PINK BOLLWORM PHEROMONE TRAPPING: ANALYSIS OF TRAP DESIGN, PHEROMONE SUBSTRATE AND FIELD SPACING

by

Michael Peter Hoffmann

A Thesis Submitted to the Faculty of the

DEPARTMENT OF ENTOMOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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SIGNED: Michael P. Hoffmann

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. T. Huber

R. T. Huber
Associate Professor of
Entomology

August 8, 1978

Date

ACKNOWLEDGMENTS

I wish to express sincere thanks and appreciation to Dr. Roger T. Huber for his advice and encouragement throughout the course of this thesis.

I also wish to thank Dr. Floyd Werner and Dr. Leon Moore, for their service in the review of this thesis and for serving as members of my graduate committee.

Thanks also go to Dr. Dave Marx, Agricultural Experimental Station Statistician, for his assistance in the analysis of data, and to Art Pacheco and Pete Hershberger for use of their crop land during the various aspects of this research. I also owe special thanks to John Busacca and Don Manley for their advice and assistance in the collection and analysis of data for this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

Research was conducted to evaluate various pink bollworm pheromone dispensers: the Conrel hollow fiber dispenser, gossyplure treated rubber tubing dispensers utilizing either a hexane or methylene chloride solvent, aged dispensers, and dispensers treated with aged pheromone. Although results varied depending on the time of year, the Conrel dispenser was generally least effective. The two solvents were equally effective. Storage of treated rubber wicks or pure pheromone for one year at 6°C did not significantly affect attractiveness. Even after 38 weeks of field exposure rubber wicks were highly attractive.

The Kitterman insect monitor trap was evaluated for use as a male pink bollworm monitor. The commercially sold design was inadequate; however, replacement of the Tanglefoot coated base with Stikem and the Conrel dispenser with a rubber wick improved the trap substantially.

To determine the optimum density at which pink bollworm pheromone traps should be deployed in a mass trapping program, a trap density study evaluated the Huber oil and Stikem traps at the rates of 2.5-15 and 7.5-15 traps/hectare, respectively. Within field populations and under the conditions of these studies the optimum density for the

Stikem trap was about 12.5 traps/hectare while that for the oil trap was greater than 15 traps/hectare.

INTRODUCTION

The pink bollworm is a serious pest of cotton throughout most of the cotton growing regions of the world. Management of the insect is generally difficult, requiring considerable time and energy.

With the recent identification, synthesis and mass production of the pink bollworm sex attractant pheromone gossyplure, an additional research and management tool has become available to assist in population survey and control of this insect pest.

To effectively utilize gossyplure in the field for population monitoring and mass trapping, several parameters must be considered. A pheromone dispenser must be available that releases the pheromone at an optimum rate and for a satisfactory duration. Trap design is also important and factors such as color, orifice type, size, and pheromone concentration should be considered. When used for monitoring, the trap should efficiently and accurately detect population fluctuations, whereas when used in mass trapping the primary design concern is maximum efficiency and capacity.

When used in mass trapping programs, factors such as competition with native females, placement, and density of the traps in the field must also be considered.

The purpose of this research was to evaluate three aspects of the use of gossyplure baited traps as tools in pink bollworm pest management. Specifically the objectives were: 1) evaluation of various gossyplure dispensers for attractancy and longevity under field conditions, 2) determination of the relative efficiency of trap design on pink bollworm male moth captures, and 3) comparison of different trap densities to help determine optimum trap placement and rates in mass trapping programs.

LITERATURE REVIEW

The Pink Bollworm

The pink bollworm, Pectinophora gossypiella (Saunders) is a serious insect pest of cotton in Arizona and most cotton growing regions of the world. The pink bollworm (PBW) probably originated in India and from there was spread in cottonseed to Egypt and subsequently to Mexico where it was discovered in 1916. The PBW was first found in the United States at Hearne, Texas in 1917 and appeared in the eastern counties of Arizona in 1926 (Noble 1969). Since the 1950's it has spread over most of the cotton growing areas of the state (Wene, Carruth and Telford 1965; Spears 1968).

The PBW is a small grayish brown moth with a wingspread of 15-20 mm. The adult lives 10-14 days and during this time the female may lay 100-200 eggs, most of which are laid on susceptible bolls or terminals of the cotton plant (Lukefahr and Griffin 1957). The eggs hatch and the larvae immediately enter squares or susceptible bolls in which they develop in 10-15 days. The larvae, while feeding within the bolls, may cause considerable loss in yield and quality (Brazzel and Gaines 1956, 1957). Fully developed fourth instar larvae exit from the bolls and fall to the ground, where they pupate. In the fall, when conditions of photoperiod are correct, the larvae enter diapause and overwinter (Noble 1969). Five to six generations are possible in a year (Wene et al. 1965).

Control of the PBW is difficult since the larval stage is protected from parasites, predators and insecticides while in the fruiting structures. The establishment of an economic threshold (Watson and Fullerton 1969) and implementation of insect pest management programs for control of the PBW have proven to be very successful (Carruth and Moore 1973).

Insect Sex Pheromones

With the development and utilization of insect sex pheromones in insect pest management programs, an additional tool has become available for both control and survey of insect pests such as the pink bollworm.

As generally accepted, the term sex pheromone is used to include all chemicals that are released from one organism and that induce responses, such as orientation, precopulatory behavior, and mating, in another individual of the same species (Karlson and Butenandt 1959; Karlson and Luscher 1959). Sex pheromones are generally active in minute amounts and induce responses from great distances. Shorey and McKelvey (1977) reviewed utilization of insect sex pheromones in agricultural crops for insect survey and control.

Development of the PBW Pheromone

Investigations into the existence of a PBW sex pheromone began with Ouye and Butt (1962). They observed the characteristic mating behavior of the male PBW when in the presence of a female PBW. The male exhibited a state of excitation, which included rapid wing vibrations with intermittent upcurving of the abdomen. These observations indicated that an attractant substance was present before and at termination of mating. Research conducted with extracts of whole mating pairs demonstrated that the attractant was specific for the male PBW, was produced by the female, and could compete with females in a mixed population.

Berger et al. (1964) determined that the terminal 2-3 segments of the abdomen of 4-5 day old female moths were the best source of the sex attractant and that the active substance could be obtained from all females regardless of time of day. Laboratory and field tests showed that the PBW sex attractant could be used to capture PBW males.

Jones, Jacobson and Martin (1966) isolated and identified what was purported to be the PBW sex attractant, propylure (10-propyl-trans-5,9-tridecadienyl acetate). Propylure elicited sexual excitement and copulatory attempts in male moths in laboratory bioassays but failed to attract males in field cages. Jones and Jacobson (1968) discovered large amounts of N,N-diethyl-m-toluamide (deet) in female

PBW and demonstrated that it was an activator of propylure in the field.

Eiter (1970) challenged the claim that propylure was the PBW sex pheromone. His research indicated no excitation of male moths by the compound in laboratory tests. However, Jacobson (1969) demonstrated that as little as 15% of the cis isomer of propylure would mask the biological activity of the natural trans isomer. Since the preparation made by Eiter (1970) was a 1:1 isomer mixture, it would not have been biologically active.

Hexalure, an unrelated chemical, was discovered by empirical screening and found to be specifically attractive to the male PBW (Green, Jacobson and Keller 1969). Extensive field testing by Keller et al. (1969) determined it to be equal or superior to five female equivalents of the natural lure and that it was attractive in the field longer than the natural lure.

Hummel et al. (1973) analyzed extracts of the female PBW and were not able to detect either hexalure, propylure or its activator with gas-liquid chromatography and found these compounds to exhibit little or no biological activity in the laboratory or field.

Jacobson and Jones (1974) refuted these findings and provided additional evidence that propylure was attractive to male PBW moths and that hexalure and a combination of propylure and deet were highly attractive to the PBW under field conditions.

Hummel et al. (1973) identified the PBW sex pheromone to be a mixture of cis,cis and cis,trans isomers of 7,11-hexadecadienyl acetate and named it gossyplure.

Bierl et al. (1974) confirmed that gossyplure was indeed the natural sex pheromone of the female PBW and established that a 1:1 ratio of the isomers was optimum. Further studies in Australia on the optimum isomer ratio by Rothschild (1975) agree with this; however, Flint et al. (1977) evaluated various isomers in Arizona over the entire season and determined that, during May, 60-67% of the ZZ isomer was more attractive than 50%, which was most attractive during June, July and August. As the season progressed an increase in males responding to ratios other than 1:1 was observed. Marks (1976) found that 55-60% of the ZZ isomer performed significantly better than other combinations in Malawi, Africa, from June 5th to July 15th.

Additional tests conducted by Flint et al. (1974); Reed et al. (1975); Neumark, Jacobson and Teich (1975); and Marks (1976) have demonstrated that gossyplure is up to 400 times more attractive to the male PBW than hexalure.

PBW Sex Pheromone: Behavioral Studies

To effectively utilize the PBW sex pheromone for survey or control, a basic understanding of the pink bollworm's behavioral responses to the pheromone is necessary.

The female PBW releases the pheromone from a gland which Jefferson, Sower and Rubin (1971) described as an eversible sac situated dorsally in the intersegmental membrane between the 8th and 9th abdominal segments. The release of pheromone by the female is circadian, taking place nightly between 1:00 and 4:00 AM. During pheromone release, the female exhibits two stereotyped postures: "initial calling" and "overt calling". During initial calling the wings are extended, elevated and separated, with the antennae resting against the anterior wing margins. The body is parallel to the substrate, the ovipositor and pheromone gland are in contact with the substrate and are manipulated against it with short circular motions. During overt calling the wings are at a 45° angle and tensely extended. The antennae are perpendicular to the body and the pheromone gland is held about 2 mm above and parallel to the substrate (Leppla 1972).

Several researchers using light traps (Graham, Glick and Martin 1964), hexalure baited traps (Sharma, Rice et al. 1971; Graham 1973) and gossyplure baited traps (Reed et al. 1975; Marks 1976; Flint et al. 1978) have established that the male PBW is most active during the early morning hours, in apparent response to the female's pheromone release. The male PBW responds in this characteristic diurnal pattern to both female moths and gossyplure wicks (Flint et al. 1978). Field and laboratory observations have also shown that mating generally occurs during these same hours (Lukefahr and Griffin 1957, Kaae and Shorey 1973).

Wind speed may alter the peaks of activity, location of pheromonal communication, and mating. On calm nights most activity occurs near the top of the foliage. However, on windy nights all activities occur at a lower level in the foliage (Kaae and Shorey 1973, Graham 1973).

Farkas and Shorey (1977) demonstrated that an aerial trail of odorous pheromone molecules extends downwind from the female PBW and that the male PBW apparently senses the boundaries of the trail during its characteristic zig-zag flight across it. The male PBW turns back into the pheromone trail as frequency of the molecules decreased. They also proposed that the mechanism by which males steer toward the odor source may not require a sensing of wind direction.

The behavior of male PBW while flying within an aerial trail of female sex pheromone is influenced by the concentration of the pheromone, spatial position, and intensity of illuminating lights and visual cues from nearby objects. Male moth airspeed and forward progress decreases as pheromone concentration increases. The decrease in air speed may be caused by the corresponding decrease in wing beat frequency. The angular change in direction of moths engaged in the zig-zag flight increases with higher sex pheromone concentration. Arrestment of flight and landing appear to be stimulated by the combined action of visual cues and high pheromone concentration (Farkas, Shorey and Gaston 1974).

Field Applications of PBW Pheromone in Pest Management

As the various PBW sex attractants and finally the true sex pheromone became available, various researchers attempted to evaluate them for practical field applications such as population monitoring or survey, mass trapping, and mating disruption.

Development and Use of PBW Sex Pheromone Traps

Early PBW population survey research was conducted by Ouye and Butt (1962) and Berger et al. (1964). They demonstrated that Tanglefoot-coated traps baited with crude extracts of the female PBW could be used in a field survey program. Graham and Martin (1963) improved upon the trap design and incorporated a cyanide killing agent. Traps containing the crude female extract plus blacklight proved to be more efficient than those with the extract only (Guerra and Ouye 1967).

Hexalure was evaluated and utilized for PBW population monitoring by several researchers including Embody (1971), Rice and Reynolds (1971) and Toscano et al. (1974). Toscano et al. (1974) developed a program which timed insecticide applications with daily PBW catch in hexalure-baited traps. Neumark, Jacobson and Teich (1975) developed a similar program in Israel using gossyplure-baited traps.

