

THE STATUS OF THE AMERICAN BOLLWORM,
HELIOTHIS ARMIGERA (HÜBNER) (LEPIDOPTERA: NOCTUIDAE),
ON SUNFLOWER IN THE CENTRAL TRANSVAAL

THESIS

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ABSTRACT

Sunflower production in South Africa has increased four fold since the 1970's. This study was done to elucidate the pest status of Heliothis armigera (Hübner) on sunflower. Field studies were undertaken at Warmbaths, Brits and Delmas during the summer seasons of 1988/89 to 1990/91. The infestations at the latter two areas were negligible throughout the study period and their statistics have not been included in this thesis.

Plant development and oviposition by natural H. armigera populations were found to be correlated as, regardless of planting date, oviposition started at six to seven weeks after planting; when the flowering stage began. A peak in egg numbers was reached by the tenth week with an average for the three seasons at two eggs per plant. The eggs were laid singly on the bracts and bases of the flower buds.

A peak in larval numbers was reached at the thirteenth week after planting with the average for the three seasons of 0,4 larvae per plant. The preferred feeding sites were on, between and under the bracts from where the larvae burrow into the pithy tissue of the receptacle. Only six percent of the larvae were found feeding directly on the achenes.

Eggs and larvae collected were reared to determine the degree of parasitism. Overall, 19% of the eggs were parasitised; 18% by Telenomus ullyetti Nixon (Scelionidae) and one percent by Trichogrammatoidea lutea (Trichogrammatidae).

Larval parasitism at Warmbaths was 23% in 1988/89, 27% in 1989/90 and 34% in 1990/91. Of the parasitised larvae, 44% succumbed to Palexorista prob. laxa (Tachinidae). The remainder were unidentified Braconidae and

Ichneumonidae. Predators, such as chrysopids, were observed during the study but their effect on egg and larvae numbers was not studied in detail. A polyhedral virus occurred late in the seasons and caused mortality of the larvae.

The low numbers of H. armigera on sunflower, the slight damage to the crop and the reasonably high rate of parasitism, all seem to indicate that H. armigera is not an economically important pest of sunflower and that additional control methods are not justified.

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1. INTRODUCTION

The production of sunflower in South Africa has increased since 1970 and in many regions has become an alternative main crop. Due to the wide range of planting dates, it also is often planted when late rains prevented the planting of other field crops such as maize. Sunflower is also increasingly being produced in some traditional cotton producing areas where the American bollworm, Heliothis armigera (Hübner), is a notorious pest on cotton.

Most research on sunflower concentrates on the breeding and physiology of the plant to increase yield and quality. Little research on H. armigera as a pest of sunflower has been done in South Africa. H. armigera is not regarded as a pest of sunflower by sunflower-researchers and most producers of the crop, although sporadic outbreaks have occurred. On the other hand, preventative chemical control against H. armigera is annually applied by some farmers. Although some laboratory experiments have shown H. armigera to prefer sunflower over cotton, the insect is generally regarded as a more serious pest on cotton than on sunflower.

The objective of this study was to determine the pest status of H. armigera on sunflower. Natural infestations of early and late sunflower fields were studied for three seasons at three different sites. The characteristics of the crop and the biology of the pest are described in the following two sections of the Introduction. The study included seasonal abundance of the pest on sunflower, the nature and positioning of the feeding larvae and natural control factors such as egg and larval parasitoids.

CHARACTERISTICS OF SUNFLOWER

HISTORY OF SUNFLOWER

The sunflower genus, Helianthus, of the family Compositae (Asteraceae), contains 67 species of which several have been brought into cultivation (Heiser 1978). Natural inter-species hybridization can occur, which creates problems with the exact taxonomy (Heiser 1978, Vermeulen 1990a). Sunflower is indigenous to the Americas and was first introduced to Europe in the 15th century as an ornamental (Putt 1978).

The open-pollinated high-oil varieties were developed in Russia, which is regarded as the first major step toward the world-wide commercial production of sunflower as an oil crop (Fick 1978). The second major step in sunflower breeding was in 1969 - 1972, with the development of cytoplasmic male sterility by introducing the Helianthus annuus genome into the cytoplasm of H. petiolaris (Heiser 1978). The system was perfected by the discovery of a single dominant gene which restores fertility (Putt 1978). In the 1970's hybrid seed production became an economic proposition with low cost seed production and an increased yield (Greyling 1990, Vermeulen 1990b)

In South Africa a full-scale sunflower breeding programme was started in 1970 by the Department of Agriculture with Rumanian sunflower hybrids based on genic male sterility (Vermeulen 1990b). Although production of the hybrid seed is more expensive than that of the open-pollinated cultivars, hybrids produce higher yields of better quality and mature uniformly (Du Toit 1979, Birch 1982a, Greyling 1990).

Sunflower is grown commercially for edible oils and protein (Doty 1978). After oil extraction, the remaining meal contains about 300 g.kg⁻¹ of protein suitable for use in livestock ration (Unger 1990). Non-oilseed sunflower and cultivars with large achenes are used for confectionery and those with small achenes as birdseed (Lofgren 1978, Unger 1990).

SUNFLOWER GROWTH AND DEVELOPMENT

Sunflower growth can be classified into four major growth stages which are readily identifiable (Unger 1990). These are emergence, budding, anthesis and maturity. The duration of each growth stage varies within cultivar, year and planting (Unger 1986, 1990). The budding and anthesis stages are preferred by Heliothis armigera (Chapter 3).

Sunflower has a relatively short growing season, and a wide range of planting dates can thus be used for the crop (Robinson 1978, Birch 1982b, Unger 1990). This again has implications for H. armigera as the later plantings are more heavily infested (Chapter 4).

The sunflower inflorescence is a capitulum (radiate seedhead) (Fig. 5, p 31), with a single row of pistillate, sterile ray-florets with large and usually yellow ligules (Heiser 1978, Knowles 1978). Between 1000 and 4000 individual, five lobed, fertile disc-florets in the face of the head are joined to the receptacle (Heiser 1978, Broadley 1980). During anthesis, ray-florets are the first flowers to mature and anthesis is complete when these ray-florets have lost their turgidity (Schneiter & Miller 1981). Disc-florets open in whorls and the head blooms for about seven days, but flowering of a sunflower field can last for 17 days (Du Toit 1988). Involucral bracts, a favourite oviposition and feeding site

for H. armigera (Chapters 3 & 4), enclose the developing seedhead (Broadley 1978, Knowles 1978).

PESTS OF SUNFLOWER.

The growth of sunflower is affected by weeds, some diseases, insects and birds, the latter being the the main problem (Unger 1990). Scarification of the back of the head by birds, hail and insects can predispose the crop to secondary fungal head rots (Broadley 1978, Forrester 1980, Swart 1987). In South Africa, fungal head rots seldom cause economic losses (Swart 1987).

Zimmer & Hoes (1978) estimated that infectious diseases cause an annual average loss of 12 % in yield in the world. The importance of diseases varies annually with biological and climatic factors and management practises. Diseases such as the Alternaria-septoria (Alternaria helianthi, A. zinniae and Septoria helianthi), white blister (Albugo tragopogonis) and rust (Puccinia helianthi) occur in South Africa, but the incidences are very low (Loubser et al. 1989, 1990) and are not a very high priority of sunflower at present (Vermeulen 1990a, 1990b).

A number of insect pests of varying economic importance is listed for North American sunflower by Schulz (1978), of which 12 species are of current concern (Fick 1978). Although Heliothis spp. occur on sunflower in North America, they are not considered important (Schulz 1978). The major pest is the sunflower moth (Homoeosoma electellum). Other pests are the banded sunflower moth (Phalonia hospes), Contarinia seed midges, the sunflower beetle (Zygogramma exclamationis) and several seed and root-infesting weevils.

Insect pests on sunflower in Australia are termed by Broadley (1978) as "...mostly generalized feeders.." and sporadic. However two species of Heliothis, H. punctigera and H. armigera are listed as pests. Other pests are bugs of the Nysius and Nezara species (Broadley & Ironside 1980, Forrester 1980).

Anneck & Moran (1982) stated that "...sunflower is not plagued overmuch by insect pests in South Africa..", but control is sometimes needed against H. armigera. Vermeulen et al. (1990) listed H. armigera, Heteronychus arator, Astylus beetles and nematodes as pests of sunflower on which pesticides have been registered with the Department of Agriculture, in terms of Act 36 of 1947.

Resistance to the sunflower moth, Homoeosoma nebulla, a major insect pest of sunflower in the U.S.S.R. and Europe, was found on sunflower varieties that contain a phytomelanin layer in the hull of the seed (Fick 1978). Similar resistance was found in the U.S.A. against larval feeding of H. electillum (Carlson et al. 1972, Johnson & Beard 1977). In addition to the "armor" layer, chemical factors were also involved in resistance (Carlson & Witt 1974). The role that phytomelanin plays in the resistance of South African sunflower varieties to H. armigera has not been fully investigated.

PRODUCTION OF SUNFLOWER.

According to the Food and Agricultural Organisation of the United Nations (United Nations. FAO 1991), more than 20 million tons of sunflower seed are produced annually in the world. The major sunflower producing areas are the U.S.S.R, Argentina, France, Eastern Europe, People's

Republic of China, Spain, Turkey and the U.S.A. (United Nations. FAO 1991). In South Africa the production of sunflower has increased four fold since 1970. South Africa produces about two-thirds of Africa's total harvest (United Nations. FAO 1991). The estimated yield for the 1990/91 season was 585 000 tons of sunflower seed (South Africa, Department of Agriculture 1991). The production by area is shown in Table 1.

TABLE 1. The area planted in hectares and the harvested seed in tons of sunflower in South Africa for the 1988/89 to 1990/91 seasons (Suid-Afrika, Departement van Landbou 1990, South Africa, Department of Agriculture 1991).

