SEX PHEROMONE SYSTEMS OF SELECTED LEPIDOPTEROUS PESTS OF GROUNDNUT

BY

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M. Sc. (Ag)

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CERTIFICATE

Kum. V.L.Lalita Kumari has satisfactorily prosecuted the course of research and that the thesis entitled **"SEX PHEROMONE SYSTEMS OF SELECTED LEPIDOPTEROUS PESTS OF GROUNDNUT"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by her for a degree of any University.

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MAJOR ADVISOR

CERTIFICATE

This is to certify that the thesis entitled **SEX PHEROMONE SYSTEMS OF SELECTED LEPIDOPTEROUS PESTS OF GROUNDNUT** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in Agriculture of the Andhra Pradesh Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Kum.V.L.LALITA KUMARI** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All the assistance and help received during the course of the investigation have been fully acknowledged by the author of the thesis.

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(LALITA KUMARI)

DECLARATION

I, **Lalita Kumari, V.L.** hereby that the thesis entitled **"SEX PHEROMONE SYSTEMS OF SELECTED LEPIDOPTEROUS PESTS OF GROUNDNUT"** submitted to Andhra Pradesh Agricultural University for the degree of **Doctor of Philosophy in Agriculture** is the result of original research work done by me. I also declare that the material contained in the thesis has not been published earlier.

V L Lalita Kumari

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ABSTRACT

Field evaluation of synthetic sex pheromones for the use of monitoring male moths of *Spodoptera litura* and *Heliothis armigera* in groundnut fields was carried out at Munivaripalem (Bapatla) of Guntur district, Andhra Pradesh during post rainy season (rabi) of 1988-'89. Significant correlations were observed between *S. litura* male moth captures in the pheromone traps and counts of egg masses, larval population and plant damage levels in groundnut when trap catches were compared with egg masses, larval populations and plant damage counts made 4,12 and 20 days later. Similary in *H. armigera* the peak larval and damage counts coincided with 8 and 18 days prior catches of male moths. Based on the regression equations worked out from the male moth trap captures, larval populations and damage counts, tentative economic thereholds in terms of trap catches were worked out for use in decision making in the chemical control of these pests.

In trap efficiency studies, ICRISAT funnel trap was more effective in trapping and as such suggested for mass trapping. For monitoring either ICRISAT funnel trap or sleeve trap could be useful. The commercially available pheromone consisting a blend of (Z)-11-hexadecenal and (Z)-9-hexadecenal in 97:3 ratio was more efficient than other blends evaluated. The studies on rhythms of sexual activity indicated that the highest

average catch was between 2.00 am to 4.00 am followed by 10.00 pm to 12.00 midnight for *S. litura* and 2.00 am to 4.00 am followed by 12.00 midnight to 2.00 am for *H. armigera*. In *H. armigera* moth emergence coincided with peak trap catches in the night.

The presence of sex pheromone in the females of *A. modicella* was demonstrated both in laboratory studies involving wind tunnel and in the field utilizing the sticky traps baited with virgin female moths. The attractancy with excised virgin abdominal tips and its extracts in methylene chloride strongly confirms the evidence of the pheromone in female moths.

The mating responses started from the first day of emergence in both sexes. The response/attractiveness was maximum at 1 day old males and females and were at peak during 4.00 am to 6.00 am. Antennae ablation studies indicated that antennae of the males are the principal organs for perception.

In *A. modicella* the female sex pheromone gland is situated dorsally in the intersegmental membrane between 8th and 9th abdominal segments in the form of eversible sac or fold. The pheromone gland in *H. armigera* is in the form of a complete ring between the 8 and 9 abdominal segments. The morphology of the female reproductive systems of *A. modicella* and *H. armigera* have been described in detail.

LIST OF ABBREVIATIONS

<	: Less than
am	: anti meridian
cm	: centimeter
g	: gram
h	: hour
m	: meter
mg	: milligram
ml	: milliliter
mm	: millimeter
pm	: post meridian

INTRODUCTION

CHAPTER I

INTRODUCTION

Insect pests constitute one of the major constraints impeding the groundnut production in our country. While 70 insect species have been reported to damage; leafminer (Aproaerema modicella Dev.) and red hairy caterpillar (Amsacta albistriga Wlk.) have been considered to be major pests of this crop. Of late, tobacco caterpillar (Spodoptera litura Fab.) and gram caterpillar (Heliothis armigera Hub.) which were secondary pests of groundnut, have now assumed serious pest status particularly during post rainy season. The matter of serious concern in the last few years is that these pests acquired resistance to commonly used insecticides (Reddy and Rosaiah, 1987) including the synthetic pyrethroids and thus leading to greater losses in yield due to the damage of these pests. The leafminer intensity and damage has also been ascending in the recent years (Amin, 1987) due to changes in the cultivars and the intensity of management practices. Serious losses due to leafminer are often caused because of non-perception of the time of application of insecticides. Even in the red hairy caterpillar which causes total damage but sporadically, the time of occurence of the pest and of insecticidal application has been visualised as major bottleneck. Thus the growing pest problems and unamenability of insect pests like H. armigera and S. litura for control by insecticides warrants a change in the strategy in pest management in groundnut. Among alternatives/new components of pest control, insect sex pheromones appear to have great promise.

Insect sex pheromones which mediate the behaviour that help in mate finding and courtship have several characteristics making them particularly suitable for use in pest management programmes. They are effective in very small quantities and unlike insecticides they are specific for the target insect. They have no effect on other organisms including parasites and predators and thus totally compatable with pest management systems utilising biological control.

Use of sex pheromones in insect pest control was first indicated by Gotz (1951). Subsequently the pheromonal chemicals responsible for the mediation and mating have been identified for several insects and many of them were incorporated in pest management programmes. As many as 674 pheromones have been isolated and identified for insect species by 1982 (Klassen et al.). The use of sex pheromones fall into three broad categories viz., monitoring, mass trapping and disruption of mating communication. Besides, lure and kill method involving the use of sex pheromones and insecticides is also being developed. Further the spread of virulent pathogens by males picked up at the pheromonal source is contemplated to open new possibilities for pheromonal manipulation. Significant progress made in the use of sex pheromones in pest management has been indicated (Shorey, 1970; Wolf et al., 1971; Oyama, 1977; Gothilf et al., 1979; Gupta and Agarwal, 1983; Lal et al., 1985; Patel et al., 1985; Pawar et al., 1988).

Although much progress has been made in the development and use of synthetic pheromones elsewhere (Campion, 1984), the field of pheromone studies is at infancy in our country. While for 22 insect pests of agricultural importance in our country the pheromones have been developed (Bajikar and Sarode, 1986) their use in the management of about half a dozen pests has been explored. In case of groundnut, pheromones of S. litura (Z,E 9,11-tetra decadienyl acetate and Z,E 9,12 - tetra decadienyl acetate in the ratio of 10:1) and H. armigera (Z,11-hexadecenal and Z,9-hexadecenal in the ratio of 97:3) are being put to limited use of management of these pests on cotton following a few exploratory studies (Patel et al., 1985).

A few such studies undertaken on tobacco (Dhandapani, 1985), blackgram (Krishnaiah, 1986 and chillies (Venkateswara Rao, 1986). On groundnut, there has been practically no studies for use of these available pheromones. Further there is no information on the sex pheromone systems of other groundnut insect pests including leafminer. Therefore, the present investigations were undertaken to study the logistics for use of available synthetic sex pheromones of S. litura and H. armigera on groundnut and to find out the presence of pheromones in leafminer. The objectives of these studies are as follows:

1. To determine the relationship between pheromone trap captures of S. litura and H. armigera and on the incidence of egg, larval and plant damage of these pests on groundnut for working out probable gross parameters, for taking decisions on the need of applying chemical control measures through tentative threshold levels.

2. To demonstrate the presence of sex pheromone in A. modicella and understand the male behavioural responses to a female produced sex pheromone.

3. To generate information on the pheromone production and perception in *A. modicella*, *H. armigera* and *S. litura*.

4. To locate and describe the sex pheromone glands and describe the morphology of female reproductive systems in *A. modicella* and *H. armigera*.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The phenomenon of one sex being attracted towards the opposite sex is not new in insects. As long ago as 1837, Von siebold recognised that odours emitted by female insects, probably sex attractants for males of the same species and that the odours secreted by some male insects were aphrodisiacs that incited females to mate. Fabre (1904) verified that a caged female of great peacock moth, Saturnia pyri (Linnaeus) could attract large number of male moths. He accepted that insect could detect the odours of other insects, but he could not believe that such odours could operate over long distances.

Before Karlson and Butenandt (1959) and Karlson and Luscher (1959) proposed the name "pheromones", various workers referred pheromones as "ectohormones", "telergones" (Kirschenblatt, 1958). Karlson and Luscher (1959) gave an etymological explanation for their term, stating that the ending "mone" is regarded as a proper suffix used in such scientific terms as "hormones", "gamones" and "termones".

Pheromones can be mainly used in three ways in pest management programmes viz., for monitoring the pest population so that chemical control measures can be undertaken at appropriate times; for removing the insects of one sex en masse from an area by mass trapping and lastly for disrupting the mating between the two sexes of a pest species (Marks, 1977). A number of recent reviews have appeared in the literature on the utility of pheromones in pest management (Grosser, 1971; Shorey, 1972; Tette, 1972; Roelofs, 1974; Shorey, 1977; Mitchell, 1979; Kydonieus and Beroza, 1982).

Various aspects of insect sex pheromones have been reviewed in a comprehensive manner by several workers (Poulton, 1927; Crescitelli and Geissman, 1962; Munakata, 1963; Kullenberg, 1964; Jacobson, 1965; Kassang, 1965; Moore, 1965; Butler, 1967; Atkins, 1968; Muto, 1968; Karlson, 1969; Pavan and Quilico, 1969; Beroza, 1971; MacConnell and Silverstein, 1971). Sex pheromones among the lepidoptera are reviewed mainly by Matthews and Knight (1963); and Jacobson *et al.* (1970). It is not within the scope of the present review to cover all these aspects, in detail, but the intention has been to restrict it to important publications that deal mainly with the pheromone systems in lepidopterous pests with special emphasis to the work done in India. Many of the aspects that are of immediate relevance to the subject of the thesis have been included in "Discussion" chapter and as such omitted from the chapter on review.

2.1 DEMONSTRATION OF SEX PHEROMONE

Living virgin female moths as baits for luring males to traps have been particularly used in sod web worm Crambus trisectus (Banerjee and Decker, 1966), Trichoplusia ni (Sower et al.1971), H.zea (Snow et al., 1972), H. virescens (Hail et al., 1973), S. litura (Tamaki and Yushima, 1973) and Earias vitella (Sardana, 1988) to demonstrate the presence of sex pheromone in females.

Positive response of males to females have been demonstrated in the wind tunnel by several workers in Rhyacionia buoliana (Daterman, 1968), Estigmene acrea (MacFarlane and Earle, 1970), S. littoralis (Murlis and Bettany, 1977), S. litura (Oyama, 1977), various Heliothis sps. (Carpenter and Sparks, 1982; Von, 1984) and Phthorimaea operculella (Ono, 1985). Following the demonstration for the presence of sex pheromone using virgin females in the wind tunnel, most of the above workers also confirmed the presence of sex pheromone in the excised female baited tips in the wind tunnel.

Ouye and Butt (1962) demonstrated the presence of a sex attractant in extracts of abdominal tips of the female pink bollworm, Pectinophora gossypiella. Since then similar responses to the extracts of the abdominal tips have been reported with H.virescens (Mitchell *et al.*, 1974), *Phthorimaea operculella* (Hindenlang *et al.*, 1976), *Rheumaptera hastata* (Werner, 1977), *Plutella xylostella* (Koshihara and Yamada, 1978), *S. exempta* (Khasimuddin and Lubega, 1984) both in the laboratory and under field conditions.

2.2 SEX PHEROMONE GLANDS

A good review of the literature pertaining to the sex pheromone glands was published by Jacobson (1966). Jefferson *et al.* (1968) described the morphology of the female sex pheromone glands of 8 species of noctuidae. The gland is situated dorsally in the intersegmental membrane between abdominal segments 8 and 9 in *Autographa californica*, *Pseudoplusia includens* and *Rachiplusia ou*. In *P. includens*, the gland is an eversible sac, but in *A. californica* and *R. ou* it may be an eversible sac or fold. In *S. exigua* and *Feltia subterranea*, the gland is an eversible sac situated ventrally in the intersegmental membrane between 8 and 9 segments. The gland in *H. phloxiphaga*, *H. virescens* and *H. zea* is a complete ring of epithelium between segments 8 and 9 which is more highly developed ventrally in *H. virescens*. Although the exact manner of pheromone release is not clearly understood, it has been postulated that in the case of *Bombyx mori*, the pheromone penetrates the cuticle and is retained on the surface in the invaginations of the non extruded gland until the latter becomes everted during calling (Steinbrecht, 1964).

2.3 BEHAVIOURAL STUDIES

It has long been known that chemical sex attractants, are detected by means of sense organs located mainly in the antennae. In lepidoptera, the antennae are probably the sole organs of chemoreception. Hauser (1880) reviewed the subject of insect olfaction, beginning with the work of Lefebvre (1838). Hauser (1880) while describing the anatomy of the antennae also stated that males of Saturnia pavonia and Porthetria dispar deprived of their antennae never mated. The fact that olfactory receptors are usually located on or in the antennae has been substantiated through antennae ablated experiments by many investigators in Trichoplusia ni (Shorey, 1964; Grant and O'Connell, 1986), H. zea (Agee, 1969), H. armigera (Konyukhov et al., 1980), Autographa californica (Payne et al., 1973), S. litura (Aihara and Shibuya, 1976), Corcyra cephalonica (Darshansingh and Sidhu, 1976) and Pectinophora gossypiella (Smith et al., 1978).

Although many species of insects may produce and emit sex pheromones during their entire life span beginning at the time of emergence, many others do not attain sex maturity until they reach a certain age and the pheromone production may cease sometimes before the natural death of the insect. Similarly, the responding sex may or may not be sexually mature at emergence. Relationship of age to calling of female moths has been reported in few instances like in S. litura (Yushima et al., 1974), S. littoralis (Kehat et al., 1976), Dia crisia obliqua (Islam and Alam, 1979) and in H. virescens (Henneberry and Clayton, 1985) for varying days after emergence. Similarly, male attractancy do differ with the insect species and differences with the age of the males have been observed in S. litura (Yushima et al., 1973; Chu et al., 1987), H. zea (Delorme and Payne, 1984) and H. virescens (Henneberry and Clayton, 1985).

Sex attractants and excitants in insects are released only immediately before or during the period of the day in which mating normally occurs and it is also known that many species produce their pheromones as they are needed. In moths mating normally occurs during the hours of darkness. The peak mating activities or presumably pheromone release do vary with the species of insect but in majority of moths mating occurs 6 to 9 hours after darkness in Dioryctria abietella (Fatzinger and Asher, 1971), Phthorimaea operculella (Ono and Sato, 1973), S. litura (Yushima, et al., 1973), Agrotis *ipsilon* (Swier *et al*., 1976), *S. littoralis* (Elsayes and Kaschef, 1977; Dunkelblum *et al*., 1987), *S. exempta* (Khasimuddin, 1978; Dewhurst, 1984) and *H. armigera* (Topper, 1987). Mating during morning (Trehan and Bhutani, 1949), day time (Pandey *et al*., 1978) as well as during the day or night (Mehra and Shah, 1970) have also been reported. Duration of response/mating have been found to be independent with the insect species and few minutes to several hours have been observed, for instance in *H. armigera* 45 seconds to 10 minutes (Singh and Singh, 1975), *S. littoralis* 80 to 100 minutes (Elsayes and Kaschef, 1977) and in *Diacrisia obliqua* 4 to 8 hours (Siddiqi 1985).

A basic knowledge of the reproductive systems may help in understanding of the pheromone systems in insects. The morphology of reproductive systems in detail have been studied in *H. zea* (Callahan, 1958; Callahan and Cascio, 1963), *Leucinodes orbonalis* (Srivastava, 1960), *Sitotroga cerealella* (Joubert, 1964), *Utethesia pulchella* (Mathur, 1965), *Diatraea grandiosella* (Davis, 1968), *Choristoneura fumiferana* (Retnakaran, 1970), *Laspeyresia pomonella* (Ferro and Akre, 1975), *Plutella xylostella* (Yang and Chow, 1978) and in *S. litura* (Ahmed *et al*., 1979).

2.4 USE OF PHEROMONES IN PEST MANAGEMENT

Active management of many of the insects, until now, been based largely on chemical control. However, there is a potential for other elements of management. Passive management, involving the witholding of sprays when insect abundance is low or when natural control factors are effective, is recognised as a first step to reducing insecticide use. Improved crop scouting has in itself led to a substantial reduction in spray application. This can be fulfilled by the monitoring of pest population by comparing the captures of males of pheromone baited traps with the number of eggs laid in the crop, the larval populations and the damage estimates.

The positive correlation between the pheromone trap catches and the egg counts have been recorded in *S. litura* (Nakasuji and Kiritani, 1976), *S. littoralis* (Iss-Hak *et al*., 1982), *H. armigera* (Rothschild *et al*., .981) and in *H. virescens* (Johnson, 1983). Highly significant positive correlation was reported in 4 trapping sites out of 27 sites for red bollworm, *Diparopsis castanea* on cotton between moth catches and oviposition (Marks, 1977).

Several researchers correlated larval population with pheromone trap catches. Kehat and Bar

(1975) in Earias insulana, McVeigh and Campion (1977) in S. littoralis, Shelton and Wyman (1979) in Phthorimaea operculella and Baker et al. (1982) in Plutella xylostella noted significant correlation between the larval population and pheromone trap moth catches. Very recently Krishnaiah (1986) in S. litura and Newton (1987) in H. armigera significantly correlated the larval populations with the moth catches.

Relationship between the damage estimates and pheromone trap catches has been noted by few workers. Madsen and Vakenti (1973), Reidle and Croft (1974), Cranham (1979) in Cydia pomonella, Shelton and Wyman (1979) in Phthorimaea operculella, Ivanov et al. (1981) in Grapholitha molesta, Kolesova and Chymr (1982) in Cydia nigricana, Page et al. (1984) in Pectinophora gossypiella and Krishnaiah (1986) in S. litura have shown positive correlation between pheromone trap catches and plant damage. In tobacco budworm H. virescens Tingle and Mitchell (1981) have established a positive correlation between trap catches, larval population and plant damage in tobacco.

In many species that have studied, the daily rhythms of sexual activity evidently are endogenous in nature and thus Circadian (Brady, 1974; Saunders, 1976; Beck, 1980). Studies with S. litura (Yushima et al., 1973; Balasubramanian, 1982; Dhandapani, 1985) S. frugiperda (Mitchell et al., 1974; Ramaswamy, 1988) S. exempta (Dewhurst, 1984) Agrotis fucosa (Ohira et al. 1974) Plutella xylostella (Yamada and Koshihara, 1980) and H. armigera (Topper, 1987; Dent and Pawar, 1988) have indicated that the pheromone trap catches vary with the species of the insect and the time of peak catches vary between dusk to dawn. It has been observed that these rhythms can be modified by exogenous environmental cues.

The trap efficiency will vary between species and for each trap design but the electric grid trap has been shown to be more efficient design (Lingren et al., 1978; Sparks et al., 1979). The efficiency of sticky traps was generally low (Marks, 1978; Lingren et al., 1978; Rabson and Mitchell, 1981) but higher trap catches also have been recorded (Timmons and Potter, 1981) with some pest species. There appears to be little published work on trap efficiencies of sleeve traps or funnel traps. Funnel traps have been demonstrated to be more efficient (Raman, 1973; Pawar et al., 1988). However, hallow cone traps (Wilson, 1984) and texas traps (Sage and Gregg 1985) have been reported to be more efficient than the funnel traps.

The search for attractants of H. armigera and H. punctigera began in 1975, with the screening of compounds known at that time to be components of sex pheromones of new world species of Heliothis, H. zea and H. virescens [(Z)-11-hexadecenal (Z11-16:ALD) and (Z)-9-tetradecenal (Z9-14:ALD)] (Roelofs et al., 1974; Tumlinson et al., 1975). The presence of Z11-16:ALD in female H. armigera was confirmed by Piccardi et al. (1977) but obtained poor trap catches under conditions. Later poor trap catches were explained by the identification of the most important minor component of H. armigera females was shown to be (Z)-9-hexadecenal. At present, monitoring H. armigera is based on 10:1 mixture of Z11-16:ALD and Z9-14:ALD. Several ratios of the major and minor components for H. armigera (Rothschild, 1978; Saltar-sade et al., 1981; Pawar et al., 1983) H. virescens (Hendricks, 1976; Mitchell, 1978; Flint et al., 1979; Ramaswamy et al., 1985) H. zea (Halfhill and Mc Donough, 1985) have been tested and obtained varying number of moth catches with different blends.

The use of sex attractants in insect control, particularly for the lepidoptera, has been pointed out in reviews by Gotz (1951), Beroza and Jacobson (1963), Shorey et al. (1967) and Knipling (1969) as well as in a number of other brief reviews (Wright, 1963; Beroza, 1965 and 1966; Asakawa, 1967; Jacobson, 1970; Shorey, 1970 and Outram, 1971).

Numerous males of certain species of moths can be lured to their deaths by the use of even crude extracts of the females placed advantageously in traps with insecticide or on sticky boards (Jacobson, 1963) and the use of a mixture of sex attractant and a chemical sterilant merits trial. Insects responding to the attractant could thus be brought in contact with the chemosterilant and then be free to fly off and mate with normal individuals of the opposite sex; such matings would, of course, result in no progeny.

2.5 PHEROMONE SYSTEMS IN GROUNDNUT PESTS

While there are numerous cases of pheromone studies in lepidopterous pests of several crops, the pheromone studies on the lepidopterous pests infesting groundnut are inadequate. Some preliminary studies have been made with S. litura (Dhandapani 1985; Patel et al., 1985; Krishnaiah, 1986; Venkateswara Rao, 1986) with H. armigera (Dent, 1985, Lal et al., 1985; Patel et al., 1985; Pawar et al., 1988) and were mostly confined to the crops other than groundnut. It may be stated in general that our knowledge of pheromone systems in insects affecting groundnut is rather very limited in India and there is considerable scope and need for undertaking research on this important aspect.

MATERIALS & METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 PHEROMONE TRAPPING

Pheromone trapping studies were undertaken on Spodoptera litura and Heliothis armigera in the farmers fields at Munivaripalam, Bapatla, Guntur district, Andhra Pradesh, which is a hot spot for these pests. The observations lasted for one crop season commencing from January 27 to April 16, 1989.

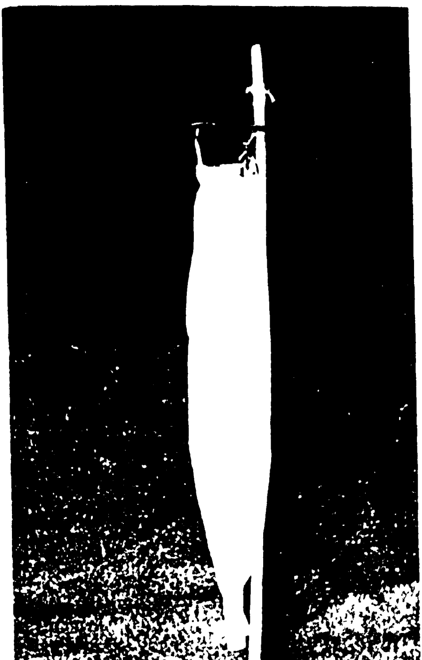
3.1.1 Trap design

A standard sleeve trap (Plate 1) supplied by "Pheromone Chemicals", B-6, Industrial Estate, Bapatla, Andhra Pradesh used for trapping both the pests. The trap consisted of a metallic frame with thin plate canopy (13.5 cm diameter) and a battering to which a 50 cm long polyethylene tube is clipped. The trap is kept in position by tying at neck and tail end to 1 m long bamboo stick.

3.1.2 Dispenser

Rubber septa of 1.5 cm length and 0.6 cm diameter impregnated with synthetic pheromone mixtures were used as dispenser which are fixed to the bottom of the canopy plate. The pheromone composition used was given below.

PLATE 1: SLEEVE TRAP



Pest	Pheromone components	Ratio	Authors
S. litura	Z,E 9,11-tetra decadienyl acetate and Z,E 9, 12 - tetra decadienyl acetate	10:1	Chiu and Chien, 1979
H. armigera	(Z)-11-hexadecenal (Z)-9-hexadecenal	97:3	Nesbitt *et al.*, 1980

These pheromones attracted the males and polyethylene tube served as retaining device. Carbaryl dust (2-3g) was sprinkled inside the tube to kill the collected moths. The moths, thus trapped were monitored daily throughout the experimental period. The dispensers were changed once in 20 days.

3.1.3 Layout of pheromone traps

In a continuous block of three groundnut fields for each pest which are designated as fields, A, B, C in case of *S. litura* and fields I, II, III in case of *H. armigera*. Each field measured an area of 1 hectare with a total of 6 hectares (Fig. 1). The sleeve traps were fixed in the field at 30 m apart maintaining a density of 3 traps (plate 2) per hectare (total 9 traps for each pest). The traps were positioned in the field from January 15, 1989, i.e., two weeks after sowing.

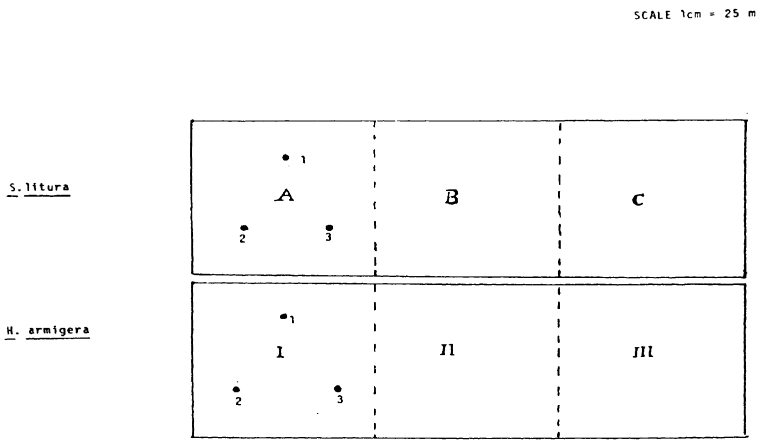


Fig. 1: INSTALLATION OF PHEROMONE TRAPS FOR MONITORING OF *S. litura* and *H. armigera* IN GROUNDNUT FIELDS.

TRAPS

3.1.4 Recording trap counts

Male moths started appearing in the traps only from January 27, 1989. Collection of moths in the traps lasted till the harvest of the crop. Male moth counts for both the pests were recorded daily at 8.00 am. Groundnut was sown by the cooperating farmer in the first week of January, 1989 and insecticidal treatments were totally avoided in these fields by paying compensation for the loss due to pest incidence.

3.1.5 Recording pest counts and damage

3.1.5.1 Egg **masses of S. litura**: Egg masses were counted from a sampling unit of 2 m x 2 m (approximates 100 plants) area demarcated at about 15 m away from each pheromone trap. There were three sampling units per one hectare field, totalling 9 sampling units. All the groundnut plants in the sampling area were observed thoroughly for locating the egg masses of S. litura.

The egg masses were removed immediately after the counting to avoid recounting during next sampling. Egg masses were counted on alternate days commencing from the appearance of moths in the traps.