Refinements in the use and placement of PBW traps were made by Sharma et al. (1973). Using traps baited with hexalure, they determined that the optimum trap height was at, or just above, the plant canopy. They suggested that when traps are too low in the canopy dispersal of the pheromone may be inadequate and when too high the PBW may not be able to visually orientate toward it. However, Marks (1976), using gossyplure-baited traps, found the best height to be one-half the height of the cotton while the second best location was just below the canopy top. Reed et al. (1975) had similar results. Traps 0.4 m high in cotton 0.8 m to 1.2 m tall caught the most moths. However, as Kaae and Shorey (1973) have indicated, the optimum height of the trap may vary with meteorological factors and the height and conditions of the surrounding vegetation.

Factors which should be considered in trap design include color, size, orifice type, and pheromone concentration. Sharma et al. (1973) evaluated several trap designs and determined that an enclosed omnidirectional trap with a large flat trapping surface and eight side openings was the best. Sharma et al. (1973); Marks (1976); and Foster, Staten and Miller (1977) noted that increasing the size of a trap did not necessarily increase its efficiency. Sharma et al. (1973) showed that too much or too little hexalure per trap reduced the PBW catch. Therefore, sex attractant release rate is important and should be considered for each trap design.

Reed et al. (1975) evaluated several adhesives for an open pan type PBW trap. Liquid paraffin, castor oil and safflower oil were equal in effectiveness, while motor grease, kerosene, sugar syrup, honey solution, water, and soap and water regularly caught moths but were less efficient. Neumark and Teich (1973) found that a polystyrene cup containing water and detergent was a very effective trapping device. Up to 600 male PBW moths were captured in one night using hexalure as the attractant.

Trap color does not appear to affect trap catch. Reed et al. (1975) found no difference between black and silver traps and Marks (1976) did not find a significant difference among seven different trap colors tested.

Coudriet and Henneberry (1976) evaluated five different trap designs for use with the PBW. Included in the evaluation were the double-cone type trap, Huber Stikem trap, saucer type, Pherocon 1C and omnidirectional Sharma trap. No statistical difference was detected among them. Flint et al. (1976) compared the Sharma and Huber trap and determined that both could be improved by the incorporation of 10% dicrotophos in the Stikem coated trap surface. Observations had shown that frequently moths entered and exited the traps without being captured because scales on legs and body were readily shed into the Stikem, allowing the moths to escape. Foster et al. (1977) showed that a modified Delta trap was better than a modified Frick, Sharma or Huber trap.

Development of Pheromone Dispensers

The utilization of sex pheromones in monitoring or mass trapping programs requires the availability of a pheromone dispenser or wick which is inexpensive, easily utilized and releases the pheromone at an optimum rate for a satisfactory duration. Repeated wick replacement may be tolerated in an insect monitoring program, but not in a mass trapping program.

Considerable research has been conducted with pheromones of numerous insect species to develop wicks which meet the above requirements. A wide variety of substrates, antioxidants and solvents have been evaluated in the development of pheromone release formulations.

Some of the more promising wick types include those which incorporate the pheromone into a solid plastic formulation. Fitzgerald et al. (1973) demonstrated with the cabbage looper pheromone that such a formulation was attractive for up to 15 months. Glass et al. (1970) tested several wicks for the pheromone of the red banded leaf-roller, Argyrotaenia velutinana and found that a small polyethylene cap yielded an optimum release rate for almost one year under field conditions. Maitlen et al. (1976), however, found that the same polyethylene cap allowed extensive chemical degradation of the codling moth, Laspeyresia pomonella (L.), pheromone. He found that red rubber stoppers when treated with 5 ug of pheromone were better and would remain attractive for up to four months. Paul and Harris (1976) have reviewed the effectiveness of the commercially available Hercon multi-layered polymeric dispenser, which has been extensively evaluated for use with numerous insects. The Conrel hollow fiber wick and some of its applications have also been reviewed (Paul and Harris 1976). Release rates from the Conrel system can be adjusted by changing the number of hollow fibers and each fiber may contain a different pheromone component for insect attraction.

Since sex pheromones are often easily chemically degraded and since the resulting degradation products are often potent inhibitors of attractants, the addition of an antioxidant may be required (Beroza et al. 1973). Wolf et al. (1972) found that the addition of antioxidant UOP 688 or UOP 88 allowed the cabbage looper, Trichoplusia ni (Hubner), pheromone to remain attractive up to 158 days. During the same time period, the pheromone without the antioxidant became completely inactive. Neumark, Waters et al. (1975) had similar success with UOP 688 when added to the pheromone of Spodoptera littoralis.

Since the discovery of the sex attractant of the pink bollworm, workers have been evaluating various means of formulating the pheromone for field use. Early work with female extracts showed that the extracts would remain attractive for up to 32 days (Ouye and Butt 1962). Berger et al. (1964), however, found similar extracts to lose attractiveness after only four to five days. Bierl et al. (1974) tested several concentrations of gossyplure on filter paper with and without the keeper trioctinoin. The trioctonoin did not improve the PBW capture and they suggested that gossyplure may be unstable and that the addition of a stabilizing agent may be required for field use. They also recommended a dosage of 100 µg of gossyplure per trap for PBW survey studies.

Since the antioxidant UOP 688 had been shown to improve the attractancy of hexalure (Newmark, Green and Teich 1972), Bierl et al. (1974) tested it with gossyplure. They determined that UOP 688 did not decrease the attractancy of gossyplure but they were unable to evaluate its effectiveness as an antioxidant for an extended period of time. Flint et al. (1974) were able to evaluate both UOP 688 and UOP 88 and found no significant increase in PBW catch due to the antioxidant during the 30 day test.

Flint et al. (1974) also tested various doses of pheromone per trap and four wick designs. Red rubber sleeve stoppers treated with 1000 μg of gossyplure proved to be better than dental roll and nylon rug sections, but were equivalent in catch to polyethylene stoppers. Doses of 50 μg to 109,350 μg gave no indication of loss of capture due to excess lure, suggesting that the emission rate of the red rubber stopper was fairly const nt or that the PBW responds to a wide range of pheromone concentrations. Flint et al. (1978) recently determined that the male PBW will respond equally well to gossyplure emission rates of 0.012-0.98 μg/h during May and July and 0.084-8.8 μg/h in September and that single virgin native females are as attractive as septa baits treated with 1000 μg of gossyplure.

Neumark, Jacobson and Teich (1975) treated 1 cm squares of Whatman filter paper with gossyplure (50-500 μg). Doses without antioxidant were inactivated within 10 days, while those with the antioxidant UOP 688 remained attractive for up to two months. Also, the UOP 688 increased PBW catch by 2.5 times, suggesting a synergistic effect. They recommended 8 mg of UOP 688 per 250 μg of gossyplure per dispencer for monitor traps, with wick changes every month for safety.

Marks (1976) evaluated gossyplure doses ranging from 10^{-3} μl to 10 μl per wick and found no significant difference in catch, but noted that concentrations of less than 1 µl exhibited apparent loss of attraction after 32 days. The addition of BHT (antioxidant) at 8.4% with gossyplure did not increase attractant life in a 28-day field test.

Work done with gossyplure by Henson (1977) indicates that it is a very stable compound that probably undergoes little change in the environment and when exposed to field temperatures would probably volatilize rapidly.

The most recent work by Flint et al. (1978) indicates that rubber septa wicks treated with 3570 µg of gossyplure (emission rate of about 0.2-2 µg/h) would be attractive for a six month period.

PBW Mass Trapping

Early male PBW mass trapping attempts were made by Graham, Martin et al. (1966) using female extracts and cyanide traps. This attempt was not successful because of a lack of field isolation and the use of too few traps. Guerra, Garcia and Leal (1969), using female extracts plus propylure, attempted to control a caged population of PBW. Results were encouraging but control was not attained, apparently because mating occurred prior to entrapment and the cotton may have been more attractive than the traps. Flint et al. (1976) conducted a mass trapping test utilizing the Huber Stikem trap and again the results were encouraging. Insecticide applications were required, but boll infestations were substantially lower than during previous years when traps were not used.

Mass trapping of other insects such as the red-banded leafroller, Argyrotaenia velutinana (Walker), (Trammel, Roelofs and Glass 1974; Taschenberg, Carde' and Roelofs 1974), gypsy moth, Prothetria dispal (L.) (Beroza et al. 1973) and codling moth, Laspeyresia pomonella (L.) (Madsen, Vakenti and Peters 1976) have provided evidence that this technique can be relatively successful.

One critical aspect of a mass trapping program is the density at which the traps must be placed in the field for optimum catch. Several parameters make determination of the optimum density difficult. Competition between native females and traps must be considered (Knipling and McGuire 1966, Campion 1974, Howell 1974). The size of the area from which the trap will attract moths, and the efficiency of the trap, are also important. Wolf, Kishaba and Toba (1971) have indicated that with a highly efficient trap the total catch can be increased without increasing the number of traps required. Finally, the percent of male moths that must be captured to obtain the desired level of control should be known. Knipling and McGuire (1966) have indicated that a high percentage (90% or more) of the males must be captured to obtain a high degree of population suppression.

Wolf et al. (1971), Hartstack et al. (1971) and McClendon et al. (1976) have proposed methods for determination of optimum trap density, based in part on field studies and theoretical models.

Using hexalure-baited traps at densities of 1, 2, 4, 8 and 16 acres per trap, Embody (1971) found that the total catch of PBW per acre increased steadily as trap density increased.

H. M. Flint (personal communication; Western Cotton Research Laboratory, USDA-ARS; Phoenix, Arizona 1978) determined that under light PBW populations, 2.5 gossyplure-baited Huber Stiky traps per hectare are optimum when the total number of captured males does not exceed about 25 moths per hectare per week. When catches increase to about 50-200 males per hectare per week, a density of 12 traps per hectare is optimum.

METHODS AND MATERIALS

Research Location

The 1976 research was conducted in commercially grown cotton fields located approximately four miles south of Marana, Arizona. Both long-staple, *Gossypium barbadense* (L.) and short-staple, *G. hirsutum* (L.) cotton fields were utilized for this research. Cotton plant development was monitored and daily temperatures were obtained from The University of Arizona experimental farm located one-half mile west of Marana, Arizona. Insect pest problems were managed according to insect pest management principles.

The single 1977 experiment was conducted in a short-staple bulk cotton planting located on The University of Arizona Casa Grande Highway Farm, Tucson, Arizona.

Trap Design

For all wick analyses and trap density research conducted, the following trap designs were utilized and maintained as described.

The Huber Stikem trap (Figure 1) developed by Roger Huber (personal communication 1975) consists of a 480 ml carton with four holes (2.5 cmd) cut in the sides. The carton is inverted and the lid coated with Stikem Special (Michel and Pelton Co., Emeryville, California). The

Figure 1. Huber Stikem Male Pink Bollworm Trap.

traps were hung by a short string from 1.9 cm x 1.9 cm x 90 cm wooden stakes.

The Huber oil trap (Figure 2) consists of a 240 ml hot/cold beverage cup and lid. Four holes (2.5 cm d) are equally spaced around the upper one-third of the container. For this research, either 120 ml of cotton-seed or light-weight machine oil was used as the trapping media. The traps were attached to 1.2 m long wooden stakes and the oil levels were maintained to within 6 mm of the bases of the trap holes at all times.

When large numbers of PBW male moths were captured in the oil traps, counting was facilitated by straining the oil through a small colander and then counting the PBW moths in the colander. A volumetric method of counting the moths was also devised but never utilized in the field. It was determined that approximately 35 moths occupy a volume of 1 ml.

The Sharma omnidirection PBW trap (Figure 3) (Sharma et al. 1973) consists of the lower portion of a one-gallon ice cream carton with eight 2.5 cm holes. The base is coated with Stikem Special and a lid is placed over the top. The trap was hung from an adjustable metal rod.

Unless indicated otherwise, whenever the various trap designs were utilized in the field, they were maintained

Figure 2. Huber Oil Male Pink Bollworm Trap.

Figure 3. Sharma Male Pink Bollworm Monitor Trap.

just above the cotton canopy. Sharma, Rice et al. (1971) determined this to be the optimum trap height.

Rubber tubing wicks were hung in the center of the various traps using T-pins while Conrel hollow fiber wicks (Controlled Release Vapor Dispensing Systems, Norwood, Massachusetts) were hung using hair Clippettes (Faberge Inc. Omaha, Nebraska). When more than one Conrel was placed within the trap at a time, the wicks were placed side by side in the Clippette.

Gossyplure Wick Design

Research was conducted in which PBW pheromone wicks of various ages and designs were analyzed for attractiveness to male PBW's. Included in the analysis were the Conrel hollow fiber wick, gossyplure treated rubber tubing wicks utilizing either hexane or methylene chloride as the solvent, and aged wicks and pheromone. The 1976 tubing wicks were treated with gossyplure produced by the Farchan Chemical Co. (Willoughby, Ohio), while the 1977 wicks were made with pheromone produced by Chemical Samples Co. (Columbus, Ohio).