SEASON	PLANTINGS (ha)	PRODUCTION (t)
1988/89	462 000	419 710
1989/90	409 000	430 009
1990/91	575 000	585 000 *

* estimate

BIOLOGY OF HELIOTHIS ARMIGERA.

The genus Heliothis are pests of agriculture of world wide importance. Of the 75 species and subspecies (King & Coleman 1989), Heliothis armigera, H. zea, H. virescens and to some extent H. punctigera, have achieved major pest status (Fitt 1989). H. zea and H. virescens occur in the Americas and H. punctigera is endemic to Australia (King & Coleman 1989). H. armigera has one of the widest distributions of any agricultural pest (Fitt 1989). The geographical range extends from the Cape Verde in the Atlantic, through Africa, Asia to Australasia, and from Germany in the north to New Zealand in the south (Reed & Pawar 1982). Ranging between latitudes 45°N and 45°S, H. armigera and H. zea are cosmopolitan species of the Old World and New World respectively (King & Coleman 1989). They were considered the same species until Common (1953) showed in Australia that a second species, H. punctigera Wallengren, existed there. In due course, in Australia and in the United States, it was noticed that H. armigera (Hübner) differed from the North American specimens and the oldest name for the New World species was confirmed as H. zea (Boddie) (Pearson & Maxwell Darling 1958).

The main factors elevating Heliothis species to major pest status are their polyphagy, high mobility, a facultative diapause and high fecundity (Fitt 1989).

LIFE HISTORY

The American bollworm, Heliothis armigera (Hübner) is a typical

noctuid moth with nocturnal habits of flight, mating and oviposition. The moths are variable in size and the colour of the forewing and thorax is brown or grey-brown with darker markings (Annecke & Moran 1982). The hindwings are creamy white with dark veins and a grey-brown marginal band (Pinhey 1975). The males are slightly smaller than the female, and are greenish.

Oviposition and the flight activity of the females is highest early in the night while male activity is highest in the early morning (Roome 1975). The almost spherical eggs are creamy white becoming brown before they hatch (Pearson & Maxwell Darling 1958), which occurs after three to four days under favourable conditions (Broadley 1978).

The first instar larvae are grey-white with a dark head capsule (Broadley & Ironside 1980). The mature larvae vary in colour from yellow, green, pink to brown-black with a white mid-dorsal line edged with black. The lateral markings of a creamy-white stigmatal line is characteristic (Pinhey 1975). The skin has a granular appearance, the surface consisting of close-set, minute tubercles (Pearson & Maxwell Darling 1958). The larvae have three pairs of thoracic legs and fleshy leglike protuberances on each of the third to sixth abdominal segments as well as on the ultimate one (Annecke & Moran 1982). The mature larvae grow to a length of 40 mm (Pearson & Maxwell Darling 1958). The larval stage lasts two to three weeks in midsummer and the pupal stage two weeks and longer (Annecke & Moran 1982).

The pupa is dark brown, smooth-surfaced, rounded both anteriorly and posteriorly, with two tapering parallel spines at the posterior end (Pearson & Maxwell Darling 1958). The pupa is 18 mm long and occurs in a cocoon, three to 17 cm below the soil surface (Broodryk *et al.* 1974). The pupal period depends on the sex of the pupa and on the season and the

female pupal period is less than that of the male in the same population (Reed 1965a). A small, but progressively increasing proportion of the pupae enter diapause during autumn and winter resulting in an extended pupal period (Pearson & Maxwell Darling 1958, Reed 1965a). The pupal period varied from 30 to 170 days (Reed 1965a, Roome 1979).

The longevity of the adult is affected by the availability of food in the form of nectar. Pearson & Maxwell Darling (1958) reported the average life-span for the males at 8,7 days (1 – 23 days) and 13,5 days (5 – 28 days) for the female.

H. armigera eggs are normally laid on surfaces exposed to direct sunshine and are hence subjected to extremes of high temperatures (Qayyum & Zalucki 1987). The eggs can develop from 14 to 38°C, the larvae from 14 to 36°C and the pupae from 11 to 34°C (Nagarkatti 1982). Qayyum and Zalucki (1987) found that the maximum development rate of all stages of Heliothis spp. occurred around 35°C. Development of eggs were retarded by long exposures to higher temperatures (> 38°C), but with high humidity, development was prolonged at high temperatures.

H. armigera has a wide taste in foodplants, making it probably the most polyphagous and potentially injurious pest of agriculture in South Africa, but in most areas the seasonal occurrence of the pest is variable (Annecke & Moran 1982).

The larvae show a distinct preference for feeding on the reproductive structures of their hosts, which increases the injuriousness of the pest and causes them to directly influence crop yield (Van den Berg et al. 1988, Fitt 1989). Feeding can also facilitate infection by pathogens (King & Coleman 1989).

An other factor which contributes to the pest status of H. armigera is the pest's proven ability to rapidly develop resistance to a range of

insecticides (Van den Berg et al. 1988, Fitt 1989, King & Coleman 1989).

HOST PLANTS

H. armigera is a major pest of most field and horticultural crops in Australia, Africa, the Indian subcontinent and south-east Asia (Firempong & Zalucki 1990a). The range of host preference differs according to environmental conditions and prevalence of host crops (Abul Nasr et al. 1976). Immature stages have been recorded as damaging to 60 cultivated crops and as many other plant species in 39 plant families in Africa, Asia and Australasia (Reed & Pawar 1982, Firempong and Zalucki 1990a).

H. armigera is the major pest of cotton in some countries such as Australia (Wardhaugh et al. 1980), Southern Africa (Parsons 1940b, Broodryk et al. 1974, Annecke & Moran 1982), India (Bilapate 1981) and Thailand (Mabbett & Nachapong 1983), but not in others e.g. Syria (Stam & Elmosa 1990). Other crops recorded as host plants are sunflower, maize, tobacco, wheat, sorghum, soya, tomato, groundnuts, pigeonpea, gram, lucerne, citrus and vegetables (Parsons 1940a, 1940b, Pearson & Maxwell Darling 1958, Roome 1975, Abul Nasr et al. 1976, Broadley 1978, Forrester 1980, Wardhaugh et al. 1980, Bilapate 1981, Annecke & Moran 1982, Kay 1982, Hassan 1984, Tripathi & Sharma 1985, Koshiya & Patel 1987, Firempong & Zalucki 1990a, 1990b).

Many factors influence oviposition in *H. armigera*, of which the presence of flowers is the most important. The attractiveness of a plant, be it host or a non-host, is highest when it is in flower and oviposition is often confined to the flowering period (Parson 1940b, Roome 1975, Wardhaugh et al. 1980, Firempong & Zalucki 1990a, 1990b). Firempong and

Zalucki (1990a) found variations in host plant utilization within populations of plant species, depending whether they flowered or not. These authors postulated that the polyphagous nature of the pest probably arose because each of the host plants became attractive at a different time of the year.

Moths also preferred ovipositing on plants with a higher relative profile (Firempong & Zalucki 1990b). They therefore select the taller plants which often are the healthier ones (Mabbett & Nachapong 1983).

Other possible ovipositing influences are nectar (Wardhaugh *et al.* 1980, Firempong & Zalucki 1990a) and kairomones (Firempong & Zalucki 1990a, Rembold *et al.* 1991).

Firempong and Zalucki (1990a) investigated *H. armigera*'s nature of polyphagy by offering moths of different sources the same set of nine host plants in oviposition trials. Sunflower and tobacco were the favoured host plants. Cotton was ranked very low in preference, confirming the conclusion of Pearson & Maxwell Darling (1958), yet it is on this crop that *H. armigera* causes the most damage.

On cotton, most *H. armigera* eggs are laid on the top third of the plant. The leaves of young plants, and in older plants, the fruiting forms (buds, flowers and bolls), were favoured for egg laying (Van der Walt 1988). Cotton produce fruiting forms during a large part of the growing season and the period from the first bud to the first bolls is 14 weeks (Rhodesia Cotton Growers' Association 1966). Larvae preferred flowers over buds and bolls, but will feed on what is available on the plant (Van der Walt 1988).

HELIOTHIS ARMIGERA ON SUNFLOWER

Heliothis armigera lay eggs singly on the upper surfaces of the apical leaves and among the bracts enclosing the developing seedhead (Broadley 1978). As expected from the sites of oviposition, young larvae are found at the plant apex. Many larvae feed in exposed sites but some burrow into the pithy tissue under the bracts (Broadley & Ironside 1980). The favoured feeding sites are the flowerheads and the florets or the tops of the developing achenes in the face of the head (Forrester 1980). Larvae also feed on the leaves and the stems (Broadley 1978). Heavy infestations in the bud stage can cause deformation of the seedhead and severely damage the crop (Broadley 1978, Broadley & Ironside 1980, Forrester 1980).

Sunflower plants are however able to support a number of larvae without significant effect on crop yields (Broadley & Ironside 1980) and damage to the developing achenes is usually slight (Forrester 1980). Forrester (1980) considers that only infestations of more than an average of two larvae per head, are worth controlling with insecticides in Australia. According to Fitt (1989), control of H. armigera on sunflower in Kenya is often required.

The short flowering time (less than three weeks) of sunflower, ensures that the crop cannot support in situ breeding by the progeny of successive generations of H. armigera (Wardhaugh et al. 1980, Broadley 1984). The final instar larvae move down the plant and pupate in the soil (Broadley & Ironside 1980). Though H. armigera may contribute to pollination of sunflower, the roles of the moths and the larvae as pollinators are considered to be insignificant (Du Toit 1988).

LARVAL DURATION AND INSTARS

According to reports in the literature, the duration of Heliothis armigera larval development when feeding on sunflower varied from 14 to 33,6 days (Table 2). The larvae obtained from our laboratory culture had a duration of 13,3 days and five larval instars (Van der Walt 1988). Five larval instars were also recorded for the larvae collected on cotton at Brits by Van der Walt (1988). As the same locality was used for the sunflower plots, no specific experiments were conducted to determine the number of larval instars.

