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A Study of the Potential Role of Behavioral Chemicals for Control of *Heliothis* Species and *Spodoptera Littoralis* in Cotton

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C. Abstract

Insect sex pheromones and related chemicals can be used to manipulate insect behavior and thus have potential utility for insect pest management. For example, permeation of the air with a sex pheromone may interfere with the mate-finding process, thereby causing reduction of subsequent populations. However, before such behavioral chemicals can be used successfully with a given insect, it is essential to obtain a fundamental understanding of their effects on insect behavior and to develop formulations to disseminate the chemicals efficiently and effectively.

The goal of this project was to improve understanding of chemical and behavioral factors that will enhance practical utilization of pheromones for management of Spodoptera littoralis (Boisduval) and Heliothis armigera (Hubner).

To achieve these objectives the pheromonal components from pheromone glands were identified and their role in the mating behavior sequence was determined. Analysis of precursors for the biosynthesis of pheromones in the pheromonal gland was also performed. Night observations were carried out to determine reliability of pheromone traps for population assessment and also for studying age structure and nocturnal activities of the pests. Mating disruption experiments were carried out in small cages, in large screened cages and in the field. In these experiments different disruptants, numbers of release point sources, and different dosages were tested.

Considerable information has been gained on the chemical composition of the pheromones, their effect on insect behavior and possibilities for their practical use as mating disruptant. In addition this investigation has provided basic information that may play an important role in future applications of behavioral chemicals in pest management.

D. Objectives of the research (as stated in the original proposal)

The main purpose of the project was to improve understanding of chemical and behavioral factors that will enhance the potential for utilization of pheromones for management of Spodoptera littoralis (Boisduval), Heliothis armigera (Hubner) and other Heliothis species.

To achieve these objectives, the research program must concentrate on the following:

a) The optimum chemical composition for mating disruption will be determined. Attractant mixtures must be tested with respect to purity, composition and release rate to maximize mating disruption. Studies of the volatile stimuli and their effects on insect behavior will be conducted in the laboratory and in the field. Field observations of mating behavior and mating frequency will supplement information provided by trapping studies.

b) The effect of inhibitors, analogues and related compounds will be investigated under similar conditions to determine whether these compounds can be useful as mating disruptants.

c) Studies of evaporator spacing will be conducted to determine optimum spacing and to relate this to mating disruption.

d) Laboratory and field studies of insect behavior will be conducted to determine the role of pheromone components and assess their importance in the sequence of behavioral events that lead to copulation. The role of chemical stimuli originating from both female and male will be examined in this context.

e). Techniques for measurement of effectiveness of pheromone treatment will be critically examined.

f) Commercially available controlled-release formulations will be evaluated for use in the research program. Physical and chemical data will be obtained and

enable us to understand or modify the performance of the formulations in laboratory and field environments.

A major benefit of success will be the reduction in insecticide use. However, if the goals of the program are achieved there will also be improved understanding of populations dynamics, behavior, and the effects of behavioral chemicals on these insect species.

E. Body of the report

I. The Egyptian cotton bollworm Spodoptera littoralis.

1. Analysis of pheromonal components from pheromone glands.

Extractions of pheromone glands for 2-5 min gave relatively clean pheromone samples. Analysis on two capillary columns confirmed the presence of Z9-14:Ac, E11-14:Ac, Z11-14:Ac, Z9,E12-14:Ac and Z9,E11-14:Ac (Dunkelblum et al., 1982, *Phytoparasitica* 10:21-26 and references therein). The most abundant components were Z9-14:Ac and Z9,E11-14:Ac (Table 1). A quantitative analysis of the amount of the major component (Z9,E11-14:Ac) as a function of age was performed with virgin females from the age of 0.5 day to the 7th day. Maximum content of pheromone (mean of 6.6 ng/♀) was observed in two-day-old females with a gradual decrease till the 4th day (4.7 ng), followed by a sharp decline in pheromone content to 1-2 ng in days 5-7. Analysis of pheromone content of 1-2 day-old females as a function of time in the scotophase showed that the maximum pheromone amount in the glands is at 2 h into scotophase. One hour before beginning of the scotophase, only about 1 ng/female of Z9,E11-14:Ac was found. The amount of the pheromone increased sharply with the beginning of darkness and remained high till the 4th hour followed by a gradual decrease till the end of the scotophase. These results can be correlated with the mating activity of S. littoralis in the laboratory which occurs mainly at the first three hours into

scotophase. The amount of pheromone decreased sharply after copulation but increased gradually to almost normal level after 24 hours. No pheromone was found in those mated females which commenced to lay eggs (Table 2). (Details in Dunkelblum et al., 1987, Ent. Exp. & Appl. 44:241-248).