In case of Heliothis, no egg count was made and only larval counts were taken due to difficulty in locating the eggs.

3.1.5.2 Larval population counts: On the basis of visual judgement of the head capsule size the larval stages of the test insects were classified into two groups viz., early larval stage - 1st, 2nd and 3rd instars; late larval stage - 4th and 5th instars incase of Heliothis and 4th, 5th and 6th instars in case of Spodoptera. Six sampling areas 2 m x 2 m (approximately 100 plants) were marked for different larval instars (one sampling area for each instar separately) 15 m away from each trap in six directions. Totally there were 18 sampling areas for Spodoptera, 15 sampling areas for Heliothis per hectare and these were demarcated with pegs. The larvae of each instar were counted from each sampling unit and removed to avoid recounting of the larvae in the subsequent count. The larvae were counted at alternate days commencing from the appearance of eggs in the field.

3.1.5.3 Assessment of damage: The damage was assessed for both Spodoptera and Heliothis by demarcating 2 m x 2 m field (approximates 100 plants) with pegs. There were three sampling areas per hectare (9 for each pest). The leaves damaged by test insects were distinguished by skeletonisation by freshy hatched larvae followed by defoliation of leaflets leaving only viens for S. litura and semi to circular holes on the leaflet margins for H. armigera. Coalescence of holes in the leaflet forming into bigger holes were common with *Heliothis* damage.

The number of leaves damaged were recorded and removed to avoid recounting in subsequent damage assessment. The quadrifoliate was taken as a unit and even if one leaflet is damaged the entire quadrifoliate was removed. The damage was assessed on alternate days following the appearance of egg masses and larval stages.

3.2 EVALUATION OF TRAP DESIGNS FOR TRAPPING *SPODOPTERA* AND *HELIOTHIS*

Two types of traps viz., ICRISAT funnel traps (Pawar *et al.*, 1983) and sleeve traps (Plate 3) were evaluated to assess the trapping efficiency in respect of *S. litura* and *H. armigera* in the groundnut fields. ICRISAT funnel trap consists of a white funnel (21 cm diameter) on which an aluminium plate (25 cm diameter) is surmounted at a height of 5 cm. A polyethylene bag is wired to the rim of the funnel to collect the trapped moths. Carbaryl dust (5%) is sprinked in the polyethylene bag to kill the moths collected in the bag. A provision is made for suspending the dispenser from the centre of aluminium plate. These funnel traps obtained from ICRISAT, Hyderabad.

PLATE 3: A. SLEEVE TRAP

B. ICRISAT FUNNEL TRAP

These ICRISAT funnel and sleeve traps were positioned in 4 hectare groudnut field (2 hectares area for each pest) maintaining 30 m distance from one another. The dispensers impregnated with respective synthetic pheromone mixtures were loaded in the traps, which were changed at 20 day intervals. The trap counts were recorded daily at 8.00 am. The observations lasted for about 70 days from February 1 to April 11, 1989.

3.3 EVALUATION OF RELATIVE ATTRACTANCY OF DIFFERENT PROPORTIONS OF ACTIVE COMPONENTS OF HELIOTHIS PHEROMONE

The two primary components of synthetic sex pheromone of H. armigera [(Z)-11-hexadecenal and (Z)-9-hexadecenal] were tested in different ratios of 97:3, 94:6, 91:9 and 88:12 using 2 mg dose in all baits. The sleeve traps baited with these ratios and were positioned at 30 m apart in 4 hectare groundnut field (1 hectare for each ratio). There were three traps for each ratio tested and in total 12 traps.

Heliothis male moths captured in pheromone traps were counted every day at 8.00 am during March 7 to April 10, 1989. The septa was changed after 20 days. The efficiency of the ratios was assessed based on the number of moths trapped in each blend.

3.4 CULTURING OF TEST INSECTS

3.4.1 Groundnut leafminer (*Aproaerema modicella*)

Groundnut leafminer pupae obtained from the groundnut field plots of ICRISAT, Hyderabad formed the nucleus culture for the present studies. The pupae were placed in a small petridish (5 cm diameter) for the emergence of moths in large cages (1 m x 1 m) having the potted plants of the groundnut variety JL-24 and the culture was maintained in the glass house, Department of Entomology, College of Agriculture, Rajendranagar, Hyderabad was used for different studies. As and when necessary, some of the field populations mostly late larval stage or pupae of the leafminer collected from the fields of Agricultural College Farm and ICRISAT fields were supplemented for the studies.

3.4.2 Gram caterpillar (*H. armigera*)

Five pairs of *H. armigera* moths obtained from the culture maintained at ICRISAT were kept in one litre glass jars. All glass jars and rearing trays were cleaned with chromic acid and then washed under tap water and finally rinsed with distilled water and dried in an oven at 160^{o}F for six hours to avoid contamination from NPV virus.

A cotton swab dipped in 10% honey was kept in the container as feed for the moths. Strips of muslin cloth were hung inside the cage for oviposition. The moths usually lay eggs on third day after emergence. The muslin cloth on which eggs were laid was taken out and rinsed in 1.8% sodium hypochlorite solution for five minutes. It was then washed under running tap water for at least fifteen minutes. This was done to avoid microbial infection which could be carried from the parent to offspring. The cloth was dried and placed in a rearing tray containing the artificial diet described by Nagarkatti and Satyaprakash (1974).

When the larvae attained second instar, they were isolated and reared individually in the partitioned tray containing the diet, as they tend to be cannibalistic. As and when the larvae entered the pupal stage, these were taken out, sexed and equal number of males and females were kept for emergene (Natarajan Paul, 1979). The moths lived for about 6 to 9 days.

Ingredients of the artificial diet of H. armigera are 105 g Bengalgram powder 10 g yeast, 12.8 g Agar-agar, 3.25 g Ascorbic acid, 1 g Sorbic acid, 2 g Methyl parahydroxy benzoate, 2 ml Formalin 10% solution, 1 capsule of Resticlin (250 mg), 3 capsules of Multivitamin and 780 ml water (Nagarkatti and Satyaprakash, 1974). Half the quantity of water was taken in a blender. While blending, all the ingredients except agar-agar and formalin were added one after another. The remaining quantity of water was boiled and agar-agar was added to it, till it got dissolved. Then, it was poured into the blender with the other ingredients and was thoroughly blended. Finally, formalin was added, blended and the mixture was poured in a shallow rearing tray. On cooling, the mixture was solidified as a cake which was used for rearing the larvae of Heliothis. The diet was stored in a refrigerator until needed. All the experiments were carried out at a temperature of $26^{o} \pm 2^{o}C$ and $65 \pm 5\%$ relative humidity with a 14 h photophase.

3.5 SEXING

Sexing of pupae was necessary for mass rearing in the laboratory, to study the morphology of reproductive systems, pheromone gland location and behavioural responses as it could not easily be done in the adult stage. The distinguishing characters observed on the eighth, ninth and tenth abdominal segments of the pupae in terms of genital openings were used as a main criteria for separating male and female pupae.

In *H. armigera*, mainly the pupae were sexed by location of genital opening and anal pores on the ninth and tenth abdominal segments in male and on the eigth, and tenth abdominal segments in female (Plate 4). In adult stage, the sexes were distinguished by the shape of abdomininal tip. The abdominal tips of females were blunt or round whereas pointed in males densely clothed with hairs (Plate 5).

The pupae and adults of (male and female) groundut leafminer, *A. modicella* were also distinguished by location of genital opening and anal pores similar to that in *H. armigera*. In the leafminer, sexing was done mostly at pupal stage. Pupae were identified with a dull purple mark (testes) Kothai, 1974 situated between fourth and fifth abdominal segments visible through the pupal skin which was not observed in female pupae (Plate 6). Sexing at the late larval stage was also done based on the visible developing testis through male larval skin. In the adult stage the leafminer moths were also sexed based on pointed abdominal tip in male and blunt tip in female (Plate 7).

3.6 DEMONSTRATION OF SEX PHEROMONE IN LEAFMINER

Presence of sex pheromone in the leafminer was demonstrated both in the laboratory and field. The

PLATE 4: VENTRAL VIEW OF THE POSTERIOR SIDE OF THE ABDOMEN OF FEMALE AND MALE PUPAE OF H. armigera SHOWING GENITAL AND ANAL APERTURE

PLATE 5: VENTRAL VIEW OF THE ABDOMENS OF ADULT H. armigera BROADLY TAPERING IN FEMALE AND NARROWLY TAPERING IN MALE

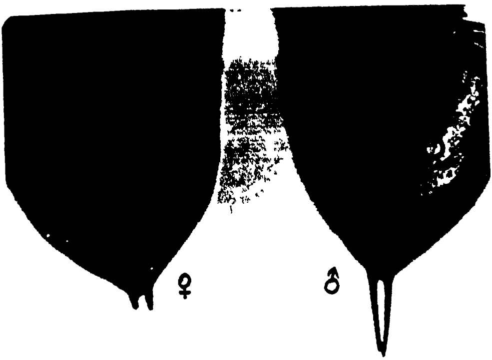


PLATE 6: DORSAL VIEW OF A modicella OF MALE PUPAE WITH DULL PURPLE LINE ON FIFTH ABDOMINAL SEGMENT AND FEMALE PUPAE WITHOUT LINE

PLATE 7: VENTRAL VIEW OF THE ABDOMENS OF ADULT A. modicella BROADLY TAPERING IN FEMALE AND NARROWLY TAPERING IN MALE

laboratory bioassay was performed using a wind tunnel and field bioassay was conducted using sticky traps. The wind tunnel experiments in the lab were conducted at room temperature during night between 6.00 pm to 8.00 am.

3.6.1 Wind tunnel

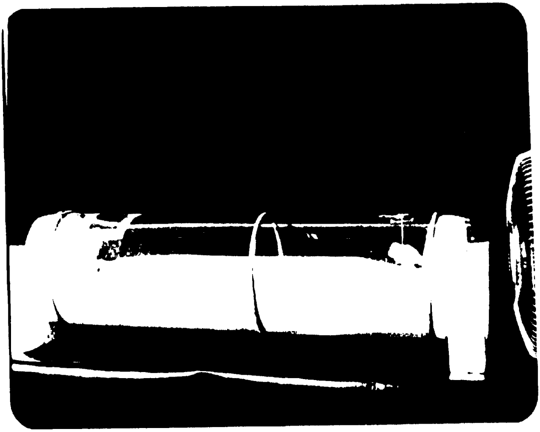
The wind tunnel was fabricated by using garware polyester transparent film, 175 microns thickness of 40" width. This film sheet was cut, turned and put in a circular position (100 cm length and 26 cm diameter) as in Plate 8 with the help of three wooden rings used in embroidary (26 cm diameter). Thermocoal sheet of 7 cm thick was cut to the size and shape of wooden rings and inserted in to them on either the sides of the tunnel to serve as support to the tunnel.

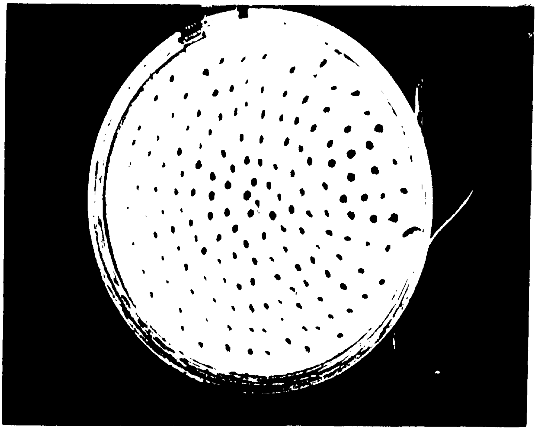
Before insertion into the tunnel, thermocoal was perforated (Plate 9) with soldering rod to have uniform sized and equally distributed holes for passage of air uniformly from the wind source (Fan). To prevent the escape of insects through the holes of thermocoal, a nylon mosquito mesh was covered on the innerside of the thermocoal.

A 35 mm film case cut at three sides (Plate 10a) pasted with nylon mesh inside (Plate 10b) (to

PLATE 8: WIND TUNNEL

PLATE 9: PERFORATED THERMOCOAL SHEET





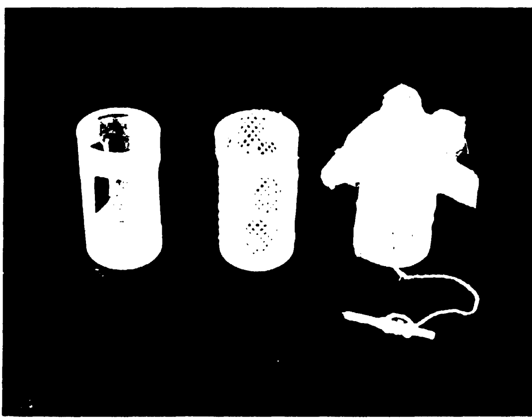
prevent the escape of insect), covered with the muslin cloth (Plate 10c) and secured with the rubber band was used to contain the females/males near the wind source. At one end of the wind tunnel (near the wind source, fan) a small flap (4x4 cm) was made cutting three sides. The flap was given a cut in the centre upto half distance to facilitate the insertion of the thread used to hang 35 mm plastic case confined with females/males. This case was hung by securing with thread from the centre of the flap.

At the other end of the wind tunnel (opposite to wind source) another flap of slightly bigger size (10x10 cm) without centre cut for the release of males/females. The wind tunnel was provided with thermocoal supports.

The air flow of the wind tunnel was regulated by adjusting the distance between the wind tunnel and table fan (wind source) and also covering fan with the muslin cloth. The stream of the air flow was adjusted to the minimum so that no movement could be observed in the cage containing the insects in the tunnel.

3.6.2 Demonstration of sex pheromone using wind tunnel

Presence of pheromone in the females of leafminer was first tested by confining 0' day old

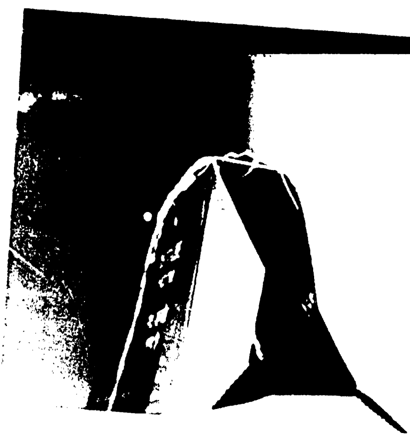


single female in a plastic cage positioned upwind in the tunnel and 10 virgin males were released downwind in the tunnel. The orientation, if any, of the males to the females was observed continously from 6.00 am to 8.00 am at 10 minutes interval in scotophase with the help of 7.5 volts torch with red filter (Cellophane paper). A continuous gentle stream of air from the fan served as a wind source. The experiment was replicated thrice. Rapid vibration of wings, erratic and fast movements with intermittant upcurving of abdomen, hovering around the encaged females and finally alighting on the cage was taken as a criteria for attraction of males to female pheromone source in all wind tunnel studies. In another wind tunnel (replicated thrice), the male was tested as a pheromone source and female response was recorded. Zero day old single male served as a pheromone source and 10 females were released down wind in the tunnel. Female movement in response to male pheromone source towards upwind was recorded.

3.6.3 Sticky traps

Sticky delta traps (pest-O-Lure insect trap), used .to demonstrate the presence of sex pheromone in female leafminer were obtained from pest control (India) Pvt. Ltd., Bombay (Plate 11). The sticky trap used was made up of gallon icecream cartons. The

PLATE 11: STICKY DELTA TRAP



inside of carton smeared with a thin layer of sticky material, trapped male moths, when males oriented to female producing pheromone.

One virgin female '0' day old was baited in a container (Plate 12) described earlier was hung from the centre of trap and the trap was tied with a thread to bamboo stick and placed in the leafminer infested groundnut field at College Farm, Rajendranagar, Hyderabad 40 cm above the ground level (Plate 13). Three such traps were installed at 20 m apart. Trap without virgin female was also kept in the field as check. The traps were installed at 6.00 pm in the night and the males caught in the each trap next day at 8.00 am in the morning were recorded.

3.6.4 Response to female abdominal tips

3.6.4.1 Wind tunnel: Abdominal tips of one day old anaesthetized (chloroform) virgin female moths served as a pheromone source to males in the wind tunnel. The terminal abdominal segments (7-10) of female moths were cut at the calling time (early hours at 4.00 am) with a fine blade under sterioscopic microscope. Three ablated abdominal tips were kept in a plastic cage (described earlier) and 10 one day old male moths were released downwind in the tunnel.

Response of male moths described earlier to female abdominal tips was observed with the help of torch light having red filter continuously until the response was ceased upto 8.00 am in the morning. The experiment was repeated in 3 wind tunnels simultaneously.

3.6.4.2 Sticky traps: Similarly one day old excised virgin female abdominal tips (ablated at 4.00 am) were kept as a pheromone source in the sticky traps and three such traps and trap without virgin female abdominal tips (check) were installed immediately in the groundnut field at College Farm, Hyderabad. Male moth counts in the sticky traps were taken at 8.00 am in the morning to assess the response of males to excised abdominal tips.

3.6.5 Response to extract of female abdominal tips

3.6.5.1 Wind tunnel: Eighteen one day old virgin females were anaesthetized (chloroform) at calling time (4.00 am) and the abdominal tips were cut with the help of fine blade under sterioscopic microscope. Immediately, these tips (18) soaked in 18 ml of methylene chloride for about 2 hours. The solvent extract was pipetted @ 1 ml, 2 ml and 3 ml (equal to 1, 2 and 3 female equivalents) per cigarette filter tip which served as absorbant septa.

Cigarette filter tip with corresponding quantity of methylene chloride served as check. The septa (cigarette filter tip)replicated thrice was kept as source of pheromone at 6.00 am in the morning in wind tunnel and the response of ten one day old males released in each of the wind tunnel was noted based on the orientation to the pheromone source described earlier. Observations continued upto 8.00 am in the morning and there were 3 replicates.

3.6.5.2 **Sticky traps:** The sticky traps baited with cigarette filter tips absorbed with one, two and three female equivalents of extract of the abdominal tips (described earlier). Septa (cigarette filter tips) were installed at 6.00 pm in groundnut field infested with leaf miner. The filter tips incorporated with the extract of the abdominal tips at 6.00 am in the morning were utilized in the sticky traps at 6.00 pm on the same day. Cigarette tip with methylene chloride alone served as the control. The male moth catches were recorded next day at 8.00 am in the morning in 3 replicates of each ml female equivalent of the extract of abdominal tips.

3.7 BEHAVIOURAL RESPONSES OF *A. MODICELLA* AND *H. ARMIGERA*

These studies includes the moth emergence, age related calling behaviour of female moths and responses of male moths, rhythm of male attraction and female attractiveness and role of antennae in pheromone perception. Effect of continuous light on response of males to female pheromone source was also studied. The laboratory studies were made in the Department of Entomology, College of Agriculture, Rajendranagar, Hyderabad and field studies in the farmers field at Bapatla and also in the College Farm, Hyderabad.

3.7.1 Moth emergence parttern in different sexes

Duration of pupal period (male and female) and time of emergence were recorded both in case of A. modicella and H. armigera. A homogeneous pupae of 50 each sex were taken (pupated on the same day) and kept in glass jars for emergence. The pupal period was recorded by daily observations at 8.00 am. A moth found in the morning was recorded as being 'O' day old. The temperature and relative humidity ranged $26^{o} \pm 2^{o}C$ and $65 \pm 5\%$ during the observation respectively.

For determining the time of emergence of moths of A. modicella and H. armigera, 20 freshly formed pupae of each sex were observed at two hourly intervals from 8.00 pm to 6.00 pm (continuous day) untill all moths emerged from the pupae. Pupae were observed starting from 9th day after pupation of Heliothis and 2 days after pupation of leafminer.

3.7.2 Age and time of pheromone release and response of *A. modicella*

3.7.2.1 Wind tunnel: Age of mating response of males to females, time and duration of mating were assessed in the laboratory using wind tunnels. To assess the optimum age of response of males to females, 0 to 5 day old females were tested with 0 to 5 day old males. In total there were 36 combinations. For each combination test, three females and males used and was replicated thrice (using three wind tunnels simultaneously). Experiment was conducted in a dark room from 6.00 pm to 8.00 am, since no response was observed in day time. Number of males responded to the female pheromone source, initiation time of response of male and duration of response were recorded. Observations lasted entire night continuously at 10 minutes interval with the help of torch light (7.5 volts) having red filter.

3.7.2.2 Sticky traps: The wind tunnel experiments conducted in the lab indicated that one day old females were more attractive to males suggesting that they have maximum calling. This was confirmed under field condition using sticky traps. Virgin females of 0 to 7 day old @ 1 female per trap was confined in a sticky trap (as described earlier) and traps were installed in a leaf miner infested groundnut field at Agricultural

College Farm, Rajendranagar. For each day old female, there were three traps with a trap to trap distance of 20 m. The traps were installed in the night between 6.00 pm and at 8.00 am next day morning. Number of males caught per trap was recorded.

3.7.3 Rhythm of sexual activity

3.7.3.1 A. modicella: To find out the peak period of attraction of male moths of groundnut leafminer, seven periods during night from 6.00 pm to 8.00 am, observations at every two hour interval were taken in groundnut field by using sticky traps. One day old one virgin female was used as a pheromone source. Number of males trapped at the lapse of each period of time were recorded.

3.7.3.2 Assessment of peak time of attraction of S. litura and H. armigera at pheromone traps: Catches of male moths of S. litura and H. armigera to the synthetic sex lures were recorded from 6.00 pm to 6.00 am at two hourly intervals. Observations were taken in three sleeve traps for each pest positioned at 30 m apart in 2 hectares groundnut field (1 hectare for each pest) for seven days from March 29 to April 3, 1989 in the farmers field at Bapatla.

The moths trapped were removed at 2 hourly intervals i.e., 8.00 pm, 10.00 pm, 12.00 midnight, 2.00

am, 4.00 am and 6.00 am and counted. The sleeve traps and the dispensers were secured from "Pheromone Chemicals", Bapatla, Andhra Pradesh.

3.7.4 Pheromone perception in *A. modicella*

It is well known that antennae is mainly involved in pheromone perception of lepidopterous pests. To test the role of antennae in pheromone perception in this species, one day old male moths of leafminer were anaesthetized by exposing them to chloroform fumes for a few seconds. Immediately the antennae were excised with microscissors under sterioscopic microscope. One day old female moths were used as a pheromone source.

The perception of males to females was assessed by confining 3 females (pheromone source) and releasing 10 ablated males in a wind tunnel. One day old males with antennae served as control. Movement based on orientation or no orientation of males towards upwind to the pheromone source was taken as a criteria to assess the role of antennae in the pheromone perception. The observations confined to 6.00 pm in the night to 8.00 am in the morning.

3.7.5 Effect of light on response of males of *A. modicella*

3.7.5.1 Wind tunnel: In laboratory, 3 females of one day old used as phermone source upwind in the tunnel and 10 males released downwind in the tunnel were kept continuously in the light for three days (72 hours) to determine the effect of continuous light (40 watts flourescent tube light) on male response towards female producing pheromone. The experiment was replicated in three wind tunnels simultaneously to assess the light effect on male attraction. The moths were observed continuously for three days at 10 minutes interval and the response if any and also duration of response was recorded.

3.7.5.2 Sticky traps: Three sticky traps baited with one day old females (three) were tested in field during day time starting at 8.00 am to 6.00 pm to observe the effect of continuous light on the attraction of males to females. The moths trapped if any in the sticky traps were recorded at 6.00 pm.

3.8 SEX PHEROMONE GLANDS IN *A. MODICELLA* AND *H. ARMIGERA*

The attraction to the female abdominal tips by male moths of leaf miner, *A. modicella* in wind tunnel and also in sticky traps under field conditions indicated the presence of sex pheromone gland in terminal abdominal segments (7-10). For the location of the pheromone gland, the moths were anaesthetized with chloroform fumes and pinned in the petridish containing wax under sterioscopic microscope and the hairs present in the abdominal tips were brushed with a camel hair brush to remove the hairs for easy location of the gland.

With the help of bent foreceps, the last abdominal segments were pressed out so that the telescoped 8th and 9th segments could protrude out. By holding the terminal abdominal segment with the forceps it was further pulled gently to locate gland. The dorsal and also the ventral sides were examined for the location of gland.

Similar procedure was followed for the gland location in the case of Heliothis also.

3.9 MORPHOLOGY OF THE REPRODUCTIVE SYSTEMS OF A. MODICELLA AND H. ARMIGERA

The morphology of the male and female reproductive systems of A. modicella and H. armigera were studied by dissecting moths under sterioscopic microscope. Prior to dissection, the moths were killed (by cyanide poisoning), tripped of wings and legs with fine scissors and pinned dorsally in a wax filled petridish containing water. Then the entire system was separated from the abdominal cavity except that left attached to the genitalia. The organs, freed from attached tracheae and fat body tissue were so arranged to facilitate all parts to observe and measure.

4.0 STATISTICAL PROCEDURES

Correlation coefficients were calculated to determine the degree of association i) involving relationship between moth catches and egg-masses ii) between the moths catches and larval population iii) between moth catches and damaged leaves. The regression coefficients and coefficient of variances were calculated to find out the dependence of egg masses/larval population/damage on pheromone trap captures of male moths. The moth catches (X) and egg-mass counts, larval population and damaged leaves (Y) were transformed into log (n + 1) values for analysis. These were done according to the methods described by Panse and Sukhatme (1957).

An analysis of variance (Panse and Sukhatme, 1957) was carried out to find out the maximum calling of virgin females and response of males of A. modicella. The catch period of three days were taken as replications and 0 to 7 day old females as treatments and also on the pheromone trap catches, to determine the peak period of attraction of S. litura and H. armigera moths. The catch period of seven days were considered as replications and the six periods of time interval as treatments.

In the ratio test, to find out the effective ratio which attracted more moths, analysis of variance method was followed. The four ratios (97 : 3, 94 : 6, 91 : 9 and 88 : 12) were taken as treatments and weekly mean moth catches as replications.

To determine the trap efficiency, A student - 't' test (Panse and Sukhatme, 1957) was performed to compare daily mean catches in ICRISAT funnel trap with sleeve traps.

RESULTS

CHAPTER IV

RESULTS

4.1 USE OF SEX PHEROMONES IN MANAGEMENT OF INSECT PESTS OF GROUNDNUT

4.1.1 Relation between male moth captures in pheromone traps and field populations

4.1.1.1 Spodoptera litura

4.1.1.1.1 Trap catches vs egg masses: *S. litura* male moths started appearing in the pheromone sleeve traps installed in all the three groundnut fields (A,B and C) from the beginning of February (1st to 3rd) to April 16, 1989 (till crop harvest) (Table 1). Trap catches ranged from 1.3 to 1014.3 moths/trap in field A, 1.0 to 1084.7 moths/trap in field B and 3.3 to 1929.0 moths/trap in field C (Fig.2 a, b,c).