H. armigera with five and six larval instars were recorded by Abul Nasr et al. (1976) on sunflower, cotton and corn (sic) in Egypt. The same

TABLE 2. Duration of the larval stages of Heliothis armigera feeding on sunflower, under different temperature and relative humidity regimes.

AUTHOR	COUNTRY	TEMPERATURE RANGE (°C)	RH (%)	DURATION (DAYS)
Coaker 1960	Uganda	—	—	33,6
Pretorius 1976	South Africa	23 – 27	60	18,7
Abul Nasr et al. 1976 *	Egypt	16 – 22	50 – 65	14,0 ±0,32
Abul Nasr et al. 1976 **	Egypt	16 – 22	50 – 65	15,7 ±0,31
Dhandapani & Balasubramanian 1980	India	24 – 28	—	19,5
Patel & Talati 1987	India	—	—	17,46

* larvae with five instars

** larvae with six instars

author recorded five larval instars on a artificial diet but six instars on tomatoes. Five larval instars were recorded on tomatoes in France (Poitout & Bues 1979), on cotton in Thailand (Mabbett et al. 1980), on gram and chickpea in India (Chaudhary & Sharma 1981) and by Toguebaye & Couilloud (1982) on an artificial diet. Several other authors also recorded six or even more larval instars. Possible explanations for the difference in number of larval instars is given by Nadgauda & Pitre (1983), who stated that additional molts were required due to low rates of food intake and in adverse conditions, additional molts aid in extending the growth and development of the larvae.

2. MATERIALS AND METHODS

The objective of this project was to determine the pest status of Heliothis armigera on sunflower. To fulfil this aim, the seasonal abundance and flight activity of H. armigera as well as the feeding preferences of the larvae on sunflower were studied over three years at three different experimental sites. Attention was also given to egg and larval parasitism. The study relied on natural pest infestations in sunflower fields under standard agricultural cultivation practices in sunflower producing areas near Pretoria. Identification of insects were done by the National Collection of Insects in Pretoria.

REARING OF HELIOTHIS ARMIGERA

Laboratory-reared H. armigera larvae were obtained from cultures maintained on a modified Shorey and Hale meridic larval diet (Van der Walt 1988). Agar was omitted from the diet as it became apparent that it was superfluous (Table 3).

The culture was kept in a room with the temperature and humidity controlled at 25 - 26 °C and 50 - 60 % RH under natural photoperiods. The females were allowed to oviposit on cloth netting which were then disinfected for 10 minutes in 2% formaldehyde, rinsed in running tap water and drip dried. The dry netting were placed in glass jars for the eggs to hatch.

First-instar larvae were transferred singly onto about 10 g of the diet that was forced into 100 x 25 mm glass vials with a domestic syringe.

The vials were stoppered with cotton wool. Under the conditions described, the larval development lasted 13,3 days (Van der Walt 1988).

The pupae were removed from the vials and disinfected with 0,2% sodium hypochlorite. The pupae were placed in 5-litre Perspex jars containing a layer of vermiculite. These jars also served as oviposition containers. A Petri dish with cotton wool soaked in a 3% sucrose solution, was placed in each container as food for the emerging adults. 30 pupae were placed in each oviposition container. Upon emergence, the adults were sorted to ensure even female : male ratios in the containers. The cloth

TABLE 3. A modified Shorey and Hale diet (Van der Walt 1988) for rearing Heliothis armigera larvae in the laboratory.

INGREDIENTS	QUANTITY
White kidney beans (powdered) *	360 g
Brewer's Yeast **	48 g
Methyl - 4 - hydroxybenzoate	3 g
Ascorbic Acid	4,8 g
Sorbic Acid	2,1 g
Formaldehyde	1,1 ml
Distilled water	1 000 ml

The water was boiled with the ingredients stirred in and left to cool for 30 minutes. After cooling, the medium was used as explained in the text.

* Phaseolus vulgaris L.

** Manufactured by Gold Star Yeast (Pty) Ltd, 86 Maraisburg Avenue, Industria, Johannesburg 2000.

netting lids of these containers served as the oviposition site and were collected daily.

FIELD TRIALS.

Field trials were conducted at three sites in the vicinity of the Plant Protection Research Institute (P.P.R.I.) in Pretoria. These sites were the Hartebeespoort Experimental Farm of the Tobacco and Cotton Research Institute, Department of Agricultural Development, near Brits; The Towoomba Research Station, Transvaal Region, Department of Agricultural Development, near Warmbaths; and the Sensako Research Farm at Delmas.

Soil was classified as Acardia at Brits and Warmbaths and as Hutton at Delmas (Loubser et al. 1989). The rainfall totals from October to April were measured at Delmas as 481 mm in 1988/89, and from October to May for the following two seasons as 493 mm in 1989/90 and 557 mm in 1990/91. The corresponding figures for Warmbaths were 630 mm, 668 mm and 562 mm, respectively (Loubser et al. 1989, 1990, 1991).

Ten plots in total with different planting dates were used during the seasons of 1988/89 to 1990/91. Different cultivars were used and the plots were of different sizes (Table 4). Three of these plots at Warmbaths were plots of the National Sunflower Cultivar Trials of the Oil and Protein Seeds Centre, Department of Agricultural Development, Potchefstroom. The objective of these cultivar trials is to supply sunflower producers and breeders with information on the performance of commercially available and new cultivars (Loubser et al. 1989). These plots consisted of 28 different cultivars in 1988/89 (Loubser et al. 1989) and 35 in 1989/90 (Loubser et

al. 1990).

The other sunflower plots at Warmbaths and those at Delmas were commercial plantings. The sunflower plots at Brits were for the sole purpose of this project. Seeds used in two plantings at Brits and one at Warmbaths were of no particular cultivar. The two plots at Delmas formed part of larger sunflower plots of different cultivars, but only the sections consisting of cultivar SNK 22 were used.

Fifty plants were randomly selected every week at each location. The diameters of the developing seedheads were measured from the bud stage to maturity. Eggs and larvae of *H. armigera* were counted, collected and their

TABLE 4. Date of planting, cultivar and size of sunflowers plots used at Delmas, Brits and Warmbaths during the 1988/89 to 1990/91 seasons.

SITE	DATE OF PLANTING	CULTIVAR	APPROXIMATE SIZE OF PLOTS IN m ²
Delmas	20/10/1988	SNK 22	1 000
Delmas	6/10/1989	SNK 22	600
Brits	12/10/1988	-	250
Brits	7/12/1988	-	250
Brits	2/11/1989	SNK 32	8 000
Warmbaths	22/11/1988	NSCT *	7 380
Warmbaths	4/01/1989	Saffola 210	10 000
Warmbaths	22/12/1989	NSCT *	7 380
Warmbaths	2/03/1990	NSCT *	7 380
Warmbaths	14/01/1991	-	20 000

* National Sunflower Cultivar Trials, Oil and Protein Seeds Centre, Potchefstroom

exact positions on the plant recorded. All larvae were counted as feeding on the plant. Dead larvae were counted as having fed upon the plant part they were found on.

The collected eggs and larvae were reared in a culture room separate from the rearing laboratory, but at the same controlled environment settings. The larvae were placed singly on the larval diet. All larvae were kept until they died or moths or parasitoids emerged. Collected eggs were kept singly in gelatine capsules within glass vials. The larvae were destroyed after hatching.

PHEROMONE TRAPS

Synthetic pheromone capsules to attract sexually mature *H. armigera* males were provided by Hoechst South Africa (Pty) Ltd. These pheromone capsules were used in Biotraps* to monitor adult flight activities at Warmbaths during the 1989/90 and 1990/91 seasons. Three Perspex Biotraps were installed per plot in a triangular shape at the height just above the crop canopy. A distance of about 100 meters separated each trap. The pheromone capsules were replaced at intervals of three weeks in the first season of use. As catches were only made in the first week after replacement, the pheromone was replaced weekly in the 1990/91 season. The traps were inspected weekly and the catches collected. Traps were installed one week before the crop was planted and removed at the end of the season when no more moths were caught.

*Biotrap: Manufactured by FBC Holdings, P.O. Box 12215, Chloorkop 1624.

3. THE POSITIONING OF HELIOTHIS ARMIGERA ON SUNFLOWER

EGGS

Sampling for H. armigera eggs was done as described in Chapter 2. The selected plants were inspected from the pre-bud stage of sunflower development. Ninety-one percent of all H. armigera eggs encountered at the three research sites, were counted on sunflower at Warmbaths. The numbers of eggs at Brits (84) and at Delmas (27), were too low to make any valid conclusion and only data of Warmbaths is included in the statistical calculations.

The number of H. armigera eggs and the percentage of plants with eggs on during the weekly surveys done at Warmbaths during the three seasons, are given in Table 5. The planting date of each plot is given in Table 4, Chapter 2.

The surveys showed four main sites for egg laying on a sunflower plant. These were the involucral bracts, where 49% of all eggs were found, the bases of the buds (33% of eggs), the stems (11% of eggs) and the uppersides of the apical leaves (7% of eggs). The number and location of the eggs on the plants are given in Table 6 for all three locations and seasons. In both the 1988/89 and 1989/90 seasons we made an early and a late planting. The early plantings are indicated as "a" and the late plantings as "b" in the table.

In every season at Warmbaths, the later plantings, planted in January or later, had the greater number of eggs and also more plants with eggs. In the very late planting (March 1990), eggs were laid over a longer period, but no definite peak in oviposition occurred. Even with a

TABLE 5. The number of *Heliiothis armigera* eggs and the percentage of sunflower plants with eggs, at Warmbaths in the 1988/89 to 1990/91 seasons. Time is given as the approximate sampling date and in weeks after planting.