2. Analysis of fatty acids from pheromone glands

Analysis of fatty acids from pheromone glands on three capillary columns by GC and GC-MS was performed. For the determination of the position of the double bond in the monounsaturated acids, dimethyl disulfide derivatization followed by GC-MS was used. The results indicate the presence of the following methyl esters (after basic methanolysis of the crude fatty extracts): 12:Me, 14:Me, Z9-14:Me, Z11-14:Me, E11-14:Me, Z9,E12-14:Me, Z9,E11-14Me, 15:Me, 16:Me, Z9-16:Me, Z11-16:Me and some higher fatty esters. There is a fair correlation between the pheromone components and the fatty esters indicating on the possible biosynthetic pathway leading to the main pheromone components in S. littoralis. The diene fatty acids Z9,E11-14:Ac and Z9,E11-14:Acid are probably formed biosynthetically from the abundant common precursor Z9-14:Acyl by a second 2-desaturation step. The abundance of the fatty acid precursors as compared to the low amounts of pheromone, raising on the onset of scotophase, may indicate on the conversion of precursors to pheromone components triggered by onset of darkness. (Details in Dunkelblum & Kehat 1987, Insect Biochem 17:877-871).

3. Evaluation of activity of pheromonal components from pheromonal glands.

It was shown previously that Z9,E11-14:Ac with small amounts (0.2-1%) of Z9,E12-14:Ac are essential for high trap catches of S. littoralis in the field. Extensive wind tunnel experiments were initiated to assess the role of these components in the sexual behaviour of males. Four characteristic behavioural

stages of the stimulated males were recorded: initial flight (IF), directed flight (DF), landing (L) and hairpencilling (HP). Most males which exhibited hairpencilling performed also copulation attempts, but it was difficult to differentiate between these two activities. The sample of Z9,E11-14:Ac used for the behavioural studies contained 0.4% of E9,Z11-14:Ac, 1.1% Z9,Z11-14:Ac and 3% E9,E11-14:Ac: no Z9,E12-14:Ac was detected (direction level below 0.1%). A few percent of unidentified impurities were also present. The major component (50 ng/lcm² filter paper) and mixtures with 0.1%, 0.5%, 1%, 2% and 5% of the minor component were tested and it was found that a high percentage of copulation attempts, from flying males, was achieved only with a mixture of the two components (Table 3). The optimal ratio was 100:1 of Z9,E11-14:Ac + Z9,E12-14:Ac resulting in 70% of males performing directed flights, 60% landing on the lure and about 60% exposing hairpencils and trying to copulate with the lure. Only 10% of the males hairpenciled with Z9,E11-14:Ac as the bait although 50% performed directed flights. Addition of 2% and 5% of Z9,E12-14:Ac resulted in decline in the percentage of landing and copulation attempts. These results show clearly that Z9,E11-14:Ac initiates directed flights in S. littoralis males but for landing on the bait and in particular for copulation attempts the presence of the minor component Z9,E12-14:Ac is essential.

At the second stage the effect of Z9-14:Ac, which was known from previous field tests to be inhibitory to S. littoralis males (Campion et al., 1974, Bull. Ent. Res. 64:89-96), on the performance of the binary blend of Z9,E11-14:Ac + 1% Z9,E12-14:Ac was tested. Amounts of 1%, 5% and 20% of Z9-14:Ac were added (Table 4) and it was found that only the addition of 20% of Z9-14:Ac had a significant impact on the activity of males. Although the same percent of males started flying, only 15% landed on the bait as compared with 60% which landed when the amount of Z9-14:Ac was 0-5%.