The Conrel wick (Con-10) consists of 10 hollow fiber strands containing gossyplure and mounted on a self-sticking adhesive backing. The wick is designed to last approximately 90 days with a release rate of 5 μg per day (D. Swenson 1976). Both a 10 fiber and a five fiber wick (Con-5) were evaluated.

For the other wicks analyzed, sections of red rubber tubing (6.25 mm ID, 3.13 mm thick) (Garlock Inc. Palmyra, New York) were utilized as the substrate. All such rubber wicks were treated with 1000 μg of gossyplure using 0.25 ml of methylene chloride (Flint et al. 1974) or hexane as the solvent.

To determine if gossyplure treated rubber wicks degraded during storage, tests were conducted using wicks (W) which had been treated with pheromone (P) in the spring of 1975 and stored at 6°C for approximately one year (75WP). These wicks consisted of 6.25 mm long cross sectional slices of tubing treated on one cut surface with gossyplure using methylene chloride as the solvent. Similarly, to test for degradation of the pheromone itself, gossyplure which had been stored at 6°C since the spring of 1975 was used to treat wicks (76W75P) in the spring of 1976. All rubber wicks for 1976 were 9.38 mm long sections of tubing which initially had been cut in half linearly. The linear cut edges were treated with gossyplure. Methylene chloride was also used as the solvent for the 76W75P wicks. The other wicks tested were treated with 1976 gossyplure utilizing hexane (76HEX) or methylene chloride (76MC) as the solvent.

Early Season Gossyplure Wick Evaluation

Four replications of each of the above wick types were tested in three different cotton fields which had been in cotton the previous year. The wick analysis was conducted in the Huber Stikem trap.

The rubber tubing wicks were changed after six weeks, while the Conrel wick, which is designed to last approximately 13 weeks, was not changed. Initially the Conrel wicks were not available for analysis. On May 22, 1976, they were placed in traps previously containing other microcapillary wicks. Therefore, the rubber tubing wicks were evaluated from May 7 through June 29 (traps checked 13 times) and the Conrels were evaluated along with the rubber tubing wicks from May 22 to June 29, 1976 (traps checked nine times).

Traps were generally checked two times per week. Whenever checked, the traps were cleaned, the male PBW moths counted, the Stikem stirred to renew its capture surface and the traps rotated one position. Trap rotation was employed to minimize any positional advantage a particular treatment may have had because of an uneven PBW population distribution in the field.

Because early season cultural practices prevented field placement of the traps, they were initially placed 60 m apart along irrigation ditches and 0.45 m off the ground. As fields became available (May 28 and June 1) the traps were transferred to them. All replications were spaced as follows: replication 1, six traps in a single row 41.4 m apart; replication 2, six traps (three per row) spaced 41.4 m apart in the row and 50 m between rows; and replications

3 and 4, 12 traps (six per row) spaced 47 m apart in the row and 65 m between rows.

Replications containing traps which had been replaced during the study because of destruction by machine operations were not included in the analysed data, since it has been noted that even though the sticky capture surface is stirred regularly, pheromone traps become less attractive to insects with age (Starratt and McLeod 1976, Westigard and Graves 1976, and Tingle and Mitchell 1975). The "trap effect" may be due to the presence of an inhibitor or repellant which originates from decaying insects in the trap, chemical changes in the sticky surface, or autooxidation or other decomposition products of the pheromone which are adsorbed by the trap and remain behind when a new wick is installed (Starratt and McLeod 1976).

Mid and Late Season Gossyplure Wick Analysis

The Huber Stikem male PBW trap was again utilized to compare the attractancy of the Conrel (Con-10) and rubber tubing wick (76MC). Twelve rows of traps spaced 22 cotton rows apart (22 m) and separated by 43.5 m in each row were placed in an approximate 8.1 hectare block of short-staple cotton. Six of the trap rows contained 10 traps with the Con-10 wick, while the alternate six rows contained nine traps with the 76MC wick. Initially on June 25, 1976 all the traps contained Con-10 wicks; however, on July 22, the wicks in the alternate rows were changed to 76MC wicks and on August 2, all the traps were cleaned, adjusted to the correct height and all stikem was stirred. The wick comparison, therefore, began on August 2nd.

The 76MC wicks were hung in the normal manner while the Con-10 wicks were stapled (parallel to the hollow fibers) in the inside top of the traps and then folded in half to maximize exposure to the atmosphere.

Trap catches were counted once on September 25 and a paired t-test was performed on the data collected from a total of 43 trap pairs which were in satisfactory condition on this date.

An additional comparison of the solvents hexane and methylene chloride for treating rubber tubing wicks was made later in the season (September 9 to November 3, 1976) in two separate 28 hectare fields of long-staple cotton. This comparison was conducted in eight Huber Stikem traps which were placed in two rows spaced 44.1 m apart and separated in each row by 43.5 m. One row of traps contained the 76HEX wicks while the other contained the 76MC wicks. The two rows of traps were centrally located within the fields.

The traps were hung on lateral branches approximately 15 cm from the tops of the cotton plants and were normally checked and cleaned every seven days. Trap counts were taken three times in field 1 and four times in field 2. Wicks and stikem bases were replaced after the third check. Data were analyzed using a paired t-test.

An additional wick evaluation was conducted to determine the effectiveness of various numbers of Con-10 wicks as compared to a single 76HEX wick when used in a Sharma monitor trap. Two Sharma traps, one containing the Con-10 wicks and the other the 76HEX wick, were centrally located in a short-staple cotton field 82.5 m apart and an equal distance into the field. The traps were rotated whenever checked for the first one-third of the study, after which rotation was discontinued. One, two and three Con-10 wicks were compared to the single 76HEX wick during the following respective time periods: July 9 to August 20, August 20 to September 8 and September 8 to November 11, 1976.

The Wilcoxon sign pair test was used to statistically analyze the data at the 0.05 level of significance (Alder and Roessler 1964). PBW catch was also graphed over time for a qualitative evaluation of the wicks.

Evaluation of Gossyplure Wick Longevity

Research was conducted in three ways to evaluate the longevity of gossyplure wicks. From May 11 to October 11, 1976 the longevity of the 76HEX and 76MC wicks were evaluated and from June 4 to October 11, 1976 the longevity of the Con-10 wicks were evaluated utilizing the Huber Stikem trap. The traps were maintained as previously described except that late in the season the traps were maintained within the top 15 cm of the cotton canopy rather than 5 to 8 cm above it. Except for early in the season when the traps were positioned along the edge of the field because of cultural operations, the research was conducted within short-staple cotton fields.

The study consisted of six traps, two with each wick type, one of which was maintained fresh by replacement and the other was left to age. The Con-10 wick replacements were on the 6th, 11th and 17th week while the 76MC and 76HEX wicks were replaced on the 10th, 15th and 21st week of the study. At termination of this study, the unchanged Con-10 wick had been aged for a total of 19 weeks and the unchanged 76MC and 76HEX had aged a total of 23 weeks.

The traps were spaced 41.1 m apart until late in the season, when they were adjusted to 20 m because of lodged cotton conditions. Traps were checked and rotated one position two to three times per week except when prevented by insecticide applications.

Trap catch data are graphed as percent efficiency of the unchanged wick compared to the changed wick (accumulated male PBW catch compared at weekly intervals), as a means of indicating any loss of attractancy in the unchanged wick over time.

An additional analysis of longevity of the 76HEX wick was conducted from August 3 to November 3, 1976 in two Sharma traps. One Sharma trap contained a wick (aged two weeks at initiation of this analysis) which was not changed throughout the study and the other contained a wick which was changed every four weeks. The comparison continued for a total of 10 weeks.

The two stationary Sharma traps were centrally located in a short-staple cotton field spaced 100 m apart and 16.5 m into the field. The traps were checked once or twice per week. Data (catch by date) were analyzed using the Wilcoxon sign paired test at the 0.05 level of significance (Alder and Roessler 1964).

A third wick longevity study was conducted in the fall of 1977 in which rubber tubing wicks with no field exposure, 15 weeks and 38 weeks field exposure, and an untreted wick were compared. Until used in the research, the wicks were aged as follows: 1) treated in the spring of 1977 and stored at 6°C; 2) treated in the spring of 1977 then exposed in a Huber oil trap in a mass trapping program from June 10 to September 20, 1977; 3) treated in the spring of 1976 (76HEX) and stored at 6°C until January of 1977, then pinned onto a wooden stake and completely exposed to the field environment; and 4) an untreated section of rubber tubing (blank). Extreme care was taken to prevent pheromone contamination among treatments.

The research was conducted in a four-acre plot of short-staple cotton and each treatment was replicated four times. The field was divided into four approximately equal blocks and within each block the four treatments were randomly placed at the corners of a square having sides of 15 m. Male PBW catches were recorded for 12 consecutive days (October 11th through October 22nd) and wicks were rotated one position at each check.

Kitterman Insect Monitor Trap Evaluation

The Kitterman Insect Monitor trap (Conrel ; Norwood, Massachusetts), which is designed to be used as a monitoring tool for a wide variety of insect pest species, was evaluated to determine its effectiveness as a male pink bollworm monitor trap. The standard design (Figure 4) and modifications of it were compared at various times throughout the cotton growing season.

The various design combinations evaluated included: 1) the commercially available design, which consists of an opaque plastic base that is precoated with a thin layer of Tanglefoot (The Tanglefoot Co., Grand Rapids, Michigan) and is baited with a Con-10 wick (Tanglefoot, Con-10); 2) the standard design except that the Con-10 wick was replaced with a 76HEX wick (Tanglefoot, 76HEX); 3) a Stikem coated green polyester base with a 76HEX wick (Stikem, 76HEX); 4) same as number three except two Con-10 wicks were used in place of the 76HEX wick (Stikem, 2Con-10); and 5) Stikem

Figure 4. Kitterman Insect Monitor Trap.

coated cardboard base with a 76HEX wick (Stikem, Cardboard, 76HEX).

The research was conducted in long-staple cotton (Pima S-5). The traps were placed on 2.4 m sectional wooden stakes and maintained at a height of 5 to 8 cm above the cotton canopy at all times. The traps were placed in a line 41.4 m from the field edge and spaced 50 m apart.

All traps were rotated one position per week for the first four weeks of the research and rotated thereafter each time the traps were checked (one to three times per week). Whenever the traps were checked, the sticky surfaces were cleaned of insects and trash and then thoroughly stirred to renew the surface.

The pheromone wicks were changed every four to five weeks and the sticky bases were replaced entirely when appropriate except late in the season when the Stikem bases were simply scraped clean and a fresh layer of Stikem was applied.

Trap catches were graphed over time for a qualitative evaluation of the various designs.

Trap Density Research

Research was conducted in an effort to determine the optimum density at which PBW pheromone traps should be deployed in a mass trapping program. Both the Huber oil and Stikem trap were evaluated at rates of 2.5-15/hectare (one to six per acre) and 7.5-15/hectare (three to six per acre), respectively. The 76HEX wick was used in both traps.

To establish the various densities the trap rows were separated by a standard distance of 25 cotton rows (25 m) and the distances between the traps were adjusted to 157.2, 78.5, 52.5, 39.3, 31.5, and 24.1 m for the respective densities of 2.5-15/hectare. In each case, two rows of alternately spaced traps were used.

The oil trap density research was conducted in three short-staple cotton fields. Replication 1 (Oil I; five-15 traps/hectare) was conducted in a single 12.4 hectare field and replication 2 (Oil II; 2.5-15 traps/hectare) was conducted in a 16 hectare and a 32 hectare field. Movement of the density traps was necessitated because of cultural activities.

Oil I (field 1) was divided into approximately one hectare rectangular blocks (142.5 m x 64.8 m) among which the various trap densities were randomly deployed. Two rows of traps were centrally located within each block. The treatment row pairs were separated from other row pairs by 40 m and edge traps were 20 m from the field edge. The end traps were placed 30 m from the end of the cotton row.

Oil II (fields 2 and 3) was set up in a similar manner, except that the end of a cotton row was considered to be a trap position. Therefore, the first trap in the field was spaced the appropriate distance from the row end depending on the density of that treatment. Also, because field 3 was larger, the treatment row pairs were separated by 69.8 m and edge rows were 32.9 m from the field edge.

The number of traps per treatment in Oil I for the rates of five, 7.5, ten, 12.5 and 15 traps/hectare were eight (two replicates of four), six, seven, nine, and ten, respectively, and in Oil II: six (two replicates of three), six (two replicates of three), five, five, seven, and seven, respectively, for the rates of 2.5, five, 7.5, ten, 12.5, and 15 traps/hectare.