APPROXIMATE SAMPLING DATE	SEASON								
	1988/89			1989/90			1990/91		
	WEEK	EGGS	PLANTS (%)	WEEK	EGGS	PLANTS (%)	WEEK	EGGS	PLANTS (%)
Jan 12	6	0	0						
Jan 19	7	7	12						
Jan 24	8	11	22						
Jan 31	9	14	16						
Feb 8	10	3	6	7	0	0			
Feb 15				8	1	2			
Feb 22				9	13	16			
Mar 1				10	24	30			
Mar 8	9	87	60	11	8	8	7	2	4
Mar 15	10	159	82	12	0	0	8	100	54
Mar 22	11	192	88				9	97	64
Mar 28	12	22	30				10	96	58
Apr 4	13	0	0				11	29	24
Apr 11							12	27	16
Apr 19				7	9	6	13	0	0
Apr 26				8	25	22			
May 4				9	34	30			
May 9				10	42	34			
May 16				11	41	36			
May 22				12	50	52			
May 30				13	30	26			
Jun 6				14	3	6			
Jun 13				15	1	2			
Jun 19				16	0	0			

TABLE 6. The number and percentage of *Heliothis armigera* eggs on the different oviposition sites on sunflower for the 1988/89 to 1990/91 seasons at Brits, Delmas and Warmbaths.

LOCATION AND SEASON	OVIPOSITION SITES						TOTAL
	INVOLUCRAL BRACTS	HEAD BASE	STEM	LEAVES	LIGULES	FLORETS	
BRITS							
1988/89a	9	4	—	3	—	—	16
1988/89b	2	1	—	—	—	—	3
1989/90	30	30	1	4	—	—	65
TOTAL	41	35	1	7	—	—	84
%	48,81	41,67	1,19	8,33	—	—	
DELMAS							
1988/89	4	6	3	—	—	—	13
1989/90	8	2	2	2	—	—	14
TOTAL	12	8	5	2	—	—	27
%	44,44	29,63	18,52	7,41	—	—	
WARMBATHS							
1988/89a	16	17	2	—	—	—	35
1988/89b	269	111	65	11	4	—	460
1989/90a	17	19	9	1	—	—	46
1989/90b	113	50	40	32	—	—	235
1990/91	160	120	37	32	—	2	351
TOTAL	575	317	153	76	4	2	1127
%	51,02	28,13	13,58	6,74	0,36	0,18	
TOTAL	628	360	159	85	4	2	1238
% (SE ±)	49,18 (3,38)	33,42 (3,78)	10,59 (2,65)	6,65 (2,19)	0,12 (0,12)	0,06 (0,06)	

a early planting
b late planting

difference in planting dates, egg laying in all plots started at six to seven weeks after planting, reaching a peak at about the tenth week (Fig. 1). The average diameter of the flowerheads with eggs at these peaks, was 100 mm.

The highest average number of eggs per plant was 3,84 at the eleventh week after the planting date in the 1988/89 season (Fig. 1). The 1990/91 season peaked at two eggs per plant at the eighth week. The 1989/90 season reached a high of one egg per plant at week 12. The highest number of eggs encountered on a single plant during all the surveys was 19.

LARVAE

Table 7 gives the numbers of *H. armigera* larvae encountered during each weekly survey over the three seasons at Warmbaths. The exact position (feeding site) of the larvae is given in Table 9 (Chapter 4).

As with the eggs, the sunflower plots planted later were more heavily infested with larvae and also over a longer period than the early season plantings. As expected from the time of egg-laying, larvae were found from the seventh week after planting, in both early and late plantings. All larvae encountered were considered as feeding or having fed upon the plant part where they were found.

A peak in larval numbers occurred at weeks 13 to 14 for the late plantings at Warmbaths (Fig. 2). These peaks were at 2,7 larvae per plant in 1988/89 and 2,1 larvae per plant in 1990/91. In the 1989/90 season, as with the number of eggs, no definite peak was reached. In all plots, no larvae were found after the 19th week. At this stage the sunflower had reached maturity and were ready for harvesting.

TABLE 7. The number of *Heliothis armigera* larvae and the percentage of sunflower plants with larvae, at Warmbaths in the 1988/89 to 1990/91 seasons. Time is given as the approximate sampling date and in weeks after planting.

APPROXIMATE SAMPLING DATE	SEASON								
	1988/89			1989/90			1990/91		
	WEEK	LARVAE	PLANTS (%)	WEEK	LARVAE	PLANTS (%)	WEEK	LARVAE	PLANTS (%)
Jan 12	6	0	0						
Jan 19	7	8	16						
Jan 24	8	3	6						
Jan 31	9	4	8						
Feb 8	10	1	2	7	1	2			
Feb 15				8	0	0			
Feb 22				9	4	8			
Mar 1				10	2	4	6	0	0
Mar 8	9	7	14	11	4	6	7	3	6
Mar 15	10	5	10	12	2	4	8	14	26
Mar 22	11	13	22	13	4	8	9	21	32
Mar 28	12	49	42	14	11	18	10	23	38
Apr 4	13	135	80	15	9	16	11	33	50
Apr 11	14	66	60	16	6	12	12	85	86
Apr 19	15	53	62	17	0	0	13	102	70
Apr 19				7	2	4			
Apr 26	16	19	28	8	3	6	14	105	68
May 2	17	9	16	9	1	2	15	58	30
May 9	18	2	4	10	5	10	16	38	38
May 16	19	0	0	11	1	2	17	12	18
May 22				12	3	6	18	4	8
May 30				13	2	4	19	2	4
Jun 6				14	7	12	20	0	0
Jun 13				15	9	14			
Jun 19				16	10	14			
Jun 27				17	9	16			
Jul 5				18	9	16			
Jul 11				19	4	8			

ADULTS

H. armigera flight activities at Warmbaths were monitored by using pheromones in Biotraps. The moths were collected weekly and compared with the number of eggs counted on the sunflower of the late planting. The pheromone was unfortunately only received late in the 1989/90 season, after the initial moth flights had already taken place.

In the 1989/90 season, pheromone capsules were replaced every third week. As most catches were made in the week of pheromone replacement, the effectiveness of the pheromone was taken as lasting not more than one week. Pheromone replacement was thus done weekly in the next season.

The number of moths caught per trap is compared with the average number of eggs per plant at Warmbaths for the 1989/90 season in Fig. 3 and that for the 1990/91 season in Fig. 4. The small number of moths trapped corresponded with the low egg count. In the 1989/90 season, the peak in moths preceded that of the eggs, but in the next season the peak in moths was only recorded after that of the eggs.

A total of 17 moths in 1989/90 and 54 in 1990/91 were caught in the Biotraps. The number of moths trapped were too few to make valid conclusions on the use of the pheromone as a method to accurately monitor H. armigera flight activities in sunflower or to predict infestations. It may yet be proven possible, though. Pheromone trap captures compared with light trap captures could indicate their effectiveness.

Bennett (1991) found that fluctuations in H. armigera pheromone trap captures in cotton, correlated with the fluctuations in larval populations, although the magnitude of the larval fluctuations could not be predicted.

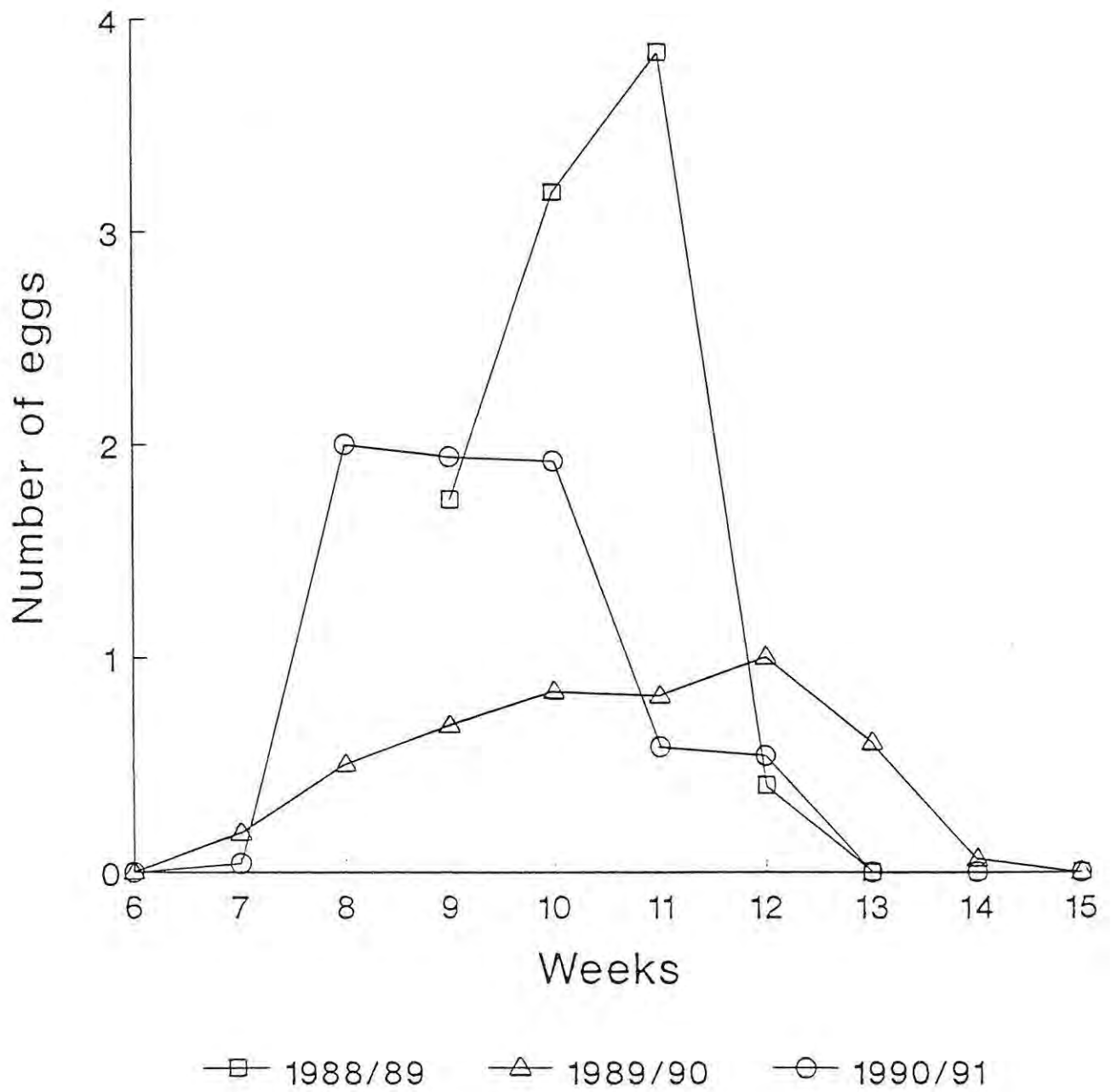


Fig. 1. The number of *Heliothis armigera* eggs per plant on sunflower of the late planting at Warmbaths in the 1988/89 to 1990/91 seasons. Time is in weeks after planting.