The activity of the saturated acetate 14:Ac was also tested. In the present work 14:Ac (10%) had no influence on the activity of either Z9,E11-14:Ac alone nor on the binary mixture of Z9,E11-14:Ac + 1% Z9,E12-14:Ac (Table 5). In flight tests performed in England (Haines, 1983, *Physiol. Entomol.* 8:29-40) it was found that this component enhanced the activity of the main component Z9,E11-14:Ac.

Finally the addition of the other components to the binary mixture of Z9,E11-14:Ac + 1% Z9,E11-14:Ac as compared to virgin females was tested (Table 6). It is clear that males flew most actively to a caged female. All the males which took directed flights completed the whole courtship sequence and their flight pattern was very smooth, almost straight towards the female. Addition of single components to the binary blend had no significant effect. However, addition of the four acetates: 14:Ac, Z9-14:Ac, E11-14:Ac and Z11-14:Ac, at 1% each, to the binary blend enhanced activity significantly and this mixture performed almost as well as a virgin female. Since the exact composition of the efluvia from S. littoralis is not known (Campion et al., 1980, *Bull. Ent., Res.* 70:417-454), more trials in the wind tunnel are necessary in order to obtain a blend which would give optimal results. The finding of the six component blend is encouraging and shows that wind tunnel tests can help in finding improved blends for S. littoralis.

4. Sexual activity of males as a function of age and time into scotophase.

The age dependence of male responsiveness was studied in a wind tunnel using paper baits (1 cm² square) containing (50 ng) of Z9,E11-14:Ac + 1% Z9,E12-12:Ac. Three characteristic behavioural stages of the stimulated males were recorded: initial flight (IF), directed flight (DF) and landing (L) on the

bait. Most of the males which landed exposed and attempted to copulate with the bait. Males started flying and landing on the lures from the first night (first scotophase: first night after night of emergence), with 30% of the males tested performing the entire courtship sequence. The response increased gradually (Fig. 1) and reached maximum at 4-days with 55% of the males landing. Activity decreased sharply between 6-7th night, in part due to aging of the males as seen from higher mortality of moths after the 6th night.

Three-to-five-day old males were monitored from the first hour of scotophase till end of the dark period (Fig. 2). Full activity started between the 3rd and 4th hour and remained constant till the 8th hour of scotophase. This timing parallels approximately the calling activity of the females.

5. Mating disruption studies in the laboratory

Laboratory studies on the sexual behavior of S. littoralis in pheromone permeated atmosphere were continued. Results indicate that when pheromone concentrations were increased mating of pairs was prevented even when pairs were kept in small closed containers. Since males under these conditions could locate the females easily and yet mating did not occur it seems that high concentrations of pheromone, directly affect the capability of males or females to copulate. Calling of females under those conditions was not affected at all. (Details in Dunkelblum et al., 1987, Ent. Exp. Appl. 44:241-248).

6. Evaluation, by direct night observations, of Z9,E11-14:Ac as mating disruptant

Night observations on the cotton leafworm, Spodoptera littoralis (Boisd.), were conducted in pheromone-treated and untreated plots in which males, females, mating pairs on plants and males caught in traps were collected. A polymeric aerosol formulation containing (Z,E)-9,11-tetradecadienyl acetate (5000 release points per ha: total of 75 g a.i./ha: release rate of approximately 3 g/ha/day), effectively reduced male captures in traps and number of females copulating in the treated field. It seems that many release points at close spacing are needed for effective mating disruption of Spodoptera littoralis. Results also indicated that males respond to pheromone traps most actively when the actual virgin female population has already declined considerably. (Details in two publications, Kehat et al., 1985, *Phytoparasitica* 13:215-220, and 1986 *J. Econ. Entomology* 79:1641-1644). Results of this study also show that the real evaluation criterion for disruption efficiency should be the reduction in the number of females copulating, as indicated by direct observations, and not the reduction in male captures in traps. (Summarized in Dunkelblum et al., 1987, IOBC-WPRS, Bulletin X/3, 27-29).