The traps in Oil I were maintained just above the cotton canopy top, while the traps in Oil II were located 20-25 cm below the canopy top because the cotton height exceeded that of the 1.2 m trap support stakes. However, the cotton in Oil II had been defoliated and picked, making the canopy very open. The Stikem traps were hung from the upper lateral branches of the cotton plants, generally within 15 cm of the plant top.

The research was conducted from October 9th to November 12th in field 1, November 1st to November 8th in field 2 and November 13th to December 6th in field 3.

Traps were checked two to three times per week for a total of ten times in field 1 and ten times in fields 2 and 3 combined. At each check the male PBW's were removed and the oil level was maintained as required.

In Oil I the two highest counts of each density treatment were not included in the data analysis, to decrease the apparent edge effect indicated by exceptionally high catches in certain border traps.

The Stikem trap density study was conducted in long-staple cotton. The treatments (7.5-15 traps/hectare) were not replicated with five, five, six, and seven traps per treatment, respectively. The research was conducted between October 11th and November 29th for a total of 35 trapping days. Due to cotton picking operations, the traps were occasionally moved and were not in the field at all times. The traps were checked a total of ten times. To eliminate a possible edge effect, the field border trap was excluded from each treatment for purposes of data analysis.

Since in both the oil and Stikem density studies the number of traps per density varies, as indicated above, the mean catch per trap was first determined and then multiplied by the number of traps for that rate. This yielded the catch per hectare for each date the traps were checked.

Data Analyses

Analyses of variance for both equal and unequal sample size, when applicable, were used to evaluate data from the early season wick comparison, the 1977 wick longevity study, and the trap density study (catch/trap) (Statistical Package, Western Michigan University 1974).

Duncan's Multiple Range Test (Duncan 1955) corrected for unequal replication number, when applicable (Steel and Torrie 1960, page 114), was used to separate means when significant differences existed. In all the above tests the significance level used was 0.05.

All data analyzed by means other than Analyses of Variance have been previously described in the text.

RESULTS AND DISCUSSION

Gossyplure Wick Analyses

Results of the early season (May and June) wick analysis (Table 1) show no significant differences among the six wicks evaluated. These results indicate that: 1) storage for up to one year of gossyplure or gossyplure-treated wicks does not cause significant loss of attractancy, 2) hexane and methylene chloride are not significantly different when used as solvents for treating gossyplure wicks, and 3) the Con-10 and Con-5 wicks are as attractive as the rubber tubing wicks.

Male PBW catch by the 76W75P wick indicates that some pheromone degradation may have occurred, though not statistically significant. The fact that the 75WP wick, which was made with the same pheromone as the 76W75P, attracted more moths indicates that the antioxidant within the rubber tubing may have prevented degradation of the pheromone, whereas the stored pheromone without antioxidant may have undergone some chemical breakdown. Prior to November of 1976 pheny-beta-naphthylamine was used as the antioxidant; since then polymerized 1,2, dihydro-2,2,4 tri-methyl-quinoline and a reaction product of diphenylamine and di-isobutylene have been used (F. P. DeRosa 1978). Neumark,

Table 1. Comparison of Gossyplure Wicks of Various Ages and Designs for Trapping of Male PBW in the Huber Stikem Trap.

	Average Catch/Trap/Day[a]			
Wick	May 7-June 29	May 22-June 29	July 21-Oct. 11	Sept. 9-Nov. 3
75WP	3.64 (4)[b]	2.54 (4)	-	-
76W75P	2.04 (3)	1.56 (3)	-	-
76MC	3.35 (3)	2.27 (3)	2.35 (2)	2.53 (8)
76HEX	3.56 (3)	2.11 (3)	2.51 (2)	2.39 (8)
Con-10	-	2.09 (4)	1.18 (2)	-
Con-5	-	2.46 (4)	-	-

[a] No significant differences at 5% confidence level.
[b] Number in parentheses equals the number of replications.

Waters et al. (1975) noted an apparent inhibition of pheromone degradation due to the presence of an antioxidant in the rubber septa they analyzed.

Maitlen et al. (1976) evaluated the effects of storage on codling moth pheromone wicks. They evaluated treated rubber sleeve stoppers after 72 days of storage at 4^{o}, -9^{o} and $-40^{o}C$. Four percent of the pheromone was lost at the two lowest temperatures, while 11% was lost at $4^{o}C$. They also analyzed treated stoppers after 30 days at room temperatures. From both tests they concluded that loss of pheromone was primarily due to evaporation and not chemical degradation. They did not evaluate the pheromone in the absence of an antioxidant (assuming one was present in the rubber septa).

Data in Table 1 also indicate that there was no significant difference between the two solvents (methylene chloride and hexane) used to treat wicks. This is in agreement with what Graham, McGough and Jacobson (1966) found. They compared several solvents, including hexane and methylene chloride, for impregnating heavy filter paper wicks with female sex attractant extracts and found no significant differences.

Results of later research conducted during July to October and September to November, which was also an evaluation of these two solvents, are in agreement with the earlier test results (Table 1).

The early season comparison also indicates no significant differences between the Con-10 and Con-5 and rubber tubing wicks (Table 1). Bierl et al. (1974), Flint et al. (1974), Marks (1976), and Neumark, Jacobson and Teich (1975) determined that male PBW respond to a very wide range of gossyplure doses per trap. This fact may explain why the Con-5 and Con-10 were not significantly different. Flint et al. (1978) have determined the emission rates of gossyplure rubber septa treated with 1000 µg of pheromone. Early in the season (May and July) male PBW respond equally well to emission rates of 0.012-0.98 µg/h and during September they respond to rates of 0.084-8.8 µg/h. The Con-10 and Con-5, which are designed to release gossyplure at the rate of 2.5 µg/day (0.104 µg/h) and 5 µg/day (0.208 µg/h), respectively, would readily fall within these ranges. Therefore, no significant differences would be anticipated.

Data from the wick comparison test (July 21-October 11) (Table 1) indicate a two-fold difference between the Con-10 and rubber tubing wicks; however, since there were only two replications of each treatment, the differences were not determined to be statistically significant. This comparison was initially designed to evaluate wick longevity; but since no loss of attractancy occurred between the changed and unchanged wicks, it was also considered a wick comparison test.

Results of two other tests in which the Con-10 wick was evaluated agree with the above (July 21-October 11) results. When compared in the Sharma monitor trap, the 76HEX wick attracted up to 15 times as many male PBW moths as did the Con-10 (Table 2) and the comparison conducted in the 8.1 hectare block of short-staple cotton showed a significantly lower catch by the Con-10 wick. The Con-10 wick captured 22.3 male PBW/trap, compared to 46.2/trap for the 76MC wick during the 54 day period of the analysis.

There are a number of possible reasons which may explain why the Con-10 varied in attractancy from early season to mid and late season. Convection and diffusion of the pheromone from the hollow fibers may have varied because of changes in wind velocity or temperature. Wind velocity in the area where this research was conducted is generally highest during April, May and June (U. S. Air Force, Air Weather Service 1945). This suggests possibly that convection and diffusion out of the hollow fibers may have been greater during the early season, thereby making the wicks more attractive. Average nightly temperatures were 8^{o}F cooler during the early season wick evaluation than during the later comparisons conducted in the Huber Stikem trap. A decrease in temperature would mean a lower release rate (Paul and Harris 1976). Whether lower release rates would have made this wick design perform better is not known.

Table 2. Comparison of Conrel Hollow Fiber and 1976 Rubber Tubing (Hexane Solvent) Gossyplure Wicks in the Sharma PBW Monitor Trap[a].

Number of Wicks	Male PBW Catch/Day		
	July 9-Aug. 20[b]	Aug. 20-Sept. 8[c]	Sept. 8-Nov. 3[b]
Con-10			
1	7.75	-	-
2	-	2.11	-
3	-	-	10.70
76HEX			
1	40.00	32.47	29.41

[a] Treatments are not replicated.
[b] Treatments significantly different at the 5% confidence level according to Wilcoxon's signed rank test.
[c] Insufficient data for statistical test.

Other factors such as humidity and debris or dust which may have clogged the hollow fibers may have also affected the performance of the Conrel wicks.

A possible reason for lower catches by the Conrel wicks in the 8.1-hectare comparison may be because these wicks were stapled to the inside top of the trap. This may have slightly reduced pheromone release by reducing convection of the pheromone away from the hollow fiber openings. This is one of the factors which determines pheromone release in the hollow fiber system (Paul and Harris 1976). Without sufficient air circulation, convection away from and diffusion out of the hollow fiber may have been retarded. Also, the canopy grew up and over some of the traps in the 8.1-hectare plot and may also have reduced air circulation.

Reduced convection may also have been a factor when the Conrel wicks were used in the Sharma trap, since less air circulation would take place within a Sharma than within a Huber sticky trap.

Other workers have evaluated the hollow fiber pheromone release system. Johnson et al. (1976) compared the Conrel wick containing grandlure with a polyethylene glycol mixture impregnated on a cigarette paper and enclosed in a glass vial. The Conrel wick was the less effective of the two. Marks (1976) evaluated narrow-bore capillary tubes and found them to be less efficient than other release systems tested. Reissig (1974) also tested the Conrel system and found that it caught considerably fewer apple maggot flies than liquid baits tested.

The hollow fiber dispenser has proven to be more attractive than a polyethylene vial dispenser for use in trapping the elm bark beetle and has proven successful in mating disruption work. Paul and Harris (1976) reviewed these and other applications of the Conrel system.

Along with the numerical evaluation of the attractiveness of the Con-10 wick, Figure 5 illustrates how the Con-10 and 76HEX wicks perform when used in a Sharma PBW monitor trap. A monitor trap should not only detect the general population fluctuations, but it should also indicate the magnitude of these fluctuations so that population density changes over time and space can be compared.

From Figure 5 it can be seen that the male PBW capture in the Con-10 baited Sharma agrees little with that of the 76HEX-baited Sharma. There is little agreement as to occurrence or magnitude of adult population changes. In addition, the peak that occurs in late September with the Con-10 wick may have been caused by high winds associated with inclement weather that occurred at this time. The wind may have increased pheromone release by increasing convection and diffusion of the pheromone away from the hollow fibers. If the Con-10 wick is readily affected by brief changes in

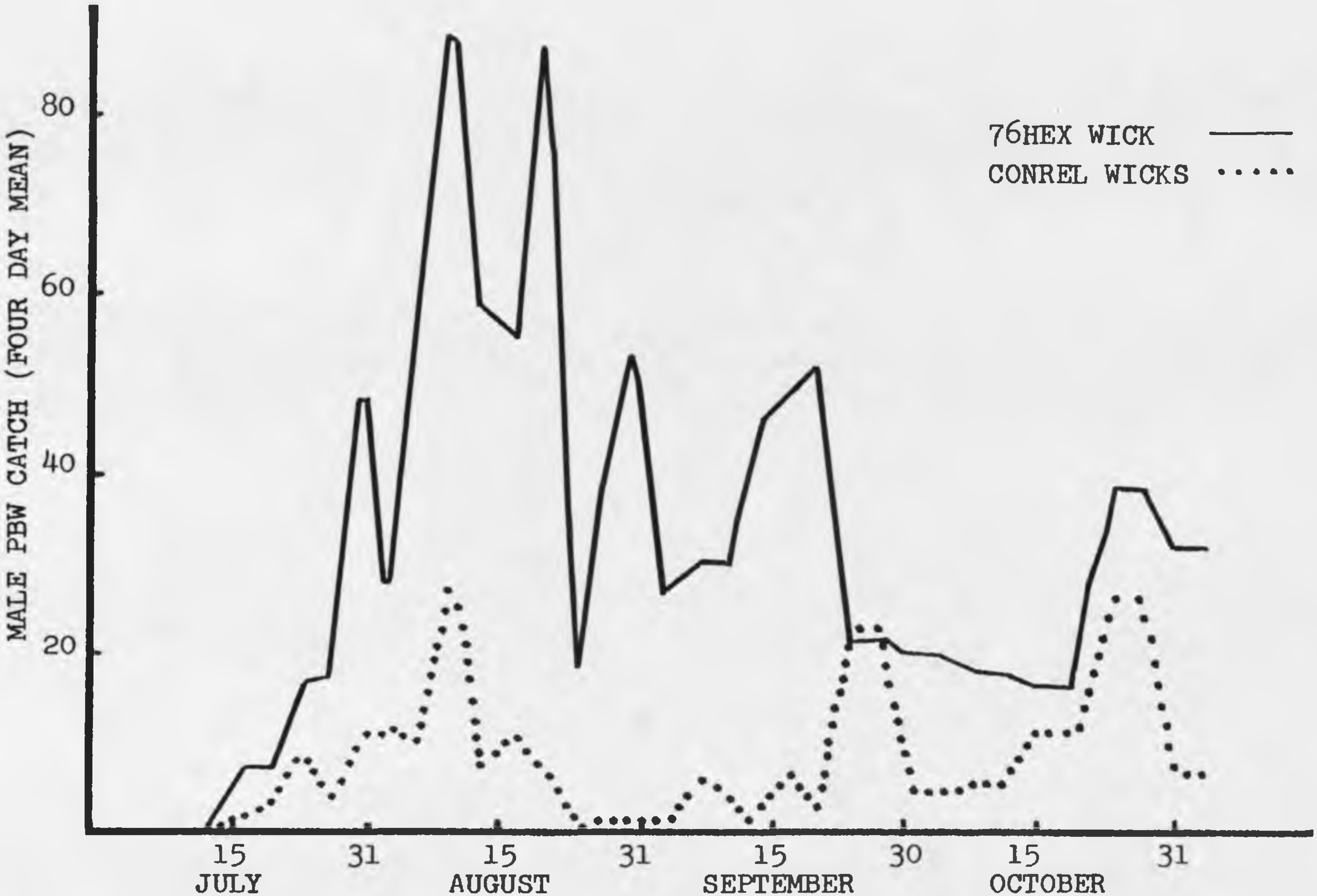

Figure 5. Pink Bollworm Population Trends in 1976 as Monitored by Two Gossyplure Wick Designs in the Sharma Monitor Trap.

the environment as suggested here, it would be undesirable for use in a monitor trap.