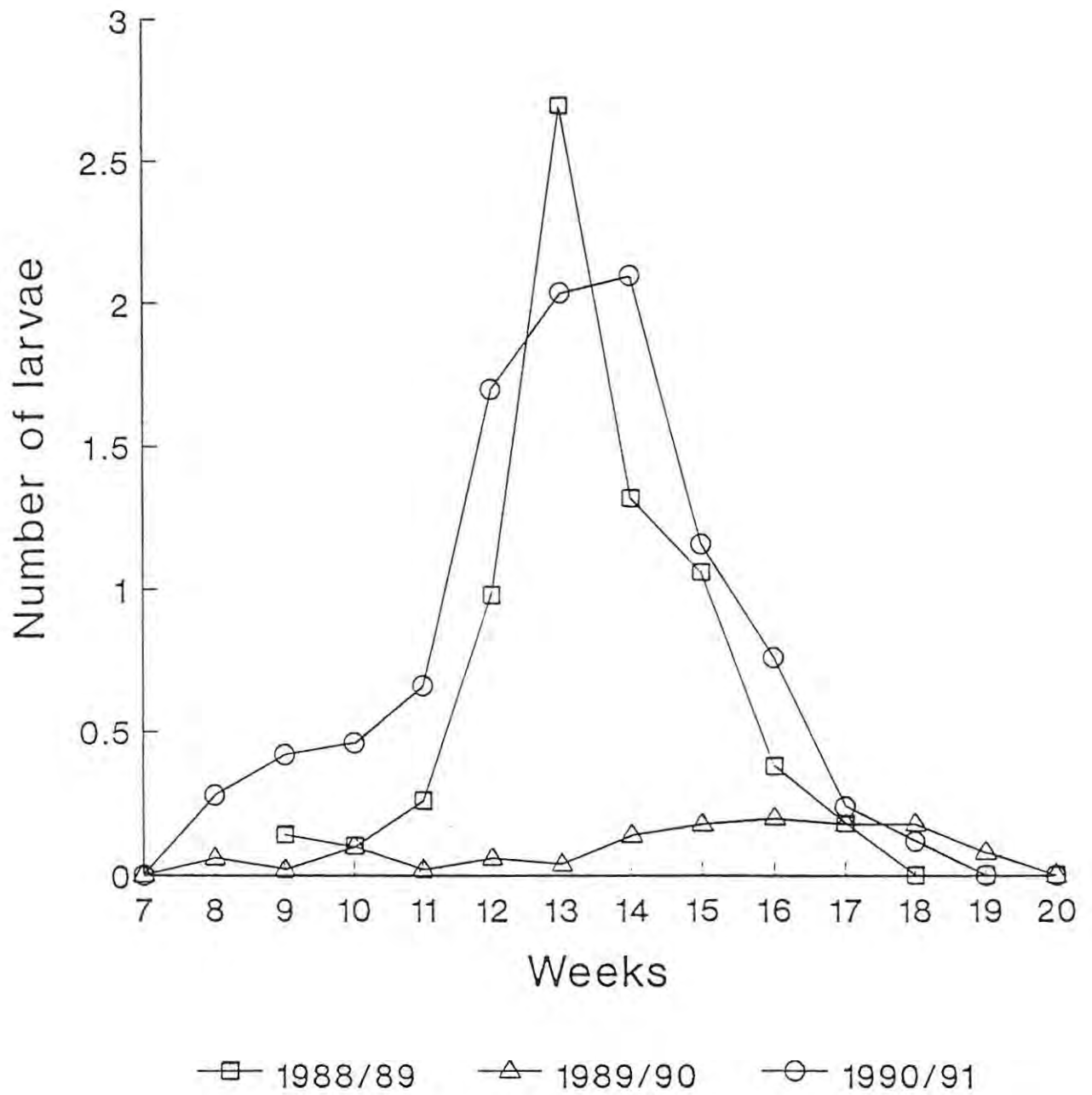


Fig. 2. The number of *Heliothis armigera* larvae per plant on sunflower of the late planting at Warmbaths in the 1988/89 to 1990/91 seasons. Time is in weeks after planting.

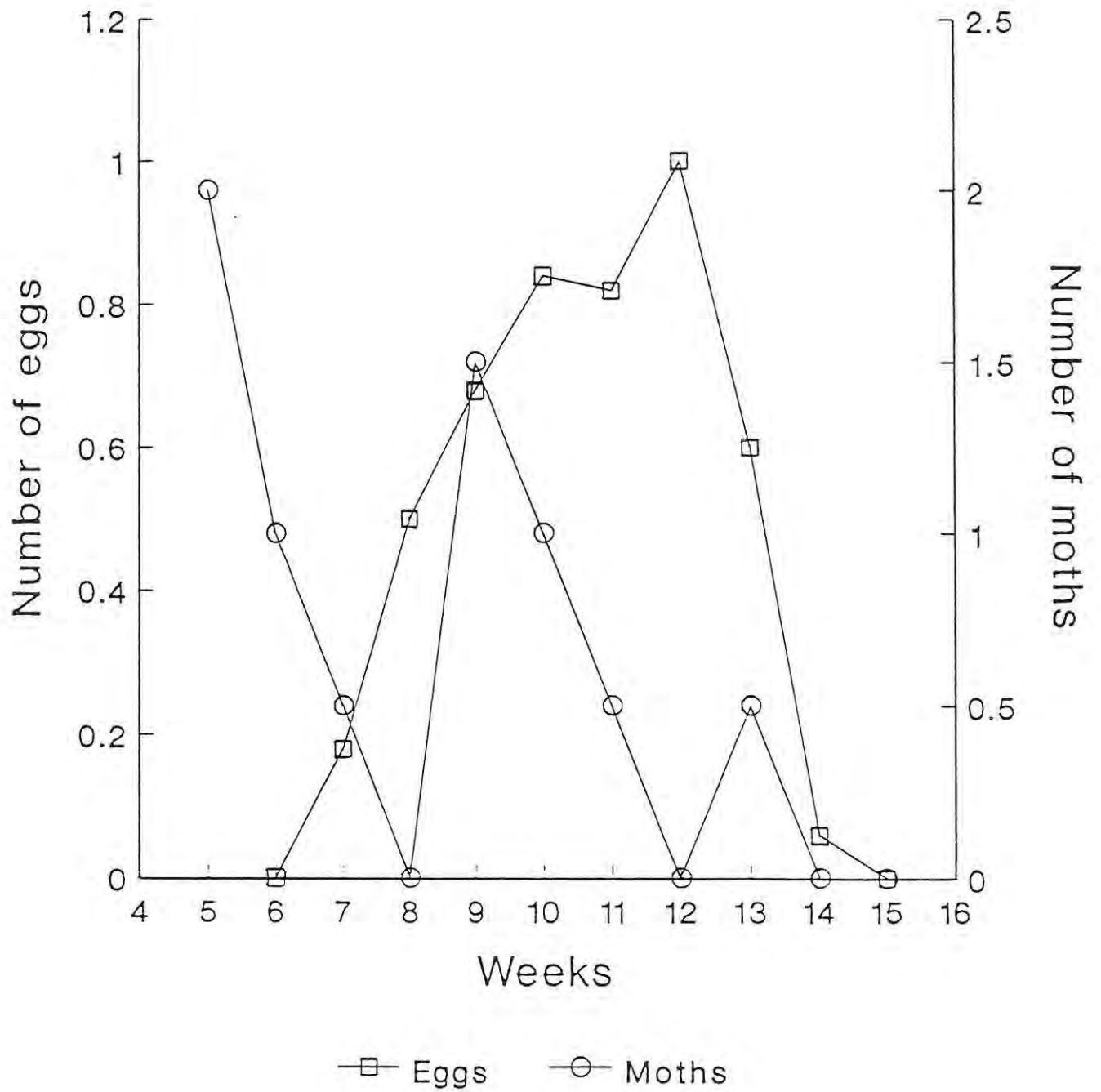


Fig. 3. The number of *Heliothis armigera* eggs per plant on sunflower of the late planting and the number of moths per Biotrap at Warmbaths in the 1989/90 season. Time is in weeks after planting.