7. Field tests for determining reliability of pheromone traps for population assessment

Night observations were conducted in pheromone-treated and untreated plots in which males, females, mating pairs on plants and males caught in traps were collected. Results indicated that emergence of a new population was rapid (8-9 days) and that the number of virgin females and of mating pairs reached a peak 5-6 days prior to that of males captured in pheromone traps. Males thus respond to pheromone traps most actively when the actual virgin female population

already declined considerably. (Fig. 3) (Details in Kehat et al., 1985, *Phytoparasitica* 13:215-220).

II. The cotton bollworm, Heliothis armigera

1. Analysis of pheromonal components from pheromone glands

Extraction of pheromone glands for 5-10 min gave relatively clean samples. However, very large variations in the amount of the pheromone (monitored with the main component Z11-16:Ald) were found. Due to this difficulty it was impossible to study the dependence of pheromone on age. Analysis of many samples, obtained from day 1-day 5, indicated that maximum amount of pheromone was present in 3-day old females, between 6-8 h into scotophase. The average composition of the extracted material is presented in Table 7.

The present results confirm previous studies (Dunkelblum et al., 1980, *Phytoparsitica* 8:209-211; Nesbitt et al., 1980, *Entomol. Exp. Appl.* 27:306-308) with one major exception, namely the identification of Z7-16:Ald. This component was previously not found, probably because the columns at that time could not separate this isomer from Z9-16:Ald.

2. Evaluation of pheromonal components activity in a wind tunnel.

Preliminary tests in the wind tunnel confirmed the essential role of Z9-16:Ald and showed that the main Z11-16:Ald component had only long range activity inducing males to start flying (Table 8). The results indicate that Z9-16:Ald is essential for the whole courtship sequence. This result is very similar to that obtained with H. zea (Vetter and Baker, 1984, *J. Chem. Ecol.* 10:193-202).

3. Field tests with methylene analogs as male attractants.

The two active components Z9-16:Ald and Z11-16:Ald were converted into the methylene analogs by a Wittig reaction:

A field test in the Bet Dagan farm (June 4 - June 18, 1985) showed that these analogs were inactive in trapping H. armigera. Four traps containing a lure of 97:3 Z11-16:Ald + Z9-16:Ald were compared with four traps baited with 97:3 of Z1,12-17:H + Z1,10-17H. The aldehyde traps caught 468 males as compared with only 5 males caught by the methylene analogs.

4. Nocturnal activity of males and females in the field.

Night observations were conducted during 1986 in a cotton field in which males, females, mating pairs on plants and males caught in traps were collected. The females collected were dissected and percentage of virgin females, and number of spermatophores per female were determined. Results (see Tab. 9) show that increase in male captures in traps (14.8-25.8.86) also indicted an increase in adult population in the field. Similar results were obtained in 1984 (see Tab. 10). This may indicate, again, the importance of pheromone traps for monitoring H. armigera populations.

Most females collected on Aug. 14, 1986 were virgin indicating an emergence of young females already developed as larvae in cotton. Ten days later most females were already mated. This is in contrast to females collected during 1984 (see Tab. 10) the majority of which were already mated. This indicates that in early summer (June 1984) the majority of H. armigera females invaded cotton fields while already mated.

Results of 1986 (Tab. 9) show that more mating pairs were collected during the first half of the night than later on (28 vs 3). This is in contrast to results obtained in 1984 (Tab 11) which show that most females mated after midnight. Results obtained during 1986 from laboratory bred H. armigera also show that most matings occurred during the second half of the scotophase (Tab 12). The accurate time of mating during the night, throughout the season, should be studied further.

5. The effect of Z11-16:Ald on mating disruption of Heliothis armigera in large screened cages (Tab. 13).

Z-11-hexadecenal was evaluated as mating disruptant at application rates commonly used for the disruption of other pests. The pheromone was evaporated (Release rate is presented in Fig. 4) from point sources (cotton dental rolls) at the rate of 27 point sources per screen field cage (5x15m) planted with cotton. Treatment efficiency was determined by observing and comparing the numbers of mating pairs (laboratory-reared moths) within the cages (control and treatment cages). Pheromone concentration of 1.6 or 3.2 g/ha/day were ineffective for mating suppression. Similar concentrations were effective in the case of Spodoptera littoralis (Kehat et al., 1986. J. econ. Ent. 79:1641-1644) or Pectinophora gossypiella, (Critchley et al., 1985. Bull. ent. Res. 75:329-345.), but not in the case of Heliothis zea (Carpenter et al., 1982. J. econ. Ent. 75:333-336). The present results are in agreement with those obtained for H. zea.

