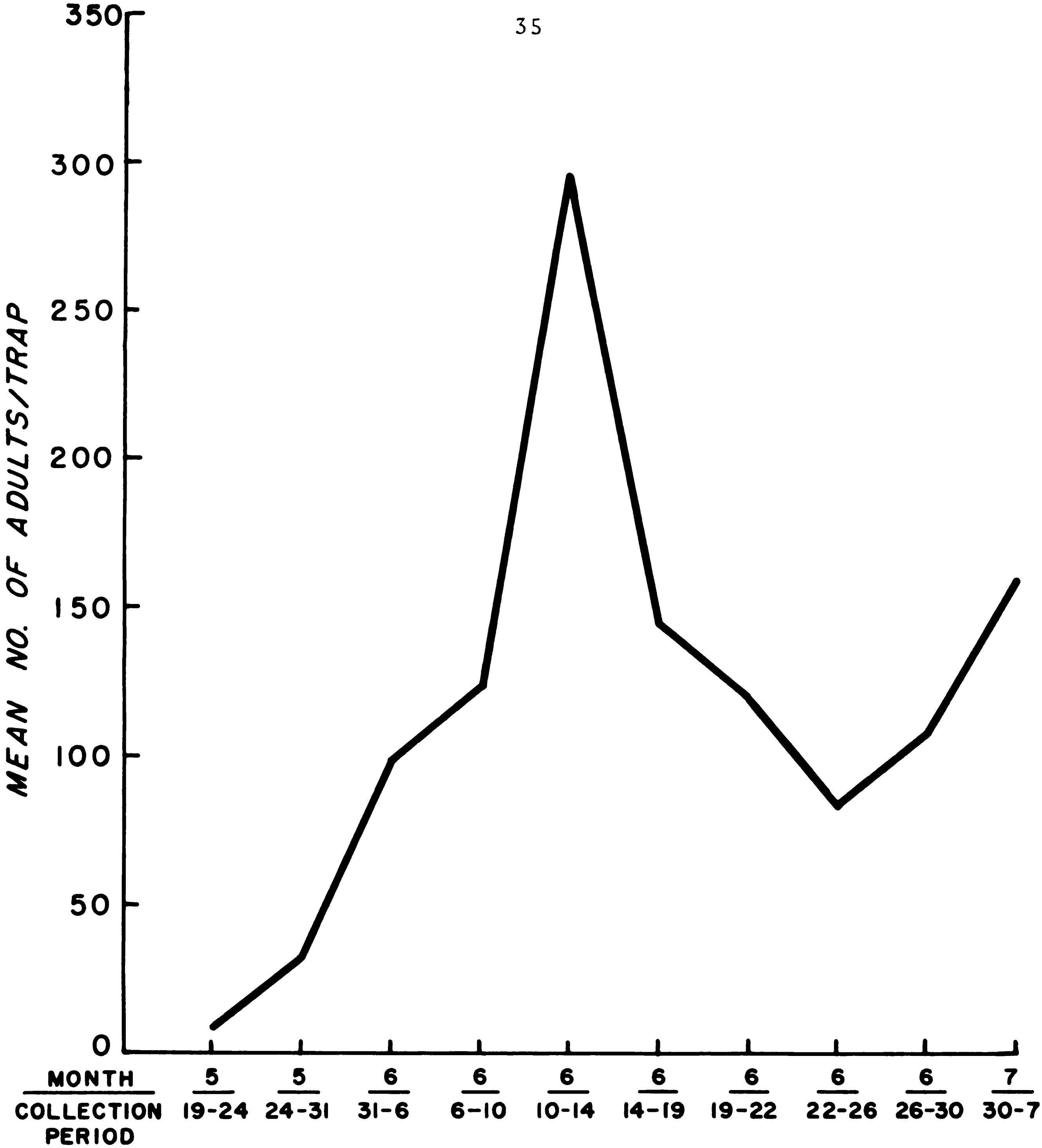


Figure 2. The mean number of adults collected in fermenting molasses ground traps in 3 wood lots. Berrien Co. Mich., 1967.

a series of short flights. Wind direction influenced the numbers of beetles collected in traps located outside the woodlots. Greater numbers were trapped when the wind carried the odors of the fermenting molasses into the woodlots.

DISCUSSION OF BIOLOGY

The biological investigations of *S. geminata* provide information as to the reasons for the high infestations of beetles and larvae which occurred in southwestern Michigan strawberry plantings during June 1966.

Results of the overwintering study (Table 5) show that the beetles do not overwinter in the fruit plantings as originally suspected. Instead they hibernate in the woodlots and bordering thickets, which are usually close to the strawberry plantings. Thus, within a short period of time, under optimum temperature conditions, a large number of adults can migrate into strawberry plantings and infest fruit.

The adult beetle is the primary stage for overwintering. In the overwintering study mortality was high in the containers placed in the strawberry plot, but this was probably due to the severity of conditions in the open field which would not exist under the woodlot duff.

The initiation of migration and the extent of migratory activity are related to temperature. Maximum daily temperatures of 85-95°F (70-75°F mean temperature) are optimum for migration. These temperatures also accelerate ripening and the production of volatile compounds--factors which attract beetles into the plantings. The combination of overripe berries and optimum migratory temperature appear to be the major factors in determining the extent of infestation.

Temperatures during the strawberry harvest in June 1966 were above normal. In addition, pickers were unable to keep pace with the rapid ripening of berries, resulting in overripe, fermenting berries which accumulated in the plantings and lured the beetles from the woodlots.

Experimental results demonstrate that migration is continuous throughout the strawberry harvest. With the population remaining within the woodlots, the possibility of migration and infestation is continually present during harvest.

The time required for a complete laboratory generation was 19 days at 75°F. However, the rate of development in the field would probably be accelerated due to higher air temperatures and the effects of radiation on the temperature of the microclimate of the beetles. Several generations are possible in one growing season since no diapause was observed in the life history.