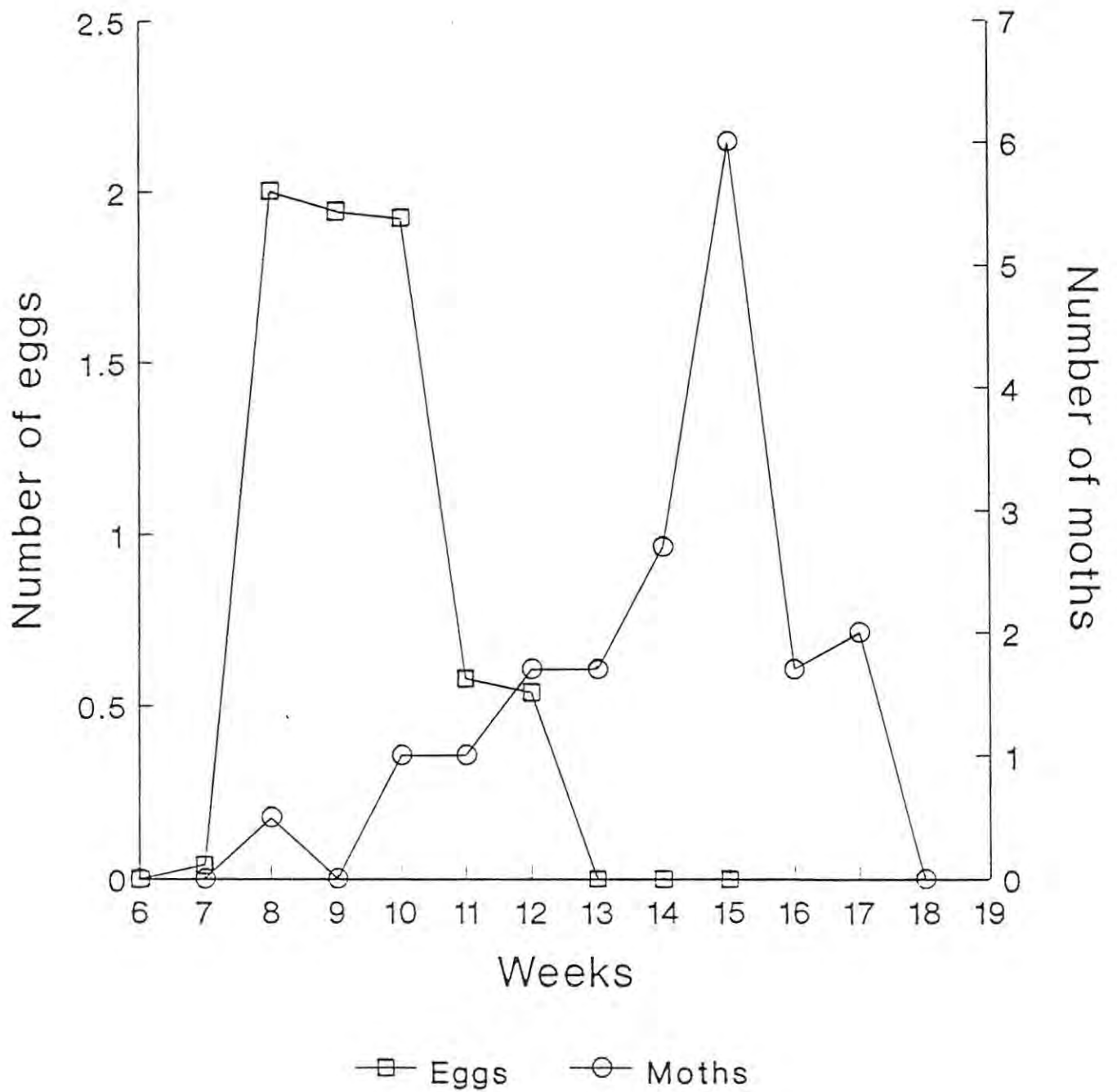


Fig. 4. The number of *Heliiothis armigera* eggs per plant on sunflower of the late planting and the number of moths per Biotrap at Warmbaths in the 1990/91 season. Time is in weeks after planting.

4. THE FEEDING OF HELIOTHIS ARMIGERA ON SUNFLOWER.

GENERAL

Sampling for H. armigera larvae was done as described in chapter 2. Larvae were only found from the budding growth stage onwards, facilitating scouting and confirming Broadley's (1984) statement that few larvae are found on crops during the vegetative stage. Weekly sampling was done until no more larvae were found.

TABLE 8. The number of weeks sampled, the number of Heliothis armigera larvae and the duration of weeks larvae were found on sunflower at Brits, Delmas and Warmbaths in the 1988/89 to 1990/91 seasons.

LOCATION	SEASON	WEEKS AFTER PLANTING	NO. OF WEEKS	NUMBER OF LARVAE
Brits	1988/89 a	weeks 7 - 13	7	31
Brits	1988/89 b	week 9	1	1
Brits	1989/90	weeks 8 - 13	6	39
Delmas	1988/89	weeks 11 - 17	7	42
Delmas	1989/90	weeks 14 - 19	6	20
Warmbaths	1988/89 a	weeks 7 - 10	4	16
Warmbaths	1988/89 b	weeks 9 - 18	10	358
Warmbaths	1989/90 a	weeks 9 - 16	8	43
Warmbaths	1989/90 b	weeks 7 - 19	13	62
Warmbaths	1990/91	weeks 7 - 19	13	500

a early planting

b late planting

Larvae were found for an average of eight weeks with 13 weeks the longest period (Table 8). The longer sampling periods were in plots that were planted later in the season. Seventy-one and 62 larvae were collected at Brits and Delmas respectively, which comprised only 12% of the total of 1112 larvae encountered at all three locations (Table 9). The number of larvae collected were too few to make any valid conclusions and therefore these two locations were not sampled in the 1990/91 season.

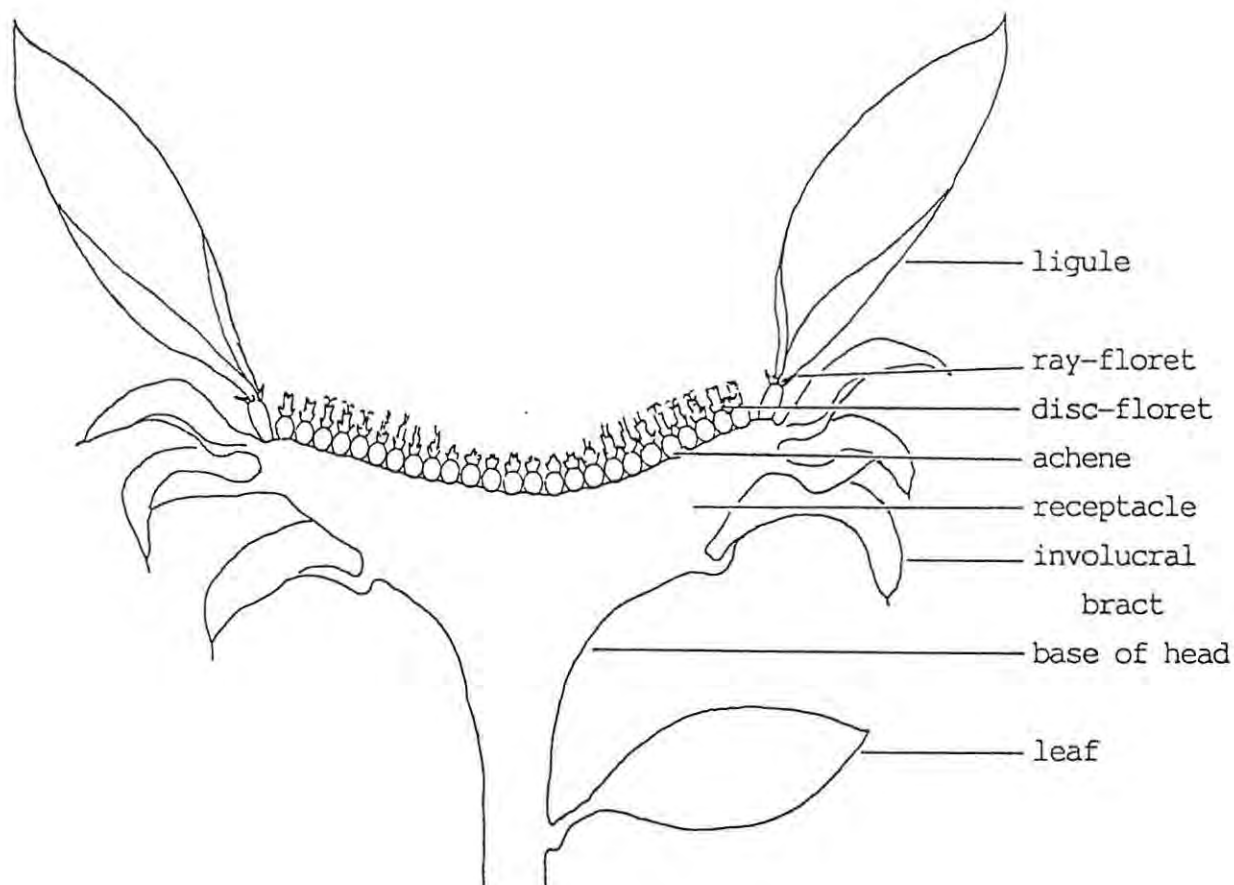


Fig. 5. Diagram of the sunflower capitulum to indicate the different feeding sites of Heliothis armigera larvae.

TABLE 9. The number and percentage of *Heliothis armigera* larvae found on the different feeding sites on sunflower at Brits, Delmas and Warmbaths in the 1988/89 to 1990/91 seasons.

LOCATION AND SEASON	FEEDING POSITION ON SUNFLOWER							TOTAL
	BURROW UNDER BRACTS	INVOLUCRAL BRACTS	FLORETS	ACHENES	BASE OF HEAD	LEAVES	LIGULES	
BRITS								
1988/89 a	10	12	3	—	5	1	—	31
1988/89 b	—	—	—	—	—	—	1	1
1889/90	11	16	10	2	—	—	—	39
TOTAL	21	28	13	2	5	1	1	71
%	29,58	39,44	18,31	2,82	7,04	1,41	1,41	
DELMAS								
1988/89	17	6	10	3	4	1	1	42
1989/90	5	8	4	3	—	—	—	20
TOTAL	22	14	14	6	4	1	1	62
%	35,48	22,58	22,58	9,68	6,45	1,61	1,61	
WARMBATHS								
1988/89 a	2	5	6	3	—	—	—	16
1988/89 b	210	57	55	18	13	1	4	358
1989/90 a	25	6	7	2	1	—	2	43
1989/90 b	34	19	4	1	1	3	—	62
1990/91	275	81	61	41	26	10	6	500
TOTAL	546	168	133	65	41	14	12	979
%	55,77	17,16	13,59	6,64	4,19	1,43	1,23	
TOTAL	589	210	160	73	50	16	14	1112
% (SE ±)	42,20 (5,16)	27,06 (4,56)	17,21 (2,48)	6,25 (1,78)	5,10 (2,16)	1,52 (0,57)	1,38 (0,44)	

a early planting
b late planting

The plant was divided into seven feeding sites from field observations of the sites where the larvae were found feeding on the plant (Fig. 5). These were the leaves, bracts, florets, achenes (seeds), ligules and the base of the head. The bracts were further differentiated into "feeding on the bracts" and "burrowing under and between the bracts into the receptacle".