Further experiments with higher concentrations (10 times fold) carried out during 1986 failed to show any significant results since there were no matings in the treatment or control cages.

These observations emphasize the need for a further evaluation of chemicals (single, blends and analogues) as mating disruptants at different concentrations, and at different population levels.

6. The effect of Z11-16:Ald on mating disruption in small (5 liters) containers

Laboratory studies on the sexual behavior of H. armigera in pheromone permeated atmosphere were initiated. Results indicate that when pheromone concentrations were increased mating of pairs was prevented even when pairs were kept in small containers. Since males under these conditions could locate the females easily and still mating did not occur it seems that high concentrations of pheromone, directly affect the capability of males or females to copulate.

7. The effect of (Z)-9-14:formate on mating disruption under field conditions (Table 14)

The effect of a Dexter (Z)-9-14:formate formulation containing the disruptant Z9-14:Formate was applied at the rate of 50 g./hectare. The release point sources (1000 per hectare) were 3-4 m apart. One hectare, 100 m away, was served as control. The effectiveness and persistence of communication disruption were measured by either reduction in male captures in traps or reduction in numbers of mating pairs in the treated vs. untreated plots, (number of mating pairs were observed directly, with the help of head lanterns, during nights).

Results indicate that reduction in male catches in traps in the treated vs. control plot lasted for at least 17 days when more than 90% reduction in trap catches was maintained. Later on disruption efficiency was reduced and 50-70% reduction in trap catches was maintained between the 17th and 33rd day. Although many males were caught in traps the actual number of females in the field, as

observed during nights, (14 nights of observations) was very low. Moreover, most females collected were mature and have already been mated for 2-4 times. The number of mating pairs found was also low - total of only 15 mating pairs for the whole experiment period, all of them were collected in the control area and none in the treated plot. Although these results are encouraging, they should further be tested since the total number of mating pairs found was small.

F. Evaluation of the research achievements

A major factor in efficient crop and fiber production is successful control of insect pests. Large quantities of insecticides must be used to control pests of corn, cotton, and other crops. Alternative or supplemental methods of pest control are essential if the environmental burden of insecticides is to be reduced. The problem of insect resistance may be mitigated if combined strategies of pest control are available to reduce the grower's reliance on routinely scheduled application of chemicals. Chemicals that affect insect behavior, such as the pheromones, may play an important part in future pest management, but their usefulness will depend on the availability of basic information. The present research contributes to augment this information and thus to aid in developing management systems for some major insect pests of cotton.

In the present investigation the pheromonal components from pheromone glands of S. littoralis and H. armigera were reexamined and their role in the mating behavior sequence was determined. Analysis of precursors for the biosynthesis of pheromones in the pheromonal gland was also performed. Night observations were carried out to determine reliability of pheromone traps for population assessment and also for studying age structure and night activities of the pests. Mating disruption experiment were carried out in small cages, in

large screened cages and in the field. In these experiments different disruptants, number of release point sources, and different dosages were tested.

Considerable information has been gained on the chemical composition of the pheromones, their effect on insect behavior and possibilities for their practical use as mating disruptant. In addition this investigation has provided basic information that may play an important part in future applications of behavioral chemicals in pests management.

G. Benefit to agriculture

Over-reliance on single techniques of pest control, such as the use of conventional pesticides, can ultimately lead to problems of pesticide resistance, pollution of water or soil, or adverse effects on natural predators, bees or other beneficial insects. Control of insect populations by behavioral chemicals provides a method that is highly specific for an individual pest species and that utilizes easily biodegradable compounds of low toxicity to nontarget species. The technique will be useful for major crops and can be easily incorporated into integrated pest management systems with other pest control components. It will benefit cotton production systems by contributing to improved pest management practices and by reducing the risk of environmental water pollution.