The above data, in conjunction with the fecundity findings which demonstrated that 5 females could lay 150 eggs per week, further elucidate the reason for the wide spread larval contamination in strawberry fruit which caused cessation of harvest on June 22, 1966.

Stelidota geminata feeds on the majority of fruit crops grown in Berrien County. However, feeding is restricted to fruit in direct contact with the soil. The only host crops other than strawberries that would appear to be endangered are muskmelons and tomatoes. As stated previously beetles were found only on decaying melons and decaying or split tomatoes. It is conceivable, however, that a problem could develop in field-ripened processing tomatoes if temperatures remained above normal.

CONTROL EXPERIMENTS AND RESULTS

MATERIALS AND METHODS

The field tests of this study were conducted in three locations in Berrien County which were selected because of their central location within the strawberry plantings of southwestern Michigan. The Dominion farm is located 1 mile south of Napier Ave. on Morgan Rd. The St. John farm adjoins the Dominion farm on the east boundary. The Swisher farm is located on highway M-140, 1 mile north of the junction of M-62 and M-140.

The Dominion strawberry plot was 400X100 ft. It was subdivided into 64 blocks, 25X25 ft in size. The infestation was observed to be unevenly distributed within the experimental area. The paired block experimental design was selected for all field tests and subsequent statistical analyses.

CHEMICAL CONTROL

1966 Field Evaluations

The failure of the growers to control *S. geminata* with conventional air-blast sprayers and materials such as azinphosmethyl, carbaryl and endosulfan during the 1966 strawberry season prompted an investigation of the suitability of controlling the beetle with high rates of spray/acre.

Based on preliminary bioassay studies, malathion and azinphosmethyl were selected as candidate insecticides. Because the tests were conducted after the normal strawberry harvest, berries grown in northern Michigan were placed in the strawberry rows. Sprays were applied with a Hudson knapsack sprayer at a rate of 400 gal dilute spray/acre. High gallonages were used so as to completely cover the foliage, fruit, and trash, and thereby test the efficacy of the insecticides and not the application method. Malathion was used at a rate of 4 lb active ingredient per acre; azinphosmethyl at the rate of 2 lb active ingredient per acre. Treatments were replicated 3 times, each replicate consisting of 1 row 13 ft long with 10 berries spaced 1 ft apart in the row. Paired checks were used in adjacent rows. Evaluations were made 1 and 2 days after treatment.

Malathion and azinphosmethyl (Table 7) were completely ineffective 2 days after treatment even though application was made at twice the recommended rate/acre. However, the materials were tested under extremely high population pressures of 50-200 beetles per berry.

TABLE 7.--The effect of foliar applied toxicants for the control of Stelidota geminata adults. Berrien Co., 1966

Compound and formulation	Lb active/acre	% damage at specified days after treatment[a]	
		1	2
Malathion, 25% WP	4.0	33	96
Azinphosmethyl, 25% WP	2.0	17	96
Control		80	100

[a]Treated: July 31, 1966. Evaluated: July 31, August 1, 1966.

1966 Laboratory Experiments

There is no published literature pertaining to the effectiveness of pesticides for controlling *S. geminata*; consequently, bioassay techniques had to be developed to screen insecticides for subsequent field testing.

Bioassays were conducted by dipping strawberries in insecticide suspensions, allowing them to dry for 30 minutes and then placing 1 berry in a 1 pint Plasti-Kan. Ten beetles were starved for 24 hr and placed in each container. A container with 1 berry and 10 adults constituted 1 replication; each compound was replicated 3 times. The containers were placed on a table in a room which was maintained at 75°F and 50-70% relative humidity. Mortality was defined as the inability of the beetle to maintain an upright position. Data were recorded at 24 and 48 hr intervals.

The definitions of the proprietary chemicals used in this study are as follows:

Azodrin--dimethyl phosphate, ester with *cis* 3-hydroxy-N-methylcrotonamide

Sumithion--0,0-dimethyl 0-(4-nitro-*m*-tolyl) phosphorothioate

GC-6506--dimethyl *p*-(methylthio) phenyl phosphate

GS-13005--S-((2-methoxy-5-oxo-Δ^2-1,3,4-thiadiazolin-4-yl) methyl) 0,0-dimethyl phosphorodithioate

Imidan--0,0-dimethyl S-phthalimido-methyl phosphorodithioate

Lannate--methyl 0-(methylcarbamyl) thiolaceto-hydroxamate

Furadan--2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate

Gardona--2-chloro-1-(2,4,5-trichlorophenyl) vinyl dimethyl phosphate

Thiocron--0,0-Dimethyl-S-(2-methoxyethyl-carbamoyl-methyl)-phosphorodithioate

Zolone--S-((6-chloro-2-oxo-3-benzoxazolinyl) methyl) 0,0-diethyl phosphorodithioate

Mortality was observed in one set of control containers so Abbott's formula (Abbott 1925) was employed in calculating mortality in the corresponding treated containers. Mevinphos, parathion, malathion and azinphosmethyl were highly effective against the adults. The majority of the chlorinated hydrocarbon materials were ineffective. Carbaryl, which was commonly employed as a spray chemical in the strawberry plantings to control S. geminata in June 1966 was non-toxic (Table 8).

1966 Greenhouse Experiments

A suitable toxicant for commercial use must have an effective residual life of from 3-5 days, must not leave a residue on the fruit in excess of that established by law, and must have a clearance for use on strawberries. Diazinon, azinphosmethyl, malathion, naled, and mevinphos met the latter two requirements but nothing was known about their residual effective life against the beetles.