The first peak moth catch was observed in all the three fields between March 1 to 5 i.e., 28 to 32 days after the first appearance of moths in the pheromone traps. Second peak moth catch was recorded between March 29 to April 2 and approximately a month after the previous peak. During the second peak moth catches ranged from 334.3 to 521.7 moths/trap were almost half in number compared to the first peak. Except in few instances the increase and also decrease in moth

Table 1 Relationship between pheromone trap catches of S litura male moths and egg masses

	Field A		Field B		Field C	
Date	Moths/trap[a]	No of egg masses/100 plants[b]	Moths/trap[a]	No of egg masses/100 plants[b]	Moths/trap[a]	No of egg masses/100 plants[b]
01-02-89	0 0	0 0	1 0	0 0	0 0	0 0
03-02 89	1 3	0 0	2 0	0 0	3 3	0 0
05 02-89	2 0	0 0	8 0	0 7	5 0	0 3
07 02-89	2 9	0 7	9 0	1 0	7 0	1 7
09 02-89	3 7	1 0	7 7	1 3	7 0	2 7
11-02-89	1 7	1 7	10 7	2 0	14 0	3 0
13-02-89	7 3	3 0	13 3	1 0	9 3	2 7
15-02 89	8 3	2 7	23 3	2 3	31 7	3 3
17 02-89	13 0	3 3	41 7	4 0	53 7	4 0
19 02-89	31 7	3 7	39 7	6 0	57 0	3 0
21 02-89	41 7	4 3	102 0	6 7	136 7	6 0
23 02-89	39 0	6 0	299 3	6 0	265 0	6 7
25 02-89	197 7	8 3	348 3	11 3	220 7	8 3
27 02-89	262 3	6 7	650 3	13 3	493 3	10 3
01 03-89	504 0	9 0	1084 7	18 0	1158 3	8 0
03 03 89	820 7	15 3	677 0	20 3	1929 0	19 3
05 03 89	1014 3	19 0	417 7	26 0	820 3	23 7
07 03 89	362 7	19 7	323 0	21 0	581 3	34 0
09 03-89	416 3	31 3	209 0	15 3	372 7	28 0
11 03-89	210 0	24 3	227 0	12 3	202 3	22 3
13 03-89	234 0	21 3	117 0	11 3	92 3	18 3
15 03 89	185 0	18 7	92 7	12 0	113 7	10 3
17 03-89	121 3	20 3	171 7	7 0	51 3	6 3
19 03 89	117 7	17 7	69 0	4 7	32 3	7 3
21 03-89	188 3	14 0	37 3	7 3	31 7	5 7
23 03-89	75 3	15 0	18 3	6 0	21 3	2 7
25 03 89	31 3	12 0	16 0	7 0	17 0	3 0
27-03-89	178 0	7 7	149 3	12 0	102 3	2 7
29 03-89	261 3	4 0	334 3	8 3	236 7	8 0
31-03-89	436 0	3 3	218 0	10 7	428 7	11 7
02-04 89	521 7	4 7	253 7	14 3	292 7	14 0
04 04 89	303 3	9 0	151 7	6 3	314 7	22 7
06 04 89	166 7	17 0	81 0	8 0	79 0	5 7
08 04 89	179 7	10 0	57 7	2 3	48 0	10 3
10-04 89	64 3	5 0	90 0	1 3	41 0	3 0
12 04 89	51 0	5 3	38 7	0 0	56 3	1 7
14 04 89	26 0	0 0	26 3	0 0	24 0	0 7
16 04-89	9 0	0 0	19 3	0 0	13 3	0 0
	0 798**		r = 0 826**		r = 0 838**	
	= 0 019+0 445x		y = -0 220+0 535x		y = -0 070+0 474x	

* Significant at P = 0 01
Mean catch from 3 traps for two nights
Mean egg masses from 300 plants for two nights
Moth catches and egg masses are transformed to log values for statistical analysis

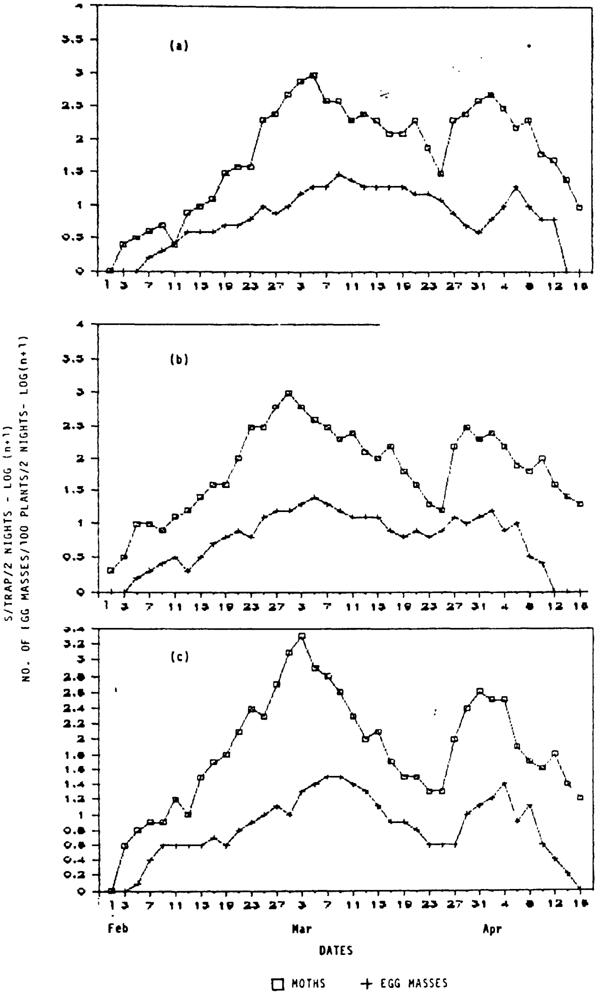


Fig.2 (a,b,c): EGG MASSES AND MOTH CATCHES OF S. LITURA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS catches in the traps were steady and gradual before and after the peak moth catches respectively in all the three fields.

Egg masses of S. litura in the groundnut fields (A, B and C) were recorded from February 5 to 7 i.e., four days after the first appearance of moths in the pheromone traps. The number of egg masses steadily increased in correspondence with the trap catches in all the fields (Table 1). Interestingly the highest number of egg masses in all the three fields coincided with the respective peak moth catches (Fig.3 a,b,c) in the pheromone traps (4 days prior to peak egg counts). The highest number of egg masses recorded in the field A B and C were 31.3, 26.0 and 34 0 per 100 plants as against the peak trap catches 1014.3, 1084.7 and 1929.0 moths/trap respectively. Similarly the higher number of egg masses observed during April 2 to 6 in all three fields (17.0 14.3 and 22.7 egg masses/100 plants in the fields A B and C respectively) coincided with the second peak moth catches recorded March 29 to April 2 i.e. 4 days prior to second peak egg count. The increase and decrease in the number of egg masses in general were in coincidence with the fluctuations in the trap catches. The correlation coefficients and regression equations of moth catches and egg masses for fields (A B and C) are as follows.

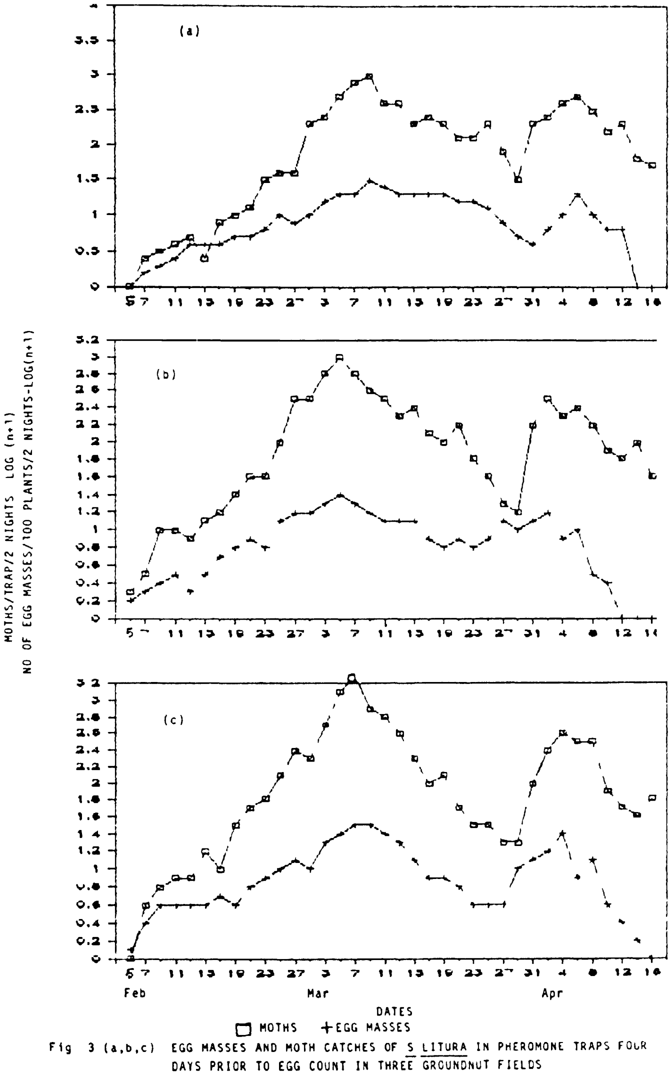


Fig 3 (a,b,c) EGG MASSES AND MOTH CATCHES OF S LITURA IN PHEROMONE TRAPS FOUR DAYS PRIOR TO EGG COUNT IN THREE GROUNDNUT FIELDS

Field	Correlation coefficient (r)	Regression equation (Y=a+bx)
A	0.798**	Y= 0.019+0.445x
B	0.826**	Y=-0.220+0.535x
C	0.838**	Y=-0.070+0.474x

x = Moth catches; Y = Egg masses

The coefficient of variance for different fields calculated to find out the dependence of egg masses based on pheromone trap captures of male moths. The per cent of variances were 63.7, 68.2 and 70.2 for all the three fields indicating that the egg mass count depend upon the moth catches.

4.1.1.1.2 Trap catches Vs Larval populations: Data on early and late larval instars recorded in three groundnut fields (A, B and C) in relation to pheromone trap moth catches are presented in the Tables 2 and 3. Early larval instars (1st, 2nd and 3rd) started appearing in the three groundnut fields between February 7 to 9 i.e., four to six days after the first appearance of male moths in the pheromone traps (Fig.4 a,b,c). Highest number of early larval instars (608.0, 519.0 and 703.3/100 plants) recorded during March 13 to 17 in the three groundnut fields coincided with the highest moth catches in the traps recorded

Table 2: Relationship between pheromone trap catches of S. litura male moths and early larval population in groundnut fields

Date	Field A		Field B		Field C	
	Moths/trap[a]	No. of early larval instars/100 plants[b]	Moths/trap[a]	No. of early larval instars/100 plants[b]	Moths/trap[a]	No. of early larval instars/100 plants[b]
01-02-89	0.0	0.0	1.0	0.0	0.0	0.0
03-02-89	1.3	0.0	2.0	0.0	3.3	0.0
05-02-89	2.0	0.0	8.0	0.0	5.0	0.0
07-02-89	2.9	0.0	9.0	1.7	7.0	1.3
09-02-89	3.7	5.0	7.7	8.7	7.0	6.0
11-02-89	1.7	8.0	10.7	6.0	14.0	9.7
13-02-89	7.3	13.0	13.3	10.3	9.3	10.3
15-02-89	8.3	14.7	23.3	22.3	31.7	14.7
17-02-89	13.0	29.7	41.7	28.3	53.7	18.7
19-02-89	31.7	41.3	39.7	32.7	57.0	32.3
21-02-89	41.7	56.3	102.0	28.0	136.7	37.0
23-02-89	39.0	47.3	299.3	42.0	265.0	57.3
25-02-89	197.7	67.0	348.3	62.3	220.7	51.3
27-02-89	262.3	89.0	650.3	96.3	493.3	72.7
01-03-89	504.0	93.0	1084.7	107.0	1158.3	162.0
03-03-89	820.7	122.3	677.0	138.3	1929.0	211.3
05-03-89	1014.3	144.7	417.7	232.0	820.3	322.7
07-03-89	362.7	192.3	323.0	234.3	581.3	415.3
09-03-89	416.3	214.3	209.0	278.0	372.7	341.3
11-03-89	210.0	240.3	227.0	342.0	202.3	515.7
13-03-89	234.0	278.3	117.0	519.0	92.3	574.7
15-03-89	185.0	416.0	92.7	404.7	113.7	703.3
17-03-89	121.3	608.0	171.7	288.3	51.3	557.3
19-03-89	117.7	408.3	69.0	231.0	32.3	372.7
21-03-89	188.3	545.0	37.3	187.0	31.7	221.6
23-03-89	75.3	292.7	18.3	212.0	21.3	174.7
25-03-89	31.3	294.7	16.0	121.7	17.0	122.3
27-03-89	178.0	242.0	149.3	69.3	102.3	150.3
29-03-89	261.3	231.3	334.3	91.3	236.7	97.3
31-03-89	436.0	181.7	218.0	32.0	428.7	56.7
02-04-89	521.7	219.0	253.7	10.7	292.7	35.0
04-04-89	303.3	79.7	151.7	38.0	314.7	27.7
06-04-89	166.7	65.0	81.0	73.0	79.0	54.7
08-04-89	179.7	72.7	57.7	163.0	48.0	68.7
10-04-89	64.3	96.3	90.0	207.3	41.0	132.7
12-04-89	51.0	115.3	38.7	54.7	56.3	153.7
14-04-89	26.0	165.7	26.3	72.3	24.0	67.3
16-04-89	9.0	67.0	19.3	21.7	13.3	22.7

Field A	Field B	Field C
r = 0.817**	r = 0.673**	r = 0.661**
y = 0.380+0.793x	y = 0.344+0.738x	y = 0.475+0.698x

** Significant at P = 0.01

a Mean catch from 3 traps for two nights

b Mean early larval instars from 300 plants for two nights

Moth catches and early larval instars are transformed to log values for statistical analysis

Table 3: Relationship between pheromone trap catches of *S. litura* male moths and late larval population in groundnut fields

Date	Field A		Field B		Field C	
	Moths/trap[a]	No. of late larval instars/100 plants[b]	Moths/trap[a]	No. of late larval instars/100 plants[b]	Moths/trap[a]	No. of late larval instars/100 plants[b]
01-02-89	0.0	0.0	1.0	0.0	0.0	0.0
03-02-89	1.3	0.0	2.0	0.0	3.3	0.0
05-02-89	2.0	0.0	8.0	0.7	5.0	0.0
07-02-89	2.9	0.0	9.0	0.3	7.0	0.0
09-02-89	3.7	0.0	7.7	0.0	7.0	0.0
11-02-89	1.7	0.3	10.7	0.0	14.0	0.7
13-02-89	7.3	1.3	13.3	0.0	9.3	1.7
15-02-89	8.3	0.0	23.3	1.7	31.7	2.3
17-02-89	13.0	0.0	41.7	2.7	53.7	3.7
19-02-89	31.7	3.0	39.7	5.3	57.0	4.3
21-02-89	41.7	6.3	102.0	9.7	136.7	5.7
23-02-89	39.0	8.3	299.3	10.7	265.0	7.3
25-02-89	197.7	10.7	348.3	13.7	220.7	15.0
27-02-89	262.3	13.7	650.3	22.3	493.3	18.0
01-03-89	504.0	15.7	1084.7	18.7	1158.3	18.7
03-03-89	820.7	15.0	677.0	43.0	1929.0	32.0
05-03-89	1014.3	21.3	417.7	54.7	820.3	41.0
07-03-89	362.7	32.3	323.0	62.0	581.3	38.0
09-03-89	416.3	60.7	209.0	99.0	372.7	50.7
11-03-89	210.0	88.3	227.0	142.7	202.3	64.7
13-03-89	234.0	94.0	117.0	160.3	92.3	70.7
15-03-89	185.0	75.7	92.7	173.0	113.7	111.7
17-03-89	121.3	143.7	171.7	219.0	51.3	89.3
19-03-89	117.7	205.0	69.0	245.3	32.3	187.7
21-03-89	188.3	232.3	37.3	322.0	31.7	288.0
23-03-89	75.3	258.0	18.3	250.7	21.3	450.3
25-03-89	31.3	382.0	16.0	182.7	17.0	281.0
27-03-89	178.0	279.7	149.3	221.3	102.3	150.7
29-03-89	261.3	264.7	334.3	115.0	236.7	74.7
31-03-89	436.0	211.7	218.0	140.3	428.7	55.0
02-04-89	521.7	246.3	253.7	102.0	292.7	35.7
04-04-89	303.3	224.0	151.7	94.7	314.7	39.7
06-04-89	166.7	199.3	81.0	58.7	79.0	29.7
08-04-89	179.7	139.0	57.7	38.7	48.0	20.7
10-04-89	64.3	162.0	90.0	55.7	41.0	19.0
12-04-89	51.0	171.3	38.7	27.0	56.3	12.0
14-04-89	26.0	72.7	26.3	21.7	24.0	15.0
16-04-89	9.0	45.7	19.3	13.7	13.3	16.3

Field A: $r = 0.714^{**}$, $y = -0.042 + 0.815x$

Field B: $r = 0.598^{**}$, $y = 0.037 + 0.744x$

Field C: $r = 0.487^{**}$, $y = 0.365 + 0.499x$

** Significant at $P = 0.01$

a Mean catch from 3 traps for two nights

b Mean late larval instars from 300 plants for two nights

Moth catches and late larval instars are transformed to log values for statistical analysis

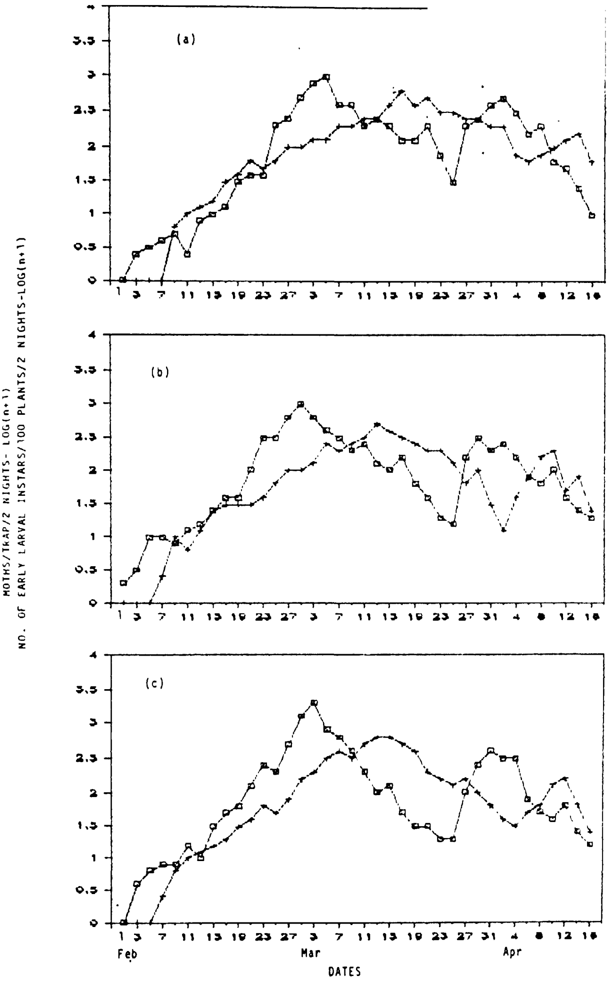


Fig.4(a,b,c): EARLY LARVAL POPULATION AND MOTH CATCHES OF S.LITURA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS.

between March 1 to 5, 12 days prior to early larval count (Fig.5 a,b,c).

The early larval instars after the peak count showed a gradual decline in number until April 6 with few marginal fluctuations over all the fields was in correspondence with the decline of moth catches in the phermone traps. The second peak in early larval population in the three fields between April 10 and 14 coincided with the second peak appearance of moths in the pheromone traps.

Interestingly, the time of peak abundance of late larval instars (4th, 5th and 6th) of S. litura (Table 3 and Fig. 6 a,b c) between March 21 to 25 in all the three fields also coincided with the first peak of moth trap catches 20 days prior to late larval count i.e. March 1 to 5 (Fig.7 a,b,c). The peak late larval population in fields ranged as high as 322.0 to 450.3/100 plants and appeared 8 days after first peak of early larval count. No second peak in the late larval population in corresponding to the second peak moth catches could be observed since the crop was harvested on April 16, 1989. The correlation coefficients and regression equations of moth catches and larval (early and late) populations for all the three fields are showed below:

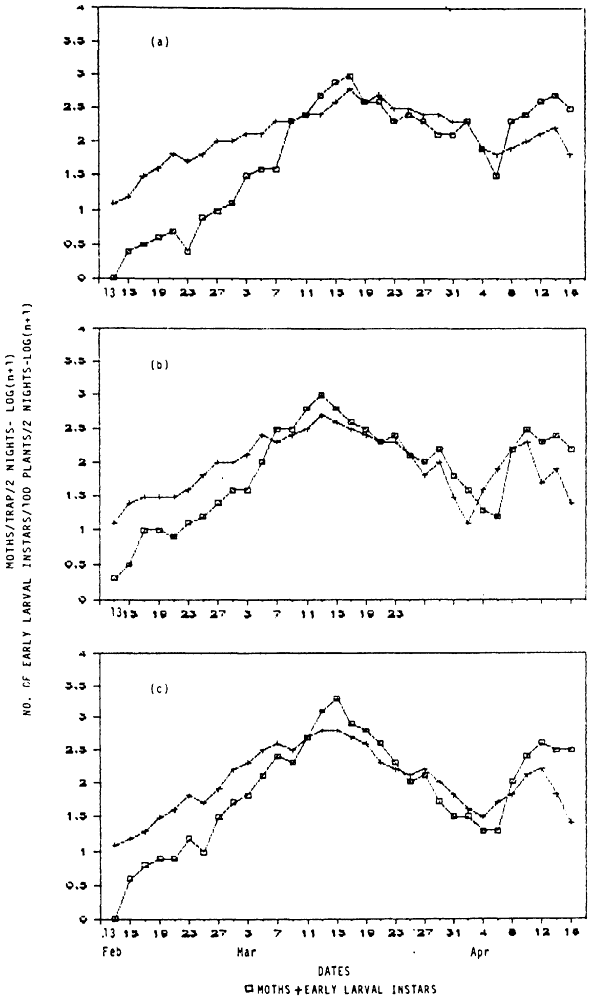


Fig5(a,b,c) : EARLY LARVAL POPULATION AND MOTH CATCHES OF S.LITURA IN PHEROMONE TRAPS 12 DAYS PRIOR TO EARLY LARVAL COUNT IN THREE GROUNDNUT FIELDS

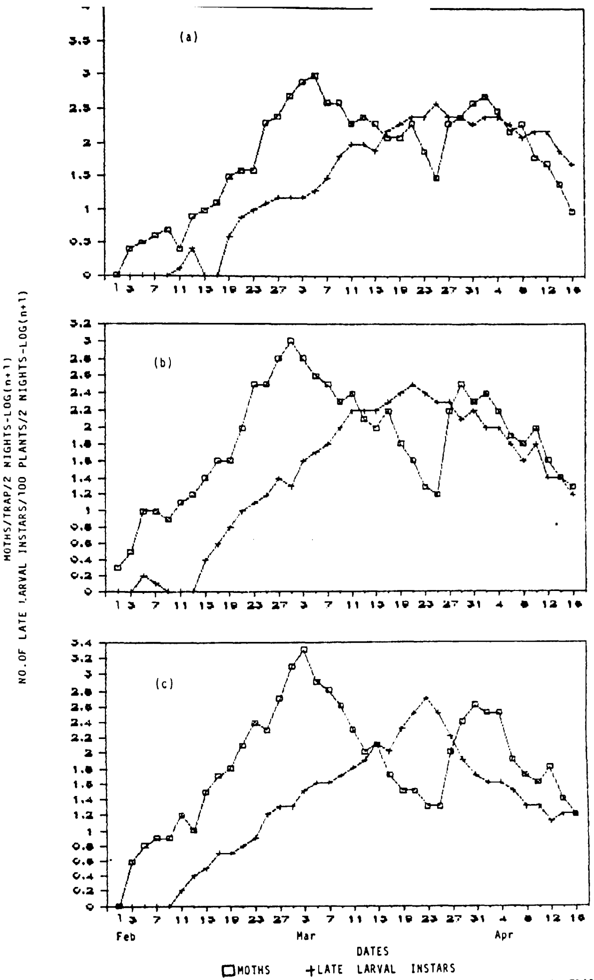


Fig.6(a,b,c):LATE LARVAL POPULATION AND MOTH CATCHES OF S.LITURA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS

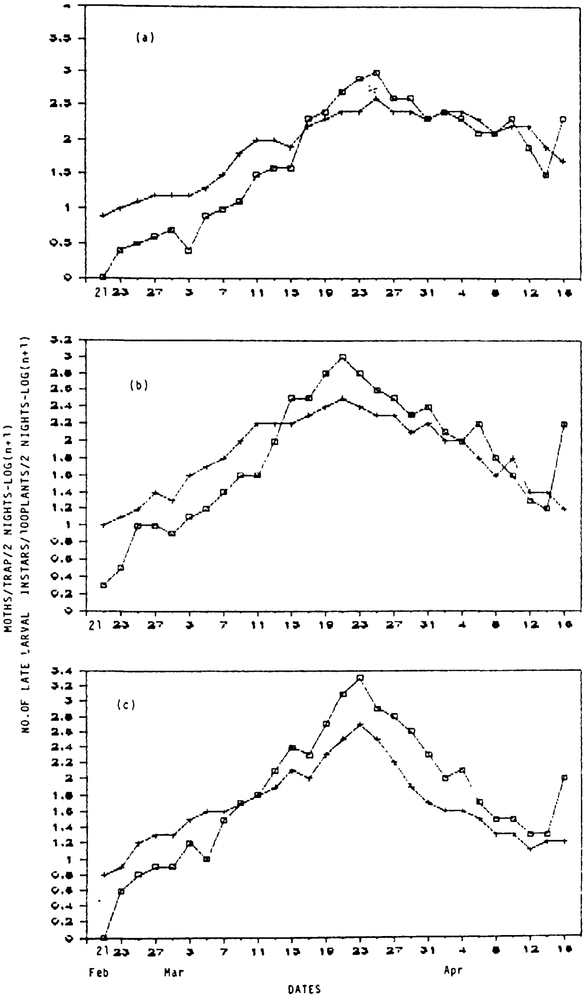


Fig. 7(a,b,c): LATE LARVAL POPULATION AND MOTH CATCHES OF S.LITURA IN PHEROMONE TRAPS 20 DAYS PRIOR TO LATE LARVAL COUNT IN THREE GROUNDNUT FIELDS

Field	Correlation coefficient (r)	Regression equation (Y=a+bx)
	Early larval population	
A	0.817**	Y= 0.0380+0.793x
B	0.673**	Y= 0.344+0.738x
C	0.661**	Y=0.475+0.698x

Late larval population

Field	Correlation coefficient (r)	Regression equation (Y=a+bx)
A	0.714**	Y=-0.042+0.815x
B	0.598**	Y= 0.037+0.744x
C	0.487**	Y= 0.365+0.499x

x = moth catches; Y = larval population

The calculated per cent of variances were 66.7, 45.3 and 43.7 (early larvae) and 51.0, 35.8 and 23.7 respectively (late larvae) for all the three fields to find out the dependence of larval population based on pheromone trap catches of male moths.

4.1.1.1.3 Trap catches Vs damage: Plant damage due to *S. litura* larvae was estimated in terms of number of quadrifoliates damaged/100 plants and the data on damage in relation to trap catches are presented in the Table 4 and Fig.8 a,b,c. Initial damage (2.7 to 3.0 leaves/100 plants) due to larvae, first observed 6 [illegible]ble 4 Relationship between pheromone trap catches of S litura male moths and plant damage in groundnut field.