The preferred feeding sites of the larvae on the plant were taken as the plant parts on which the most larvae were counted. Calculated as a percentage of the total, these were; burrowing under and between the bracts into the receptacle (42%); feeding on the bracts (27%) and feeding on the florets (17%). Only 73 (6%) of the larvae were found feeding on the achenes. The remaining feeding sites had even less. The number and percentages of larvae on the different feeding sites are indicated in Table 9.

The preferred feeding site of each larval instar at Warmbaths during the three seasons is indicated as a percentage of each instar in Table 10. The majority of young larvae (first to second instars) "nibbled" at the surface of the bracts. With larval development, the larvae moved between and under the bracts, where they made holes and continued feeding on the contents, thus burrowing into the pithy tissue of the receptacle. The older larval instars fed on more of the plant material than the younger larvae, consequently doing more damage. This compares favourably with the postulation of Nadgauda & Pitre (1983) that the ability of the larvae to feed on plant tissues, improved with the increase in size of the larvae. A similar *H. armigera* feeding pattern on cotton fruiting forms was described by Van der Walt (1988).

Fifty-six percent of the larvae counted were burrowing into the receptacle. Only a very small percentage (6%) of the larvae were found on

TABLE 10. The preferred feeding sites on sunflower of the different larval instars of *Heliothis armigera*, expressed as the percentage of larvae in each instar found on the different feeding sites, at Warmbaths in the 1988/89 to 1990/91 seasons.

LARVAL INSTAR	BURROW UNDER BRACTS	INVOLUCRAL BRACTS	FLORETS	ACHENES
1st	3,03 ($\pm 3,03$)	90,91 ($\pm 9,09$)	6,06 ($\pm 6,06$)	0
2nd	32,04 ($\pm 9,33$)	40,37 ($\pm 7,36$)	18,52 ($\pm 1,85$)	0,93 ($\pm 0,93$)
3rd	50,07 ($\pm 1,38$)	19,65 ($\pm 3,13$)	15,41 ($\pm 2,48$)	5,57 ($\pm 1,86$)
4th	64,06 ($\pm 0,35$)	13,01 ($\pm 4,26$)	11,09 ($\pm 1,36$)	6,19 ($\pm 2,14$)
5th	66,68 ($\pm 3,77$)	11,40 ($\pm 1,75$)	10,54 ($\pm 1,39$)	6,85 ($\pm 1,40$)
TOTAL	55,96 ($\pm 0,50$)	18,86 ($\pm 2,48$)	12,99 ($\pm 1,73$)	5,56 ($\pm 1,54$)

the achenes, the number of larvae increasing from nil in the first instar to seven percent of the fifth instar.

Since egg laying only started during the early flowering stage (bud stage onwards), no mature larvae were encountered on the sunflower buds. The small larvae were concentrated on the bracts, surrounding leaves and florets and this was probably due to the availability of these feeding sites close to where the eggs had been laid.

FEEDING ON THE BUD

Of the 979 larvae found at Warmbaths, only 70 (7%) were found on the sunflowers bud stage of development (Table 11). Of these larvae, 67% were feeding on the involucral bracts, which represented 27% of all larvae

TABLE 11. The preferred feeding sites on sunflower buds of *Heliothis armigera* larvae, expressed as the number of larvae feeding on the different feeding sites and the percentage of the total, at Warmbaths in the 1988/89 to 1990/91 seasons.

SEASON	FEEDING POSITION ON THE SUNFLOWER BUD					% *
	INVOLUCRAL BRACTS	FLORETS	LEAVES	LIGULES	TOTAL	
1988/89	18	9	1	1	29	(7,75)
1989/90	5	—	3	—	8	(7,62)
1990/91	25	7	1	—	33	(6,60)
TOTAL	48	16	5	1	70	
% (SE ±)	66,78 (4,49)	17,42 (9,16)	14,66 (11,42)	1,15 (1,15)		
% (SE ±) *	26,63 (3,36)	17,42 (4,47)	70,00 (30,00)	8,33 (8,33)	7,32 (0,36)	

* Percentage of total larvae on all development stages of sunflower.

feeding on the bracts at all stages of sunflower development. 17% of the bud feeders burrowed through the bracts to the developing florets. 70% of all larvae feeding on the leaves, did so during the bud stage.

Since egg laying only started from the bud stage onwards and the majority of larvae occurred in the anthesis growth stage, the vulnerable bud stage escaped serious feeding damage. Heavy infestations in the bud stage can cause deformed seedheads (Broadley 1978). The high percentage of larvae on the leaves is due to the number of eggs oviposited on the leaves

when they surrounded the bud in the early bud stage.

FEEDING ON THE ACHENES

As only a small percentage (6%) of larvae were found to feed on the achenes, that part of the crop that is harvested, laboratory trials were conducted to test larval feeding on the achenes.

Ten larvae of each of the the second to fifth instars, were kept on a no-choice diet of sunflower achenes of the SNK 32 cultivar. Mature (hard) achenes and young (wet) achenes from sunflower in the maturing growth stage, were used. All larvae were obtained from the *H. armigera* culture maintained on the artificial larval diet. Larvae were kept singly in 100 x 25 mm glass vials, stoppered with cotton wool. Five achenes per vial was maintained throughout the trials. The artificial larval diet served as the control. Larvae were kept on these diets until they pupated or died.

The second-instar larvae were unable to feed on the mature achenes. Few feeding marks were found on the mature achenes and only the larvae that were in the fifth instar at the start of the experiment, managed to pupate and developed into adults (Table 12).

The wet achenes proved almost as unsuitable as the mature achenes for the second to fourth instar larvae. Although all the fifth-instar larvae managed to pupate, only one fourth-instar larva managed to pupate. All other larval instars died before pupation. All the larvae from the control pupated successfully.

Boldt et al. (1975) found similar results with larvae feeding on soya pods and declared that mortality was due to the inability of early instars to penetrate the hairs and epidermis of the pods. The same conclusion was

TABLE 12. The number of *Heliothis armigera* larvae of different larval instars developing into adults after feeding on sunflower achenes.

DIET	STAGE	LARVAL INSTAR			
		2nd	3rd	4th	5th
Wet achenes	larvae	10	10	10	10
	pupae	0	0	1	10
	adults	0	0	1	10
Mature achenes	larvae	10	10	10	10
	pupae	0	0	0	0
	adults	0	0	0	0
Control	larvae	10	10	10	10
	pupae	10	10	10	10
	adults	10	10	10	10

made by Nadgauda & Pitre (1983).

Since the initial South African hybrid-sunflower breeding programme was started with Rumanian sunflower hybrids and as the achenes of the SNK 32 cultivar are darkly pigmented, it is possible that they contain a phytomelanin layer in the hull (Chapter 2). A chemical feeding deterrent could also be involved. Further studies are needed before any conclusions can be made.

5. NATURAL ENEMIES OF HELIOTHIS ARMIGERA

Heliothis species are attacked by a large complex of natural enemies. Most of the parasitoids of Heliothis spp. are specific to the genus or are oligophagous. Comparisons of the parasitoid spectrum in Africa, Australia, India and the U.S.A., show taxonomic and functional similarities (Greathead & Girling 1982). Van den Berg et al. (1988) listed 83 identified and 93 records of partially identified natural enemies recorded from H. armigera in Africa.

The rate of population increase of Heliothis armigera outpaces that of its natural enemies; consequently the damage to crops had already been done by the time the natural enemy populations reached significant levels (Nagarkatti 1982, Reed & Pawar 1982, King & Coleman 1989).

Much research has been done in South Africa in attempts to control H. armigera on cotton by mass-releases of the egg parasitoids, Trichogrammatoidea lutea and Telenomus ullyetti. The attempts so far have been unsuccessful as high rates of parasitism were never attained (Annecke & Moran 1982). The work produced little evidence that inundative releases of these parasitoids could be relied upon to provide biological control at low host population levels (Pearson & Maxwell Darling 1958, Annecke & Moran 1982). High egg parasitism has little effect on the larval population (Parsons 1940a, Greathead & Girling 1982) and a high egg population is not necessarily followed by a high larval population (Reed 1965b). Van Hamburg (1981) stated that egg counts on cotton provide poor estimates of larval densities due to variations in egg viability and variation in egg parasitism. Reed (1965b) reported that poor egg survival later in the season was due to predation.

EGG PARASITISM

Field collected *H. armigera* eggs and larvae were reared in a temperature and humidity controlled room (Chapter 2). All eggs were kept until they hatched or parasitoids emerged. As eggs were easily damaged during collection and to minimize damage to the sunflower buds where the eggs had to be cut from the plant tissue it adhered to, only eggs laid on plant hairs or eggs that could easily be removed, were collected. A total of 50 eggs were thus collected on sunflower at Brits, 9 at Delmas and 122 at Warmbaths during the 1988/89 and 1989/90 seasons. No eggs were collected in 1990/91. The number of eggs collected at the various locations and the parasitism rates are given in table 13.