To test these materials, strawberries were obtained from strawberry plants grown in No. 10 cans. Strawberry clusters were dipped in the insecticide suspensions and labeled. Greenhouse

TABLE 8.--Effect of various treatments applied for control of *Stelidota geminata* adults

Compound and formulation[a]	Formulation/ 100 gal	% mortality at specified time after treatment	
		24 hr	48 hr
Mevinphos, 5 lb/gal EC	0.8 pt	100	100
Malathion, 57% EC	1.0 pt	100	100
Azinphosmethyl, 2 lb SC	1.0 pt	100	100
Diazinon, 4 lb/gal EC	1.0 pt	100	100
Naled, 8 lb/gal EC	0.5 pt	100	100
Parathion, 8 lb/gal EC	0.2 pt	96	100
GC-6506, 4 lb/gal EC	0.5 pt	100	100
Lannate, 90% WP	4.5 oz	100	100
Sumithion, 4 lb/gal EC	11.0 fl oz	100	100
GS-13005, 3.67 lb/gal EC	1.0 pt	100	100
Azodrin, 5 lb/gal EC	5.0 fl oz	85	96
Furadan, 50% WP	1.0 lb	93	93
Imidan, 3 lb/gal EC	12.0 fl oz	60	85
Dieldrin, 1.5 lb/gal EC	1.0 pt	60	77
Perthane, 4 lb/gal EC	1.0 qt	0	9
Endosulfan, 2 lb/gal EC	1.0 qt	0	7
TDE, 50% WP	2.0 lb	0	0
Methoxychlor, 50% WP	3.0 lb	0	0
Oxydemetonmethyl, 2 lb/gal EC	1.0 pt	0	0
Carbaryl, 50% WP	2.0 lb	0	0
Thiocron, 2.5 lb/gal EC	12.0 fl oz	0	0
Zolone, 3 lb/gal EC	20.0 fl oz	0	0
Gardona, 2 lb/gal EC	2.0 qt	0	0
Chlorphenamidine, 50% EC	1.0 qt	0	0
Control A		10[b]	15[b]
Control B		0	0

[a]EC = emulsifiable concentrate; SC = spray concentrate; WP = wettable powder.

[b]Mortality in checks corrected by use of Abbott's formula (Abbott 1925).

temperature was maintained at approximately 75 ± 10^{o}F. The berries were picked at daily intervals and bioassays were conducted as described.

The results of this study are presented in Figure 3. Diazinon and naled broke down after 2 days, malathion and mevinphos had residual activity for 3 days, azinphosmethyl remained effective for 11 days and was still effective when the experiment was concluded.

1967 Field Experiments

Stelidota geminata infests fruit just prior to and during harvest. Only those chemicals which can be applied close to harvest would be adaptable to a control program. Mevinphos, which has a 1 day interval from application date to harvest, and malathion, which has a 3 day interval, were chosen for work in the strawberry plot of the Dominion farm. Applications were made with a Skibbe high pressure sprayer equipped with a single row boom consisting of 3 nozzles. The lateral nozzles were set at an inward angle, the middle nozzle directed overhead so that the spray was directed into the row. Pressure was set at 60 lb/in^2 and the sprayer was calibrated to deliver 250 gal of spray/acre. Malathion was applied at a rate of 2 lb active ingredient/acre, and mevinphos at 1 lb active ingredient/acre. To determine whether molasses enhanced the efficiency of malathion by attracting beetles to the spray deposit, 2 gal of raw molasses/100 gal of water were added to malathion as a separate treatment. Malathion, 4% dust, was applied with a hand duster at the rate of 2 lb of active ingredient/acre. Each treatment was replicated 4 times, a replicate consisted of 6 strawberry rows 25 ft in length. The baits, sprays