[illegible]ate	Field A Moths/trap[a]	Field A No of damaged leaves/100 plants[b]	Field B Moths/trap[a]	Field B No of damaged leaves/100 plants[b]	Field C Moths/trap[a]	Field C No of damaged leaves/100 plants[b]
[illegible] 02 89	0 0	0 0	1 0	0 0	0 0	0 0
[illegible] 02 89	1 3	0 0	2 0	0 0	3 3	0 0
[illegible] 02 89	2 0	0 0	8 0	0 0	5 0	0 0
[illegible] 02 89	2 9	0 0	9 0	3 0	7 0	0 0
[illegible] 02-89	3 7	3 0	7 7	8 0	7 0	2 7
[illegible] 02 89	1 7	7 3	10 7	9 3	14 0	3 0
[illegible] 02 89	7 3	12 0	13 3	14 0	9 3	[illegible]5 0
[illegible] 02-89	8 3	13 0	23 3	18 7	31 7	7 3
[illegible] 02 89	13 0	18 0	41 7	27 3	53 7	11 3
[illegible] 02 89	31 7	25 3	39 7	32 3	57 0	22 0
[illegible] 02 89	41 7	31 7	102 0	34 7	136 7	26 3
[illegible] 02 89	39 0	39 0	299 3	40 3	265 0	35 0
[illegible] 02 89	197 7	58 0	348 3	50 7	220 7	41 3
[illegible] 02 89	262 3	66 0	650 3	85 7	493 3	56 0
[illegible] 03 89	504 0	104 0	1084 7	52 7	1158 3	90 0
[illegible] 03 89	820 7	147 7	677 0	218 0	1929 0	194 0
[illegible] 03 89	1014 3	262 0	417 7	265 7	820 3	157 0
[illegible] 03 89	362 7	364 7	323 0	388 3	581 3	223 7
[illegible] 03 89	416 3	477 0	209 0	448 0	372 7	328 7
[illegible] 03 89	210 0	593 0	227 0	417 3	202 3	414 3
[illegible] 03 89	234 0	664 0	117 0	524 3	92 3	185 0
[illegible] 03 89	185 0	635 0	92 7	623 0	113 7	643 7
[illegible] 03 89	121 3	819 0	171 7	786 0	51 3	614 0
[illegible] 03 89	117 7	891 3	69 0	884 0	32 3	880 3
[illegible] 03-89	188 3	997 0	37 3	1018 7	31 7	969 3
2[illegible] 03 89	75 3	1056 0	18 3	510 7	21 3	1147 3
2[illegible] 03 89	31 3	1223 7	16 0	397 7	17 0	751 7
[illegible] 03 89	178 0	308 7	149 3	247 3	102 3	548 7
2[illegible] 03 89	261 3	299 0	334 3	172 0	236 7	407 7
[illegible] 03 89	436 0	217 3	218 0	188 0	428 7	285 3
[illegible] 04 89	521 7	238 0	253 7	146 3	292 7	304 7
[illegible] 04 89	303 3	133 0	151 7	75 7	314 7	119 7
[illegible] 04 89	166 7	72 0	81 0	77 0	79 0	38 7
[illegible] 04 89	179 7	39 3	57 7	54 0	48 0	31 3
[illegible] 04 89	64 3	32 0	90 0	61 7	41 0	25 0
[illegible] 04 89	51 0	24 7	38 7	22 3	56 3	19 3
14 04 89	26 0	8 7	26 3	18 3	24 0	10 3
[illegible] 04-89	9 0	5 0	19 3	14 7	13 3	6 0

Field A	Field B	Field C
r = 0 815**	r = 0 653**	r = 0 612**
y = 0 097+0 943x	y = 0 337+0 806x	y = 0.291+0 779x

** Significant at P = 0 01

a Mean catch from 3 traps for two nights

b Mean damaged leaves from 300 plants for two nights

- Moth catches and damaged leaves are transformed to log values for statistical analysis

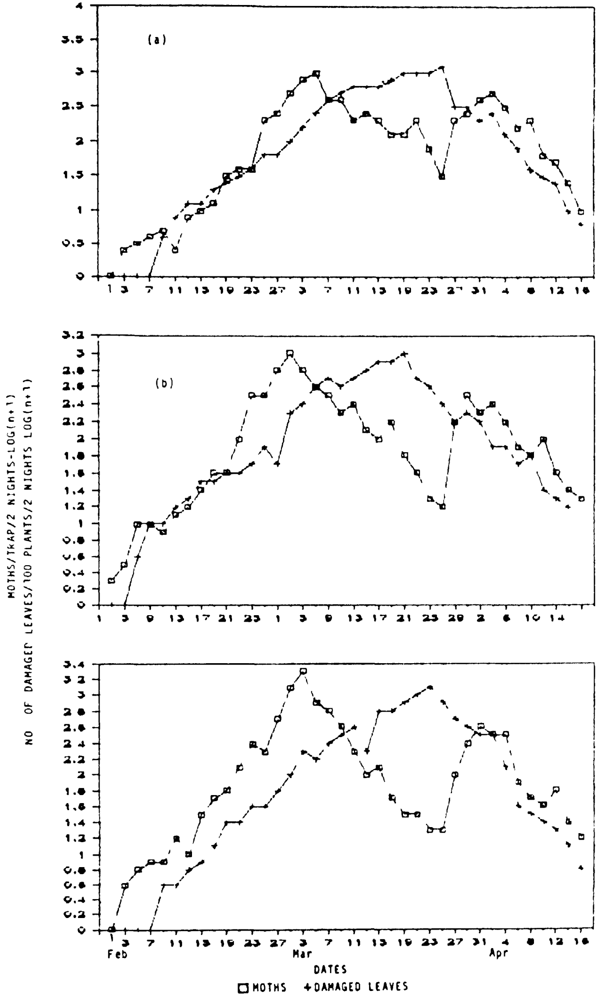
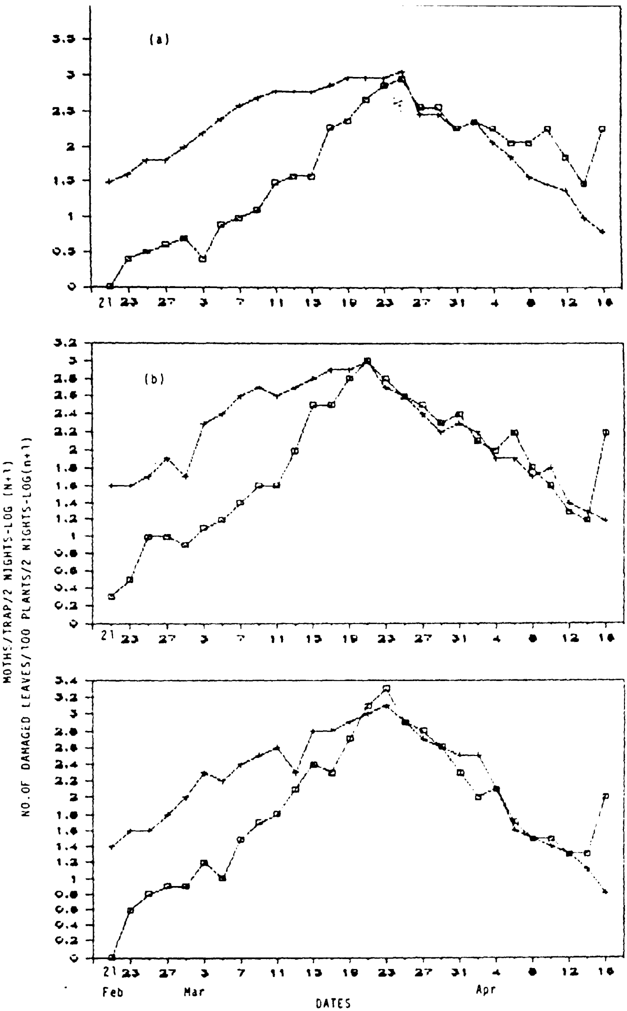


Fig 8(a,b,c) DAMAGED LEAVES AND MOTH CATCHES OF S LITURA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS days after appearance of moths in the traps in all three groundnut fields. The peak plant damage counts recorded were 1223.7, 1018.7 and 1147.3 quadrifoliates/100 plants in the fields A, B and C during March 21 to 25 and it coincided with the peak moth trap catches appeared from March 1 to 5, 20 days prior to damage counts (Fig.9 a,b,c). Incidentally, the peak damage counts observed from March 21 to 25 coincided with the peak late larval counts in all three groundnut fields. The damage counts were made only upto April 16 (harvest date of the crop) and no second peak of damage could be recorded. The correlation coefficients and regression equations of moth catches and damaged leaves are indicated below.

ield	Correlation coefficient (r)	Regression equation (Y=a+bx)
A	0.815**	Y=0.097+0.943x
B	0.653**	Y=0.337+0.806x
C	0.612**	Y=0.291+0.779x

x = moth catches; Y = damaged leaves

The calculated per cent of variances 66.4, 42.6 and 37.5 for all the three fields indicate that the plant damage depend upon the moth catches in pheromone traps.



□moths +damaged leaves

Fig.9 (a,b,c): DAMAGED LEAVES AND MOTH CATCHES OF S.LITURA IN PHEROMONE TRAPS 20 DAYS PRIOR TO DAMAGED LEAVES COUNT IN THREE GROUNDNUT FIELDS

4.1.1.2 *H. armigera*

4.1.1.2.1 Trap catches Vs larval population: Pheromone trap catches data of male *H. armigera* presented in the Table 5 indicated that moths started appearing in the traps initially in small numbers from January 27 to 29 in the three groundnut fields (I, II and III). From the day of appearance of moths in the traps, there was a gradual increase in the moth catches and the highest catches of 641.0, 723.0 and 539.0 moths/trap were recorded from February 26 to March 2 i.e., approximately one month after the first appearance of moths in the traps (Fig.10 a,b,c).

After the peak appearance, the moth catches declined steadily. The second peak moths appeared 32 days after the first peak in all the three fields. However, the number of moths/trap was relatively lower than the first peak.

Early larval instars (1st, 2nd and 3rd) of *H. armigera* were observed 4 to 6 days after the first appearance of moths in the traps and reached the peak larval population 8 days after peak moth catches in all the three (I, II and III) groundnut fields (Fig.11 a,b,c). The peak early larval populations recorded were 318.0, 340.7 and 274.3/100 plants in the fields

Table 5 Relationship between pheromone trap catches of H armigera male moths and early larval population in groundnut fields

	Field A		Field		Field C	
Date	Moths/ trap [a]	No of early [b] larval ins- tars/100 plants	Moths/ trap [a]	No of early [b] larval ins- tars/100 plants	Moths/ trap [a]	No of early [b] larval ins- tars/100 plants
27-01-89	0 0	0 0	9 0	0 0	0 0	0 0
29-01-89	1 0	0 0	11 0	0 0	0 3	0 0
31-01-89	3 3	0 0	22 3	1 7	3 0	0 0
02-02-89	7 3	1 3	35 0	3 0	9 0	0 0
04-02-89	11.0	2 3	71 7	3 3	11 3	1 3
06-02-89	31 0	2 7	67 0	4 3	7 0	3 7
08-02-89	16 0	4 0	124 0	9 3	24 0	4 7
10-02-89	24 7	6 3	226 3	12 0	37 7	5 7
12-02-89	98 0	8 0	364 0	16 3	41 0	6 7
14-02-89	67 0	15 3	315 0	14 0	62 3	4 0
16 02-89	187 7	9 3	356 7	22 3	56 0	11 7
18-02-89	205 0	23 7	412 0	37 3	121 7	14 7
20-02-89	369 0	34 3	387 0	88 7	164 3	20 7
22-02-89	277 0	32 7	489 3	102 3	257 7	28 0
24 02-89	386 0	71 0	564 0	128 3	264 0	38 3
26-02-89	521 7	98 7	723 0	173 7	315 0	31 3
28-02-89	641 0	120 7	478 7	215 0	444 3	75 0
02-03-89	365 3	152 3	315 0	265 7	539 0	128 7
04 03 89	218 0	220 3	292 3	301 7	321 3	141 3
06-03-89	264 7	241 7	168 0	340 7	264 0	199 3
08 03-89	185 7	318 0	193 7	272 3	294 7	229 0
10 03 89	104 3	247 0	106 0	209 7	196 0	274 3
2-03-89	121 0	170 7	78 0	191 0	172 3	231 7
4 03-89	85 3	189 3	35 7	114 0	143 0	160 3
16-03-89	65 3	105 0	42 0	120 3	93 3	164 7
18-03-89	40 7	89 7	116 0	59 0	47 7	105 7
20 03-89	16 0	103 7	124 0	62 0	61 0	98 0
22 03 89	96 3	98 7	191 0	34 7	24 3	72 7
24 03-89	127 7	54 0	145 7	38 7	65 0	65 0
26 03 89	116 0	26 0	227 7	17 3	89 7	47 0
28-03 89	239 0	11 3	362 3	21 7	184 0	28 7
30 03-89	317 0	14 0	482 7	18 0	105 0	31 7
01 04-89	407 0	22 3	216 3	7 7	212 7	10 3
03-04-89	201 0	18 0	105 0	15 3	332 0	14 7
05 04-89	89 0	29 7	94 3	20 7	215 3	19 7
07 04 89	116 0	32 0	78 0	35 0	128 0	13 7
09-04-89	63 0	40 7	86 7	17 0	72 0	23 7
11-04-89	21 0	21 3	24 0	9 0	44 0	28 0

0 670** r = 0 565** r = 0 760**

0 90+0 710x y = -0 257+0 824x y = -0 152+0 823x

** Significant at P = 0 01

Mean catch from 3 traps for two nights

Mean early larval instars from 300 plants for two nights

- Moth catches and early larval instars are transformed to log values for statistical analysis

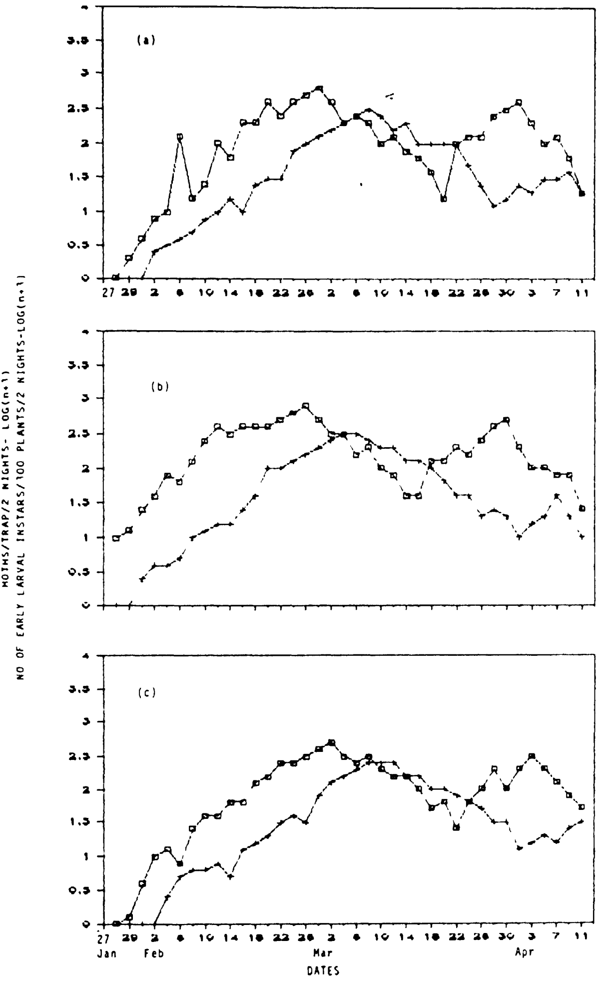


Fig.10(a,b,c) EARLY LARVAL POPULATION AND MOTH CATCHES OF H. ARMIGERA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS

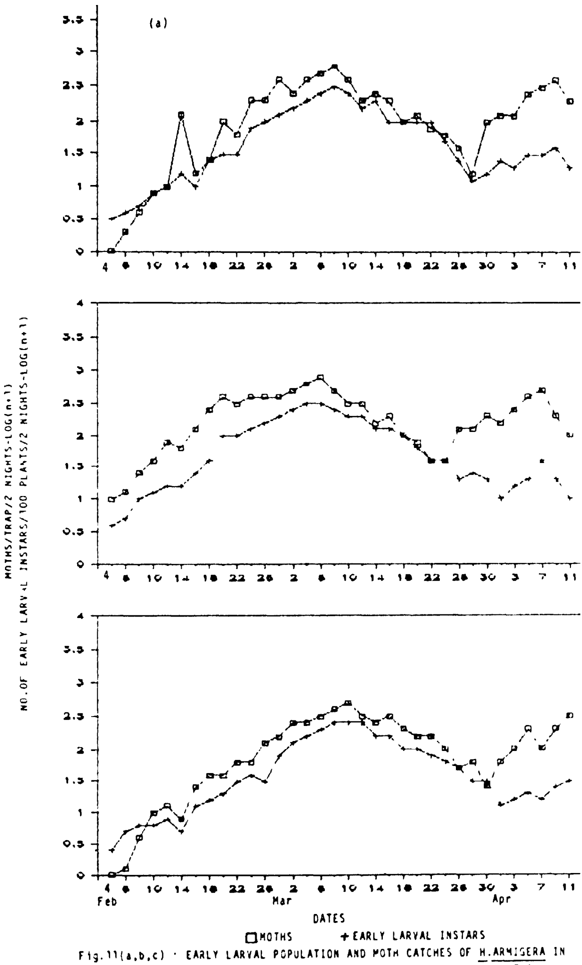


Fig.11(a,b,c) · EARLY LARVAL POPULATION AND MOTH CATCHES OF H.ARMIGERA IN PHEROMONE TRAPS 8 DAYS PRIOR TO EARLY LARVAL COUNT IN THREE GROUNDNUT FIELDS.

I, II and III respectively against peak moth catches observed 641.0, 723.0 and 539.0/trap.

Late larval instars (4th and 5th) as high as 155.3, 167.0 and 117.0/100 plants. (Table 6 and Fig.12 a,b,c) recorded 18 days after the peak moth catches in all the groundnut fields. In general the peak appearance and decline in the number of late larval population coincided with the corresponding moth catches, at 18 days prior to late larval count depicted in the figure (13 a,b,c) with adjusted dates.

The correlation coefficients and regression equations for moth catches and larval (early and late) population are as follows:

Field	Correlation coefficient (r)	Regression equation (Y=a+bx)
Early larval populations		
A	0.670**	Y-0.90+0.710x
B	0.565**	Y=-0.257+0.824x
C	0.760**	Y=-0.152+0.823
Late larval population		
A	0.535**	Y=0.131+0.530x
B	0.446**	Y=-0.117+0.610x
C	0.658**	Y=-0.075+0.631x

x = moth catches ; Y = larval population

Table 6: Relationship between pheromone trap catches of *H. armigera* male moths and late larval population in groundnut fields

Date	Field A		Field B		Field C	
	Moths/trap[a]	No. of late larval instars/100 plants[b]	Moths/trap[a]	No. of late larval instars/100 plants[b]	Moths/trap[a]	No. of late larval instars/100 plants[b]
27-01-89	0.0	0.0	9.0	0.0	0.0	0.0
29-01-89	1.0	0.0	11.0	0.0	0.3	0.0
31-01-89	3.3	0.0	22.3	0.0	3.0	0.0
02-02-89	7.3	0.0	35.0	0.0	9.0	0.0
04-02-89	11.0	0.0	71.7	1.0	11.3	0.0
06-02-89	31.0	0.0	67.0	1.7	7.0	0.7
08-02-89	16.0	2.3	124.0	0.7	24.0	1.3
10-02-89	24.7	4.3	226.3	6.0	37.7	4.0
12-02-89	98.0	4.7	364.0	7.3	41.0	5.3
14-02-89	67.0	5.7	315.0	10.3	62.3	6.3
16-02-89	187.7	6.7	356.7	12.3	56.0	8.0
18-02-89	205.0	10.7	412.0	13.7	121.7	9.7
20-02-89	369.0	13.0	387.0	17.7	164.3	11.3
22-02-89	277.0	10.3	489.3	21.3	257.7	12.7
24-02-89	386.0	16.0	564.0	19.7	264.0	14.0
26-02-89	521.7	20.3	723.0	25.0	315.0	10.3
28-02-89	641.0	22.0	478.7	32.0	444.3	25.7
02-03-89	365.3	14.7	315.0	37.3	539.0	28.0
04-03-89	218.0	31.7	292.3	44.7	321.3	29.7
06-03-89	264.7	41.3	168.0	50.3	264.0	32.0
08-03-89	185.7	65.3	193.7	62.3	294.7	38.3
10-03-89	104.3	59.7	106.0	54.7	196.0	52.0
12-03-89	121.0	91.3	78.0	98.3	172.3	59.7
14-03-89	85.3	132.7	35.7	118.7	143.0	61.7
16-03-89	65.3	138.3	42.0	167.0	93.3	74.7
18-03-89	40.7	155.3	116.0	128.0	47.7	89.7
20-03-89	16.0	122.3	124.0	101.0	61.0	117.0
22-03-89	96.3	70.3	191.0	70.3	24.3	94.7
24-03-89	127.7	35.7	145.7	40.3	65.0	55.3
26-03-89	116.0	53.7	227.7	25.7	89.7	64.0
28-03-89	239.0	28.3	362.3	38.7	184.0	32.3
30-03-89	317.0	30.3	482.7	20.3	105.0	25.3
01-04-89	407.0	15.3	216.3	14.0	212.7	21.7
03-04-89	201.0	10.3	105.0	3.7	302.0	11.3
05-04-89	89.0	4.7	94.3	6.3	215.3	4.0
07-04-89	116.0	10.7	78.0	7.0	128.0	2.7
09-04-89	63.0	8.7	86.7	11.7	72.0	3.7
11-04-89	21.0	9.0	24.0	4.7	44.0	5.7
	$r = 0.535^{**}$		$r = 0.446^{**}$		$r = 0.658^{**}$	
	$y = 0.131 + 0.530x$		$y = -0.117 + 0.610x$		$y = -0.075 + 0.631x$	

** Significant at $P = 0.01$

[a] Mean catch from 3 traps for two nights

[b] Mean late larval instars from 300 plants for two nights

[c] Moth catches and late larval instars are transformed to log values for statistical analysis

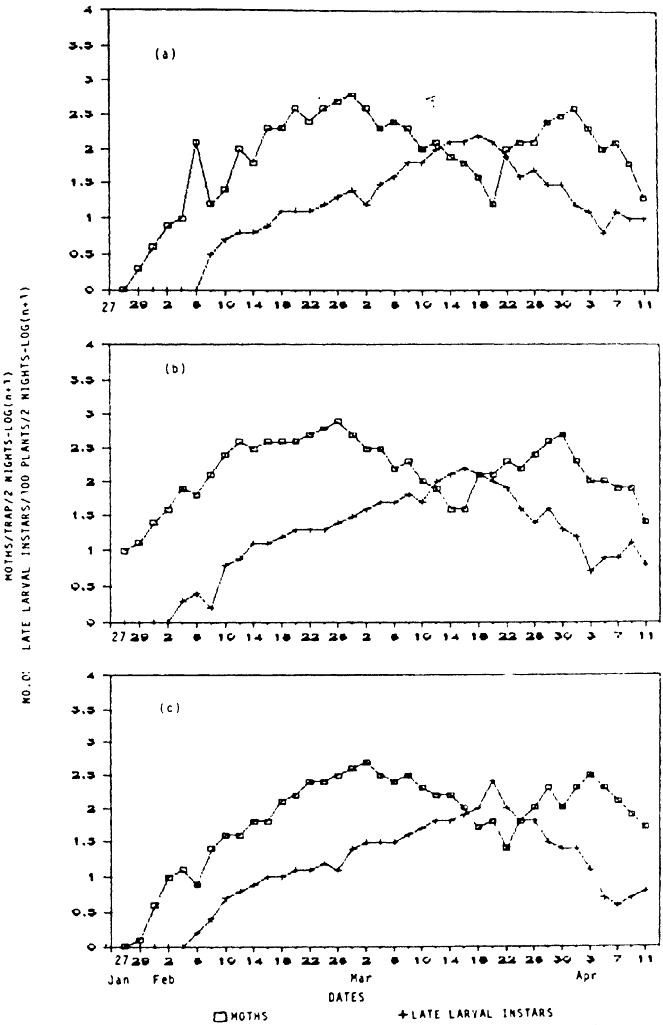


Fig. 12(a,b,c): LATE LARVAL POPULATION AND MOTHS CATCHES OF H.ARMIGERA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS.

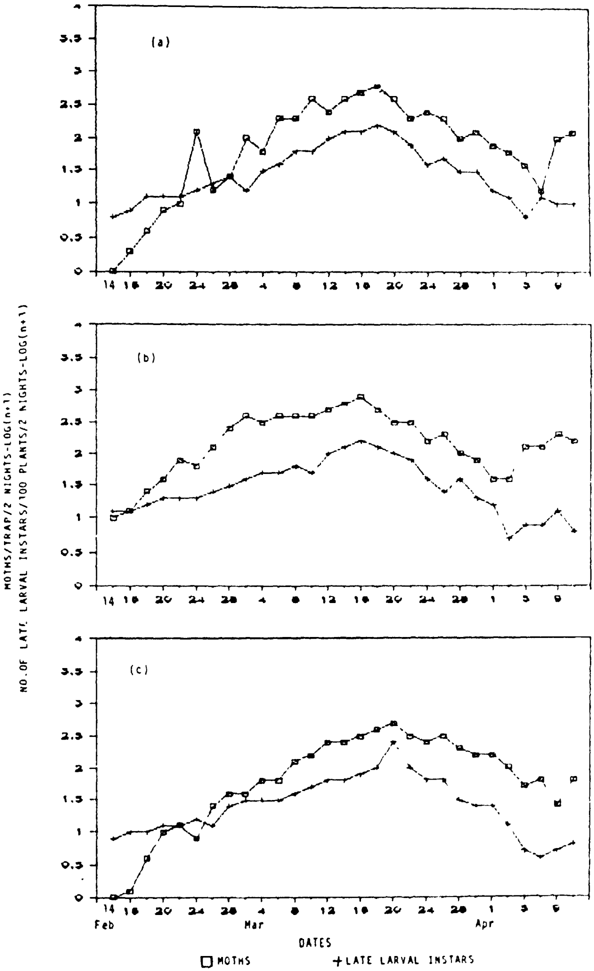


Fig. 13(a,b,c) : LATE LARVAL POPULATION AND MOTH CATCHES OF H.ARMIGERA IN PHEROMONE TRAPS 18 DAYS PRIOR TO LATE FLARVAL COUNT IN THREE GROUNDNUT FIELDS.

The calculated per cent of variances were 44.9, 31.9 and 57.8 for early larval instars and 28.6, 19.9 and 43.3 for late larval instars in all the three fields to observe the dependence of larval population based on moth catches in pheromone traps.

4.1.1.2.2 Trap catches Vs damage: Perusal of the data (Table 7) on the damage to groundnut leaves and moth catches in the pheromone traps in all the three groundnut fields (Fig.14 a,b,c) clearly indicated that highest damage counts (1051.3, 1092.3 and 981.7 quadrifoliates/100 plants) were in correspondence with the first peak moth catches recorded 18 days prior to peak damage counts (Fig.15 a,b,c) in field I, II and III. Incidentally, the highest moth catches observed in field II also had more early and late larval populations and recorded highest damage counts indicating the moth trap catches are directly related with larval populations and damage. It was also evident from the data (Table 7)that the peak damage counts observed from March 16 to 20 coincided with the peak late larval counts in all the three groundnut fields. Due to harvest of the crop on April 16, the damage counts corresponding to the second peak moth catches could not be recorded. The correlation coefficients and regression equations of moth catches and plant damage are given below.