In this comparison, the 76HEX wick more accurately detects population fluctuations and their magnitude and, therefore, is the better wick to be used in the Sharma monitor trap.

Gossyplure Wick Longevity

Figure 6 illustrates the comparative attractiveness of the aged versus fresh gossyplure wicks in the Huber Stikem trap. To indicate if any loss of attractiveness occurred between the fresh and aged wicks over time, the respective male PBW catches were accumulated and converted to percent attractiveness of the aged compared to the fresh wicks at weekly intervals.

Considering the 76MC and 76HEX wicks only after the initial ten week period during which time no wicks were changed, there is no indication that the unchanged (aging) wick accumulated PBW males at a rate less than that of the changed (fresh) wick. From week 10 to 23 no loss of attractiveness occurred in the aging wick. If a loss of attractiveness had occurred, there would have been a decrease in percent attractiveness of the aged wick when compared to the fresh wick over time.

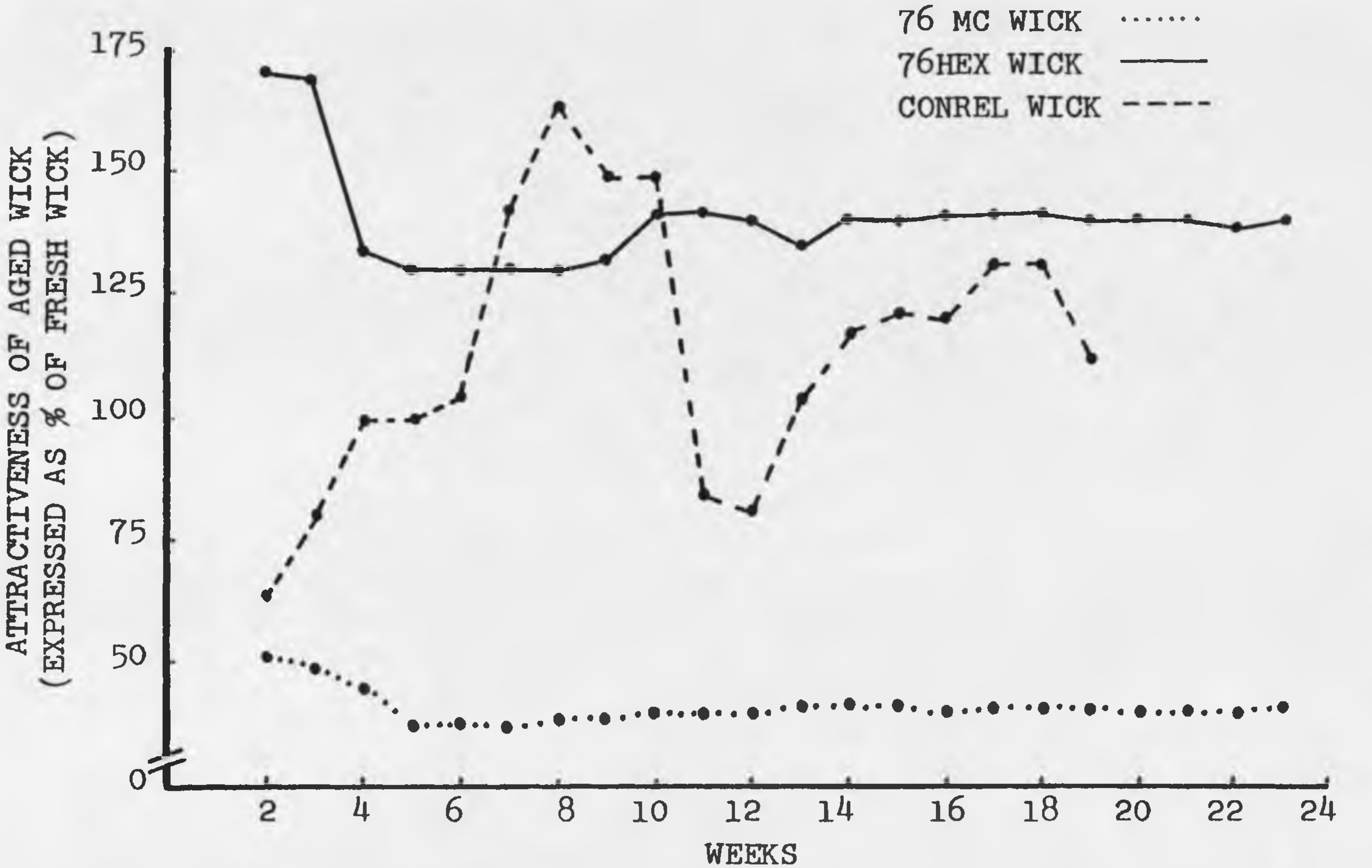

Figure 6. Attractiveness of Aged and Fresh Gossyplure Wicks.

Accumulated male PBW catches are compared at weekly intervals, Huber Stikem Trap.

There are differences in percent attractiveness between the respective wick comparison pairs; however, these differences are consistent throughout the test period and may be explained by normal variability in individual wick attractiveness or some inherent character of the particular trap containing the wick.

No apparent loss of attractiveness occurred in the Con-10 wick. There is considerable variation in percent attractiveness of the aged compared to fresh wick, but no general loss of attractiveness is indicated over the 19 week test. This research indicates that the Con-10 wick will remain attractive beyond the 90 day duration for which it is designed.

Results of the 76HEX wick longevity study conducted in the Sharma traps agree with the above results. Male PBW catch per day for the trap with the unchanged wick was 30.1, while the trap with the regularly changed wick was 31.2 per day. A sign rank test by date indicated no significant difference at the 5% confidence level.

In addition, results of the 1977 longevity study indicate that after complete exposure to the environment for a duration of up to 38 weeks, the wicks were still highly attractive (Table 3). The significantly higher catch by the 1976 exposed wick may have been due to the fact that they were treated with gossyplure manufactured

Table 3. Comparison of Attractiveness of Variously Aged Rubber Tubing Wicks Treated with Gossyplure.

Conducted in Huber Oil Trap from October 11 through October 22, 1977.

Gossyplure Treatment	Previous Field Exposure (weeks)[a]	Male PBW Catch/ Day/Trap[b]
1977HEX	None	46.48 c
1977HEX	15 (in Oil Trap)	36.65 c
1976HEX	38 (Completely Exposed)	78.71 d
None	Blank	0.27 e

[a] Four traps per treatment.
[b] Means followed by the same letter do not differ significantly at the 5% confidence level according to Duncan's Multiple Range Test.

in 1976, which may have been of higher quality than the 1977 gossyplure. There is no significant difference, however, between the field aged (oil trap) and fresh 1977 wicks.

In all the tests there is agreement that the gossyplure-treated rubber tubing wicks remain attractive for a considerable length of time and, therefore, can safely be used in male PBW mass trapping programs and monitoring situations without replacement during the cotton growing season.

Considerable research effort has gone into the testing and development of long-lasting pheromone dispensers for numerous insect species. Efforts with the pink bollworm sex pheromone have been restricted to fairly short time periods, until recently. Flint et al. (1974) evaluated longevity of rubber sleeve stoppers treated with 1000 μg of gossyplure. They found no difference in longevity when adding antioxidants to pheromone during the 30 day trial. Neumark, Jacobson and Teich (1975) evaluated gossyplure (1000 μg) squares of Whatman filter paper and did find a significant difference when an antioxidant was added to the pheromone. In the presence of an antioxidant, the gossyplure was attractive for up to two months (length of test) while gossyplure without antioxidant lost its attractiveness within 14 days. The different results obtained by these workers may be explained by the different substrates used in the research. Flint et al. (1974) used rubber septa which may have already contained an antioxidant which preserved the gossyplure in the control wicks. The Whatman filter paper probably did not contain an antioxidant, and thus allowed chemical degradation to occur.

Neumark, Waters et al. (1975), when evaluating the two different types of rubber septa for the sex pheromone of *Spodoptera littoralis*, obtained different durations of attractiveness depending on the septa used, indicating that the presence of antioxidants within the rubber septa themselves was important in preserving the pheromone.

As previously mentioned, the rubber tubing used in this research contained the antioxidant pheny-beta-naphthylamine prior to November of 1976 and since then, polymerized 1,2, dihydro-2,2,4 trimethyl-quinoline and a reaction product of diphenylamine and di-isobutylene. These apparently are important in preventing gossyplure degradation. Whether the antioxidant used prior to November of 1976 had a synergistic effect on the pink bollworm sex pheromone, as Neumark, Jacobson and Teich (1975) noted as an explanation for significantly higher catches obtained by the 76HEX wick evaluated in the 1977 longevity study, is not known.

Along with preserving gossyplure, the rubber tubing apparently retains the pheromone even at high temperatures and prevents the rapid volatilization that Henson (1977) noted. The rubber tubing also protects the pheromone from photooxidation, which could rapidly inactivate it. Photooxidation has been found to occur in the sex pheromones of <u>Plodia interpunctella</u> (Bruce and Lum 1976) and <u>Prodenia eridania</u> (Goto, Masuoka and Hiraga 1974).

The 1977 longevity study confirms what Flint et al. (1978) indicated. If gossyplure-treated rubber septa and rubber tubing have approximately equal emission characteristics and allowance is made for differences in exposures of the wick (delta trap vs. oil trap and complete exposure), a relative comparison can be made. Based on what Flint et al. (1978) determined, the initial 1000 µg dose on the rubber tubing would omit gossyplure at a rate of 0.25 µg/h and by the end of the 38 week (2.2 half-lives) evaluation, the emission rate would have been about 0.05 µg/h. This is just slightly below the range found to be optimum (0.084-8.8 µg/h). Allowing for the fact that the rubber tubing wicks would have had a lower emission rate early in the spring and late in the fall and somewhat higher in mid-season, the emission rates of the rubber tubing wicks would still be near the optimum.

The Conrel wick, which is designed to last 90 days and release pheromone at 5 µg/day (0.208 µg/h), would no doubt still fall within the optimum emission range after 120 days exposure as in this research. Therefore, the reduced catches, as previously described, must be due to one of the following factors: 1) pheromone degradation, 2) the use of poor-quality pheromone, or 3) poor pheromone release because of clogged fibers or incompatible trap design.

Kitterman Insect Monitor Trap Evaluation

Figure 7 illustrates the responce of various trap designs at various times during the season under different PBW population levels. It can be seen that population fluctuations were generally identified with each design; however, those designs using Tanglefoot (including commercially sold design) as the capture surface generally caught so few moths that large changes in the population were not readily identified. Though not apparent because catch data are modified (four day mean), the designs with Tanglefoot occasionally did not capture any moths while other designs did. Under light populations this low capture efficiency could make the actual detection of the insect difficult. Designs using Stikem as the capture surface, however, caught more moths, thereby readily identifying population changes.