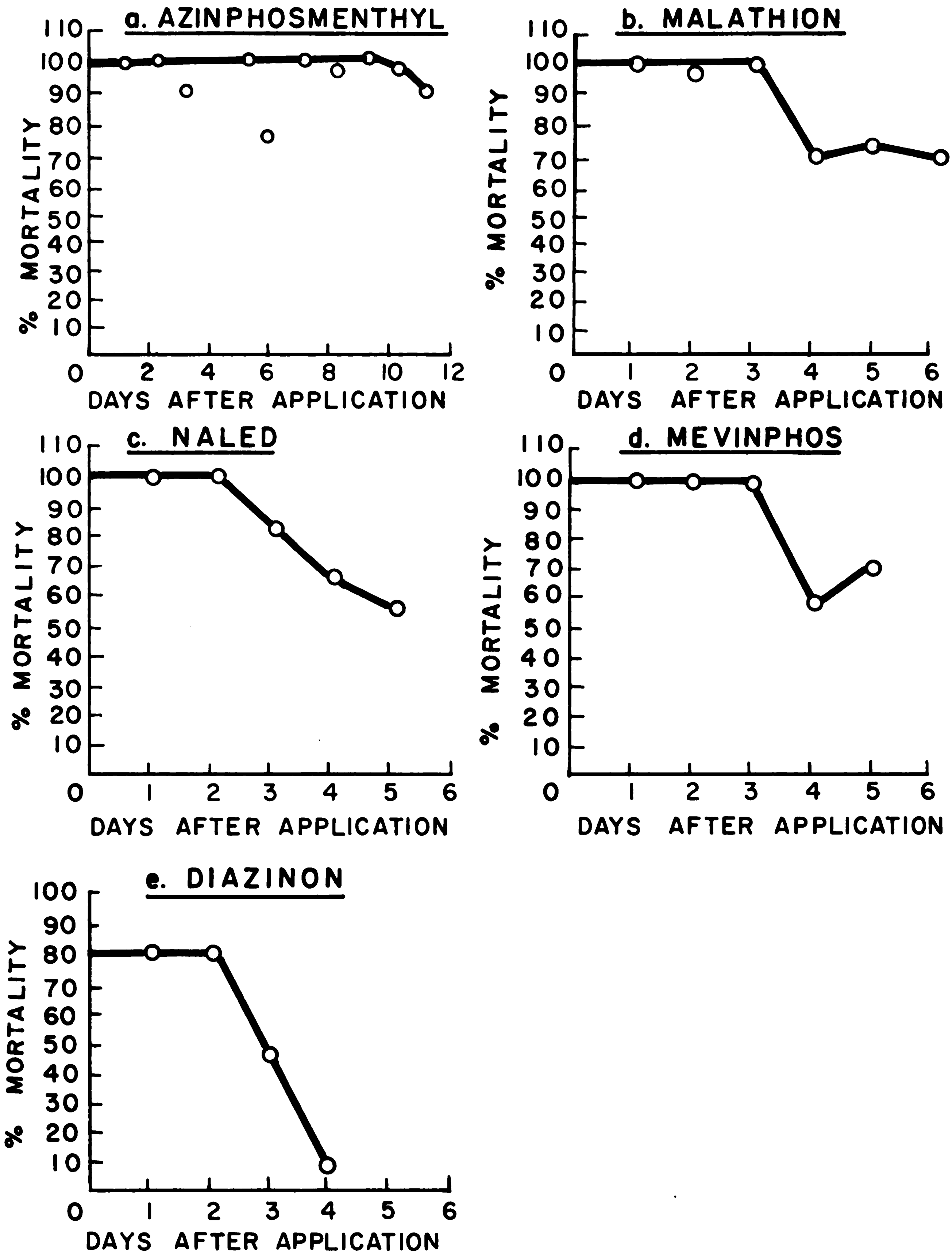


Figure 3. Residual toxicity of selected insecticides to *Stelidota geminata* adults. a, azinphosmethyl; b, malathion; c, naled; d, mevinphos; e, diazinon.

and dust were applied on June 13 and June 20, 1967. Control evaluations were made on June 27 on the basis of percent damage to 25 of the ripest berries in clusters which were in contact with the ground. The middle 2 rows were evaluated in each block; the outer 2 rows were employed as buffer rows.

The malathion and mevinphos treatments reduced injury by 8 and 3% respectively. Greater injury was recorded in the malathion plus molasses spray and malathion dust treatments (Table 9). None of the treatments gave commercial control of S. geminata.

INVESTIGATIONS INVOLVING SYNTHETIC ATTRACTANTS

During the summer of 1966 a chance observation of a large response of a picnic beetle, Glischrochilus fasciatus, to a paint touch up job on a car in East Lansing, suggested the potential of a paint attractant for S. geminata. The paint used was Duplicolor touch-up (General Motors Midnight blue, Stock No. DP-GM 44).

1966 Field Tests

Fourteen different paint products, including 12 Duplicolor products and 2 Martin Senour products, were evaluated in July for attractant properties. A trap was constructed by attaching a yellow card 4-1/2X9-1/2 inches to a metal pole 3 ft above the ground and fastening a 10-ml vial to the upper 3rd of the card. Both sides of the card were then covered with Tanglefoot (to trap the insects attracted to the boards). Two milliliters of paint were injected

TABLE 9.--Effectiveness of various insecticide formulations in the control of *Stelidota geminata* on strawberries. Dominion farm, Berrien Co., 1967

Treatment	Formulation/ acre	Mean % damage by adults to ripest berries of clusters touching the ground		
		Treated	Check	% difference[a]
Corncob-molasses- 5% malathion bait	40 lb	28	51	23a
Apple pomace-molasses- 1.25% azinphosmethyl bait	40 lb	29	44	15a
Corncob-molasses- 1.25% azinphosmethyl bait	40 lb	40	49	9a
Apple pomace-molasses- 5% malathion bait	40 lb	34	42	8a
Malathion, 25% WP	8 lb	37	45	8a
Mevinphos, 5 lb/gal EC	1.75 pt	33	36	3a
Malathion, 4% dust	50 lb	45	44	-1a
Malathion, 25% WP + 2 gal molasses/100 gal	8 lb	54	30	-24b

[a]Figures not followed by the same letter differ at the 5% level of significance (Tukey's multiple range test).

into the individual vials by means of disposable tuberculin syringes; a separate syringe was used for each material to avoid contamination. A wick was put in each vial to increase vaporization of the paint. The traps were spaced approximately 20 ft apart. Each series of paints was replicated 3 times--once each in the following sites: Dominion pear orchard, east side of Dominion strawberry patch and west side of strawberry patch. When only small numbers of beetles were present, trap captures were tabulated by removing S. geminata beetles from the Tanglefoot. Sticky cards which contained large numbers of adults were tabulated and the entire card replaced.

The response of S. geminata to the series of paints is demonstrated in Table 10. Beetles were attracted to all the traps but, DP-GM 3 acrylic red primer was outstanding as an attractant (Plate VI).

Since the paint products were different in color, additional investigations were initiated to determine the affect of color on response. The same method as described previously was used with the following exceptions: 12 different colored cards were used in place of the canary yellow cards, the vials were covered with masking tape, and only DP-GM 3 primer was used. No differences were found between colors; however, the maximum response obtained was only 7 beetles.

Employing methods previously described in test 1, further work was conducted between August 18 and September 1, 1966 to determine the possible component or components in the DP-GM 3 primer responsible for response. Samples of the individual components of the DP-GM 3 primer and related compound groups including alcohols, ketones and auto p

Stock

DP-GM

DP-GM

DP-12

DP-CC

DP-19

DP-FX

3007

DP-14

DP-1

DPS-

DP-C

6281

DPS-

DP-

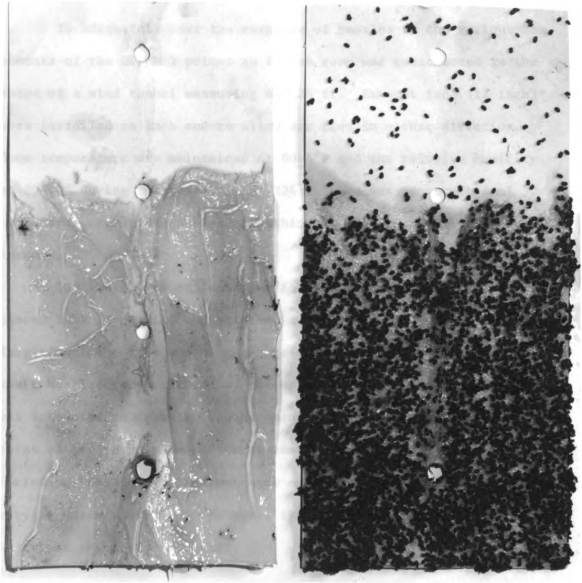
Bla

are

TABLE 10.--Response of *Stelidota geminata* adults to touch-up auto paints. Dominion farm, Berrien Co., 1966