Table 7: Relationship between pheromone trap catches of *H. armigera* male moths and plant damage in groundnut fields

	Field A		Field B		Field C	
Date	Moths/trap[a]	No. of damaged leaves/100 plants[b]	Moths/trap[a]	No. of damaged leaves/100 plants[b]	Moths/trap[a]	No. of damaged leaves/100 plants[b]
27-01-89	0.0	0.0	9.0	0.0	0.0	0.0
29-01-89	1.0	0.0	11.0	0.0	0.3	0.0
31-01-89	3.3	0.0	22.3	2.3	3.0	0.0
02-02-89	7.3	1.7	35.0	3.3	9.0	0.0
04-02-89	11.0	2.7	71.7	4.7	11.3	1.0
06-02-89	31.0	4.0	67.0	7.7	7.0	6.3
08-02-89	16.0	6.3	124.0	8.3	24.0	5.0
10-02-89	24.7	4.0	226.3	10.3	37.7	9.0
12-02-89	98.0	6.3	364.0	14.0	41.0	12.0
14-02-89	67.0	8.0	315.0	16.3	62.3	13.7
16-02-89	187.7	15.3	356.7	19.0	56.0	16.3
18-02-89	205.0	20.7	412.0	24.7	121.7	17.3
20-02-89	369.0	29.0	387.0	36.3	164.3	24.3
22-02-89	277.0	39.3	489.3	101.3	257.7	58.3
24-02-89	386.0	60.3	564.0	99.3	264.0	48.7
26-02-89	521.7	98.7	723.0	173.7	315.0	64.3
28-02-89	641.0	179.0	478.7	222.3	444.3	104.7
02-03-89	365.3	140.3	315.0	364.3	539.0	168.7
04-03-89	218.0	228.3	292.3	271.3	321.3	264.7
06-03-89	264.7	454.0	168.0	421.0	264.0	228.0
08-03-89	185.7	581.3	193.7	631.3	294.7	289.3
10-03-89	104.3	535.7	106.0	667.0	196.0	337.3
12-03-89	121.0	820.7	78.0	819.7	172.3	421.3
14-03-89	85.3	887.7	35.7	921.0	143.0	514.3
16-03-89	65.3	949.3	42.0	1092.3	93.3	656.3
18-03-89	40.7	1051.3	116.0	710.7	47.7	780.7
20-03-89	16.0	602.0	124.0	471.7	61.0	981.7
22-03-89	96.3	232.0	191.0	288.0	24.3	652.3
24-03-89	127.7	141.3	145.7	207.0	65.0	298.3
26-03-89	116.0	172.0	227.7	103.0	89.7	208.0
28-03-89	239.0	55.7	362.3	74.7	184.0	234.0
30-03-89	317.0	38.3	482.7	37.0	105.0	115.0
01-04-89	407.0	31.7	216.3	25.3	212.7	69.0
03-04-89	201.0	27.3	105.0	32.3	302.0	39.0
05-04-89	89.0	25.0	94.3	10.3	215.3	23.7
07-04-89	116.0	22.0	78.0	7.7	128.0	21.3
09-04-89	63.0	19.3	86.7	5.0	72.0	10.7
11-04-89	21.0	15.0	24.0	3.7	44.0	3.7
	0.560**		r = 0.412*		r = 0.683**	
	0.217+0.745x		y = -0.058+0.766x		y = -0.085+0.929x	

Significant at P = 0.05

Significant at P = 0.01

Mean catch from 3 traps for two nights

Mean damaged leaves from 300 plants for two nights

- Moth catches and damaged leaves are transformed to log values for statistical analysis

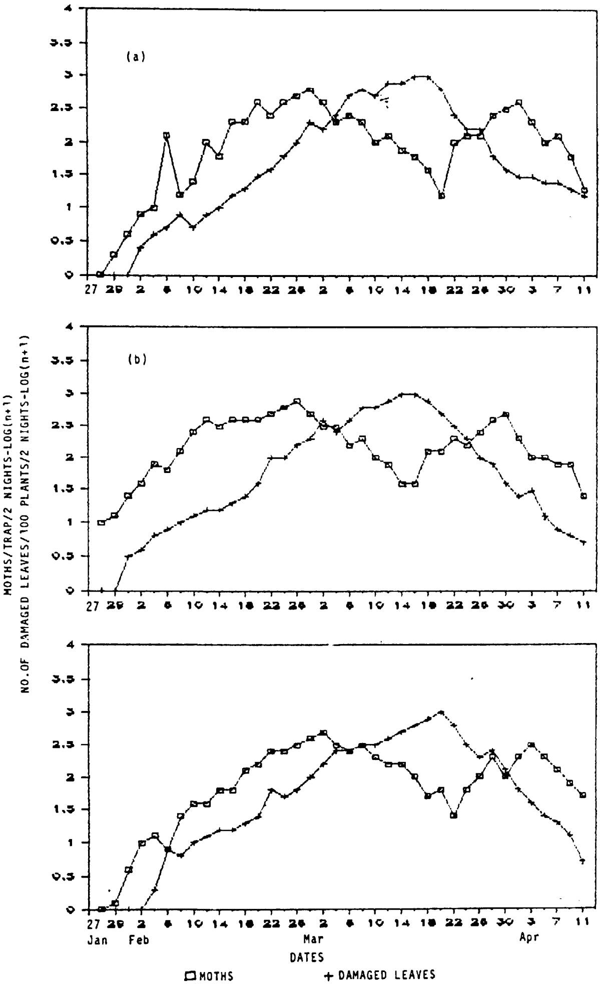


Fig. 14(a,b,c) : DAMAGED LEAVES AND MOTH CATCHES OF H.ARMIGERA IN PHEROMONE TRAPS IN THREE GROUNDNUT FIELDS.

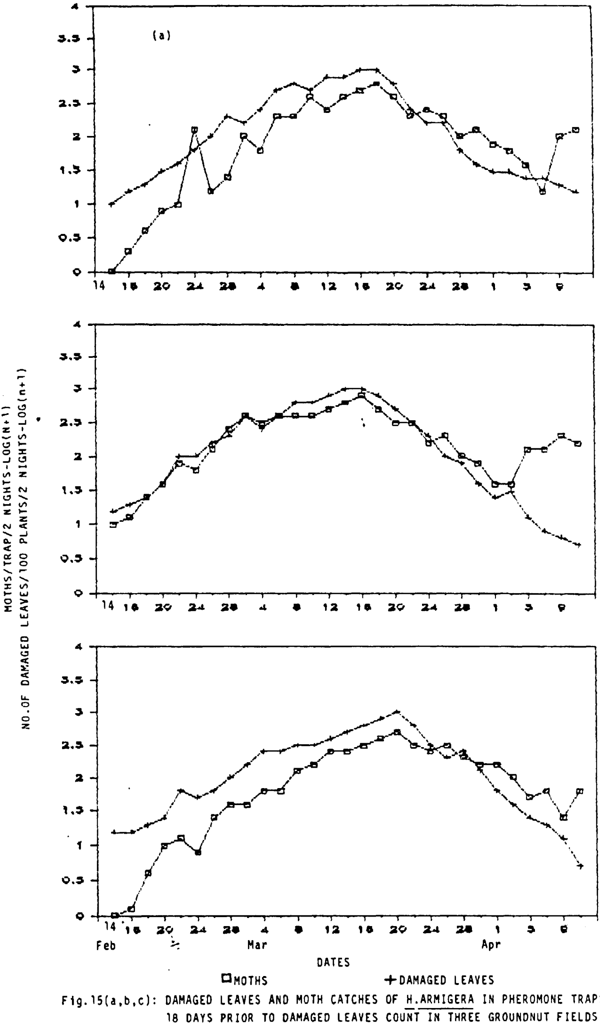


Fig.15(a,b,c): DAMAGED LEAVES AND MOTH CATCHES OF H.ARMIGERA IN PHEROMONE TRAPS 18 DAYS PRIOR TO DAMAGED LEAVES COUNT IN THREE GROUNDNUT FIELDS

Field	Correlation coefficient (r)	Regression equation (Y=a+bx)
A	0.560**	Y=0.217+0.745x
B	0.412*	Y=0.058+0.766x
C	0.683**	Y=-0.085+0.929x

x = moth catches ; Y = Damaged leaves

The per cent of variances were calculated to determine the dependence of plant damage based on pheromone trap captures of male moths. The per cent of variances were 31.4, 17.0 and 46.6 for all the three fields indicate that the plant damage depend upon the moth catches.

4.1.2 Relative efficiency of funnel trap and sleeve trap

ICRISAT funnel traps and sleeve traps were compared for their efficiency by observing male moth catches of <u>S. litura</u> and <u>H. armigera</u> over the observational period of 70 days (February 1 to April 11, 1989). The data on the daily moth captures are presented in the Tables 8 and 9.

4.1.2.1 <u>S. litura</u>: The male moths of <u>S. litura</u> (Table 8) appeared from February 1st and the number gradually increased reaching peak on March 2 at both the traps. In general ICRISAT trap recorded

Table 8: Relative efficiency of ICRISAT and sleeve traps in capturing male moths of *S. litura*

	Moths/trap*			Moths/trap*			Moths/trap*	
Date	Sleeve trap	ICRISAT trap	Date	Sleeve trap	ICRISAT trap	Date	Sleeve trap	ICRISAT trap
01-02-89	0.3	2.7	25-02-89	150.7	262.0	21-03-89	20.7	36.3
02-02-89	1.7	4.0	26-02-89	207.0	274.0	22-03-89	13.0	26.0
03-02-89	1.7	3.3	27-02-89	285.0	310.0	23-03-89	8.3	12.3
04-02-89	2.3	6.0	28-02-89	543.0	604.0	24-03-89	6.0	11.0
05-02-89	2.7	8.0	01-03-89	614.0	696.3	25-03-89	10.0	15.7
06-02-89	3.0	9.3	02-03-89	752.0	824.7	26-03-89	47.7	52.0
07-02-89	4.0	9.7	03-03-89	643.7	756.0	27-03-89	55.0	64.3
08-02-89	3.0	7.7	04-03-89	475.3	424.0	28-03-89	98.3	107.7
09-02-89	5.0	12.0	05-03-89	345.0	356.7	29-03-89	138.7	144.3
10-02-89	8.3	14.7	06-03-89	276.0	289.0	30-03-89	177.0	215.0
11-02-89	6.3	11.0	07-03-89	305.7	324.3	31-03-89	251.3	324.0
12-02-89	3.7	15.3	08-03-89	170.0	187.0	01-04-89	181.7	211.7
13-02-89	5.7	12.0	09-03-89	202.0	225.0	02-04-89	111.7	154.7
14-02-89	18.0	23.0	10-03-89	128.3	142.7	03-04-89	105.0	136.0
15-02-89	13.0	25.7	11-03-89	73.0	85.3	04-04-89	176.7	189.3
16-02-89	21.0	34.0	12-03-89	55.0	64.0	05-04-89	47.0	66.0
17-02-89	32.3	57.3	13-03-89	37.7	56.0	06-04-89	32.0	51.7
18-02-89	18.7	32.0	14-03-89	72.3	85.7	07-04-89	21.3	39.0
19-02-89	38.7	71.7	15-03-89	41.0	53.0	08-04-89	27.0	42.3
20-02-89	47.0	72.0	16-03-89	28.7	45.0	09-04-89	24.7	38.0
21-02-89	90.7	164.7	17-03-89	23.0	34.3	10-04-89	16.3	27.7
22-02-89	121.7	201.0	18-03-89	18.0	19.0	11-04-89	12.7	21.0
23-02-89	143.3	196.3	19-03-89	13.3	21.7			
24-02-89	69.0	124.7	20-03-89	10.0	18.0			

t = 6.786*

Significant at P-0.01

Mean catch from three traps

Table 9: Relative efficiency of ICRISAT and sleeve traps in capturing male moths of H. armigera

	Moths/trap*			Moths/trap*			Moths/trap*	
Date	Sleeve trap	ICRISAT trap	Date	Sleeve trap	ICRISAT trap	Date	Sleeve trap	ICRISAT trap
01-02-89	14.0	24.3	25-02-89	308.3	317.7	21-03-89	89.0	97.0
02-02-89	21.0	29.0	26-02-89	415.0	424.0	22-03-89	102.3	125.3
03-02-89	28.3	36.7	27-02-89	268.7	305.0	23-03-89	95.7	107.7
04-02-89	43.7	52.0	28-02-89	210.0	229.7	24-03-89	50.0	61.0
05-02-89	48.0	55.0	01-03-89	174.3	196.0	25-03-89	98.0	94.3
06-02-89	19.0	29.3	02-03-89	140.0	162.0	26-03-89	129.7	141.0
07-02-89	58.7	67.0	03-03-89	160.7	183.3	27-03-89	163.0	176.7
08-02-89	65.0	73.0	04-03-89	132.0	161.0	28-03-89	198.3	214.0
09-02-89	88.0	100.0	05-03-89	98.3	112.0	29-03-89	208.0	236.0
10-02-89	138.3	149.7	06-03-89	69.0	85.7	30-03-89	274.7	289.3
11-02-89	165.0	181.3	07-03-89	128.0	133.0	31-03-89	133.0	165.0
12-02-89	198.0	212.0	08-03-89	65.0	79.0	01-04-89	82.0	94.7
13-02-89	201.7	224.3	09-03-89	57.7	61.0	02-04-89	65.7	76.0
14-02-89	113.0	129.0	10-03-89	48.3	53.7	03-04-89	39.0	42.0
15-02-89	140.0	237.7	11-03-89	44.0	47.0	04-04-89	51.7	65.7
16-02-89	216.7	241.0	12-03-89	34.0	36.3	05-04-89	43.3	56.0
17-02-89	107.3	119.0	13-03-89	24.7	29.0	06-04-89	42.0	51.3
18-02-89	224.0	246.3	14-03-89	11.0	21.0	07-04-89	35.7	42.7
19-02-89	203.7	225.0	15-03-89	18.3	30.0	08-04-89	40.3	61.0
20-02-89	183.0	197.7	16-03-89	23.0	36.7	09-04-89	46.0	54.3
21-02-89	230.7	242.7	17-03-89	47.7	59.0	10-04-89	18.7	21.0
22-02-89	288.0	314.0	18-03-89	68.0	82.7	11-04-89	5.0	9.0
23-02-89	274.0	293.3	19-03-89	59.3	64.0			
24-02-89	289.0	302.0	20-03-89	64.0	51.0			

t = 9.732**

Significant at P=0.01

Mean catcn from three traps

significantly higher catches in all days. The mean catches with ICRISAT and sleeve traps were 132.3 and 110.2/trap/night respectively. Difference between these means was found significantly different through paired 't' test (Table 8). Thus ICRISAT trap was found to be more efficient than sleeve trap by 1.2 times. However, on the day of highest moth capture on March 2 (752 moths/sleeve trap/night and 824.7 moths/ICRISAT trap/night), the difference was relatively less. At one instance (March 4) the sleeve traps captured large number (475.3 moths/ trap) than the ICRISAT trap (424 moths/trap).

4.1.2.2 H. armigera: Similar observations were recorded with H. armigera, where ICRISAT trap captured a mean number of 128.8 moths/trap/night in comparision to 108.7 male moths/trap/night in the sleeve trap (Table 9). It was found that ICRISAT trap significantly superior to sleeve trap with 1.19 times efficiency.

4.1.3 Sex pheromone blend specificity of response by male moths of H. armigera

Three different blends of the pheromone components [(Z)-11-hexa-decenal and (Z)-9-hexa- decenal] viz., the ratios of 94:6, 91:9 and 88:12 were compared with the commercially marketed blend 97:3 for their efficiency in trapping H. armigera.

Data on the number of male moths trapped are presented in the Table 10 and Fig. 16. The commercial blend (97:3) trapped significantly more number of moths 465.5/trap/week than others evaluated. The ratios 94:6, 91:9 and 88:12 recorded 308.0, 220.9 and 113.2 moths/trap/week, respectively during five weeks period. The ratio 88:12 obtained least moth catches. Thus the moth catches decreased with increase in the minor component [(Z)-9-hexadecenal].

4.2 STUDIES ON SEX PHEROMONE SYSTEMS

4.2.1 Evidence of potent sex pheromone in A. modicella through laboratory (wind tunnel) and field (sticky traps) studies

4.2.1.1 Virgin female baits

4.2.1.1.1 Wind tunnel: To identify the female or male moths producing sex pheromone, observations were made through out the night (scotophase) at 10 minutes interval by using both the sexes as a pheromone source placed at upwind in the tunnel.

The males showed the response and orientation towards female pheromone source. Thus the female pheromone appeared to have induced the upwind and

Table 10: Captures of male <u>H. armigera</u> in the traps baited with different proportions of components in the pheromone mixture (2 mg)

Ratio		Moths/trap/week*	Per cent moth catch
Z, 11-hexadeceenal	Z, 9-hexadecenal		
97	3	465.5 (21.57)a	42.0
94	6	308.0 (17.55)b	27.8
91	9	220.9 (14.86)c	20.0
88	12	113.2 (10.64)d	10.2
S.Ed.		0.82	
C.D. at 5%		1.67	

* Mean of three traps for 5 weeks

Figures in parentheses are $\sqrt{x}$ transformed values.

Means not followed by a common letters are significantly different.

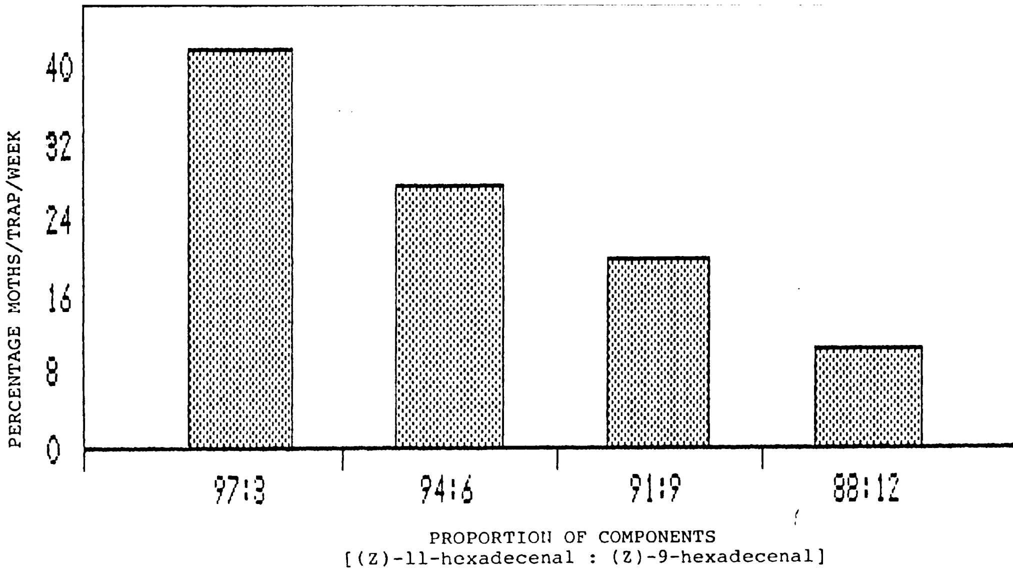


Fig.16: Male moth captures of *H.armigera* in traps baited with different proportions of (Z)-11-hexadecenal and (Z)-9-hexadecenal in the pheromone mixture (2 mg per lure.

searching flight of males in the wind tunnel. The observations revealed the orientation flight of males involved searching the females characterised by rapid vibration of wings (fluttering) and flying movements like erratic and fast motive movements with intermittent upcurving of the abdomen while being stationary or crawling. Subsequently they were found to move around the cage and settle there on with brisk movements. However, the male moths that hovered around the encaged females with or without alighting on the cage and in its vicinity were considered as the attracted males to the pheromone source. A mean of 7 males (70%) per tunnel responded to female pheromone stimulus (Table 11). However, females did not respond when males were baited as pheromone source.

4.2.1.1.2 Sticky traps: Female baited sticky traps placed in the groundnut fields infested with leaf miner trapped male leaf miner moths, confirming the obseva-tions recorded in the wind tunnel that females serve as a pheromone source (Table 12). A total of 61 male moths were observed in the sticky trap with one female bait. While, there was no moth in the male baited and also control traps (trap without virgin female).

4.2.1.2 Baits of female abdominal tips

4.2.1.2.1 Wind tunnel: The excised abdominal tips kept as pheromone source in the wind tunnel evoked response

Table 11: Response of A. modicella male moths to different types of female pheromone sources in wind tunnel

Wind tunnel No.	No. of males released	No. of males responded				
		Type of female pheromone source				
		Virgin female*	Female abdominal tips**	Extract in ml (female equivalents)		
				1	2	3
1	10	7	8	0	6	7
2	10	9	6	0	7	9
3	10	5	6	0	6	8
Mean		7.0	6.7	0	6.3	8.0
		(70)	(67)	0	(63)	(80)

One female confined in a case.

** Three female abdominal tips in cage

Figures in parentheses are % male response.

Table 12: Male moth captures of <u>A. modicella</u> to different types of female pheromone source in sticky traps

Sticky trap No.	No. of male moths captured				
	Type of female pheromone source				
	Virgin female*	Female Abdominal tips**	Extract in ml (female equivalents)		
			1	2	3
1	48	94	0	72	79
2	65	73	0	46	96
3	70	97	0	47	80
Mean	61	88	0	65	85

One female confined in a cage

Three female abdominal tips in a cage.

in the released males. As high as 6.7 males per tunnel (67%) showed upwind orientation to the pheromone source with excised abdominal tips indicating the presence of sex pheromone in the terminal abdominal segments of females (Table 11).

4.2.1.2.2 Sticky traps: The observations of the excised female abdominal tips baited sticky traps confirmed the results of wind tunnel that the pheromonal source is situated in the terminal abdominal segments (Table 12) as the sticky traps baited with abdominal tips trapped as high as 88 male moths/trap/night whereas no moths were trapped in check traps devoid of pheromone source.

4.2.1.3 Female abdominal tip extracts

4.2.1.3.1 Wind tunnel: Out of the three concentrations of virgin female abdominal tip extracts i.e , 1 ml, 2 ml and 3 ml representing 1, 2 and 3 female equivalents the males showed the orientation to the female abdominal extracts of 2 and 3 female equivalents (Table 11). In both concentrations as high as 63 and 80 per cent of male response/tunnel was observed No response was observed in 1 ml concentraion (one female equivalent).

4.2.1.3.2 Sticky traps: Of the sticky traps loaded with cigarette filters adsorbed with 1, 2 and 3 ml of methylene chloride extracts of female abdominal tips, only the traps with 2 and 3 ml female pheromone equivalents, entrapped 65 and 85 males/trap/night respectively (Table 12). No moths were recorded in the sticky traps with 1 ml female equivalent and also in the control sticky traps. Thus, these observations confirm the findings with wind tunnel.

4.2.2 Behavioural studies

4.2.2.1 Moth emergence: The pupal periods and time of emergence of moths of groundnut leafminer and H. armigera varied with the sex and the data are presented in the Tables 13, 14, 15 and 16.

4.2.2.1.1 Pupal duration of A. modicella: Pupal period of the groundnut leafminer (Table 13) ranged between 2 to 6 days with a mean of 3.9 days for both sexes, but varied with sex. Mean pupal periods of males and females were 2.9 and 4.9 days respectively and thus male pupal duration was shorter by 2 days. Male pupal duration ranged from 2 to 4 days with about 76% of emergence by 3rd day. On the otherhand female pupal duration fluctuated between 4 to 6 days with 82% emergence in five days.

4.2.2.1.2 Time of emergence of A. modicella: Emergence time of male and female moths of groundnut leafminer

Table 13: Emergence pattern of different sexes of *A. modicella* from pupae

Days after pupation	Moth emergence — No. of moths emerged		
	Male	Female	Total
2	17 (34)	0 (0)	17
3	21 (42)	0 (0)	21
4	12 (24)	15 (30)	27
5	0 (0)	26 (52)	26
6	9 (0)	9 (18)	9
Mean pupal period (days)	2.9	4.9	3.9

Figures in parentheses are % of emergence.

Table 14: Time of emergence of <u>A. modicella</u> from pupae

Periods	No. of moths emerged	
	Female	Male
6.00 pm to 8.00 pm	2	0
8.00 pm to 10.00 pm	0	0
10.00 pm to 12.00 mid night	3	2
12.00 mid night to 2.00 am	3	4
2.00 am to 4.00 am	6	4
4.00 am to 6.00 am	4	7
6.00 am to 8.00 am	0	0
8.00 am to 10.00 am	0	0
10.00 am to 12.00 noon	0	1
12.00 noon to 2.00 pm	0	0
2.00 pm to 4.00 pm	1	2
4.00 pm to 6.00 pm	1	0

Table 15: Emergence pattern of different sexes of *H. armigera* from pupae

Days after pupation	Moth emergence: No. of moths emerged – Male	Female	Total
9	0 (0)	11 (22)	11
10	9 (18)	27 (54)	36
11	12 (24)	12 (24)	24
12	29 (58)	0 (0)	29
Mean pupal period (days)	11.4	10.0	10.7

Figures in parentheses are % of emergence

Table 16: Time of emergence of H. armigera from pupae

Periods	No. of moths emerged	
	Female	Male
6.00 pm to 8.00 pm	1	2
8.00 pm to 10.00 pm	2	1
10.00 pm to 12.00 mid night	0	0
12.00 mid night to 2.00 am	7	3
2.00 am to 4.00 am	6	7
4.00 am to 6.00 am	0	2
6.00 am to 8.00 am	0	0
8.00 am to 10.00 am	1	0
10.00 am to 12.00 noon	0	0
12.00 noon to 2.00 pm	0	1
2.00 pm to 4.00 pm	2	0
4.00 pm to 6.00 pm	1	2

was observed continuously at two hourly intervals after two days of pupation (Table 14) irrespective of the sex, moths emerged both during day and night times, but the majority emerged during night time (Table 14).

The peak emergence time of both sexes was between 2.00 am to 4.00 am and 4.00 am to 6.00 am with about 50 per cent moths emerging during this time. The per cent emergence between 10.00 pm to 2.00 am was about 30. Thus greater proportion of moths tended to emerge from 10.00 pm to 6.00 am. The emergene of moths during day time did not follow any specific trend.

4.2.2.1.3 Pupal duration of H. armigera: Pupal duration varied with sex. Unlike in groundnut leafminer, females of H. armigera emerged earlier than the males. The females pupal period ranged from 9 to 11 days with a mean of 10 days as against 11.4 days pupal period in males ranging from 10 to 12 days. Greater proportion (76%) of emergence of females was on 9 and 10 days while it was 11 and 12 days (82%) in respect of males (Table 15).

4.2.2.1.4 Time of emergence of H. armigera: Although the moths emerged (Table 16) all round the clock, but it was mostly confined to night time with about (75 to 80%). There also seemed to be no variation with regard to peak emergence time of males and females. About 65%

females emerged between 12.00 mid night to 4.00 am as against 50% males during the same time.

4.2.2.2 Age and time of pheromone release and response of *A. modicella*: Premating period for males and females, peak calling period of females and peak response of males, commencement and duration of response in different day old males to females of *A. modicella* was studied in the laboratory using wind tunnel and the data are presented in Table 17. Calling time of females utilising sticky traps was (Table 19) also assessed in the groundnut field.