The designs utilizing Stikem captured from two to almost four times as many moths as the Tanglefoot-coated traps (Table 4). Graham and Martin (1963) noted that Tanglefoot tended to harden and lose its adhesiveness after one to two days. In this research, hardening was not

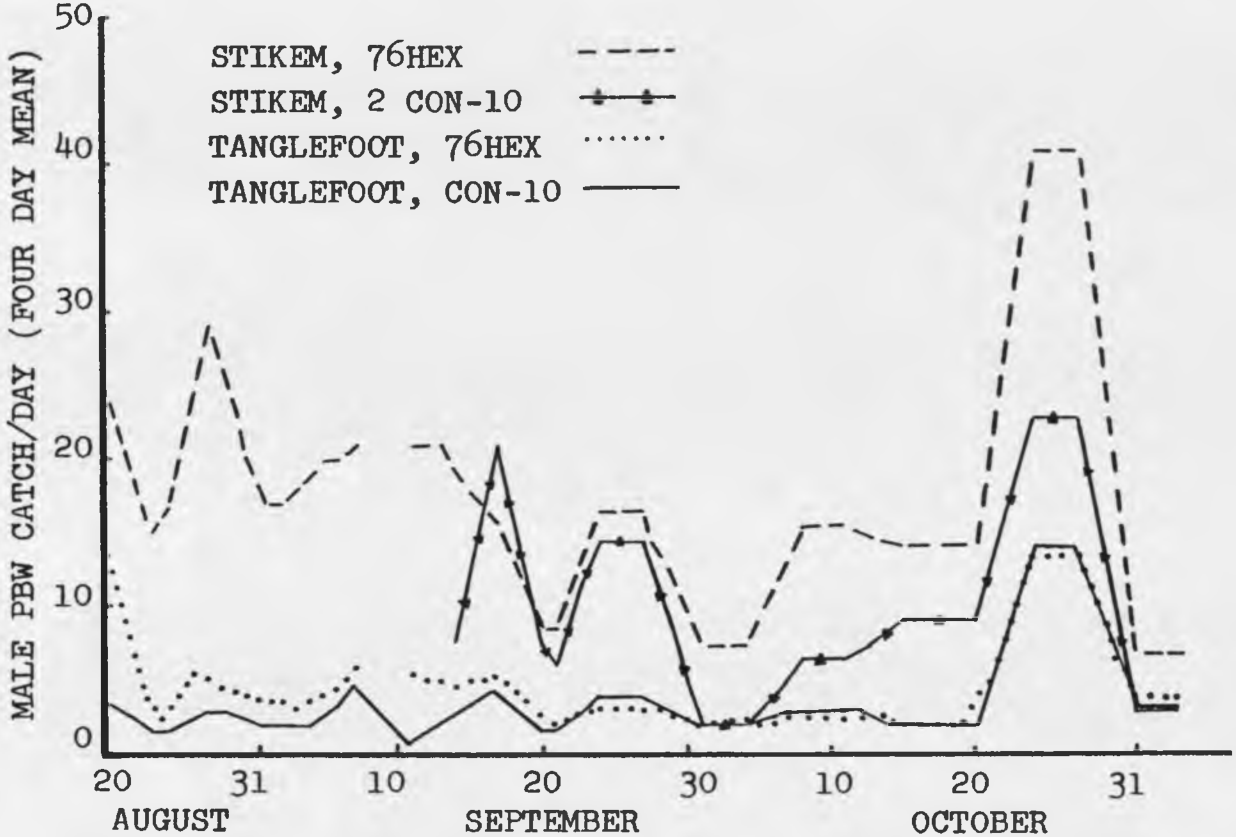

Figure 7. Comparison of Male PBW Trapping Efficiencies between Standard and Modified Kitterman Insect Monitor Traps at Marana, Arizona from August 20 to November 3, 1976.

Table 4. Comparison of Male PBW Catch in Standard and Modified Kitterman Insect Monitor Traps Conducted from September 10 to November 3, 1976.

Trap Design	Male PBW Catch/Day	Percent of Standard
Tanglefoot, Con-10[a]	4.26	100.0
Tanglefoot, 76HEX	4.33	101.7
Stikem, Con-10	9.69	227.4
Stikem, 76HEX	16.37	384.3

[a] Standard design.

noticed, but rather that after only a few cleanings (moth removals) the Tanglefoot-coated surface lost much of its adhesive quality because of the accumulation of dust and scales; when replaced with a new surface the catch increased substantially. This was noted in the Stikem-coated traps as well, but to a lesser degree.

From September 8th to 10th untreated wicks were accidentally installed in the 76HEX-baited traps. Therefore, male PBW catch for those dates are not included in Figure 7.

Reed et al. (1975) evaluated several adhesives other than Tanglefoot and Stikem and did not detect substantial differences among them. The differences in male PBW capture efficiency between Tanglefoot and Stikem may be explained by differences in chemical constituents, which may interfere with normal pheromonal communication, or by differences in physical properties. These factors would vary in importance depending on the insect being trapped. Lewis and Macauley (1976) found Tanglefoot to be seven times better than Stikem for capture of the pea moth, *Cydia nigricana* (Steph.).

When compared in traps with Tanglefoot as the capture surface, no difference in catch was noted between the Con-10 and 76HEX wick. Apparently, the Tanglefoot will capture and retain only a limited number of moths, no matter how many are actually attracted to the trap. When these same wicks were compared in designs with Stikem there were obvious differences (Table 4).

The Con-10 wick is designed for use in the Kitterman trap and, supposedly, has an emission rate which falls within the optimum range (Flint et al. 1978). However, in this research two Con-10 wicks did not attract as many moths as did a 76HEX wick, under conditions for which it was designed. These results and those from other research indicate that either the Con-10 wick does not actually emit gossyplure at the rate claimed, or the quality of the gossyplure used in the wicks evaluated was less than that in the 76HEX wicks.

Results from the comparison between a Stikem-coated cardboard base and a Stikem-coated green plastic base indicate that the plastic base is the better of the two. The cardboard base was less durable and rapidly lost its original shape, probably explaining why it caught fewer moths. For the period of this comparison (July 21-August 16) the plastic base caught an average of 26.6 male PBW/day, compared to 18.6 male PBW/day by the cardboard base.

Environmental factors such as relative humidity, temperature, wind and rainfall affect insect activity and their responses to pheromone traps (Krambias 1976, Marks 1977). These environmental factors affect the release rates of pheromone from the various wicks. How these factors affected male PBW catches in the various trap designs in this evaluation is difficult to assess, since factors such as trap rotation and base replacement may have also affected the catch.

Previous research has been conducted with traps of designs similar to the Kitterman trap. Sharma, Shorey and Gaston (1971) designed a covered open-sided circular trap with a large trapping surface for the cabbage looper. When it was evaluated in preliminary work for use as a PBW monitor, with hexalure as the bait, it rapidly became covered with unwanted insects and trash and did not efficiently capture moths. It was modified, therefore, to have only eight 2 cm holes around the edge (Sharma et al. 1973).

Marks (1976) found that a flat plywood disc with a small roof over the pheromone was not significantly different from that of a trap similar to the Sharma.

Trap Density Research

Figures 8 and 9 depict the results of the trap density studies. It can be seen that there is considerable variation in PBW catch at the various densities and between the two locations of the oil trap density study. Some of this variability may be explained by the unusually large catch of the 10 trap/hectare density in Oil I. This may be explained by the fact that in Oil I the blocks of traps were arranged across both the width and the length of the field.

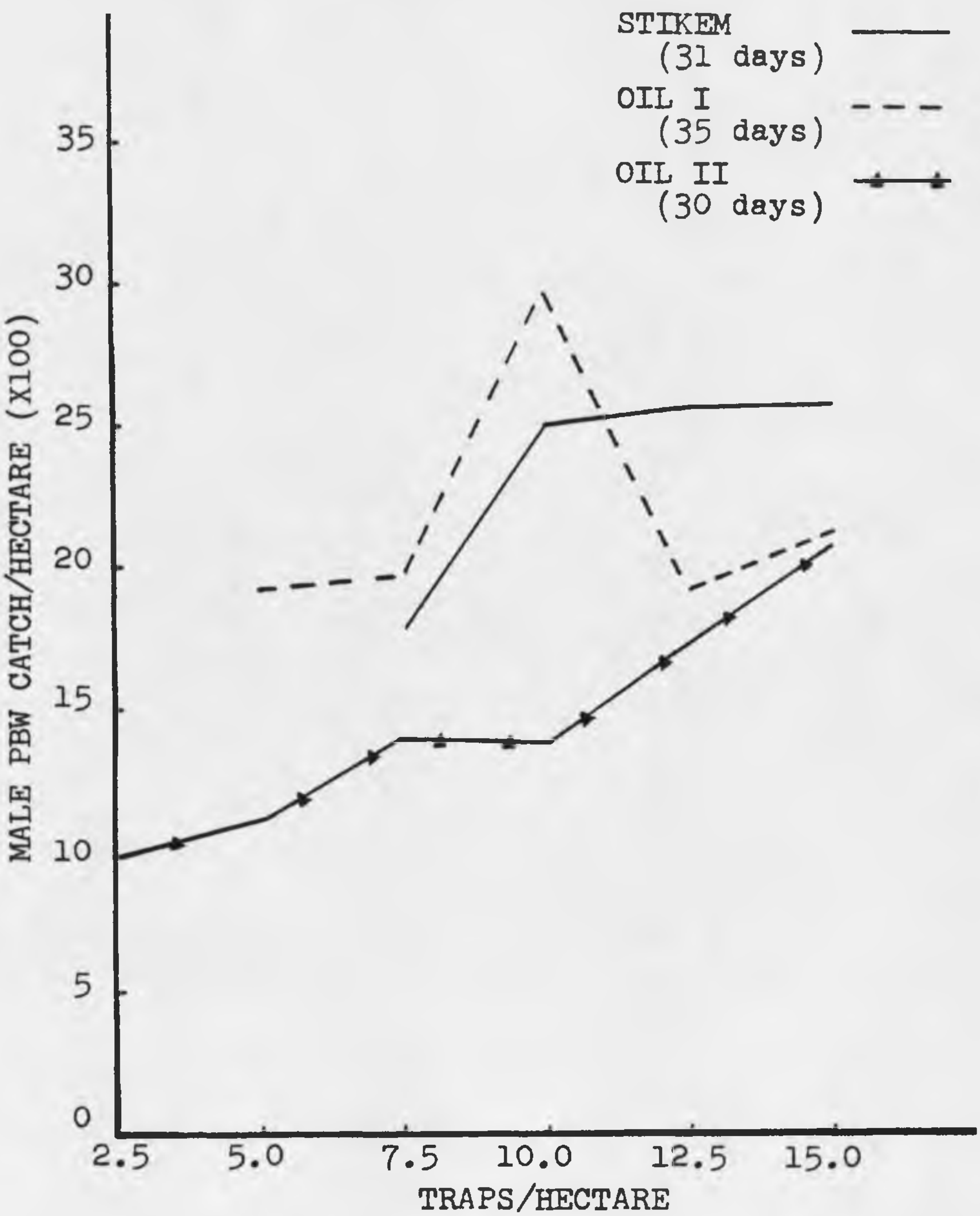

Figure 8. Male Pink Bollworm Catch per Hectare with the Huber Oil and Stikem Traps at Various Densities.

Stikem traps in long-staple and oil traps in short-staple cotton.