Stock No.[a]	Color of paint	Mean number of beetles captured during a 24 hr exposure period
DP-GM-3	Acrylic Primer (Red)	1883
DP-GM-3	Acrylic Primer (Red)	1395
DP-129	Colonial White	127
DP-CC-146	Powder Blue	65
DP-199	Auto White	52
DP-FM-48	Caspian Blue	48
3007	Clear Mix Acrylic	34
DP-1420	Antigua Red	32
DP-166	Green (Sherwood)	30
DPS-55	Gloss-Clear finish	9
DP-GM-44	Midnight Blue	8
6282	Clear Lacquer	7
DPS-15	Solvent (Clear)	5
DP-GM-2	Acrylic Solvent	4
Blank-Ck	______________	5

[a]Dupli-Color paints except material No. 6282 and 3007 which are products of Martin Senour Paints, Inc., Chicago, Illinois.



Control | DP-GM 3
Panel | Acrylic paint primer

Plate VI.--Response of *Stelidota geminata* adults to DP-GM 3 acrylic paint primer. Berrien Co. July 1966.

aldehydes were tested. During this period response to the primer was very low and no response was observed to the other materials tested.

1966 Laboratory Experiments

To adequately test the response of beetles to the various components of the DP-GM 3 primer an in-lab room was constructed in the shape of a wind tunnel measuring 6X9X26 ft. Exhaust fans (12 inch) were installed in each end to allow air flow in either direction. Room temperature was maintained at 80 ± 5^{o}F and the relative humidity at 60-70% during the tests. A 5X7X24 ft cage was constructed of 32-mesh Saran screen and suspended within the room to contain the test insects.

The tests were conducted as follows: 1 ml of paint primer was placed in a 10-ml vial and attached to a yellow card covered with Tanglefoot; the card was hung at one end of the room; one hundred adult beetles were released at the opposite end; and the exhaust fan was activated to draw the vapors eminating from the vial across the point of beetle release. Several tests were conducted in this room including beetles of different ages and beetles deprived of food for varying periods of time. However, there was no response to the primer in any of the tests conducted.

NATURAL ATTRACTANTS

1966 Field Studies

The response of *S. geminata* to fermenting fruits was reported by several workers (Table 1) and also was observed by the author under field conditions. To verify these observations, experiments were designed to determine response in the field to 2 natural attractants.

Ground traps containing fermenting grape juice and fermenting molasses were placed in the Dominion cherry orchard and strawberry field. Three traps of each test product were set out at 20 ft intervals in each location on August 1, 1966. Data were collected the following day.

Both fermenting grape juice and fermenting molasses attracted large numbers of beetles in the 19 hr test period (Table 11). The population in the strawberry planting was very large at this time due to adult emergence from the soil; thus, the number of beetles collected in the traps placed in the strawberry planting was greater than the number collected in the cherry orchard where the population was a result of migration to decaying cherries on the soil.

TABLE 11.--Response of Stelidota geminata to fermented grape juice and molasses. Berrien Co., Mich. August 1966

	Mean no. of adults collected in each location during a 19 hr period	
Material	Strawberry field	Cherry orchard
Fermenting grape juice	302	58
Fermenting molasses	390	38
Control	0	0

1967 Laboratory Studies

Preliminary field tests indicated a direct response to fermenting plant products. My next step in developing an attractant bait mixture, which could be used as a field control, was a test of suitable carriers. Two natural plant products, apple pomace and wheat bran, were tested.

Five petri dish covers each containing a teaspoonful of different bait were randomly placed in a Saran screen covered cage measuring 16X16X16 inches. Three cages were employed, each cage representing a replicate. Twenty-five beetles starved for 24 hr were placed in the center of each cage. The number of beetles present in each of the baits was tabulated after 6 hr.

The response to the moist baits was significantly different from the dry baits and the control (Table 12), indicating that the moisture content of the bait in the field will be a factor in determining its effectiveness as a competetive lure with the ripe berries.

To determine whether beetle response to the baits could be increased, several fruit essences and natural plant products were added to the baits. The additives included: apple, grape, and cherry essences; grape juice and fermenting grape juice. Spent grain, a by-product of the brewing industry, was also tested as a possible attractant.

The essences of grape, apple, and cherry did not increase response to the bait mixtures (Table 13). The response to grape juice was significantly greater (Chi^2 Test, 5% level) than moist bran as

TABLE 12.--Efficiency of various carriers in attracting *Stelidota geminata* adults during a 6 hr exposure period

Bait	No. of beetles/replicate			
	I	II[a]	III[a]	Total[b]
Moist apple pomace	8	15	10	33
Moist bran	13	3	9	25
Dry bran	2	1	1	4
Dry apple pomace	0	1	0	1
Control (moist filter paper)	2	0	0	2

[a]Five beetles in replicates II and III were not feeding on the baits at the time of counting.

[b]Response to the moist baits is significantly greater than the dry baits and controls as determined by Chi^2 Test ($Chi^2 \geq 69.5$, df = 2, $\alpha = .01$).