4.2.2.2.1 Wind tunnel: Male and female moths showed the mating responses from the very first day (0 day) to 6 days (5 day old) of emergence. This was based on the clear cut orientation of 0-day old males to 0-day female pheromone source but no response in 6 day old males and 6 day old females. Peak responsiveness (males) and peak calling (females) during one day old moths was indicated by 100 per cent male moth response (Table 17). Zero to 5 day old male moths showed greater response to 1 day old females (12.3 males/tunnel) than to that of other ages of females. Responsiveness of one day old male moths to 0 to 5 day old females, was of the order of 13.6 males/tunnel

Table 17: Time and duration of response of different aged males of <u>A. modicella</u> to different aged females in wind tunnel

Age of moths (days)		Male response		Time of male response	
Female	Male	Moth number per tunnel*	Percentage (%)	Commencement (hours of day)	Duration (minutes)
0	0	2.0	66.7	5.55	30
0	1	2.0	66.7	4.05	45
0	2	2.3	76.7	4.35	45
0	3	2.7	90.0	5.10	35
0	4	1.0	33.3	5.45	30
0	5	1.3	43.3	6.00	45
1	0	2.0	66.7	4.55	40
1	1	3.0	100.0	4.10	95
1	2	2.0	66.7	4.35	50
1	3	2.3	76.7	4.25	40
1	4	1.0	33.3	4.40	35
1	5	2.0	66.7	4.35	30
2	0	1.3	43.3	5.45	45
2	1	2.0	66.7	4.45	55
2	2	2.7	90.0	4.30	45
2	3	1.3	43.3	6.00	40
2	4	2.0	66.7	6.10	35
2	5	1.0	33.3	7.15	30
3	0	1.3	43.3	6.30	45
3	1	2.3	76.7	5.10	60
3	2	1.0	33.3	6.10	40
3	3	1.7	56.7	7.45	35
3	4	2.3	76.7	7.10	25
3	5	1.0	33.3	5.40	30
4	0	1.7	56.7	7.25	35
4	1	2.0	66.7	7.40	45
4	2	1.0	33.3	6.35	30
4	3	2.0	66.7	7.05	35
4	4	2.3	76.7	7.40	20
4	5	1.0	33.3	7.35	20
5	0	1.3	43.3	7.15	25
5	1	2.3	76.7	6.45	40
5	2	1.0	33.3	7.20	25
5	3	2.0	66.7	6.40	35
5	4	1.0	33.3	6.10	20
5	5	1.3	43.3	6.55	30

Mean of three wind tunnels
-Three females confined in cage and three males released in wind tunnel

which was higher than the response of other age groups of the males (Table 17a).

Mating response was noticed between 4.00 am to 8.00 am with a peak response at 4.30 am to 4.59 am as indicated by the highest number of males responded (14.0) with a 22.4 per cent response in a normal frequency distribution (Table 17b and Fig.17).

In general the maximum mating response of males (35.9%) was at 30-39 minutes duration followed by 40-49 (34.9%) minutes. Isolated responses of longer (90-99 minutes) or shorter (20-29 minutes) duration (Table 17b and Fig. 18) were also observed.

4.2.2.2.2 Sticky traps: Male moth catches in the different day old baited sticky traps varied with the age of the virgin females. The data on the number male moths trapped in 0 to 7 day old female baited traps are presented in the Table 18 and Fig.19. It is evident from the data that significantly the highest number of male moths were trapped (102.7 moths/trap) in the 1-day old female baited sticky traps. The response was almost similar to each other in 2-day old and 0-day old females with the trap catches of 18.0 and 16.6 per cent respectively. The trap catches showed a decreasing trend from 3 day old to 7 day old female baited sticky

Table 17a: Calling and response of different day old females and males of A. modicella in wind tunnel

Age of female moth	No. of 0-5 day old male moths attracted to female/tunnel*	Age of male moth	Response of male moth to females of 0 to 5 day old/ tunnel*
0	11.3	0	9.6
1	12.3	1	13.6
2	10.3	2	10.0
3	9.6	3	12.0
4	10.0	4	9.6
5	8.9	5	7.6

Mean of three wind tunnels

Table 17b: Frequency distribution of time and duration of response of different day old males of <u>A. modicella</u> to different day old females in wind tunnel

Male response			
Initiation (hours of day)	Moth number per tunnel*	Duration (minutes)	Moth number per tunnel*
4.00 - 4.29 am	7.3 (11.7)	20-29	8.9 (14.3)
4.30 - 4.59 am	14.0 (22.4)	30-39	22.4 (35.9)
5.00 - 5.29 am	5.0 (8.0)	40-49	21.8 (34.9)
5.30 - 5.59 am	5.3 (8.5)	50-59	4.0 (6.4)
6.00 - 6.29 am	5.6 (9.0)	60-69	2.3 (3.7)
6.30 - 6.59 am	8.9 (14.3)	70-79	0 (0)
7.00 - 7.29 am	9.3 (14.9)	80-89	0 (0)
7.30 - 7.59 am	7.0 (11.2)	90-99	3.0 (4.8)

* Mean of three wind tunnels
Figures in parentheses are % of male response

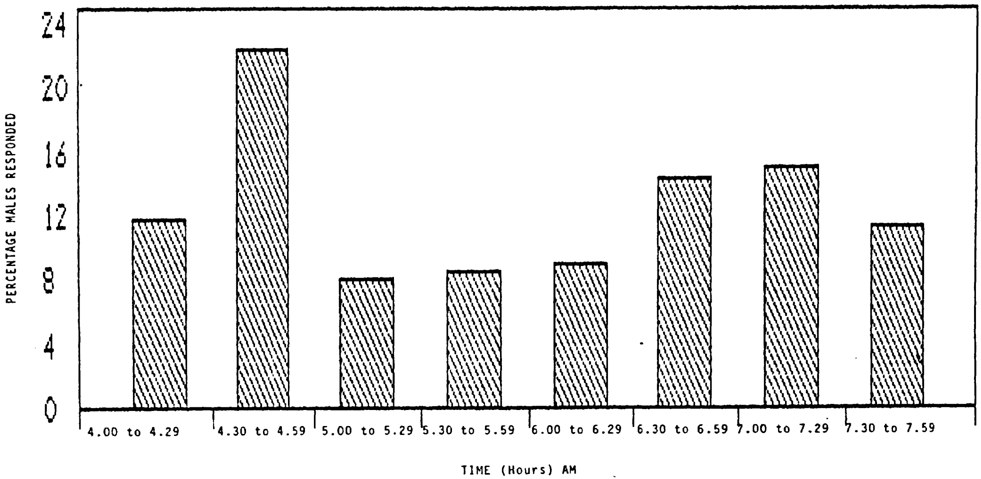


Fig.17: TIME OF MATING RESPONSE OF A. MODICELLA MALES TO FEMALES BAITED IN WIND TUNNEL

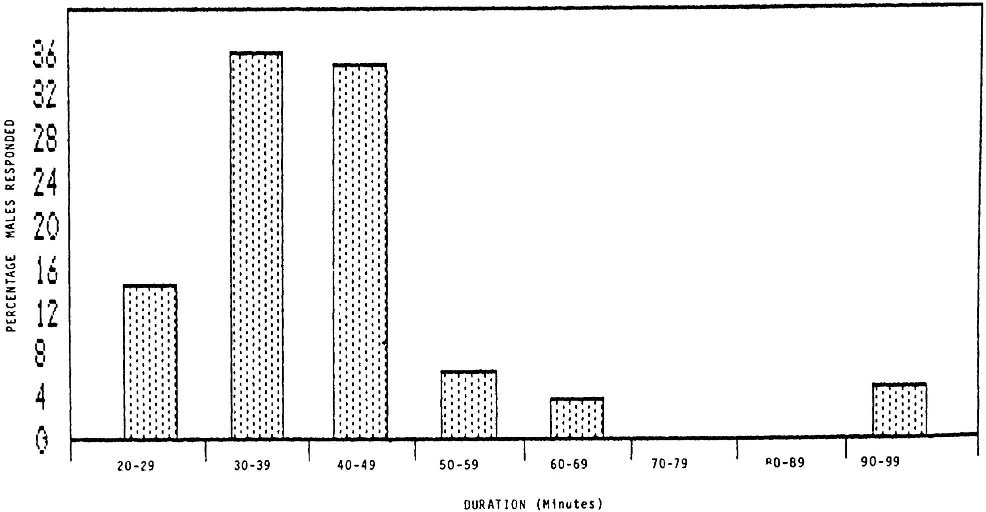


Fig. 18: DURATION OF MATING RESPONSE OF MALES OF *A. MODICELLA* TO FEMALES BAITED IN WIND TUNNEL

Table 18: Male moth catches of _A. modicella_ in sticky traps baited with different day old virgin females

Age of virgin females (day old)	Moths/trap/night*	Per cent moth catch	Cumulative per cent moth catch
0	65.3 (8.08)bc	16.6	16.6
1	102.7 (10.13)a	26.1	42.7
2	71.0 (8.43)b	18.0	60.7
3	58.7 (7.66)bc	14.9	75.6
4	47.3 (6.88)c	12.0	87.6
5	36.0 (6.00)c	9.1	96.7
6	10.3 (3.21)d	2.6	99.3
7	2.7 (1.64)c	0.7	100.0
S.Ed.	0.65		
CD at 5%	1.33		

* Mean of three traps for seven days

Figures in parentheses are $\sqrt{x}$ transformed values

Means not followed by a common letter are significantly different.

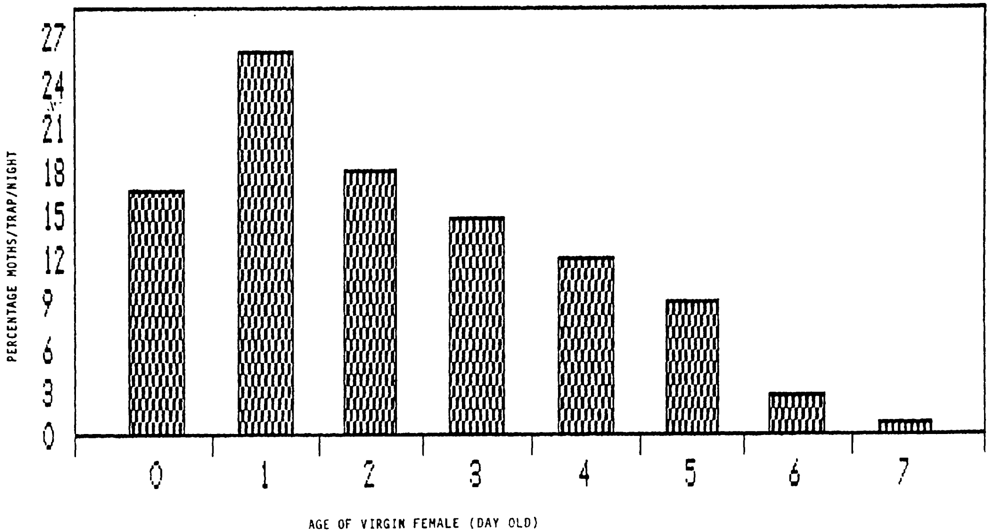


Fig. 19 · PERCENT MALE MOTH CATCHES OF <u>A. MODICELLA</u> IN STICKY TRAPS BAITED WITH DIFFERENT DAY OLD VIRGIN FEMALES traps. Seven day old females attracted only 2.7 males per trap.

4.2.2.3 Rhythm of male attraction and female attractiveness: Effectiveness of the sex pheromone in general, is directly related to the response of males to pheromone source. Therefore, to understand the initiation of response and peak period of attraction, the number of Aproaerema, Spodoptera and Heliothis males caught at the pheromone source in different periods of time during night were counted and presented in Tables 19, 20 and 21.

4.2.2.3.1 A. modicella: Male moth catches of A. modicella observed at 2 hourly interval during different periods in the night indicated that females calling was mostly confined between 4.00 am to 8.00 am (Table 19). The highest number (97.3/trap/night) of male moths were observed at 4.00 am to 6.00 am in the morning in the one day old virgin female baited sticky traps followed by 6.00 am to 8.00 am (36 moths/trap/night).

Very few male moths (2.3) were trapped between 2.00 am to 4.00 am. No moth catches were recorded from 6.00 pm to 2.00 am. The highest peak moth chatches between 4.00 am to 6.00 am was similar to the response time observed in the wind tunnel experiments.

Table 20: Moth catches of *S. litura* at different times of the night in sleeve traps

Periods	Moths/trap/ night*	Per cent moth catch	Cumulative per cent moth catch
6.00 pm to 8.00 pm	22.8 (4.77)c	14.1	14.1
8.00 pm to 10.00 pm	25.9 (5.09)c	16.0	30.1
10.00 pm to 12.00 mid night	36.0 (6.00)b	22.2	52.3
12.00 mid night to 2.00 am	17.0 (4.12)d	10.5	62.8
2.00 am to 4.00 am	51.3 (7.16)a	31.7	94.5
4.00 am to 6.00 am	8.9 (2.98)c	5.5	100.0
S.Ed.	0.25		
C.D. at 5%	0.50		

* Mean of three traps for seven days

Figures in parentheses are $\sqrt{x}$ transformed values

Means not followed by a common letter are significantly different.

Table 21: Moth catches of H.armigera at different times of the night in sleeve traps

Periods	Moths/trap/night*	Per cent moth catch	Cumulative per cent moth catch
6.00 pm to 8.00 pm	18.0 (4.24)c	13.2	13.2
8.00 pm to 10.00 pm	4.0 (1.99)e	2.9	16.1
10.00 pm to 12.00 mid night	12.3 (3.50)cd	9.0	25.1
12.00 mid night to 2.00 am	35.1 (5.92)b	25.7	50.8
2.00 am to 4.00 am	59.8 (7.73)a	43.7	94.5
4.00 am to 6.00 am	7.5 (2.73)de	5.5	100.0
S.Ed.	0.52		
C.D. at 5%	1.07		

* Mean of three traps for seven days

Figures in parentheses are $\sqrt{x}$ transformed values

Means not followed by a common letter are significantly different.

4.2.2.3.2 **S. litura**: Variations were noted in S. litura moth catches, recorded at all periods in the night (Table 20) and significantly the highest moth catch of 51.3 males/trap consisting of 31.7% of the captures were recorded at 2.00 am to 4.00 am followed by 10.00 pm to 12.00 mid night with 22.2%. The number of moths recorded during other periods in the descending order were 25.9, 22.8 and 17.0 moths/trap/night at 8.00 pm to 10.00 pm, 6.00 pm to 8.00 pm and 12.00 midnight to 2.00 am forming 16.0, 14.1 and 10.5 respectively (Fig. 20). However, the moth captures recorded at 8.00 to 10.00 pm and 6.00 to 8.00 pm were on par with each other. The moth catch of 8.9/trap/night (5.5 per cent) was the lowest observed at 4.00 am to 6.00 am.

4.2.2.3.3 **H. armigera**: Variations in male moth captures of Heliothis were also observed at different periods during scotophase. Significantly the highest per cent (43.7) of male moth catches was observed between 2.00 am to 4.00 am followed by 12.00 mid night to 2.00 am (25.7%) (Table 21). The lowest moth catch of 2.9% was recorded at 8.00 to 10.00 pm. The moth catches of 18/trap/night at 6.00 pm to 8.00 pm and 12.3/trap/night between 10.00 pm to 12.00 midnight and were on par with each other. Similarly, no significant difference in the moth catches was observed between 10.00 pm to 12.00 midnight and 4.00 am to 6.00 am (7.5 moths/trap/night).

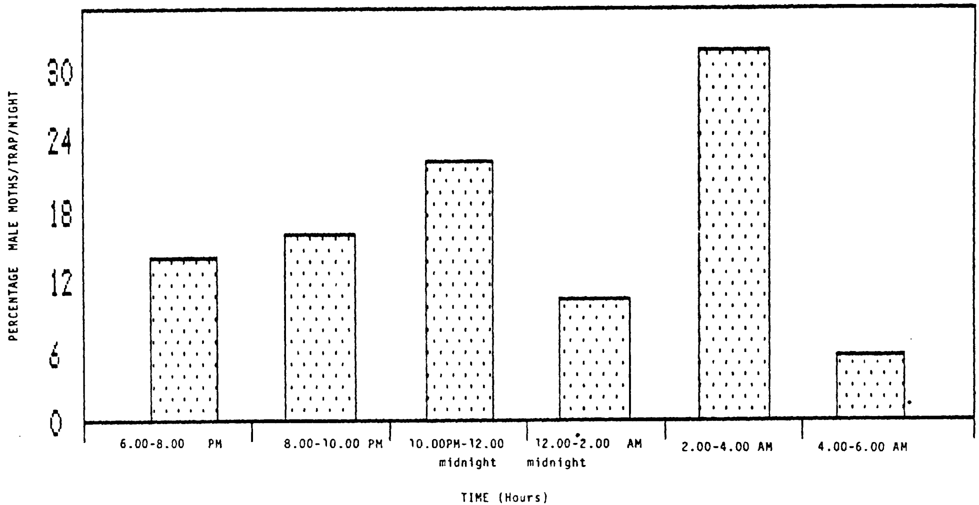


Fig.20 : MALE MOTH CATCHES OF S. LITURA AT DIFFERENT TIMES OF THE NIGHT IN THE PHEROMONE TRAPS

Moth catch at 8.00 pm to 10.00 pm was also low (4 males/trap/night). Thus the peak period of male moth response was between 12.00 mid night to 4.00 am (Fig. 21). No capture of male moths was observed during photophase.

4.2.2.4 Pheromone perception in A. modicella: In the wind tunnel experiment, male moths of the leaf miner deprived of their antennae did not respond to female pheromone source. Out of 10 males with ablated antennae released in the wind tunnel, none of the males exhibited any response to the female pheromone source provided in the upwind of the tunnel and this was true in all the three tunnels used. However, with antennae intact, males showed response to the female pheromone source as high as 8 males per tunnel (80%) (Table 22). The results confirm that antennae play major role in the chemoreception.

4.2.2.5 Effect of light on response of males of A. modicella in wind tunnel and sticky traps: Response of males to the female pheromone source was observed in the continuous light for three days in the wind tunnel and positioning the sticky traps baited with the females during day time in the field infested with groundnut leafminer. There was no response of males to female pheromone source in the wind tunnel under

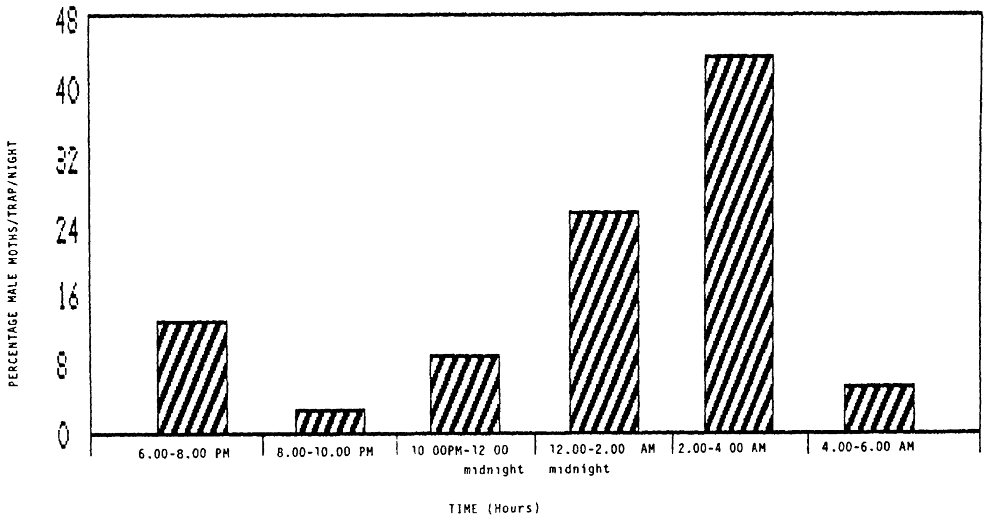


Fig 21 · MALE MOTH CATCHES OF H ARMIGERA AT DIFFERENT TIMES OF THE NIGHT IN THE PHEROMONE TRAPS

Table 22: Response of *A. modicella* males with and without antennae to virgin females in wind tunnel

Wind tunnel No.	No. of males released	No. of males responded to virgin females*	
		Male with ablated antennae	Male with antennae
1	10	0	6
2	10	0	9
3	10	0	9
Mean		0	8 (80)

* Three females confined in a cage

Figures in parentheses are % male response.

continuous light during three days. In the female baited sticky traps (installed in the field), there was no moth catch during day time (8.00 am to 6.00 pm) indicating that there is no response of males to pheromone source in continuous photophase.

4.2.3 Sex pheromone glands

4.2.3.1 A. modicella: The gland that produce the female sex pheromone in A. modicella is in the form of an eversible sac or eversible fold situated dorsally in the intersegmental area between the 8th and 9th abdominal segments (Fig. 23). The 8th segment of A. modicella is densely clothed with hairs. Normally, the 8th and 9th segments are telescoped into the 7th segment. They are retracted by muscles having their origin in the 7th segment and inserted on the anterior margin of the 8th tergum and the anterior ends of the apophyses anteriors and apophyses posteriors.

4.2.3.2 H. armigera: In H. armigera, the sex pheromone gland is in the form of a complete ring of glandular epithelium situated around the body in the intersegmental membrane between 8th and 9th abdominal segments (Fig. 22) when the 8th and 9th segments are retracted the ventral portion of the gland is deeply invaginated in the body cavity.

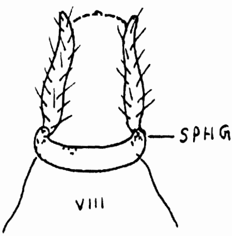


FIG.22: SEX PHEROMONE GLAND OF H. *armigera*

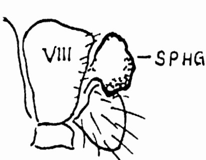


FIG.23: SEX PHEROMONE GLAND OF A. *modicella*

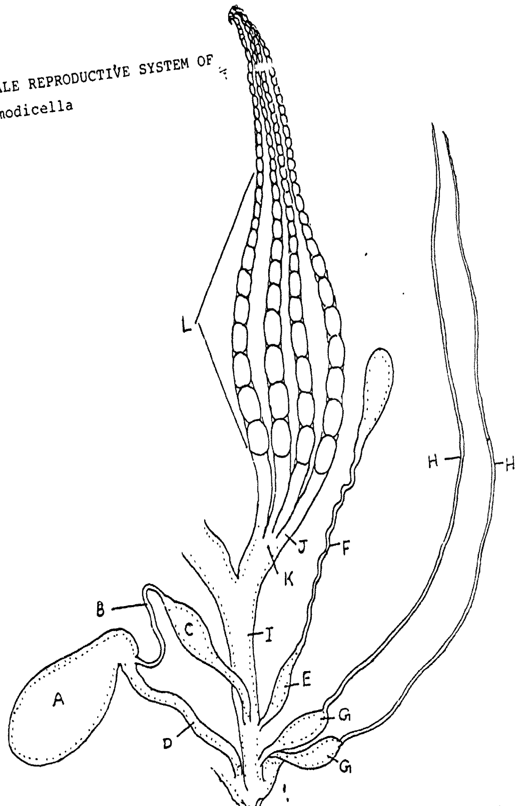
4.3 MORPHOLOGY OF THE REPRODUCTIVE SYSTEMS

4.3.1 Female reproductive system of A. modicella

The internal reproductive system of the female is illustrated in Fig. 24. The vulva is the external opening to the bursa copulatrix between the 7th and 8th sterna and receives the aedeagus during mating. The bursa copulatrix, the largest and most conspicuous organ in the female system, is divided into the bulbous portion or corpus bursae 1.0 mm long and 0.4 mm in diameter. The cervix bursae which is the narrow portion leading to the seminal duct and the duct leading to vulva, the ductus bursae 0.7 mm long. The corpus bursae receives the spermatophore and on its anterior wall are located 2 heavily sclerotized spines or signa pointing into the lumen. Internally, where the base of corpus bursae joins the cervix bursae, is a heavily sclerotized plate with several spines pointing inwardly.

The cervix bursae is continued apically as a thin duct, the seminal duct 1.2 mm long. A bulbous structure is bulla seminalis 0.6 mm long and 0.5 mm in diameter opens into the seminal duct joins the common oviduct.

FIG.24: FEMALE REPRODUCTIVE SYSTEM OF A. modicella



A. Bursa copulatrix B. Seminal duct C. Bulla seminalis D. Ductus bursae E. Spermathecal reservoir F. Spermathecal gland G. Accessory gland reservoir H. Accessory gland I. Common oviduct J. Calyx K. Lateral oviduct L. Ovary

The spermatheca is a single lobed organ. The long 0.9 mm coiled spermathecal gland orginates from the spermathecal reservoir (0.3 mm long) as it enters the common oviduct exact opposite to the seminal duct and ended with lobe like structure (0.3 mm long). The large convoluted dilation of the spermathecal gland was termed as utriculus.

The reservoirs of the accessory glands 0.3 mm long main duct which enters the common oviduct. Each reservoir when filled with secretions 0.4 mm in diameter and 0.3 mm long. The narrow accessory glands emerge from this reservoir are 3.2 mm long and joins the reservoirs at their apices. The ovipore and anus open on 9th and 10th segment between the ovipositor lobes which forms the eversible pseudo-ovipositor of the female.

The common oviduct extends from the vestibulum to the lateral oviduct and is 0.3 mm long. The oviductus lateralis is 0.1 mm long from its bifurcation to the calyx where the paired ovaries each branch into four polytropic ovarioles.

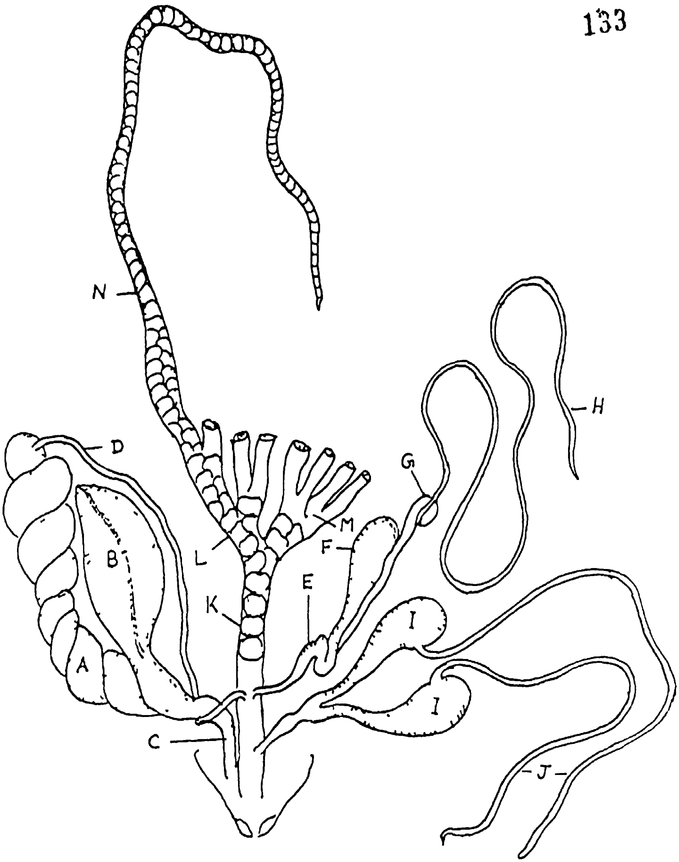
The ovaries lie dorsolaterally along the abdominal wall and extend anteriorly to the 2nd or 3rd abdominal segment. The apical half of each ovary is tightly coiled upon itself. Like the rest of reproductive system, the ovaries are held in place by tracheal mesh and fat bodies. Each ovariole is 3.8 mm long divided into 3 main regions, pedical, egg tube and terminal filament. The 1st region, pedicel, from the calyx of lateral oviduct (Fig. 24) to egg chamber. In a newly emerged moth (1 day old virgin female) a distance of 2.6 mm constitute fully matured eggs stored with chorion.