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Table 1

Pheromone Composition in Spodoptera littoralis^a

14:Ac	5.0%
Z9-14:Ac+E11-14:Ac	68.8% ^b (ratio was between 1.5% to 1/1)
Z11-14:Ac	13.1%
Z9,E12-14:Ac	1-2% ^c
Z9,E11-14:Ac	100%
Z9,Z11-14:Ac	1-2% ^c

a. Average of five samples

b. The percentages were calculated from the analysis on a DB 225, 30m x 0.25 mm capillary column which gave the best overall separation except for the two acetates Z9-14:Ac and E11-14:Ac. These two components were separated on a DB 5, 30 m x 0.25 mm column, however some other components were barely separated on this column and it was difficult to calculate percentages.

c. The amount was too low for electronic integration and therefore amounts are approximate.

Table 2

Pheromone content in pheromone gland of o Spodoptera littoralis after mating.

Mating status	Pheromone content (ng/♂) ^{a,b}								Mean ^c ± S.E.	
Virgin (control)	3.4	6.1	3.3	3.9	1.8	3.2	2.1		3.40x	0.53
3 h after mating	0.2	0	0	0.3	0.3	0.4	0		0.17y	0.06
24 h after mating, prior to egg laying	3.5	1.7	0.5	1.4	3.7	3.0	2.9		2.39x	0.45
24 h after mating, after egg laying	0.1	0.2	0.5	0	0.5	0.4	0		0.24y	0.08

^aMeasured on batches of five glands each.

^bAmounts below 0.5 ng approximate due to difficulties in electronic integration of the low quantities.

^cMeans followed by same letter do not differ significantly at 5% level according to Duncan's Multiple Range Test.

Table 3

Influence of the addition of Z9,E12-14:Ac to Z9,E11-14:Ac on the preformance of Spodoptera littoralis males in flight tests (n=20)*

% of Z9,E12-14:Ac in Z9,E11-14:Ac	IF(%)	DF(%)	L(%)	HP(%)
0**	80a	50a	20b	10c
0.1	85a	60a	50a	40ab
0.5	90a	70a	50a	50ab
1	90a	70a	60a	60a
2	80a	65a	50a	45ab
5	80a	55a	40ab	30bc

*Percentages followed by the same letter are not significantly different according to X^2 test of independence ($P < 0.05$).

**Amount of Z9,E12-14:Ac not detectable, certainly below 0.1%.

Table 4

Effect of the addition of Z9-14:Ac on the activity of the binary mixture (BM) of Z9,E11-14:Ac + 1% Z9,E12-14:Ac

Mixture	n*	IF%	DF%	L%	HP%
BM	72	96a	67a	58a	56a
BM + 1% Z9-14:Ac	20	100a	65a	60a	45a
BM + 5% Z9-14:Ac	20	95a	85a	50a	45a
BM + 20% Z9-14:Ac	20	85a	35b	15b	10b

*Percentages followed by the same letter are not significantly different according to χ^2 test of independence ($P < 0.05$).

Table 5

Effect of the addition of 14:Ac on the activity of Z9,E11-14:Ac and of the binary mixture of Z9,E11-14:Ac + 1% Z9,E12-14:Ac

Mixture	n*	IF%	DF%	L%	HP%
Z9,E11-14:Ac	20	80a	50a	20b	10b
Z9,E11-14:Ac	20	80a	45a	15b	0b
+ 10% 14:Ac					
Z9,E11-14:Ac	72	96a	67a	58a	56a
1% Z9,E12-14:Ac					
Z9,E11-14:Ac	20	100a	60a	55a	55a
1% Z9,E12-14:Ac					
+ 10% 14:Ac					

*Percentages followed by the same letter are not significantly different according to χ^2 test of independence ($P < 0.05$).