TABLE 13.--The response of *Stelidota geminata* adults to fruit essences

Material	Mean no. of beetles feeding on bait after 3 hr exposure period
Investigation I	
Cherry essence + pomace	3
Pomace + bran mixture	13
Investigation II	
Grape essence + pomace	9
Pomace + bran mixture	10
Investigation III	
Apple essence + pomace	7
Pomace + bran mixture	11

shown in Table 14 (Investigation 1). There was no significant difference in response to moist bran and spent grain, a brewry by-product (Investigation 2). The corncob-molasses mixture attracted a significantly greater number of beetles than moist bran (Investigation 3).

TABLE 14.--Response of *Stelidota geminata* adults to natural baits placed in cages

Type of bait	Replicate[a] I	II	III	Total[b,c]
	Investigation 1			
Bran-pomace mixture + fermenting grape juice	9	21	14	44a
Bran-pomace mixture + grape juice	10	6	6	22a
	Investigation 2			
Moist bran	6	15	13	34a
Moist spent grain	9	8	12	29a
	Investigation 3			
Corncob + molasses	14	15	20	49a
Moist bran	9	10	5	24b

[a]Thirty adults/cage were released in Investigations 1 and 2, 25 adults/cage were released in Investigation 3. Counts were made 12, 3 and 10 hr after release in Investigations 1, 2 and 3 respectively.

[b]The total numbers of beetles found not feeding on the baits were 24, 25 and 2 for Investigations 1, 2 and 3 respectively.

[c]Totals followed by the same letter are not significantly different at the 5% level as determined by the Chi^2 Test ($Chi^2 \geq 9.86$, .87 and 44.2 for Investigations 1, 2 and 3 respectively.

BAITS

Laboratory Investigations

Control of adult beetles by growers with most of the commercially available insecticides was not successful during the 1966 strawberry harvest season. Preliminary field tests demonstrated the ineffectiveness and impracticability of spray chemical control methods. Field, laboratory, and greenhouse experiments demonstrated that beetles could be attracted to certain baits and response to these baits could be improved by the addition of certain natural plant products. The addition of an insecticide to the bait mixture, an old and accepted control practice, could provide commercial control of S. geminata in strawberry plantings.

To determine the effectiveness of insecticide-attractant baits in protecting strawberries the following experimental method was employed. A ripe strawberry was placed on wet sand in a petri dish and the sand was sprinkled with the bait mixture at a rate equivalent to 40 lb/acre. The dish was placed in a cage with 15 beetles that had been starved for 72 hr. Ten different insecticide-attractant baits, replicated 3 times, were tested in the laboratory for their efficiency in killing S. geminata (Table 15). The number of holes in each berry and the percent mortality were recorded after 24 hr.

Although the ratio of beetles to strawberry fruit was high the majority of the bait mixtures produced a high degree of mortality and protected the fruit from damage (Table 15). All of the mixtures that contained grape juice or molasses as an attractant gave complete protection from injury, demonstrating their effectiveness as a competitive lure with the ripe fruit.

TABLE 15.--Efficiency of insecticide-attractant baits in protecting strawberry fruit from *Stelidota geminata*

Type of bait	Mean no. of holes/berry	Mean % mortality after 24 hr
Apple pomace-grape juice-yeast-1.25% azinphosmethyl	0	100
Pomace-1.25% azinphosmethyl	0	100
Corncob-molasses-1.25% azinphosmethyl	0	100
Corncob-molasses-2.5% malathion	0	98
Attapulgus clay-molasses-2.5% malathion	0	95
Apple pomace-5% Furadan	0.3	98
Wheat bran-5% malathion	0.3	95
Apple pomace-5% Dylox	1.3	91
Bran-apple pomace-1.25% azinphosmethyl	2	80
Bran-citrus pomace-5% Dylox	1.3	76
Control[a]	1/3-1/2 berry consumed	0

[a]Initially several feeding holes were made but after 24 hr they coalesced into 1 or 2 large cavities.

1967 Field Evaluations

The corncob-molasses-insecticide (malathion or azinphosmethyl) combination was selected for preliminary field tests because of its commercial availability and relatively low cost. Tests were conducted at the Dominion strawberry plot in May. At this early date, strawberries were not present in the field so ripe fruit had to be provided. Each treatment consisted of a 1 X 1 ft area in the strawberry row. Laboratory studies had shown that the presence of moisture affected response to the baits; therefore, two thirds of the treated plots were pre-moistened. Three berries were placed in each section and the bait was distributed at a rate equivalent to 40 lb/acre. Fifteen beetles were put in each area and a wood frame covered with 32-mesh Saran screen was placed over them. Each treatment was replicated 3 times.

As shown in Table 16 the strawberry fruit in the plots that were pre-moistened and treated with the corncob-molasses baits, had significantly less injury than the controls as determined by Duncan's multiple range test at the 5% level (Duncan 1957).

Further testing of the effectiveness of baits as a control measure for *Stelidota geminata* was conducted during the harvest season in the strawberry plots in Berrien County. Four formulations of baits were applied as shown in Table 9. The replicates, dates of application and evaluation method were the same as described previously in the "Chemical Control-1967 Field Experiments" section. The fine granule corncob-molasses-5% malathion bait gave the best protection. The maximum reduction in injury was 23%, the minimum was 8% (Table 9).

TABLE 16.--Reduction of Stelidota geminata adult feeding on strawberry fruit in plots treated with corncob-molasses baits. Dominion farm, Berrien Co., Mich., May 1967

Treatment	Mean no. feeding holes/berry[a]
On moist ground	
Corncob-molasses-1.25% azinphosmethyl	.66a
Corncob-molasses-5.0% malathion	1.00a
On dry ground	
Corncob-molasses-1.25% azinphosmethyl	2.33ab
Control	5.5b

[a]Means followed by the same letter are not significantly different, as determined by Duncan's multiple range test for correlated and heteroscedastic means at the 5% level.

To further determine the effectiveness of the corncob-molasses-5% malathion bait another series of treatments was evaluated in the blocks previously treated with this bait. Infested berries were removed from an 8 ft section in 4 treated and adjoining check rows. The bait was immediately spread over the rows by hand at a rate equivalent to 40 lb/acre. Each treatment was replicated 4 times. Treatments were made on June 28 and July 1, 1967. On July 4, 1967 all ripe berries in the rows were harvested and classified. Evaluation showed injury in 4.3% of the berries in the treated plots and in 20.6% of the check berries.