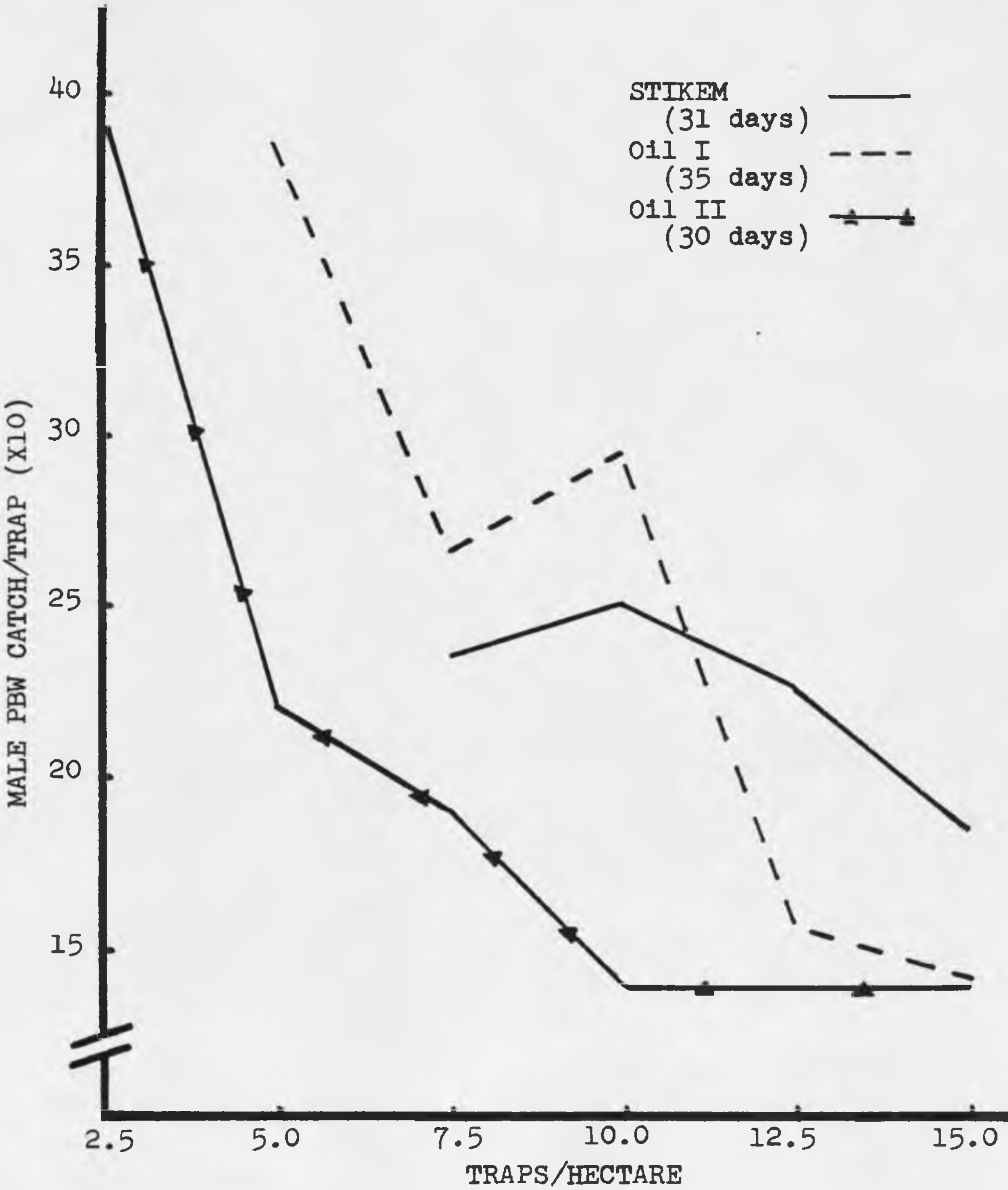

Figure 9. Average Male Pink Bollworm Catch per Trap in the Huber Oil and Stikem Traps at Various Densities.

Stikem traps in long-staple and oil traps in short-staple cotton.

Blocks arranged lengthwise along the field edge were inclined to capture more moths, especially the 10 trap/hectare density treatment, which bordered on a long staple field located about 40 miles away. In this area, prevailing winds are from the southeast (U. S. Air Force, Air Weather Service 1945). These traps were directly upwind from the long-staple field and, therefore, were subjected to additional PBW pressure. All of the other lengthwise edge blocks were bordered by fallow ground. In Oil II all trap blocks were located side by side except one at each end of the field; thus the "edge effect" was minimized.

Since the conditions under which the density studies were conducted varied, combining the data for statistical analyses would not be valid. Factors which varied between locations included: 1) trap height, 2) harvest stage of cotton, 3) number of traps/treatment, 4) spacing between treatments and distances from field edge, 5) time of year, and 6) PBW population densities. All of these factors could have an effect on determining optimum trap densities, by influencing moth behavior and/or pheromone dispersal.

It appears that in both of the oil trap density studies (Figure 8) there is a general increase in total catch/hectare as trap density increases. This trend is evident even without the large catch by the 10 trap/hectare treatment. Over these same densities there is a decrease in catch/trap as density increases (Figure 9). This would be expected since there are more traps to divide the catch at the higher densities.

These results indicate that the optimum density for the oil trap, under the conditions of these tests, may be higher than 15 traps/hectare. Optimum density may be defined as that density which captures the maximum number of insects. Densities above the optimum would not increase the number of insects captured.

Under the conditions of this study, the Stikem trap appears to reach its optimum density at about 12.5 traps/hectare. There is no major increase in catch/hectare above this density (Table 5). There is no significant difference between the catch/trap at the various densities (Table 6).

H. M. Flint (personal communication 1978) determined the optimum density of the Huber Stikem trap to be 2.5 traps/hectare when the total number of males caught does not exceed 25 male PBW/hectare/week and 12 traps/hectare when catches increase to 50-200 males/hectare/week. In this research the PBW population pressure was greater, yet the optimum trap density was found to be 12.5 per hectare. This difference may be due to the more frequent removal of male moths from the Stikem traps in the present study (two-three times per week) compared to only once per week in

Table 5. Total Male Pink Bollworm Catch per Hectare with the Huber Oil and Stikem Trap at Densities of 2.5 to 15 per Hectare.

	Total Male PBW Catch/Hectare		
Traps/Hectare	Stikem (31 days) (Oct. 11-Nov. 29) Long-Staple	Oil I (35 days) (Oct. 9-Nov. 12) Short-Staple	Oil II (30 days) (Nov. 1-Dec. 6) Short-Staple
2.5	-	-	962.1
5.0	-	1897.8	1095.0
7.5	1755.1	1954.5	1391.1
10.0	2479.4	2956.1	1361.5
12.5	2778.5	1891.3	1713.2
15.0	2790.9	2093.6	2049.4

Table 6. Total Male Pink Bollworm Catch per Trap with the Huber Oil and Stikem Trap at Densities of 2.5 to 15 per Hectare.

Traps/Hectare	Average Total Male PBW Catch/Trap[a]		
	Stikem (31 days) (Oct. 11-Nov. 29) Long-Staple	Oil I (35 days) (Oct. 9-Nov. 12) Short-Staple	Oil II (30 days) (Nov. 1-Dec. 6) Short-Staple
2.5	-	-	389.5 c (6)[b]
5.0	-	384.7 c (6)	221.7 d (6)
7.5	236.8 c (4)	263.8 d (4)	191.4 d (5)
10.0	250.9 c (4)	295.2 d (5)	138.7 d (5)
12.5	224.4 c (5)	153.3 e (7)	138.4 d (7)
15.0	188.9 c (6)	141.3 e (8)	138.4 d (7)

[a] Means followed by the same letter do not differ significantly at the 5% confidence level according to Duncan's Multiple Range Test.

[b] Values in parentheses equal the number of traps used for statistical analyses at the indicated densities.

Flint's study. The removal of male moths increased the efficiency of our traps.

Wolf et al. (1971) has pointed out that trap performance is the most important factor when determining the optimum density at which traps should be deployed and that by increasing trap efficiency, fewer would be required to obtain the same total catch.

Release/recapture studies conducted by H. M. Flint (personal communication 1978) indicate that the Huber Stikem trap is very efficient. At a trap density of five traps per hectare and under light population conditions, 77.2% of the released male PBW moths were recaptured.

Results from the trap density research indicate a definite overlap in trapping area of the traps. Results in Oil I are obscured, but in Oil II there is a general increase in catch/trap as density decreases which is not significant until 2.5 per hectare (Table 6). This indicates that the effective radius of an oil trap is at least 157 m and probably more, but greater spacings were not evaluated in this research.

Embody (1971) has determined the effective radius of a hexalure baited trap to be 16 acres (128 m) and found that catches per acre increased over rates of one, two, four, eight and 16 acres/trap. Since gossyplure, which is far more attractive than hexalure, was used in this research, the effective trap radius would be expected to be greater than 128 m.

It is often suggested that as the trap density increases the chances of the moths being confused by permeation of the air with the pheromone becomes greater (Embody 1971, Taschenberg et al. 1974). This does not appear to have occurred in this research since there is no significant differences in actual catch/trap at the higher densities (Table 6). If confusion had occurred, the catch/trap would have decreased. Reed et al. (1975) have indicated that when PBW populations are heavy, male PBW moths can be captured within 1.5 m of gossyplure-baited traps if virgin females are used as bait. Therefore, it would be unlikely that confusion would be preventing PBW males from orienting to traps even at densities of 15 traps/hectare (24.1 m apart).

The total number of male PBW moths removed from the 12.1 hectare (Oil I) field was approximately 40,000. This indicates the trapping capacity of the oil trap as well as the number of male PBW moths which can be trapped over a relatively short time period (eight weeks, from mid-September to mid-November). During this time the density research was being conducted along with various other oil trapping research. On November 15 an infestation check was made of green bolls and an infestation of 16.5% was found over the entire field. Whether the removal of the large number of moths had an effect on infestation is not known, but it at least indicates the magnitude of the moth population present in a cotton growing area at this time of the year and the potential for the oil trapping system.

CONCLUSIONS

The results of this research indicate that rubber tubing is an ideal substrate for gossyplure when treated with either hexane or methylene chloride. The emission rate from the rubber tubing is apparently optimum, the gossyplure is preserved in the tubing by antioxidants already present there and the tubing dispenser will remain attractive for the entire cotton growing season. These characteristics make the rubber tubing wick ideal for traps used in both monitoring and mass trapping of the male pink bollworm. The rubber tubing wick was also found to be more attractive than the Conrel wick.

The Kitterman insect monitor trap as commercially sold was found not to be an effective male pink bollworm monitor trap. Replacement of the Tanglefoot-coated base with Stikem and replacement of the Conrel wick with a 76HEX wick substantially increased male pink bollworm catch, thus making the trap a much better population monitor.

Results of the trap density studies indicate that optimum trap density under field populations like those during this research are 12.5 traps/hectare for the Huber Stikem trap while the optimum density for the oil trap is probably greater than 15 traps/hectare. Results also indicated that the effective radius of an oil trap is at least 157 m and that confusion by permeation of the air with pheromone at the higher trap densities does not appear to inhibit male moth capture in traps.

LITERATURE CITED

Alder, H. L., and E. B. Roessler. 1964. Introduction to Probability and Statistics. Freeman and Co., San Francisco.

Berger, R. S., J. M. McGough, D. F. Martin, and L. R. Ball. 1964. Some properties and the field evaluation of the pink bollworm sex attractant. Ann. Entomol. Soc. Am. 57:606-609.

Beroza, M. L., J. Stevens, B. A. Bierl, F. M. Philips, and J. G. R. Tardif. 1973. Pre- and postseason field tests with disparlure, the sex pheromone of the gypsy moth, to prevent mating. Environ. Entomol. 2:1051-1057.

Bierl, B. A., M. Beroza, R. T. Staten, P. E. Sonnet, and V. E. Adler. 1974. The pink bollworm sex attractant. J. Econ. Entomol. 67:211-216.

Brazzel, J. R., and J. C. Gaines. 1956. The effect of pink bollworm infestations on yield and quality of cotton. J. Econ. Entomol. 49:852-854.

Brazzel, J. R., and J. C. Gaines. 1957. Cotton yield losses caused by various levels of pink bollworm infestation. J. Econ. Entomol. 50:609-613.

Bruce, W. A., and P. T. M. Lum. 1976. UV (ultraviolet) radiation: Effect on synthetic sex pheromone of the Indian meal moth (Plodia interpunctella). Fla. Entomol. 59:53-54.

Campion, D. G. 1974. The use of sex pheromones in the control of Spodoptera littoralis Boisd. European and Mediterranean Plant Protection Organization Bull. 4:357-362.

Carruth, L. A., and L. Moore. 1973. Cotton scouting and pesticide use in eastern Arizona. J. Econ. Entomol. 66:187-190.

Coudriet, D. L., and T. L. Henneberry. 1976. Captures of male cabbage loopers and pink bollworms: Effect of trap design and pheromone. J. Econ. Entomol. 69:603-605.

DeRosa, F. P. 1978. Mechanical Rubber Products Division. Garlock Inc., Palmyra, New York. Personal communication.

Duncan, P. B. 1955. Multiple range and multiple F tests. Biometrics 11:1-42.

Eiter, K. 1970. Recent work on insect sex attractants. Angew. Chem. Internat. Edit. 9:468-469.

Embody, D. R. 1971. Possible methods for measuring the effective range of the sex-lure for pink bollworm. USDA, ARS Bull. 81-43.

Farkas, S. R., and H. H. Shorey. 1977. Chemical trail following by flying insects: A mechanism for orientation to a distant odor source. Science 178:67-68.

Farkas, S. R., H. H. Shorey, and L. K. Gaston. 1974. Sex pheromones of Lepidoptera. Influence of pheromone concentration and visual cues on serial odor-trail following by males of Pectinophora gossypiella. Ann. Entomol. Soc. Am. 67:633-638.

Fitzgerald, T. D., A. D. St. Clair, G. E. Datterman, and R. G. Smith. 1973. Slow release plastic formulation of the cabbage looper pheromone cis-7-dodecenyl acetate: Release rate and biological activity. Environ. Entomol. 2:607-610.