Table 6

Effect of the addition of different components on the activity of the binary mixture (BM) of Z9,E11-14:Ac + Z9,E12-14:Ac

Mixture	n*	IF%	DF%	L%	HP%
BM	72	96a	67a	58bc	56bc
BM+1% Z9-14:Ac**	20	100a	65a	60abc	45c
BM+1%E11-14:Ac**	16	100a	81a	44c	44c
BM+1% Z11-14:Ac**	20	100a	60a	55bc	55bc
BM+4% Z9,Z11-14:Ac	22	86a	86a	64abc	64abc
BM+1% Z9-14:Ac					
+1%E11-14:Ac	60	100a	80a	73ab	72ab
+1%Z11-14:Ac					
+1% 14:Ac					
Virgin female	31	94a	84a	84a	84a

*Percentages followed by the same letter are not significantly different according to χ^2 test of independence ($P < 0.05$).

**Addition of 5% of each of these monounsaturated acetates gave statistically the same results.

Table 7
Pheromone composition in Heliothis armigera^{ab}

16:Ald	3.0%
Z7-16:Ald	0.5% ^c
Z9-16:Ald	2.5%
Z11-16:Ald	100 %
Z11-16:OH	5.5%

a. Average of three samples

b. The percentages were calculated from the analysis on a DB225, 30 m x 0.25 mm capillary column which gave a good separation of the isomeric hexadecenals.

c. The amount was too low for electronic integration and is therefore approximate.

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Table 8

Response of male Heliothis armigera to the two main pheromone components
(n=20)^{x,y}

Chemicals	IF%	DF%	L%	HP%
20 ng Z11-16:Ald	95a	65%b	15b	5b
20 ng Z11-16:Ald + 5% Z9-16:Ald	100a	100a	100a	85a

x Males were 4-5 days old at 7-8 hr into scotophase (L:D; 14:10)

y Percentages followed by the same letter are not significantly different
according to χ^2 test of independence ($P < 0.05$).

Table 9

Nocturnal activity of adults Heliothis armigera in cotton, 1986. (Data reflects 4 nights of observation in a cotton field located at the Coastal plain (Habonim))

Date	Hour of observation	Number of singles collected *				No. of pairs * collected	Mean no. collected per observer night per 30 min	Total δ trap/
		δ	$\frac{\text{total}}{\text{virgin}}$	$\frac{\text{mated}}{\text{mated}}$	$\frac{\text{total}}{\text{total}}$			
14.8	23:20-23:50 01:30-02:30	21 -	15 -	13 -	2(1,3) -	4 2	11.0 -	7.2
19.8	23:15-24:15 02:15-02:45	14 12	16 11	13 10	3(1,2,2) 1(1)	12 1	6.7 6.2	14.0
25.8	22:20-23:20 01:40-02:40	12 4	12 9	3 1	9(7x1,2x2) 8(5x1,1x2,2x3)	12 0	6.0 1.6	5.2
31.8	21:15-22:15 23:00-24:00	0 1	1 1	1 0	0 1(1)	0 0	0.1 0.5	1.4
		64	65					

*by four observers

**numbers in brackets indicate number of spermatophores

Table 10

Nocturnal activity of adults Heliothis armigera in cotton, 1984 (Data reflects 10 nights of observation in a cotton field located at Izrael Valley)

Date	Number of singles collected*			Mating pairs	Mean No. collected/ observer/ 30 mins	Total No. ♂ captured trap/night
	singles					
	♂	♀				
		total	virgin			
1.6.84					0	4.8
4.6.84	1	1	0	1	0	7.4
10.6.84	7	1	0	1	1	14.4
12.6.84	5	6	1	5	1	21.0
14.6.84	3	7	1	6	1	44.0
19.6.84	10	8	4	4	3	27.0
21.6.84	9	6	2	4	3	41.1
25.6.84	2	9	2	7	5	54.1
28.6.84	0	6	2	4	0	29.1
2.7.84	0	1	0	1	1	4.3

*3 observers for 6x30min

Table 11

Dial pattern of adults Heliothis armigera in cotton, 1984 (Data reflects 10 nights of observation (1.6-2.7.84) in a cotton field located at Izrael Valley