Work was initiated in June 1967 to compare the relative attractiveness of liquid and dry baits. The following baits were included: liquid molasses-1% azinphosmethyl, liquid molasses-yeast-1%

azinphosmethyl, corncob-molasses-1.25% azinphosmethyl, and apple pomace-1.25% azinphosmethyl plus DP-GM 3 primer. The liquid molasses traps were the same type as described previously. The granular baits were placed in piles on Saran screen on the ground. The purpose of the primer-pomace combination was to study response to the paint rather than the pomace, which was employed as a medium to trap the adults. A 10-ml vial with 5 ml of primer was placed on the pomace pile. The traps were distributed in 4 woodlots and left for 4 days.

Table 17 shows the outstanding attractant properties of the fermenting molasses-azinphosmethyl liquid baits in contrast to the other baits tested. Molasses-corncob-azinphosmethyl baits placed in piles possessed the least attractant qualities.

To demonstrate the usefulness of fermenting molasses traps as a control measure, a typical commercial setting at the St. John farm was selected. The field is bordered by a woodlot on the south, a cherry orchard on the east, apple orchard on the west and melon field on the north. Ground traps, consisting of 50% raw molasses, yeast and 1% azinphosmethyl in 7 oz paper cups, were distributed around the perimeter of the field at intervals of 20 ft. The cups were set on the ground at a 45° angle and pointed away from the irrigation sprinklers. The traps in the woodlot were located 5 ft in from the edge, the orchard traps were placed under each tree in the 1st row and traps at the north end of the field were put in the strawberry row 2 ft from the end. The traps were set out on June 12, and evaluated June 16, 1967. Two aerial applications of corncob-molasses-1.25% azinphosmethyl bait were applied over the entire field.

TABLE 17.--Response of *Stelidota geminata* to liquid and dry bait formulations placed in woodlots. Berrien Co., Mich., June 1967

Bait	Number of adult beetles/trap in each woodlot location				
	Dominion	St. John(N)	St. John(S)	Swisher	Total
Liquid molasses-1% azinphosmethyl	0	19	6	31	56
Liquid molasses-yeast-1% azinphosmethyl	265	247	54	117	683
Molasses-corncob-1.25% azinphosmethyl bait pile	2	3	0	12	17
Apple pomace-1% azinphosmethyl + vial of DP-GM 3 acrylic paint primer	1	6	0	22	29

The greatest number of beetles was trapped in the woodlot (Table 18). Approximately 4500 beetles were trapped in 4 days in the woodlot. Traps placed in this habitat the following week averaged 30 beetles in 4 days. After 2 weeks approximately 150 beetles were collected per trap. The data in Table 18 show that the smallest number of beetles was collected farthest from the woodlot. Observations of berries in the field showed the infestation to be minimal. Ripe and overripe berries were observed uninjured within 12 ft of the edge of the woodlot.

TABLE 18.--Response of Stelidota geminata adults to fermenting molasses ground traps placed around a 2.5 acre strawberry field. St. John farm, Berrien Co., Mich., June 1967

	Mean no. of beetles collected per trap during a 4 day period at specified distance (ft) north of the woodlot					
Site	0	20	100	200	350	450
Edge of woodlot	540	---	---	---	---	---[a]
Cherry orchard	---	445	400	125	35	17
Apple orchard	---	19	18	11	6	14
North end of field	---	---	---	---	---	30

[a]Not tested.

The main disadvantage to the above means of control is the inherent high mammalian toxicity of azinphosmethyl. The oral LD_{50} of this material to rats is about 18 mg/K of body weight. Thus, these bait stations contain a lethal dose for a human. The choice of a material is limited because less toxic materials to humans such as carbaryl and methoxychlor are non-toxic to S. geminata. However, malathion is highly toxic to S. geminata and has an oral LD_{50} to rats of 1,400-5,800 mg/K making it one of the safest of all insecticides to humans.

To determine the residual activity of malathion, tests were conducted with 2 formulations; malathion (25% WP) and Malathion LV Concentrate. The mixtures prepared were (1) 50% molasses solution plus enough malathion WP to make 2.5% active ingredient, (2) 5 fl oz of 50% molasses solution plus one half milliliter of Malathion LV Concentrate. Bioassays were carried out daily by placing 10 adults in a 1 pint Plasti-Kan container along with a sample of the bait. Each mixture was replicated 3 times.

Within 2 days the malathion WP-molasses mixture was non-toxic to adult beetles. The mixture that contained Malathion LV Concentrate resulted in 100% mortality throughout the test period which was terminated after 1 week.

To determine what effect the odor of Malathion LV Concentrate had on the response of beetles to fermenting molasses a comparison between liquid molasses ground traps containing azinphosmethyl (25% WP) or Malathion LV Concentrate was carried out with methods described previously. The toxicant employed was found to have no effect on the response of the beetles to the molasses.

Ground traps, to be economically practical, must have a field longevity of several days. The longevity of fresh and 5-day old fermented molasses solutions containing 1% azinphosmethyl was tested in ground traps in 3 locations within the Dominion woodlot.

Both mixtures retained their attractant properties during the test period. However, as shown in Table 19, the response to the fresh mixtures is significantly different from the 5-day old mixtures as determined by the F test (5% level).

TABLE 19.--Response of *Stelidota geminata* to 5-day old and fresh molasses + yeast ground traps. Berrien Co., Mich., 1967

Age of fermenting mixture at beginning of exposure period	Mean no. of beetles/trap[a]	
	July 2-4	July 4-7
0 days	27a	82a
5 days	4b	39b

[a]Means flanked by the same letter are not significantly different at the 5% level (F test).