Flint, H. M., L. Butler, L. M. McDonough, R. L. Smith, and D. E. Forey. 1978. Pink bollworm: Response to various emission rates of gossyplure in the field. Environ. Entomol. 7:57-61.

Flint, H. M., S. J. Kuhn, B. R. Horn, and H. A. Sallam. 1974. Early season trapping with gossyplure. J. Econ. Entomol. 67:738-740.

Flint, H. M., R. L. Smith, L. A. Bariola, B. R. Horn, D. E. Forey, and S. J. Kuhn. 1976. Pink bollworm: Trap tests with gossyplure. J. Econ. Entomol. 69: 535-538.

Flint, H. M., R. L. Smith, D. E. Forey, and B. R. Horn. 1977. Pink bollworm: Response of males to (Z,Z-) and (Z,E-) isomers of gossyplure. Environ. Entomol. 6:274-275.

Foster, R. N., R. T. Staten, and E. Miller. 1977. Evaluation of traps for pink bollworm. J. Econ. Entomol. 70:289-291.

Glass, E. H., W. L. Roelofs, H. Arm, and A. Comeau. 1970. Sex pheromone trapping red-banded leaf roller moths and development of a long-lasting polyethylene wick. J. Econ. Entomol. 63:370-373.

Goto, G., Y. Masuoka, and K. Hiraga. 1974. Photooxidation of the sex pheromone (Z,E)-9,12-tetradecdienyl-1-acetate. Chemistry Letters 11:1275-1278.

Graham, H. M. 1973. Hourly response of laboratory-reared and native male pink bollworms to traps baited with hexalure. Environ. Entomol. 2:965.

Graham, H. M., P. A. Glick, and D. F. Martin. 1964. Nocturnal activity of adults of six Lepidopterous pests of cotton as indicated by light-trap collections. Ann. Entomol. Soc. Amer. 57:328-332.

Graham, H. M., and D. F. Martin. 1963. Use of cyanide in pink bollworm sex-lure traps. J. Econ. Entomol. 56:901-902.

Graham, H. M., D. F. Martin, M. T. Ouye, and R. M. Hardman. 1966. Control of pink bollworms by male annihilation. J. Econ. Entomol. 59:950-953.

Graham, H. M., J. M. McGough, and M. Jacobson. 1966. Influence of solvents on effectiveness of sex lure for pink bollworm. J. Econ. Entomol. 59:761-762.

Green, N., M. Jacobson, and J. C. Keller. 1969. Hexalure, an insect sex attractant discovered by empirical screening. Experientia 25:682-683.

Guerra, A. A., R. D. Garcia, and M. P. Leal. 1969. Suppression of populations of pink bollworm in field cages with traps baited with sex attractant. J. Econ. Entomol. 62:741-742.

Guerra, A. A., and M. T. Ouye. 1967. Catches of male pink bollworm in traps baited with sex attractant. J. Econ. Entomol. 60:1046-1048.

Hartstack, A. W., Jr., J. P. Hollingsworth, H. L. Ridgway. and H. H. Hunt. 1971. Determination of trap spacings required to control an insect population. J. Econ. Entomol. 65:1090-1100.

Henson, R. D. 1977. Environmental fate of gossyplure. Environ. Entomol. 6:821-822.

Howell, J. F. 1974. The competitive effect of field populations of codling moth on sex attractant trap efficiency. Environ. Entomol. 3:803-807.

Hummel, H. E., L. K. Gaston, H. H. Shorey, R. S. Kaae, K. J. Byrne, and R. M. Sylverstein. 1973. Clarification of the chemical status of the pink bollworm sex pheromone. Science 181:873-875.

Jacobson, M. 1969. Sex pheromone of the pink bollworm: Biological masking by its geometrical isomer. Science 163:190-191.

Jacobson, M., and W. A. Jones. 1974. Attraction of pink bollworm moth under laboratory and field conditions. Environ. Letters 6:297-301.

Jefferson, R. N., L. L. Sower, and R. E. Rubin. 1971. The female sex pheromone gland of the pink bollworm, Pectinophora gossypiella (Lepidoptera: Gelechiidae). Ann. Entomol. Soc. Am. 64:311-312.

Johnson, W. L., G. H. McKibben, J. Rodriguez V., and T. B. Davich. 1976. Boll weevil: Increased longevity of grandlure using different formulations and dispensers. J. Econ. Entomol. 69:263-265.

Jones, W. A., and M. Jacobson. 1968. Isolation of N,N-diethyl-m-tolumide (deet) from female pink bollworm moths. Science 159:99-100.

Jones, W. A., M. Jacobson, and D. F. Martin. 1966. Sex attractant of the pink bollworm moth: Isolation, identification, and synthesis. Science 152:1516-1517.

Kaae, R. S., and H. H. Shorey. 1973. Sex pheromones of lepidoptera. 44. Influence of environmental conditions on locations of pheromone communication and mating in Pectinophora gossypiella. Environ. Entomol. 2: 1081-1084.

Karlson, P., and A. Butenandt. 1959. Pheromones (ecto-hormones) in insects. Annu. Rev. Entomol. 4:39-58.

Karlson, P., and M. Luscher. 1959. Pheromones: A new term for a class of biologically active substances. Nature (London) 183:55-56.

Keller, J. C., L. W. Sheets, N. Green, and M. Jacobson. 1969. Cis-7-hex-adecen-1-ol-acetate (hexalure), a synthetic sex attractant for pink bollworm males. J. Econ. Entomol. 62:1520-1521.

Knipling, E. F., and J. U. McGuire, Jr. 1966. Population models to test theoretical effects of sex attractants used for insect control. USDA Inf. Bull. 308.

Krambias, A. 1976. Climatic factors affecting the catches of potatoe tuber moth _Phthorimaea operculella_ (Zell.) (Lepidop era: Gelechiidae) at a pheromone trap. Bull. Entomol. Res. 66:81-85.

Leppla, N. C. 1972. Calling behavior during pheromone release in the female pink bollworm. Ann. Entomol. Soc. Am. 65:281-282.

Lewis, T., and E. D. M. Macaulay. 1976. Design and evaluation of sex attractant traps for pea moth, _Cydia nigricana_ (Steph.) and the effect of plume shape on catches. Ecol. Entomol. 1:175-187.

Lukefahr, M. J., and J. A. Griffin. 1957. Mating and oviposition habits of the pink bollworm moth. J. Econ. Entomol. 50:487-490.

Madsen, H. F., J. M. Vakenti, and F. E. Peters. 1976. Codling moth: Suppression by male removal with sex pheromone traps in an isolated apple orchard. J. Econ. Entomol. 69:597-599.

Maitlen, J. C., L. M. McDonough, H. R. Moffit, and D. A. George. 1976. Codling moth sex pheromone: Baits for mass trapping and population survey. Environ. Entomol. 5:199-202.

Marks, R. J. 1976. Field evaluation of gossyplure, the synthetic sex pheromone of _Pectinophora gossypiella_ (Saund.) (Lepidoptera, Gelechiidae) in Malawi. Bull. Entomol. Res. 66:267-278.

Marks, R. J. 1977. The influence of climatic factors on catches of red bollworm, Diparopsis castanea Hampson (Lepidoptera: Noctuidae) in sex pheromone traps. Bull. Entomol. Res. 67:243-248.

McClendon, R. W., E. B. Mitchell, J. W. Jones, J. M. McKinion, and D. D. Hardee. 1976. Computer simulation of population suppression: A theoretical example. Environ. Entomol. 5:799-806.

Neumark, S., N. Green, and I. Teich. 1972. The pink bollworm attractant, hexalure: Improvement by formulation with an antioxidant. J. Econ. Entomol. 65:1709-1711.

Neumark, S., M. Jacobson, and I. Teich. 1975. Evaluation of gossyplure, compared with hexalure, for monitoring pink bollworm infestations in cotton fields of Israel. Environ. Letters 10:13-23.

Neumark, S., and I. Teich. 1973. Pink bollworm: Constant-level liquid device for use in trapping moths. J. Econ. Entomol. 66:298.

Neumark, S., R. M. Waters, M. Jacobson, and I. Teich. 1975. Improvement of attractiveness of Spodoptera littoralis sex pheromone, and its possible use in safety belts around cultivated areas to control the pest in Israel. Environ. Letters 10:97-120.

Noble, L. W. 1969. Fifty years of research on the pink bollworm in the United States. USDA Agric. Handbk. No. 357.

Ouye, M. T., and B. A. Butt. 1962. A natural sex lure extracted from female pink bollworms. J. Econ. Entomol. 55:419-421.

Paul, R. D., and F. W. Harris. (editors). 1976. Controlled Release Polymeric Formulations. American Chemical Society Symposium Series 33. Washington D. C.

Reed, W., G. Vedamoorthy, M. Vijaya Raghavan, and M. P. Rajan. 1975. Pink bollworm moths: Catches in sex-attractant traps and nocturnal behavior in south India. Cotton Grow. Rev. 52:350-359.

Reissig, W. H. 1974. Field tests of traps and lures for the apple maggot. J. Econ. Entomol. 67:484-486.

Rice, R. E., and H. T. Reynolds. 1971. Seasonal emergence and population development of pink bollworm in southern California. J. Econ. Entomol. 64:1429-1432.

Rothschild, G. H. L. 1975. Attractants for monitoring *Pectinophora scutigera* and related species in Australia. Environ. Entomol. 4:983-985.

Sharma, R. K., R. E. Rice, H. T. Reynolds, and R. M. Hannibal. 1973. The effect of trap design and relative release rate of hexalure on catches of pink bollworm males. J. Econ. Entomol. 66:377-379.

Sharma, R. K., R. E. Rice, H. T. Reynolds, and H. H. Shorey. 1971. Seasonal influence and effect of trap location on catches of pink bollworm males in sticky traps baited with hexalure. Ann. Entomol. Soc. Am. 64: 102-105.

Sharma, R. K., H. H. Shorey, and L. K. Gaston. 1971. Sex pheromones of noctuid moths. XXIV. Evaluation of pheromone traps for males of *Trichoplusia ni*. J. Econ. Entomol. 64:361-364.

Shorey, H. H., and J. McKelvey. (editors). 1977. Chemical Control of Insect Behavior: Theory and Application. Wiley and Sons Inc., New York.

Spears, J. F. 1968. The westward movement of the pink bollworm. Bull. Entomol. Soc. Am. 14:118-119.

Starratt, A. N., and D. G. R. McLeod. 1976. Influence of pheromone trap age on capture of the European corn borer. Environ. Entomol. 5:1008-1010.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics with Special Reference to the Biological Sciences. McGraw-Hill Book Co. Inc. New York.

Swenson, D. 1976. Controlled Release Vapor Dispensing Systems (Conrel). Norwood, Mass. Personal communication.

Taschenberg, E. F., R. T. Carde', and W. L. Roelofs. 1974. Sex pheromone mass trapping and mating disruption for control of redbanded leaf roller and grape berry moth in vineyards. Environ. Entomol. 3:239-242.

Tingle, F. C., and E. R. Mitchell. 1975. Capture of _Spodoptera frugirerda_ and _S. exigua_ in pheromone traps. J. Econ. Entomol. 68:613-615.

Toscano, N. C., A. J. Mueller, V. Sevacherian, R. K. Sharma, T. Niilus, and H. T. Reynolds. 1974. Insecticide applications based on hexalure trap catches versus automatic schedule treatments for pink bollworm moth control. J. Econ. Entomol. 67:522-524.

Trammel, K., W. L. Roelofs, and E. H. Glass. 1974. Sex pheromone trapping of males for control of redbanded leaf roller in apple orchards. J. Econ. Entomol. 67: 159-164.

U. S. Air Force, Air Weather Service. 1945. Data Control Division, National Weather Record Center, Uniform Summary of Surface Weather Observations, Sept. 1942-Sept. 1945. Tucson, Az., Marana AAF. Station No. 23113.

Watson, T. F., and D. G. Fullerton. 1969. Timing of insecticidal applications for control of the pink bollworm. J. Econ. Entomol. 62:682-685.

Wene, G. P., L. A. Carruth, and A. D. Telford. 1965. Arizona cotton insects: Descriptions and habits. Ariz. Agric. Exp. Stn. Bull. No. A-23.

Westigard, P. H., and K. L. Graves. 1976. Evaluation of pheromone baited traps in pest management programs on pears for codling moth control. Can. Entomol. 108:379-382.

Wolf, W. W., A. N. Kishaba, and H. H. Toba. 1971. Proposed method for determining density of traps required to reduce an insect population. J. Econ. Entomol. 64:872-877.

Wolf, W. W., H. H. Toba, A. N. Kishaba, and N. Green. 1972. Antioxidants to prolong the effectiveness of cabbage looper sex pheromone in the field. J. Econ. Entomol. 65:1039-1041.