Status of adults collected	Total collected	% Collected at different hours of night							
		21	22	23	00	01	02	03	04
		22	23	24	01	02	03	04	05
♂	37	8.1	18.9	27.0	16.2	16.2	10.9	0	2.7
♀	45	0	22.2	13.3	11.1	28.9	20.0	4.5	0
mating pairs	15	0	0	20.0	6.6	13.3	46.7	6.7	6.7
♂ in traps	716	9.8	9.6	9.6	11.3	18.7	13.2	17.3	10.6

Table 12

Mating of laboratory bred Heliothis armigera (1986)

Exp. No.	Date of Exp.	Age of ♂ tested	No. of ♀ pairs tested	No. of pairs mated	%	Numbers mated at different hours of scotophase*								
						0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
1	21.7	2	35	7	20.0	0	0	0	1	1	2	3	0	
	22.7	3		15	53.5	0	0	0	3	4	2	3	3	
2	11.9	1	25	3	12.0	0	0	0	0	0	2	1	0	
	12.9	2		2	9.1	0	0	0	0	0	1	1	0	
3	11.9	2	25	11	44.0	0	0	1	1	0	5	3	1	
	12.9	3		7	50.0	0	2	0	0	3	1	0	1	
4	14.9	3	31	12	38.7	0	0	2	1	0	2	4	3	
						57	0	2(3.5)	3(5.3)	6(10.5)	8(14.0)	15(26.3)	15(26.3)	8(14.0)

*Numbers in brackets indicate percentage of the total

Table 13

Efficacy of pheromonal applications as mating disruptants of Heliothis armigera when evaporated in large screened cages (1986).

Date	No. of moths		Pheromone* (mg)	No. mating pairs collected		% disruption
	released			control	Treatment	
	♂	♀				
7.8.86	10	10	27(=1.6g/ha/day)	1	2	0
14.9.86	15	15	54(=3.2g/ha/day)	5	6	0

*27 release point sources evenly distributed in a 75 m² (15x5) screen cage.

A rate of 54 mg pheromone/75m² is equivalent to 720 mg/dunam (7.2 g/ha). Only 45% of this amount is released within a day (see Fig 3) = 324 mg/dunam/day (3.2 g/ha/day). Therefore, for a lasting effect of 14 days (average of other formulation-ICI Sandoz, BASF) a total of 4.5/dunam/14 days (=45 gr/ha/14 days) is needed.

Table 14 .

Mean number of male/trap/night and % disruption of H. armigera

Date	Control plot	Treated plot 1	% disruption	Treated Plot 2	% disruption
29/5					
31/5	6.6	0	100		
1/6	4.8	0	100		
2	8.6	0.5	95.3		
4	7.4	0.1	98.6		
5	8.3	0	100		
6	7.8	0.2	97.4		
8	13.5	0.7	94.8		
10	14.4	1.2	91.7		
11	15.0	0.7	95.3		
12	21.0	2.2	89.5		
13	22.9	6.0	73.8	0	100
14	44.0	4.5	89.8	0	100
16	39.5	9.9	74.9	0.1	99.7
18	35.9	14.8	58.8	0	100
19	26.3	13.0	50.6	0.7	97.3
20	27.0	-	-	0.2	99.2
22	41.1	12.2	70.3	-	-
24	35.5	5.5	84.5	1.1	96.9
26	54.1	15.7	70.9	3.2	94.1
28	29.1	8.6	70.4	1.5	94.8
30	13.0	3.2	75.4	0.7	94.6
2/7	4.3	2.0	53.5	0.6	86.0

Fig. 1. Response (%) of S. littoralis males to baits containing 50 ng of Z9,E11-14:Ac + 1% Z9,E12-14:Ac on 1 cm² filter paper as a function of age (IF=initial flight; DF = directed flight; L = landing).

Fig. 2. Response (%) of *S. littoralis* males to baits containing 50 ng of Z9,E11-14:Ac + 1% Z9,E12-14:Ac on 1 cm² filter paper as a function of hrs into scotophase. (IF = initial flight; DF = directed flight; L = landing).

Fig. 3. Number of Spodoptera littoralis single insects and mating pairs collected on cotton plants, and number of males captured in traps.

Fig. 4. Release rate of Z11-16:Ald from cotton wigs.