CONTROL DISCUSSION

In field studies in 1966 and 1967 indicated that chemicals sprayed on the strawberry foliage did not provide satisfactory control of *Stelidota geminata*. This was probably caused by the dense plant foliage, which limited the penetration of sprays and the adult feeding on the underside of the fruit, which made the chance of contact with insecticide remote.

The outstanding response to DP-GM 3 auto paint primer in 1966 could not be duplicated in 1967 even though many experiments were conducted in the laboratory and field. One obvious difference between the populations was that the beetles responding in July 1966 were emerging from the strawberry plantings that were devoid of berries whereas the population studied in 1967 was in the woodlot--a habitat where decaying vegetation and moisture were available.

The injury to the fruit in the strawberry plots treated with spray chemicals and baits appear to be excessive (Table 9); however, the injury represents only that present in overripe berries touching the soil. Thus, the total percentage of injury in all ripe berries would be less than that shown in Table 9.

Several factors influenced the results of the plots at the Dominion farm. A major factor was that each set of treatments was followed by heavy rainfall. Rainfall of this nature rapidly decreases the effectiveness of the baits because it washes the molasses from the carrier. In addition, washing and hydrolysis decrease the activity of the chemical materials. Secondly, the plots were under heavy population pressure from adjoining checks. However, to correct this situation would have necessitated treatment of the entire planting. Thirdly, the experimental area was not representative of commercial plantings because it was not mulched, irrigated or harvested. Mulch in the commercial fields was observed to contribute significantly to the effectiveness of the baits because it kept the bait moist and provided shelter under which the beetles could feed. Harvesting presumably would increase the chance of contact with bait since removal of the injured berries would cause the beetle to move in search of food. The above factors probably reduced the effectiveness of the baits more than the effectiveness of chemical treatments and probably accounted for the lack of significant difference between treatments.

Growers who treated their plantings with the corncob-molasses bait were able to completely harvest the crop in 1967, even though infestation occurred before control applications were made. The use of fermenting bait stations to intercept the migration of _S. geminata_ proved to be a satisfactory means of control. This method has the advantages of high drawing power, economy, safety, no residue problem, ease of distribution and little interference with non-target species.

The only materials and equipment required for preparation of the bait stations are raw molasses, yeast, water, Malathion LV Concentrate and an eye dropper. Distribution of the bait stations requires no elaborate or expensive equipment and little time. One man had no trouble preparing and distributing bait stations for a 2.5 acre field in 2 hr.

The bait station is the most economical of the control methods tested. A comparison of costs between bait stations and bait broadcasting of a 2.5 acre field disclosed that 1 aerial treatment costs $14/acre or $35 for the field. If 3 applications are made, the total cost for protection is $105. Paper cup bait stations spaced 20 ft apart would cost approximately $3/application or $12-15 total for 4-5 baitings during the season. A difference of $90-93 for the season.

The findings that Malathion LV Concentrate had residual activity of at least 1 week was probably due to immiscibility which did not allow hydrolysis of the malathion. The use of malathion as a toxicant negates the hazard aspect.

Liquid bait stations have no affect on non-target species. The only other specimens commonly collected were picnic beetles, Glischrochilus sp., therefore, this technique would be adaptable to a future integrated control program.

SUMMARY

A new pest of strawberries--the strawberry sap beetle, *Stelidota geminata*--caused an estimated 2-3 million dollar loss to the Michigan economy in June 1966. Damage was caused by the feeding of adults and larvae.

Mass rearing in the laboratory for biology and control studies was carried out by culturing beetles in 2-quart, wide-mouth jars. Moist peaches were provided as a food source.

Life cycle studies showed that there are 3 larval instars and completion of development from egg to adult requires an average of 19 days at 75°F. Adult lifespan averaged 127 days; the oviposition period averaged 101 days; and the average number of eggs per day was 4.3 with a maximum of 16.

Adult beetles fed primarily on the underside of ripe and over-ripe fruit in contact with the ground. One to several feeding galleries were made in the strawberry fruit depending on the number of beetles present. The individual galleries coalesced into large cavities after several hours of feeding. Larvae also fed in the interior of the fruit. Host crops of *Stelidota geminata* in Berrien Co. were sour and sweet cherry, dewberry, tomato, muskmelon, peach, pear and apple.

Fermenting molasses ground traps were employed to determine the side of overwintering and time of migration. Adults overwinter

in the woodlots and thickets around the fruit plantings. When the mean temperature was above 65°F migration from the woodlots occurred. The odor of ripe, overripe or decaying strawberries attracted adults to the strawberry plantings. The peak of migration coincided with the peak of the strawberry harvest.

Application of spray chemicals on the strawberry foliage and fruit at rates up to twice the recommended gallonage per acre did not produce control. Bioassays of 24 chemical compounds showed that the following were toxic to S. geminata adults: mevinphos, malathion, azinphosmethyl, diazinon, naled, parathion, GC-6506, Lannate, Sumithion, GS-13005, Azodrin, Furadan, Imidan, and dieldrin. The other compounds tested were ineffective.

Outstanding response to a synthetic attractant, Duplicolor auto primer touch-up paint DP-GM 3 was demonstrated in July 1966. However, subsequent work in 1966 and 1967 in the laboratory and field failed to demonstrate exceptional attractant properties of this material.

Adult beetles showed significant response to the following natural attractants: bran, apple pomace, fermenting molasses, and fermenting grape juice. Fermenting grape juice and fermenting molasses were highly attractive. Two methods of control were developed that employed molasses as an attractant. The first method utilized a bait consisting of corncob-molasses-1.25% azinphosmethyl that was broadcast over the strawberry fields at a rate of 40 lb/acre. This bait was applied over a majority of the commercial strawberry acreage in southwestern Michigan in June 1967 and produced satisfactory control. The second method of control was the placement of liquid fermenting molasses-yeast-insecticide poison bait stations around the perimeter of the strawberry field to intercept the migration of adults.

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