There are usually 6-9 fully matured eggs in this region in one day old emerged females. The rest of the ovariole (second region) is referred to as the egg tube 1.2 mm long and consists of 2 sections. The vitellarium, where oocytes alternate with trophocytes and the germarium, where oogonia are formed from follicle cells (cystocytes) in the germ tissue. Immediately anterior to this region (third region) is the terminal filament. The apices of four ovarioles of each ovary are united by connective tissue. The variations in the lengths of the germarium and vitellarium was also observed and varied with the age of the females. The ovary in Fig. 24 illustrates how the eggs appear within 48 hours of emergence and also shows how the mature eggs are compressed in the egg chamber.

4.3.2 Female reproductive system of *H. armigera*

The complete reproductive system of the female *H. armigera* are shown in Fig. 25. The bursa copulatrix is the largest and most conspicuous organ in the female insect. The arm or cervix bursae of the organ is approximately 10 mm long and 2 mm in width in 2-day old virgin females. The sides are comparatively thick and are twisted in much the same manner as a long French pastry roll. At the posterior end of the arm is a sack-like pouch or corpus bursae (Fig.25). On four sides of the interior wall of this structure are located signa or long bands of closely associated selerotized spines at the base of the corpus bursae, where it opens in conjunction with the cervix bursae, the ductus bursae. The entire organ is connected by the ductus bursae to the external copulatory vulva or ostium bursae in the 7th - 8th intersegmental cuticula and extends forward to the second abdominal segment on the left dorsal side of the abdominal cavity.

The common oviduct has 3 ducts leading into it before it merges into the lateral oviductus . The first of these 3 ducts is the seminal duct. From the cephalad end of the cervix bursae, a very thin seminal duct, the ductus seminalis runs posteriorly (11-12 mm long) where it becomes the most anterior duct connecting with oviductus communis exact opposite to



A Cervix bursae B. Corpus bursae C. Ductus bursae
D. Seminal duct E. Ductus receptaculi F. Lagena
G. Utriculus reservoir H. Spermathecal gland I. Accessory gland
J. Accessory glands K. Common oviduct
L. Lateral oviduct M. Calyx N. Ovariole

FIG.25: FEMALE REPRODUCTIVE SYSTEM OF *H. armigera*

the junction of the spermathecal duct (ductus receptaculi).

The second most anterior duct leading into the oviductus communis comes from the bilobed spermatheca where sperms are stored after having passed down the seminal duct. The longer and larger lobe, the utriculus is 2.5 - 3 mm long and the smaller one, the lagena is 2 mm long and 0.7 mm in diameter. A narrow spermathecal gland 23 mm long enters the utriculus laterally at a point above the lagena. The apex of the utriculus is crescent shaped, while that of the lagena is rounded. The spermathecal duct is slightly twisted for approximately 2 mm of its length and narrows as it enters the common oviduct. The last of 3 ducts entering the common oviduct is the duct leading from the two sickle shaped reservoirs of the accessory glands. The reservoirs of the accesory glands join the 2 mm long main duct which enters the common oviduct. Each reservoir when filled with secretions 1 mm in diameter and 3 mm long. The narrow accessory glands are 15 mm long and joins the reservoirs laterally. A second external aperture, the oviporus, opens caudad from the oviductus communis just ventral of the anus. Both the oviporus and anus open in the 9th and 10th segments between the papillae anales which form the eversible ovipositor of the female.

Approximately, 3 mm cephalad of the oviporus, the oviductus communis divides into two short lateral oviducts, the oviductus lateralis (1mm long) these again divide into four ovarioles, each four constituting an ovarium. The ovaria lie on either side of the abdominal cavity and extend anteriorly to the second abdominal segment, then loop back and forward again to where the four ovarioles of each ovarium fuse as a single unit (40 mm long). No common suspensory ligament could be demonstrated.

The ovarioles can be divided into 3 recognizable parts. The base of the ovariole just before it enters the lateral oviductus is the pedicel where, the full grown eggs with chorion are stored. In a 2 day old emerged moth (virgin female) each pedicel may hold upto 60 ridged eggs. The rest of the ovariole is termed as a polytrophic type egg tube and consists of two sections, the vitellarium, where oocytes alternate with trophocytes or nurse cells and the germarium, where oogonia are formed in the follicles from germ cells. The apices of the four ovarioles of each ovarium are closely united by connective tissue. The calyx is situated at the point where the lateral oviduct joins the 4 arms of the pedicel.

DISCUSSION

CHAPTER V

DISCUSSION

5.1 USE OF PHEROMONES IN THE MANAGEMENT OF GROUNDNUT PESTS

The potential uses of sex pheromones fall into three broad categories of biomonitoring, mass trapping of attracted males and disruption of mating. In the case of *S. litura*: Z,E 9,11-tetra decadienyl acetate and Z,E 9,12-tetra decadeinyl acetate (10:1) (Chiu and Chien, 1979) and *H. armigera*: (Z)-11- hexadecenal and (Z)-9-hexadecenal (97:3) (Nesbitt *et al.*, 1980) synthetic pheromones are available for commercial use. Several investigators attempted to utilise these pheromones in different crops; tobacco (Dhandapani, 1985) blackgram (Krishnaiah, 1986) and chillies (Venkateswara Rao, 1986) for *S. litura* and ICRISAT mandate crops pigeon pea and chick pea (Dent, 1985: Pawar *et al.*, 1988) for *H. armigera*. No such information is available on groundnut for any of these pests. During the present investigations, attempts are made to generate information for use of pheromones to monitor the populations of *S. litura* and *H. armigera* in taking decisions of their control by insecticides.

5.1.1 Use of pheromones in monitoring

5.1.1.1 Spodoptera litura

5.1.1.1.1 Trap catches vs egg masses: In the present investigations the correlation coefficients between egg mass counts and moth catches in pheromone traps were found to be significant for fields A, B and C (r = 0.798, 0.826 and 0.838) (Table 1) and the peak egg mass counts coincided with the peak moth catches four days prior to egg count in all fields, (Fig.3). Sreedhar (1983) also found similar correlation between the moth catches of S. litura (4 days prior to egg count) and egg masses. It is evident from the life history studies of S. litura (Amin, 1987), that the preoviposition period is 2-4 days and the time lag between the appearance of moths in the traps and egg laying (4 days) in the present investigations clearly indicated there is a definite correlation between the trap catches and egg counts. However, Nakasuji and Kiritani (1976) observed the correlation between the egg masses and moth catches obtained 10 days prior to egg count. Such correlations between egg counts and moth catches with pheromones have been worked out in other pests like H. armigera (Rothschild et al., 1981), S. littoralis (Iss-Hak et al., 1982), H. virescens (Johnson,1983). However, Hartstack et al., (1978) did not found correlation between peak moth catches of *H. virescens* and peak egg counts.

It is evident from the data (Table 1) that two peaks exists in the moth catches of *S. litura* and in egg counts as well in all the three groundnut fields and the interval between the peaks was 4 weeks. The 4 week interval corresponds to one complete generation period. A similar instance has been reported by Dent (1985) in the case of *H. armigera*.

The catches of male tobacco caterpillar *S. litura* moths in pheromone traps may be used in conjunction with the scouting technique popular with the estimation of egg masses. Using the regression equation ($Y = 0.019+0.445x$) calculated from this data on egg masses vs trap catches and a tentative economic thresholds of 5 egg masses for 100 plants (observed by Reddy, 1984) 17 moths/trap/night (Table 23) has been worked out as ET values. It indicates that the egg masses at ET levels may occur 4 days after this moth capture.

5.1.1.1.2 Trap catches and larval population: Significant correlations were obtained between *S. litura* moth catches and early larval instars (1st, 2nd and 3rd) population in fields A, B and C (r = 0.817, 0.673 and 0.661). It is evident from the data (Table 2) that

Table 23: Tentative economic thresholds of <u>S.litura</u> in terms of pheromone trap captures on groundnut

Stage of the pest	Threshold level	Regression equation	Calculated economic threshold moths/trap/night
Egg masses	5 egg masses/ 100 plants	Y=0.019+0.445x	17
Early larval instars	1 early larvae/ plant	Y=0.380+0.793x	58
Late larval instars	1 late larvae/ 2 plants	Y=-0.042+0.815x	68
Damaged leaves	5 per cent	Y=0.097+0.943x	138

there are two distinct peaks in moth catches and early larval population in all these groundnut fields. Highest number of early larval population in the field A, B and C coincided with the 12 days prior highest moth catches recorded. Correlations have been observed by McVeigh and Campion (1977) between the number of male moths of S. littoralis in traps and the populations of early larval instars 2 weeks (12 to 14 days) later.

Similarly when data on moth catches of S. litura and late larval instars (4th, 5th and 6th) from fields A, B and C were analysed, significant correlation (r=0.714, 0.598 and 0.497) was obtained (Table 3). The peak moth catches coincided with the first peak of late larval population 20 days later the moth catch (Fig. 7). Similarly significant correlation was observed by Krishnaiah (1986) between S. litura moth catches and larval population in blackgram grown in rice fallows. Evidences on significant correlation between trap catches and larval populations have been presented in other pests like Earias insulana (Kehat and Bar, 1975), Phthorimaea operculella (Shelton and Wyman, 1979) and Plutella xylostella (Baker et al., 1982). However, there was no correlation of S. litura moth catches with larval population in the studies made by Dhandapani (1985).

Regressions based on moth counts in pheromone traps and their relationship to larval populations can be used to estimate or predict damage. Reddy (1984) based on his experience during surveys considered one early larva per plant and one late larva per two plants have been considered as an economic threshold for *S. litura* on groundnut. Based on the data (Table 23), regression equation for early larvae (Y = 0.380+0.793x) and late larvae (Y = 0.815x-0.042), one early larva per plant or one late larva per two plants in groundnut would be expected after 30 days of *S. litura* male moth captures in pheromone traps reach a total 58 to 68 moths/trap/ night (Table 23).

5.1.1.1.3 Trap catches and plant damage: A significant relationship between 20 days prior trap catches and plant damage or late larval counts on groundnut fields in all the three (A, B and C) groundnut fields (Table 4 and Fig.9 a,b,c). Similar relationship was seen with *S. litura* on blackgram (Krishnaiah, 1986). Such instances have been reported in other pests like *Cydia pomonella* (Madsen and Vakenti, 1973; Reidl and Croft, 1974; Cranham, 1979) *Cydia nigricana* (Kolesova and Chymr, 1982).

It has been tentatively considered (Table 23) 5 per cent leaf damage in groundnut around flowering as an economic threshold for *S. litura*. On the basis of regression equation (Y = 0.097+0.943x) worked out from this data, a 5% damage level to foliage would correspond to 20 days prior catch, when a 138 moths per trap per night. It implies that a foliage damage of 5% can be anticipated 20 days after a trap catch of 138 per trap per night.

5.1.1.2 *H. armigera*

5.1.1.2.1 Trap catches and larval population: Linear regression analysis showed that correlations were significant between trap catches of *H. armigera* and early larval instars in groundnut fields I, II and III (Table 5). Peak moth catches in all fields correlated with peak early larval population 8 days later (Fig.11 a,b,c). Similarly, significant correlations (r = 0.535, 0.446 and 0.658) were noticed between moth catches of *H. armigera* and late larval population (4th and 5th instars) (Table 6). Highest moth catches of *H. armigera* in pheromone traps were significantly correlated with late larval population which occured 18 days later (Fig.13 a,b,c). A similar correlation between moth catches of *H. armigera*, 14 and 21 days prior larval counts (Dent, 1985; Newton, 1987), also has been observed. Such correlations have been reported in *H. virescens* by Tingle and Mitchell (1981). However, Kehat *et al*. (1982) observed no correlation between trap catches of *H. armigera* and larval population.

A figure of 25 early larvae/ 100 plants and 12 late larvae/100 plants has been suggested as a threshold density in groundnut for H. armigera at which chemical control measures to be taken up. Based on the regression equation Y=0.823x-0.152 (for early larvae) and Y=631x-0.075 (for late larvae) (Table 24) Of the present analyses, a density of 25 early larvae and 12 late larvae/ 100 plants were associated with mean pheromone trap captures of 38 and 34 respectively/trap/ night. This indicates probable occurrence of early and late larval stages of H. armigera after 8 and 18 days of moth captures at around 40/trap/night.

5.1.1.2.2 Trap catches and plant damage: H. armigera moth catches significantly correlated with the plant damage in three groundnut fields (r=0.560,0.412 and 0.683) (Table 7), peak moth catches coinciding with maximum plant damage 18 days after moth catch. Similar correlations between H. virescens moth catches and plant damage has been demonstrated by Tingle and Mitchell (1981).

Based on the available information, 2% damage to foliage of groundnut by H. armigera (Table 24) around flowering can be considered as economic threshold, would be expected when the moth catches in pheromone traps reach a daily average of 88 per trap on the basis of regression equation Y = 0.929x-0.085 worked out from

Table 24: Tentative economic thresholds of *H. armigera* interms of pheromone trap captures on groundnut

Stage of the pest	Threshold level	Regression equation Y=a+bx	Calculated economic threshold moths/trap/night
Early larval instars	25 early larvae/ 100 plants	Y=-0.152+0.823x	38
Late larval instars	12 late larvae/ 100 plants	Y=-0.075+0.631x	34
Damaged leaves	2 per cent	Y=-0.085+0.929x	88

present investigation, the 2% (Table 4) foliage damage would correspond to a moth catch of 88/trap/night, 18 days prior to damage. Hence this can be considered as an economic threshold for H. armigera.

Eventhough the correlations between moth catches and egg mass counts, larval population (early and late larval instars), damaged leaves count in respect of both the pests were significant in the present study, inconsistent relationship was observed among variables in S. litura (Fig.2,4,6 and 8 in S. litura, Fig.10, 12 and 14 in H. armigera). The sudden influx of migrant moths, particularly mated and unmated females was one of the reasons for the inconsistent relationships between egg masses, larval population, plant damage and moth catches (Rothschild et al., 1981). Sudden influx of mated females might boost the number of eggs without a comparable increase in the male moth catches in the pheomone traps. The larval popualtion and plant damage in turn depend on the egg number, while migration of virgin females might divert males away from the pheromone traps.

Another reason for in consistency this could be, the sudden migration of male moths from the surrounding untrapped areas, resulting in dramatic increase in pheromone trap catches without a comparable increase in the egg number (Hartstack *et al*., 1978), larval population of *H. armigera* (Kehat *et al*., 1982) and *S. litura* (Dhandapani, 1985) and damaged fruits of *Cydia pomonella* (Cranham, 1979). Marks (1977) suggested that the variation in moth catches may be due to the position of the trap, local migratory movements, emergence patterns and meteorological factors.

Most of previous studies were confined to the trap catches and its relationship with single factor either egg masses or larval population or damage estimates. In the present investigations the egg mass counts, larval population and the extent of damage have been involved to correlate with the pheromone trap captures to obtain satisfactory or reliable measure of monitoring.

No attempts have yet been made to use pheromone traps as a basis for planning chemical control measures in India against *S. litura* and *H. armigera* infecting groundnut. At this stage, experimental results suggests that pheromone traps (1) indicate when moths first invade a crop (2) provide information on oviposition levels, larval populations and damage estimates. Although further confirmatory work relating egg/larval and damage in the groundnut crop to adult trap captures is necessary, the data on the trap captures indicated probable threshold levels of moths of S. litura and H. armigera do serve as guide lines for suggesting chemical control measures on groundnut.

5.1.2 Behavioural studies of S. litura and H. armigera

5.1.2.1 Moth emergence of H. armigera: Male pupae took longer time than female pupae for emergence into adult H. armigera. The pupal duration ranged from 9 to 11 days with a mean of 10.0 days in females and it ranged from 10 to 12 days with a mean of 11.4 days in males (Table 15). Jayaraj (1981) stated that in India the pupal period of H. armigera ranged between 5-8 days. But in other countries the wider variation in the pupal period was observed to vary 15-57 days due to differences in the temperatures. Unlike groundnut leafminer, H. armigera females emerged earlier than males. Based on our own observations under field conditions and also according to Jayaraj (1981) overlapping generations are common in H. armigera. Hence emergence of females 1-2 days earlier than males may not result in any decrease in the mating chances in females. Mass trapping and mating disruption can be successful at peak mating days.

Peak time of emergence of H. armigera of both sexes (50-65%) was mostly between 12 mid night to 4.00 am and males tended to be lag behind females by 2 hours at peak emergence (Table 16). Dent (1985) also observed delay in emergence of males than females by 1 hour, but the majority emerged before mid night. Several workers (Singh and Singh, 1975) observed H. armigera moths to emerge in the evening time after 4.00 pm with a peak emergence at 8.00 pm to 10.00 pm. But the emergence time recorded in the present investigations was 12.00 mid night to 4.00 am which coincided with peak pheromone trap catches (Table 21). Dent and Pawar (1988) had also earlier observed peak pheromone trap catch at 2.00 am. It seems plausible that peak pheromone trap catches coincide with the peak emergence of H. armigera moths. Similar instances of emergence of moths coinciding with the peak pheromone trap catches have been reported in the case of S. litura (Yushima et al., 1973; Parasuraman, 1979; Balasubramanian, 1982; Dhandapani, 1985).

5.1.2.2 Time of attractancy of pheromones in S. litura and H. armigera: In the present studies it has been observed that sexual activity in S. litura occurs in two peaks i.e., 2.00 am to 4.00 am (31.7%) and 10.00 pm to 12.00 midnight (22.2%) based on 2 hourly trap catches (Table 20 and Fig.20). Balasubramanian (1982) also found the sexual activity to occur at two peaks 11.00 pm to 12.00 midnight and 3.00 am to 4.00 am in S. litura. However, the variation in the sexual activity has been observed by Yushima *et al*. (1973) and Dhandapani (1985), the former recording at 10.00 pm to 12.00 midnight and the latter recording at 8.00 to 10.00 pm in *S. litura*. The two peaks of sexual activity at different times in the night have also been recorded in the related species at 11.00 pm to 3.00 am in *S. frugiperda* and 12.00 midnight to 3.00 am (Ramaswamy et al 1988 and Mitchell *et al*., 1974) in *S. exempta* at 12.00 midnight to 2.00 am and 00.30 to 3.00 am (Dewhurst, 1984 and Khasimuddin, 1978). Eventhough the possibility of male moth emergence time has been attributed to the peak catch in the traps at the same time (Parasuraman, 1979), but the response of the males to the pheromone source immediately after emergence is not known.

The distinct major peak periods of sexual activity in *H. armigera* observed in the groundnut field in the present investigation at 2.00 am to 4.00 am (43.7%) (Table 21 and Fig.21) is in coincidence with results reported at 2.00 am by Dent and Pawar (1988). The second peak of moth activity observed at 12.00 midnight to 2.00 am (25.7%) in the present investigations has not been reported earlier. However, Topper (1987) recorded the peak moth catches of *H. armigera* at different time at dusk (6.15 pm to 7.15 pm). The variations in the peak sexual activity of the female moths have been attributed to the change in the environment (Swier et al., 1977). The catch response to the pheromone traps at 2.00 am to 4.00 am has been explained that the adults which have emerged during midnight make a maiden flight during the later part of the night which would be made in order to feed and move away from siblings before they are able to mate in *H. armigera*. Such flight would explain the peak catch between 2.00 am to 4.00 am (Dent, 1985). Mass trapping of *H. armigera* through pheromone traps during maiden flight is useful in reducing the mating success.

5.1.3 Relative trap efficiency

In the present studies, the high moth catches of *S. litura* and *H. armigera* in the funnel traps (ICRISAT) compared to the sleeve traps positioned in groundnut fields clearly indicated that the trap efficiency was 1.2 times higher in funnel traps (Tables 8 and 9). Pawar et al. (1988) while recording higher trap catches of *H. armigera* in pigeon pea and chick pea in the funnel trap compared to five other traps attributed its high trap efficiency to mechanism facilitating the moths that flew through funnel neck to fall down in the poly-ethylene bags with no chance to escape. Raman (1993) also demonstrated that funnel traps were more efficient and ideal for high moth catches than other traps. Hallow cone traps and texas traps have been reported to be more efficient than the funnel traps (Wilson, 1984; Sage and Gregg, 1985). In case where monitoring of the pest to predict the chemical control is the objective, sleeve traps can be used since they are almost equally effective in capturing moths as ICRISAT funnel traps. When we attempt for mass trapping where the maximum population should be removed from the area to reduce the chances of mating, under such conditions ICRISAT funnel traps should be preferred.

5.1.4 Response of males of *H. armigera* to blend specificity

Nesbitt *et al* (1980) reported that pheromone mixture containing of (Z)-11-hexadecenal and (Z)-9-hexadecenal in the ratio of 97:3 to attract the male moths of *H. armigera* efficiently . Possibilities of achieving higher catch by increasing the proportion of minor component were explored. Significantly a higher trap catch (42%) was recorded in the blend with 97:3 ratio (Table 10 and Fig.16) which confirms the effectiveness of the reported pheromone mixture. Pawar *et al*. (1983) also found that 97:3 was better blend for *H. armigera*. Interestingly for *H. zea*, the same two components in two ratios (97:3 and 99.7:0.3) attracted similar number of moth catches (Halfhill and McDonough, 1985). Several basic components have been isolated from *H. armigera*, *H.virescens* and *H. zea* (Teal *et al*., 1984;

Ramaswamy and Rousch, 1986) and were tested with the wider ratios of 20:1 and 70:1 [(Z)-11-hexadecenal and (Z)-9-tetradecenal] also recorded higher moth catches of *H. armigera* and *H. punctigera* (Rothschild, 1978). The preceeding discussion indicates that several components with different blends may be attractive to a lesser or greater extent to *Heliothis sp.*, but the mixture containing (Z)-11-hexadecenal and (Z)-9-hexadecenal in 97:3 is specific to *H. armigera*.

5.1.5 Sex pheromone gland of *H. armigera*

The pheromone gland of *H. armigera* observed in the present investigations is in the form of a complete ring of glandular epithelium in the intersegmental membrane between 8th and 9th abdominal segments (Fig.22) similar to *H. virescens*, *H. zea* and *H. phloxiphaga* (Jefferson *et al.*, 1968). Pheromone gland type and location varies with the insect species It has been observed ventrally in 8th and 9th abdominal segments in *S. exigua*, *Feltia subterranea* (Jefferson *et al.* 1968) and *Prodenia litura* (Jefferson and Rubin, 1970). However, the pheromone gland is a dorsal sac or fold in the four species of *Trichoplusia* of Plusinae (Jefferson *et al.*, 1966) and protrusible sent ring in *Cucullia argentea* and *C. verbasci* (Urbahn, 1913). Sekul and Cox (1967) located the pheromone gland within the last abdominal segment in *S. frugiperda*. The location of the pheromone gland between 8th and 9th abdominal segment in *H. armigera* confirmed that it serves as a source of the female sex pheromone.

5.2 SEX PHEROMONE SYSTEMS IN GROUNDNUT LEAFMINER

5.2.1 Evidence of potent sex pheromone in female moths of *A. modicella*

Presence of sex pheromone in female *A. modicella* has been quite evident by the positive mating responses of male moths to female pheromone source of virgin female baits, female abdominal tips and the lures incorporated with extracts of female abdominal tips (Tables 11 and 12) in the laboratory wind tunnel and in the field sticky traps.

In the wind tunnel, virgin female baits evoked mating response in 70 per cent of the released males (Table 11) while baits containing males were not attractive to the released females. Several workers have demonstrated the presence of sex pheromone in the females using wind tunnel based on orientation of males. Some of the examples are: *Estigmene acrea* (MacFarlane and Earle, 1970), *Trichoplusia ni* (Sower *et al.*,1971)*Cydia pomonella* (McDonough *et al.*, 1972), *S. litura* (Oyama, 1977), *S. littoralis* (Murlis and Bettany, 1977), *H. zea* (Carpenter and sparks, 1982), *H. virescens* and

Grapholitha molesta (Von, 1984) and in Phthorimaea operculella (Ono,1985). The orientation and searching of males for the females of the leafminer is characterised by rapid vibration of wings and flying movements like erratic and fast motive movements of males to pheromone followed by alighting on the pheromone bait containers. More or less similar orientation and behavioural responses of males have been observed in S. littoralis (Murlis and Bettany, 1977), Grapholitha molesta and H. virescens (Von, 1984) and in Phthorimaea operculella (Ono, 1985).

The male moth captures in the virgin female leafminer baited sticky traps installed in the infested groundnut field ranged from 48 to 70/trap/night (Table 12) which confirmed the presence of sex pheromone in the females. Presence of sex pheromones have been demonstrated utilising the female baited sticky traps in Pectinophora gossypiella (Guerra, 1968), Trichoplusia ni (Sower et al 1971), Cydia pomonella (McDonough et al., 1972; Charmillot, 1978), H. zea (Snow et al, 1972; Haile et al., 1973), H. virescens (Haile et al., 1973), S. litura (Tamaki and Yushima, 1973; Huang et al., 1981), Cydia molesta (Audemard et al., 1977) and Earias vitella (Sardana, 1988) under field conditions. No moth catch in male leafminer adult baited sticky traps clearly demonstrated that only the females serve as the pheromone source. Similar trials with S. litura also confirmed the presence of pheromone source in females (Huang et al., 1981). According to Klassen et al. (1982) out of 674 pheromones identified, 475 pertained to lepidoptera in which the females produced the pheromones.

In the wind tunnel, 67 per cent released males showed mating response to abdominal tips of female moths (Table 11). Sticky traps charged with female abdominal tips captured as many as 88 male moths/trap/night from the infested field (Table 12). These observations confirmed the presence of pheromone in the female moths and are released from the gland located in the abdominal tips of A. modicella. Similar confirmations were made in Pectinophora gossypiella (Guerra, 1968), Cydia pomonella (McDonough et al., 1972) in the wind tunnel and in Pediasia trisecta (Banerjee, 1969), Cydia pomonella (McDonough et al., 1972) H. virescens (Mitchell et al., 1974) with the sticky traps baited with abdominal tips.

The abdominal tip extracts evoked mating response in males to the tune of 63 to 80 per cent attracted in wind tunnel (Table 11) and 65 to 85 males/trap/night in the sticky traps (Table 12) placed in severely infested groundnut fields. The fact that one female equivalent (one ml) did not induce mating stimulus while 2 and 3 female equivalents attracted males in wind tunnel as high as a mean of 6.3 and 8.0 moths/tunnel is indicative of loss of pheromone material in the course of solvent extraction. Similar responses have been reported in the wind tunnel with Pectinophora gossypiella (Guerra, 1968), Phthorimaea operculella (Hindenlang and McLaughlin, 1976), Plutella xylostella (Koshihara and Yamada, 1978), S. exempta (Khasimuddin and Lubega, 1984) and with pheromone extract baited traps under field conditions with Pediasia trisecta and P. teterrella (Banerjee, 1969), H. virescens (Mitchell et al., 1974).