A total of 181 eggs were collected of which 19% were parasitised. Except for two eggs from Brits parasitised by *Trichogrammatoidea lutea* (Trichogrammatidae) in the 1988/89 season, all the others were parasitised by *Telenomus ullyetti* Nixon (Scelionidae). The average parasitism rate was 30% in the 1988/89 season and 10% in the 1989/90 season. The *H. armigera* infestation in the 1989/90 season was also smaller than in the previous season. On average, only 20% of the eggs collected hatched. An average of 61% of the eggs yielded no parasitoids or larvae. Whether this was due to egg mortality during collection and transport to the laboratory or due to infertility of the eggs, has not been determined.

Egg parasitoids can prolong the presence of the host stage they attack in the field thus field samples of host eggs can overestimate parasitism levels (Van den Berg *et al.* 1988).

TABLE 13. The number of *Heliothis armigera* eggs collected, the number of eggs hatched and parasitised at Brits, Delmas and Warmbaths on sunflower, in the 1988/89 and 1989/90 seasons.

LOCATION	SEASON	EGGS COLLECTED	EGGS HATCHED	EGGS PARASITISED
Brits	1988/89	18	2	8
Brits	1989/90	32	7	1
Delmas	1988/89	2	1	1
Delmas	1989/90	7	3	0
Warmbaths	1988/89	66	9	17
Warmbaths	1989/90	56	14	8
TOTAL		181	36	35

LARVAL PARASITISM

A total of 709 *H. armigera* larvae were collected at the sites during the three seasons (Table 14). On average, 27% of the collected larvae were parasitised and 59% successfully pupated and developed into adults. The larval parasitism rates at Warmbaths in 1988/89 of 23%, increased to 27% in the second season and to 34% in the third season (Table 15).

Broadley (1984) calculated the level of larval parasitism by dividing the number of parasitoids emerged by the sum of the number of parasitoids and moths emerged. The mean percentage parasitism for *Heliothis* spp. on sunflower in South Queensland, Australia, for the 1979/80 to 1981/82 seasons was 36,5%, 25,0% and 21,8% respectively. By using the same calculations for the 1988/89 to 1990/91 seasons at Warmbaths, the mean

TABLE 14. The number of Heliothis armigera larvae collected on sunflower, developing into adults and parasitised, at Brits, Delmas and Warmbaths in the 1988/89 to 1990/91 seasons.

LOCATION	SEASON	LARVAE COLLECTED	ADULTS DEVELOPED	LARVAE PARASITISED
Brits	1988/89	7	7	0
Brits	1989/90	30	23	1
Delmas	1988/89	34	24	8
Delmas	1989/90	16	11	1
Warmbaths	1988/89	193	134	44
Warmbaths	1989/90	71	40	19
Warmbaths	1990/91	358	178	120
TOTAL		709	417	193

TABLE 15. Parasitism of Heliothis armigera larvae on sunflower during the 1988/89, 1989/90 and 1990/91 seasons at Warmbaths.

SPECIES	PARASITISM (%)		
	1988/89	1989/90	1990/91
Diptera: Tachinidae			
<u>Palexorista</u> prob. <u>laxa</u> (Curran)	10,88	2,82	15,92
Hymenoptera: Ichneumonidae			
<u>Temelucha</u> sp.	0	9,86	5,59
Unidentified Ichneumonidae	4,66	9,86	2,79
Hymenoptera: Braconidae	7,25	4,23	9,22
Mean Percentage Parasitism	22,79	26,77	33,52

percentage larval parasitism was 24,72%, 32,20% and 40,27% respectively, which compared favourably with Broadley's figures.

Parasitism of H. armigera larvae at Warmbaths is given in Table 15. A tachinid, Palexorista prob. laxa (Curran) was the most abundant parasitoid at Warmbaths. This tachinid contributed 44% to the total parasitism rate. For the individual years the Palexorista sp. parasitised 11% of the larvae in 1988/89 and 16% in 1990/91. In the 1989/90 season when the H. armigera infestation was lower, only 3% of the collected larvae were parasitised by the tachinid.

A Temelucha sp. parasitised 10% and 6% of the larvae at Warmbaths in the 1989/90 and 1990/91 seasons respectively, but did not occur in our samples in the 1988/89 season. The other ichneumonid species parasitised 10% of the larvae in 1989/90. Other larval parasitoids were of the Braconidae, very similar to Apanteles spp., but have so-far not been identified. The braconids parasitised 9% of the larvae at Warmbaths in 1990/91.

PREDATORS

The predators feeding on Heliothis spp. are usually polyphagous (Room 1979). A number of predators were observed feeding on H. armigera eggs and larvae in the field, but no specific data was collected. The most numerous predator at all three sites and seasons was a Chrysopa sp. Eggs of Chrysopa sp. were also noticed on the sunflower head. Other predators were species of Cheilomenes, Hippodamia, Lioadalia and Scymnus of the Coccinellidae, Orius spp. (Anthocoridae) and species of Reduviidae. Spiders were also observed feeding on the larvae. Ants attacked larvae

that fell to the ground during sampling.

The army ant, Dorylus sp. and mice, (Mastomys natalensis), were the main predators of H. armigera pupae at Brits and Delmas (Watmough 1989, 1991). These trials on the predation of the pupae were done in cotton, maize and sorghum crops adjacent to the sunflower plots used.

MICROBIAL AGENTS

A polyhedral virus occurred in the field on H. armigera larvae and more often so later in the season. The younger larval instars were the

TABLE 16. The number and percentage of Heliothis armigera larvae that succumbed to a polyhedral virus on sunflower at Brits, Delmas and Warmbaths in the 1988/89 to 1990/91 seasons.

LOCATION	SEASON	NUMBER	PERCENTAGE OF POPULATION
Brits	1988/89a	2	6,45
Delmas	1988/89	3	7,14
Warmbaths	1988/89a	3	18,75
Warmbaths	1988/89b	7	1,96
Brits	1989/90	3	7,69
Delmas	1989/90	5	25,00
Warmbaths	1989/90a	5	11,63
Warmbaths	1989/90b	25	40,32
Warmbaths	1990/91	16	3,20

a early planting

b late planting

most susceptible. The wilted appearance of affected larvae was similar to that described by Coaker (1958). The diseased larvae turn brown after death and the body contents liquefy. The numbers of diseased larvae were too few to permit a valid estimation of their mortality rate, with percentage larval mortalities ranging from two to 40% (Table 16). To avoid introducing the virus into the laboratory cultures, no diseased larvae were collected in the field.

6. DISCUSSION

With an increased demand for vegetable oils and proteins, coupled with the development of sunflower hybrids, the production of sunflower has increased four fold in the past two decades. With increases in production and in areas of production, a corresponding increase in insect infestations can be expected (Schulz 1978). With a relatively short growth season which allows planting until late in summer, sunflower offers an almost continuous infestation source for a mobile and highly fecund pest such as Heliothis armigera. H. armigera is a notorious pest of cotton. Since sunflower production in the "traditional" cotton producing areas such as around Brits in the Western Transvaal and on the Springbok Flats had increased, high H. armigera infestations on sunflower were expected in these areas.

Low infestations of H. armigera at all three locations, i.e. Brits, Delmas and Warmbaths were experienced during the study period of three seasons. The numbers of H. armigera at Brits and Delmas were too few to permit valid estimations of the infestation rates and data from these areas were excluded from the statistical calculations. Only Warmbaths provided infestations from which any conclusions could be drawn and even here the infestations never exceeded an average of four eggs or three larvae per plant.

H. armigera oviposition is correlated with the flowering period of sunflower, as it is on many other crops. Oviposition started from six weeks after planting when the plants had reached the bud stage, and increased to a peak by the 10th week. This happened in early and late plantings. The bracts and bases of the flower buds were favoured for

oviposition. As could be expected from the oviposition sites, initial larval feeding occurred on the bracts, the young larvae nibbling at the surface. As they developed, the larvae moved between and under the bracts, eventually burrowing into the pithy tissue of the receptacles. Larvae appeared in the plots at seven weeks after planting and their numbers peaked by the 13th week.

Since the majority of H. armigera larvae clearly prefer to feed on the bracts and the receptacles, their main attack is not directed to the plant parts harvested as happens in cotton and on various fruit crops. The impact of infestations on sunflower yield can therefore be expected to be considerably less than on some other crops.

The late plantings of the crop, planted after January, attracted more eggs and larvae and more plants were infested. By planting earlier in the season, the higher infestations can thus be avoided.

The numbers of larvae on the plants were lower than those of the eggs found on the plants. This was probably due to egg parasitism of 19%, predation, and infertile eggs, although the large percentage of eggs that did not hatch could have been due to mortality caused by the sampling method used. The higher egg than larval numbers concurs with Reed's (1965b) statement that high egg populations do not necessarily lead to high larval populations.

My conclusion that H. armigera is not a pest of economic importance on sunflower is based on:

- (1) The relatively short flowering period and growth season of the crop;
- (2) the ability of the plant to support a number of larvae without significant effect on the crop yield (Broadley & Ironside 1980);
- (3) the feeding preference of the larvae for the bracts and receptacles, the plant parts not harvested;

- (4) the inability of the larvae to survive on a achene only diet;
- (5) the existence of the natural enemies, parasitoids, predators and the polyhedral virus as biocontrol agents; and overall,
- (6) the low infestations recorded.

The implementation of further control methods, apart from planting early, does not seem justified at present. Monitoring and scouting for H. amigera eggs and larvae is advisable though, as large outbreaks have reportedly occurred in the past. Scouting is facilitated by the fact that ovipositing corresponds with flowering and infestations only occur from the sixth to thirteenth weeks after planting. Scouting is further made easy by the habit of the moths to oviposit on exposed sites on the plant and by the easily observable feeding sites of the larvae.

A world wide concern exists regarding intensive chemical pesticide applications and the negative effect it has on global ecology. This has resulted in a growing interest in sustainable agriculture and also organic farming. The emphasis is on the implementation of production systems that are environment friendly, socially acceptable and economical. This necessitates intelligent pest control and a reduction in the dependance on agricultural chemicals. Sunflower, with no major pests requiring intensive chemical control, could be used to great benefit in sustainable agriculture programmes in the central Transvaal areas.

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