The attraction of leafminer males to the lures containing 2 and 3 female equivalents of solvent extracts and no response to one female equivalent both in the wind tunnel and field experiments in the present investigations indicated that the qualitative differences in the sexual behaviour of males elicited might be due to differences in the concentration. This was clearly demonstrated in Pectinophora gossypiella through olfactometer experiments, that the response of males depends on the concentration of extract (Guerra, 1968).

It is evident from the preceding discussion that the pheromone source is in the abdominal tips of leafminer females as evidenced by the attraction of males to the virgin females, female abdominal tips and also solvent extracts of abdominal tips both in the wind tunnel and also in sticky traps. The response of males to the solvent extracts of the female abdominal tips indicated that the pheromone could be extracted into the solvent (methylene chloride).

5.2.2 Behavioural studies of *A. modicella*

5.2.2.1 Moth emergence: Pupal period of the leafminer varied with the sex, i.e., 2.9 days for males and 4.9 days for females with a mean of 3.9 days for both the sexes (Table 13). Several workers (Cherian and Basheer, 1942; Kothai, 1974; Patnaik and Senapathi, 1974) have found the duration of pupal period to varv in the leafminer from 3 to 7 days, but the sex dependent variation was not observed. However, Cherian and Basheer (1942) indicated that leafminer males would emerge earlier than the females. The present investigations, while confirming the above findings the early male emergence, have clearly indicated that males emerged 2.0 days early than the females (Table 13). It has been observed under field conditions during the experimentation and also in our earlier studies on survey, that the leafminer occurs in distinct groups and overlapping generations are not common. This situation of early emergence of males or synchronous emergences of both sexes facilitates the mass trapping for reducing the chances of mating in the leafminer by utilizing sex pheromone.

There has been general observation among the workers that the lepidopterous pests emerge mostly during night time (Yushima et al., 1973; Parasuraman, 1979; Dewhurst, 1984). In the present studies the leafminer males and females emerged during night time but the maximum emergence was mostly in the early hours 2.00 am to 4.00 am (Table 14). The emergence time also coincided with the peak catches in the virgin female baited sticky traps (Table 19). This information is useful in timing the extraction of pheromone from the virgin female moths.

5.2.2.2 Age and attractiveness of A. modicella: In many species of insects the daily rhythms of sexual activity are endogenous in nature. But rhythms are modified by exogenous environmental cues (Brady, 1974; Saunders, 1976; Beck, 1980). During the present investigations, calling behaviour of females and male responsiveness in the leafminer were observed in the freshly emerged moths (<1-day old) indicated sexual maturity in the both sexes at the time of emergence (Table 7). Time of these mating behavioural responses varied with species. Maturity of freshly emerged males and females have been reported in *Pediasia teterrella* and *P. trisecta* (Banerjee, 1969), *Andraca bipuncta* (Banerjee, 1971), 36 minutes to 32 hours after emergence in *H. armigera* (Singh and Singh, 1975), 9 hours after emergence in *H. virescens* (Henneberry and Clayton, 1985), 18 hours after emergence in *Diacrisia obliqua* (Siddiqi, 1985), 14 to 24 hours after emergence in *Phyllocnistis citrella* (Pandey and Pandey, 1964), one day after emergence in *Pectinophora gossypiella* (Ouye *et al*., 1965), *Cydia pomonella* (Nowosielski and Suski, 1977), *S. litura* (Howell *et al*., 1978; Chu *et al*., 1987) and 2 days after emergence in *S. littoralis* (Elsayes and Kaschef, 1977) *S. exempta* (Khasimuddin, 1978).

The results clearly showed that in the leafminer, maximum attractancy of females and the pattern of calling of females vary with age. One day old females produced maximum calling stimulus in the wind tunnel (Table 17) and maximum catch under field conditions in the female baited sticky traps (Table 18). The attractiveness of females decreased with increase in age. Maximum calling of females one day after emergence in *Diacrisia obliqua* (Islam and Alam, 1979 and *S. littoralis* (Kehat *et al*., 1976), two days after emergence in *Cydia pomonella* (Nowosielski and Suski, 1977) and *H. virescens* (Henneberry and clayton, 1985), 2 to 4 days after emergence in *S. exempta* (Dewhurst, 1984), 3 days after emergence in Diparopsis castanea (Marks, 1976), H. armigera and Agrotis segetum (Kravchenko, 1982), S. exempta (Khasimuddin and Lubega, 1984), 3 to 4 days after emergence in Pediasia teterella and P. trisecta (Banerjee, 1969). S. litura (Yushima et al., 1973) and 4 days after emergence in Agrotis ipsilon (Swier et al., 1977).

The increase and decrease in attractancy with age of females in A. modicella probably related to reproductive maturity even in 1 day old after that the attractiveness of decents and ceased after 7 days (Table 18). The decrease in attractancy with increase in the age of the females like in leafminer was observed in sugarcane borer (Perez and Long, 1964), Sod webworm (Banerjee, 1969), Cydia pomonella (Howell and Thorp, 1972). It can be concluded that females of A. modicella produce maximum quantity of pheromone when they are one day old (Table 17a), eventhough the production continues probably in lower quantities upto 5 days and thereafter. It has been suggested by Swier et al. (1976) that the reduced calling in Agrotis ipsilon with increase in age of females is mostly related to the presence of large number of mature eggs and the peak ovarian development. Time and age of maximum mating activity of females which reflects on the maximum production of pheromone facilitates in extraction of pheromone components.

The calling time varied with the age i.e., delayed with the advancement of the age of the females. Early calling observed in 1 day old females than the freshly emerged females (Table 17) may be attributed to the time necessary for the development and maturation of eggs as reported in Agrotis ipsilon (Swier et al., 1976). Generally earlier calling in the older females is common to increase their probability of mating by being the first to attract males (Swier et al., 1976), but in the present investigations, the calling time delayed with the age of the leafminer and probably it may vary with the species of the insect.

The onset of female calling is mediated through a hormone from the Corpora cardiaca (Riddiford and Williams, 1971). If a similar hormone existed in leafminer female, the timing of its release may some how be influenced by the state of maturation of the ovaries. However, the presence of eggs is not necessary for calling as some females call when possessing no eggs (Swier et al., 1977).

The maximum attractancy of 1 day old males of leafminer to the female pheromone source in the wind tunnel and decrease in response with increase in age (Table 17a) may be similar to that reported in Pediasia trisecta and P. teterrella (Banerjee, 1969), S. litura (Fujiie and Miyashita, 1973; Yushima et al., 1973; Chu *et al.*, 1987) *Agrotis ipsilon* (Swier *et al.*, 1976), *H. zea* (Delorme and Payne, 1984), *S. exempta* (Khasimuddin and Lubega, 1984), *H. virescens* (Henneberry and Clayton, 1985). It is clear from the above studies that the male response and female calling age differ with the different species of insect.

Male mating response and female calling time recorded in the leafminer in the present studies was between 4.00 am to 8.00 am with a peak response at 4.30 am to 4.59 am (Table 17b). Similar time of response was also (4.00 am to 8.00 am) observed under field conditions in the female baited sticky traps (Table 19). In moths the periodicities of female pheromone emission and male responsiveness have been accepted to be temporarly synchronous and rigidly programmed and to serve as isolating mechanisms among species utilising a communication system (Roelofs and Carde, 1977). In moths generally the mating starts at night but the specific time in the night vary with the species. Some such examples where the mating occurs in the early hours like the leafminer are *Dioryctria abietella* (Fatzinger and Asher, 1971), *Lamprosema indicata* (Kapoor *et al.*, 1972), *Phthorimaea operculella* (Ono and Sato, 1973), *Agrotis ipsilon* (Swier *et al.*, 1976), *S. littoralis* (Elsayes and Kaschef, 1977; Dunkelblum *et al.*, 1987) *S. exempta* (Khasimuddin, 1978;

Dewhurst, 1984) Diacrisia obliqua (Siddiqi, 1985). In the moths of Polymatus boeticus (Pandey et al., 1978), the mating accomplished during the day time. On the other hand in Thiacidas postica, it can occur at any time during the day or night (Mehra and Shah, 1970). Information on the rhythms of sexual activity is of great importance in working out strategies of pest management.

The maximum duration of male response to female phermone source lasted by 30-39 minutes, eventhough the responses were observed which were of longer (90-99 minutes) or shorter (20-29 minutes) duration (Table 17b). Eventhough the literature on mating response is not available but the duration of mating for varying periods 45 seconds to 10 minutes in H. armigera (Singh and Singh, 1975), 1 to 4 minutes in Porthetria dispar (Doane, 1968), 5 minutes in Cnaphalocrocis medinalis (Velusamy and Subramaniam, 1974), 5 to 10 minutes in Parnara mathias (Teotia and Nand, 1966), 15 to 30 minutes in Phyllocnistis citrella (Pandey and Pandey, 1964), 15 minutes to 3 hours in Lamprosema indicata (Kapoor et al., 1972), 20 minutes in Trichoplusia ni (Sower et al., 1971), 20-25 minutes in Polytella gloriosae (Sachan and Srivastava, 1965), 30 to 350 minutes in H. virescens (Henneberry and Clayton, 1985), 45 to 90 minutes in H. zea (Agee, 1969), 80 to 100 minutes in *S. littoralis* (Elsayes and Kaschef, 1977), 117 minutes in *Agrotis ipsilon* (Swier et al., 1977), 4 to 18.30 hours in *Diacrisia obliqua* (Siddiqi, 1985) and 10-12 hours in *Thiacidas postica* (Mehra and Shah, 1970) has been observed. The wider variation in the duration of response/mating period may be related to the duration and rate of pheromone release.

5.2.2.3 Pheromone perception: From results of pheromone perception experiment in *A. modicella* where the male leafminer moths deprived of their antennae did not show any response to female pheromone source and the 80 per cent response observed in the antennae intact males (Table 22) indicated that antennae in males act as primarily olfactory and tactile organ for perception of pheromone. Antennae ablation experiments in *Trichoplusia ni* (Shorey, 1964; Grant and O'connell, 1986), *Grapholitha molesta* (George, 1965; Baker and Haynes, 1989), *H. zea* (Agee, 1969), *Dioryctria abietella* (Fatzinger and Asher, 1971), *Cydia pomonella* (Sherman, 1972; Hutt and White, 1977), *Corcyra cephalonica* (Darshan Singh and Sidhu, 1976), *S. littoralis* (Ellis and Combe, 1980) and *H. armigera* (Konyukhov et al., 1980) had also shown similar results. The antennae posses sensory receptors essential for recognising the courting females (Payne et al., 1973) and the perception may be attributed to the fact that the multiporous sensilla present in the antennae may perceive the pheromone released by opposite sex. This has been very distinctly demonstrated based on the electroantennogram studies that the olfactory receptor cells at the basal region of the *Sensillum trichodeum* in males of *S. litura* (Aihara and Shibuya,1976). Based on the experiments conducted by Smith *et al*. (1978) on *Pectinophora gossypiella* where the antennae ablated at the basal segment did not mate but with 2-5 antennal segments remaining intact could to mate.

5.2.2.4 **Effect of continuous light on mating in *A. modicella*:** In the present studies no male mating response was observed following the exposure of males for three days continuously to a 40 watts flourescent light in the wind tunnel male moths were not trapped at sticky traps during day time (8.00 am to 6.00 pm) indicated that mating is inhibited in the presence of light (Fletcher, 1920). No response of males in the continuous light was also observed in *Autographa californica*, *H. virescens*, *S. exigua* and *Trichioplusia ni* (Shorey *et al*., 1965), *Pectinophora gossypiella* (Henneberry and Leal, 1979) and *Phthorimaea operculella* (Toth, 1985).. However, Ouye *et al*. (1964) observed mating of pink boll worm during day time when provided with continuous light.

5.2.2.5 Sex pheromone gland of A. modicella: The female sex pheromone gland in the Lepidoptera, according to Gotz (1951), have orginated from an intersegmental fold and are typically situated between the 8th and 9th abdominal segments.

In the present study, A. modicella gland is in the form of an eversible sac or eversible fold situated dorsally in the intersegmental membrane of 8th and 9th abdominal segments (Fig.23) similar to Pseudoplusia includens, Rachiplusia ou and Pectinophora gossypiella (Jefferson et al., 1968 and 1971). However, it was a bulbous structure in Phthorimaea operculella (Adeesan et al., 1969) and pad like structures in Estigmene acrea (MacFarlane and Earle, 1970). In Plutella xylostella, Chow et al. (1976) observed the pheromone gland situated in 3 different parts of the abdomen i.e., at intersegmental folds of eighth and ninth segments, thick epidermal cells on the dorsal inner surface of ninth abdominal segment and the epithelium around ostium bursae.

Location of the gland in the leafminer, positive bioassay results with the abdominal tips and extracts of abdominal tips both in the laboratory and field (sticky traps), give rise a strong possibility of isolation and identification of the sex pheromone components.

5.3 REPRODUCTIVE SYSTEMS OF A. MODICELLA AND H. ARMIGERA

Apart from the importance of reproductive systems as such (Stitz, 1903; Munroe, 1964) understanding of female reporductive organs is also essential before one can attempt to know the pheromone systems of insects. Surprisingly enough little is known regarding the reproductive systems of the important groundnut pests like leafminer belonging to the family gelichidae and H. armigera belonging to noctuidae.

5.3.1 Female reproductive system of A. modicella

Like in majority of Lepidoptera, A. modicella also possess two genital openings, the anterior one or the ostium bursae is situated on the ventral surface of eighth abdominal segment while the posterior one representing the opening of the oviduct is situated on the ninth sternal region (Srivastava, 1960). But in some Lepidopterans of Hepialidae, Micropterygidae, Adelidae etc., there is only one genital aperture situated on the ninth abdominal sternum which communicates with the common oviduct (Srivastava, 1960).

The bursa copulatrix of A. modicella is the largest and most conspicuous organ and is divided into the bulbous portion or corpus bursae and the cervix bursae which is the narrow portion (Fig.24) similar to

Leucinodes orbonalis (Srivastava, 1960), Diatraea grandiosella (Davis, 1968) and Laspeyresia pomonella (Ferro and Akre, 1975). In contrast, H. zea (Callahan, 1958), cervix bursae had many ridges comparatively thick and are twisted like long french pastly roll.

The cervix bursae of A. modicella is similar to that of Laspeyresia pomonella (Ferro and Akre, 1975) continued apically as a thin duct (the seminal duct) which connects the corpus bursae with the common oviduct and a bulbous organ is bulla seminalis opening into the seminal duct (Fig.24). However, a seminal duct without bulla seminalis has been observed in Leucinodes orbonalis (Srivastava, 1960), Diatraea grandiosella (Davis, 1968) and in S. litura (Ahmed et al., 1979).

In A. modicella long, coiled spermathecal gland originates from the spermathecal reservoir (Fig.24), exactly opposite to the junction of seminal duct connecting to oviductus communis and similar spermathecal gland was noticed in Diatraea grandiosella (Davis, 1968) and Laspeyresia pomonella (Ferro and Akre, 1975). The large convoluted dilation of the spermathecal gland in the leafminer is the utriculus like in the cabbage looper Trichoplusia ni (Holt and North, 1970). This is primary storage site for sperm after leaving the spermatophore.

The posterior most of the 3 ducts leading into the common oviduct connects with the accessory gland reservoir is observed in A. modicella (Fig.24). Similar accessory gland reservoir was observed in Laspeyresia pomanella (Ferro and Akre, 1975). However, the variations in the shape and number of accessory gland reservoirs were observed as two spherical structures of accessory glands in Leucinodes orbonalis (Srivastava, 1960), one elongated structure of accessory gland in Diatraea grandiosella (Davis, 1968). The accessory gland reservoirs appear to contain a white fluid. Most researchers think that the accessory glands produce a substance that is useful in sticking eggs to their host plants. However, Callahan and Cascio (1963) thought that secretion of accessory gland function as a medium in which sperm live and move within the various ducts.

Both the common oviduct and anus of leafminer open on the 9th and 10th abdominal segments between the ovipositor lobes which form the eversible pseudo-ovipositor of the female similar to Leucinodes orbonalis (Srivastava, 1960), Diatrea grandiosella (Davis, 1968) and Laspeyresia pomonella (Ferro and Akre, 1975).

The common oviduct in A. modicella divides into 2 short lateral oviducts. Each ovary is comprised of 4 polytrophic ovarioles. The 2 ovaries lie dorsolaterally along the abdominal wall and extend anteriorly to the 2nd and 3rd abdominal segments. Each ovariole is divided into 3 main regions are pedicel, egg tube and terminal filament (Fig.24). Similar type was observed in *Leucinodes orbonalis* (Srivastava, 1960), *Diatraea grandiosella* (Davis, 1968) and *Laspeyresia pomonella* (Ferro and Akre, 1975).

5.3.2 Female reproductive system of *H. armigera*

The female *H. armigera* has two external openings that are directly concerned with reproduction. First is the oviporous that serves as the opening for egg laying and occurs on the 9th abdominal segment. The 2nd is the ostium bursae (vulva). This opening facilitates the transformation of male spermatophore into the female bursa copulatrix. The ostium bursae occurs in the intersegmental cuticula of the 7th-8th abdominal segment. The external openings were similar to *H. zea* (Callahan, 1958) *Diatraea grandiosella* (Davis, 1968), *Laspeyresia pomonella* (Ferro and Akre, 1975) and *S. litura* (Ahmed *et al*., 1979).

The bursa copulatrix of *H. armigera* is the largest and most conspicuous organ. The cervix bursae appeared as a long French pastry roll and twisted (Fig.25). Similarly, it has been demonstrated in *H. zea* reported by Callahan, (1958). But the shape and structure of bursa copulatrix is different and no such structure of cervix bursae is present in *S. litura* (Ahmed *et al.*, 1979). Out of three ducts first is the seminal duct arise from cervix bursae connecting exactly opposite to junction to spermathal duct with oviductus communis (Fig.25), similar to the ductus seminalis of *H. zea* (Callahan, 1958).

The second most anterior duct is spermathecal duct in *H. armigera* leading into the oviductus communis comes from the bilobed spermatheca with long coiled spermathecal gland where sperms are stored after having passed down the seminal duct (Fig.25). Similar bilobed spermatheca was observed without spermathecal gland in *H. zea* (Callahan, 1958) and bifurcated spermathecal gland at tip in *S. litura* (Ahmed *et al.*, 1979).

The most posterior of the three ducts leading into oviductus communis passes from the two sickle shaped reservoirs of the accessory glands (Fig.25) similar to that of *H. zea* accessory glands (Callahan, 1958). However, in *S. litura*, the accessory gland reservoirs appeared as elongated tubular structures (Ahmed *et al.*, 1979). The accessory glands of female lepidoptera secrete the adhesive substance by which the moth glues its eggs to host plants. Davis (1968) stated that the accessory gland secretion in *Rhodnius prolixus* is reponsible for medium for the sperm in the spermatophore and also for the activation of the muscle of the reproductive duct. Ovipore and anal opening in on 9th and 10th abdominal segments is observed in *H. armigera* like in *H. zea* (Callahan, 1958), *Pseudaletia unipuncta* and *Peridroma saucia* (Callahan and Chapin, 1960) and *S. litura* (Ahmed *et al*., 1979).

The common oviduct divides into two short lateral oviducts in *H. armigera*, further divides into four ovarioles, each four constituting the ovarium. The ovaria lie on either side of abdominal cavity and extend anteriorly to the second abdominal segment, then loop back and forward again to where the four ovarioles of each ovarium fuse as a single unit (Fig.25). Similar ovarioles have been observed in *H. zea* (Callahan, 1958), *Pseudaletia unipuncta* and *Peridroma saucia* (Callahan and Chapin, 1960) and in *S. litura* (Ahmed *et al*., 1979).

In the light of results presented and the discussion that followed, the following broad conclusions can be drawn. Based on the consistant information on the relationship of the pheromone trap catches of male moths with egg and larval population counts and plant damage in groundnut, tentative economic thresholds of male moths of *S. litura* and *H. armigera* have been suggested. Although, they are subjected to refinement through additional studies in different hot spots, they can neverthless serve as guidelines in taking up pest control decisions. It may be worth while veryfying these thresholds on the farmers fields before final recommendations. In the behavioural studies of H. armigera indicating an almost synchronous emergence of male and females moths were observed. This gives a scope of utilising the pheromones for direct control of pest through mass trapping technique. Further for more efficient captures in mass trapping technique for both Heliothis and Spodoptera, ICRISAT funnel trap is preferable for monitoring either ICRISAT or sleeve trap serve the purpose. In case of H. armigera commercially available blend consisting of (Z)-11-hexadecanal and (Z)-9-hexadecenal in 97:3 ratio is the most efficient among other combinations of the proportions of the said pheromone components.

The demonstration of the presence of sex pheromone of A. modicella in the virgin female moths for the first time, opened up several new areas to be probed in. The positive response of the males of A. modicella to female abdominal tip extracts gave an strong indication that the pheromone could be extracted with methylene chloride, isolated and identified. This can be taken as a priority line of work as the leafminer management warrants immediate attention. Meanwhile leafminer can be monitored by utilising female baited sticky traps. Further the generated information that leafminer males emerge earlier than females gave ample scope for utilising the pheromones for management of the pest through mass trapping. From the behavioural studies, it is evident that the female calling and male responses are maximum in one day old males and females and are at peak during 4.00 am to 6.00 am indicating that effective extraction of pheromone can be achieved during this time. Location and identification of the sex pheromone gland of the leafminer facilitates in extraction of the pheromone from the glands directly which needs further studies.

SUMMARY

CHAPTER VI

SUMMARY

Studies on the relationship of male moth captures of tobacco caterpillar (*S. litura*) and gram caterpillar (*H. armigera*) at pheromone traps to the incidence of pests on groundnut and behavioural studies of these pests and of groundnut leafminer in respect of pheromone production and perceptions were undertaken during 1988-89 in the laboratory and in groundnut fields located in pest endemic areas.

In the field experiments at Munivaripalem, Bapatla, Guntur district, Andhra Pradesh with the lures containing sex pheromones of *S. litura* (Z, E 9,11-tetra decadienyl acetate and Z,E 9,12-tetra decadienyl acetate in the ratio of 10:1) and *H. armigera* [(Z) - 11 hexadecenal and (Z)-9-hexadecenal in the ratio of 97:3)], consistent information on the relationship of the pheromone trap catches of male moths and with egg and larval population counts and also plant damage could be generated. There was significant correlation between *S. litura* male moth captures in the pheromone traps and egg masses in the field 4 days after the appearance of moths; of early and late larval counts with 12 and 20 days prior catches of male moths. The relationship with damage was similar to that of late larval counts.

On the basis of regression equations worked out from the data on egg masses, larval population and plant damage of S. litura and based on the information on economic thresholds, 17 male moths for egg masses, 58 to 68 moths for early and late larval populations and 138 moths per trap per night for plant damage have been reckoned as thresholds for possible occurence of pest at damaging level after 4, 12, 20 and 20 days later respectively.

In similar studies with H. armigera, a significant correlation of male moth catches in pheromone traps with early, late larval population and plant damage was obtained in groundnut fields and these were coincided with moths appeared at peak in the traps 8, 18 and 18 days prior captures of male moths.

Based on the regression equations worked out from the present investigations and thresholds available 38, 34 and 88 H. armigera moths/trap/night have been suggested as thresholds for early larvae, late larvae and plant damage respectively in groundnut.

Studies on the relative trap efficiency indicated although both ICRISAT and sleeve traps trapped the male moths in higher numbers, ICRISAT funnel trap was more efficient by 1.2 times over sleeve traps in capturing male moths of both S. litura and

H. armigera particularly on the days with low moth catches.

The commercial blend of pheromone components [(Z)-11-hexadecenal and (Z)-9-hexadecenal)] containing 97:3 trapped significantly more number of H. armigera moths/trap/week than the other evaluated blends 94:6, 91:9 and 88:12.

The presence of sex pheromone in the females of A. modicella was demonstrated in the laboratory through wind tunnel and in field sticky traps with female baits. In the wind tunnel the orientation flight males in search of female pheromone source was characterized by rapid vibration of wings, erratic and fast motive movements with intermittent upcurving of the abdomen followed by hovering around the encaged females and alighting on the cage. The number of males attracted to pheromone source 7 per tunnel (70%). Under field conditions the female baited sticky traps captured as high as 61 male moths/trap/ night.

The excised female abdominal tips (7-10 segments) of A. modicella at calling time (4.00 am) kept as a pheromone source in the wind tunnel evoked positive response of 67 per cent in the males indicating the presence of sex pheromone gland in the terminal abdominal segments. The sticky traps baited with female abdominal tips and positioned in the groundnut fields trapped as high as 88 male moths/trap/ night.

The female abdominal tips extract of 2 and 3 female equivalents of _A. modicella_ adsorbed on cigarette filters evoked a positive mating response of males in the wind tunnel and also entrapped 65 and 85 males/trap respectively and gave an indication that the pheromone can be extracted. The lures with 2 and 3 female equivalents of the extract were found to attract the males both in the wind tunnel and in the field.

In behavioural studies following observations were important. Males of _A. modicella_ emerged 2 days earlier than the females. The maximum emergence of males and females was between 4.00 am to 6.00 am followed by 2.00 am to 4.00 am.

Females of _H. armigera_ emerged earlier than males with the mean pupal period being 10 days in the case of females and 11.4 days in males. Emergence of moths was mostly confined to night time with a maximum emergence during 12.00 midnight to 4.00 am.

Males and females of _A. modicella_ exhibited mating responses from the very first day of emergence (0 day old) upto 6 days (5 day old). Peak responsiveness of males and peak calling of females to the tune of 100 per cent was observed in 1-day old moths. The peak response (22.4%) of males was also observed between 4.30 am to 4.59 am. Mating response of males lasted 30-39 minutes in maximum number of males (35.9%) with isolated responses of longer (90-99 minutes) or shorter (20-29) minutes) duration.

Studies with sticky traps baited with females of A. modicella also confirmed that 1 day old females which entrapped 102.7 moths/trap/night were more attractive than the females of other ages.

Investigations on the rhythm of male attraction and female attractiveness indicated that in the case A. modicella, the female calling time was mostly confined to 4.00 am to 8.00 am which entrapped the highest number of males/trap/night. No male moths were trapped from 6.00 pm to 2.00 am and few moths were trapped between 2.00 am to 4.00 am.

In S. litura, moth catches were observed throughout scotophase, but the highest moth catch 31.7 per cent was recorded at 2.00 am to 4.00 am followed by 10.00 pm to 12.00 midnight with 22.2% moth captures.

In H. armigera the moth catches in the pheromone traps were observed throughout scotophase but significantly the highest per cent (43.7) of male moth catches was observed between 2.00 am to 4.00 am followed by 12.00 midnight to 2.00 am (25.7%).

In pheromone perception studies conducted in the wind tunnel it has been confirmed that the antennae is the main principal organ of olfactory response. The leafminer males deprived of their antennae did not show any response to female pheromone source.

Field and laboratory studies with female baits on the male leafminer did not evoke any response to female pheromone source in the continuous light.

In *A. modicella*, the sex pheromone gland has been located dorsally in the intersegmental area between 8th and 9th abdominal segments in the form of a eversible fold.

In *H. armigera*, the sex pheromone gland has been observed in the form of a complete ring of glandular epithelium situated around the body in the intersegmental membrane between 8th and 9th abdominal segments.

The detailed morphology of female reproductive systems of *A. modicella* and *H. armigera* have also been described.

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