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FINAL REPORT

DAQ450/DAQ21L POPULATION DYNAMICS OF *HELIOTHIS* ON THE DARLING DOWNS

PERIOD:	July 1985 - June 1989
ORGANISATION:	Queensland Department of Primary Industries
LOCALITY:	Toowoomba
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GENERAL

This project completed its 4-year term on 30 June 1989. It was funded jointly by the Cotton Research Council and the Oilseeds Research Council with a total allocation of $88 000.

This report gives perspective to the overall achievements of the project, however several more specific analyses of data are incomplete at this time. Since the results of such analyses will not change that perspective, the report is tendered in satisfaction of Research Council guidelines for reporting. Specific details of all results will be supplied as reprints of published articles during 1990.

SUMMARY

Heliothis punctigera Wallengren and *H.armigera* (Hübner) are two serious pests of field crops in Australia. They are highly polyphagous and attack a wide range of food, fibre, oil and fodder crops as well as many horticultural and ornamental plants. Control of *Heliothis* outbreaks has a heavy reliance on insecticides, but insecticides are not a long-term solution to *Heliothis* management. Alternative tactics and strategies will ultimately be forced upon pest managers. An understanding of the basic ecology of the species provides a sound basis for the assessment of future pest management options.

The objectives of this study were:

(i) To study the population dynamics of *Heliothis* on the Darling Downs and to quantify the significance of the major controlling influences (predators, parasites, pathogens, weather and host plant quality) on population changes within the species, and,

(ii) To assess the potential for an area-wide management approach to the suppression of *Heliothis* populations through the identification of ecological bottlenecks and the practical manipulation of the controlling factors.

The seasonal abundance of *Heliothis* spp. and local variation in densities of their immature stages on different crops were studied by

routine sampling of medium to large larvae on major crops on the Darling Downs. Chickpeas were confirmed as an early season "nursery" crop for the first (Spring) generation of Heliothis. Second generation larval densities peaked in reproductive maize and sunflower, and a third generation peaked in soybean, sorghum and late sunflower. Generally, the proportion of H.armigera within collected larvae increased as the season progressed. Natural enemies were detected in most crops but were low in numbers in early season (September to mid October).

Factors affecting survival of eggs and larvae were studied through both field and laboratory studies. In the field, marked individuals were continually observed as they developed on plants up to the time that they pupated in the soil. The observed mortality of individuals was divided into five broad categories, namely that due to parasitism, predation, disease, weather and host plant effects. The dislodgement of eggs from plants and the disappearance of first instar larvae accounted for the major decrease in Heliothis numbers. Hence the major mortality factors responsible were not knowable from direct observation.

While parasitism, predation and diseases each had measurable effects on Heliothis mortality in most of the crops studied, none of these components were related to the Heliothis densities on which they acted. This placed emphasis on the roles played by weather and host plant effects in causing mortality.

Average moth emergence (= pupal survival) of natural pupal populations under crops was 37%. Parasitism accounted for 37% pupal mortality but was highly variable. Mortality from predators and disease was generally low.

Under field cages, in the absence of cultivation, and with predators and parasites excluded, survival of pupae (mostly over-wintering) was high (>80%). These studies demonstrated that pupae could successfully over-winter and reinfest crops in the spring. However, substantial spring flights of moths occurred before local emergence from over-wintering pupae.

The importance of migration in local population dynamics and the source(s) of immigrants are critically important in determining our management strategy and relevant control tactics. As immigration is important in early season before the emergence of local moths, the possible effectiveness of any Wide-Area Management is decreased. Therefore, control may be restricted to finding ways to increase local mortality rates. Later in the season, Heliothis are generated locally and immigration is probably less important. It is then that interference with source populations may limit the size of successive generations.

Highly variable pupal development, especially in H.punctigera, and diverse diapause strategies, highlight how well these species are adapted to the Australian environment. The pathway towards improved Heliothis management will not be straightforward.

INTRODUCTION

Heliothis (Helicoverpa) punctigera Wallengren and H.armigera (Hübner) are two of the most important pests of field crops in Australia. Larvae feed mostly on growing points and fruiting structures of host plants. In Queensland, Alcock and Twine (1980) estimated that Heliothis spp. cost over $16M annually, with the major losses on sorghum, cotton and oilseeds. Although the two species are very similar, they are sufficiently different in phenology, host range and resistance status to warrant being studied separately.

Control of Heliothis outbreaks still relies heavily on the use of insecticides. This is especially so in intensive production of high value crops such as cotton. Associated with this dependence on insecticides is the increasing problem of insecticide resistance. The economic impact of insecticide resistance is difficult to assess but it casts serious doubt on the long term viability of the classical insecticide approach. An insecticide management strategy was introduced for the 1983-84 season in order to prolong the useful life of all insecticides, but particularly the pyrethroids. This strategy continues to be used at present, although modifications have been made on an annual basis.

Insecticides are not a long-term solution to Heliothis management and ultimately alternative tactics and strategies will be forced upon pest managers. What has become obvious is the need to investigate the viability of non-insecticidal methods of pest mitigation as well as further refining of the insecticide management strategies now in operation. Both of these options emphasise the need for a complete understanding of the basic ecology of the species.

While a thorough understanding of the ecology of a species in an area offers no guarantee of the availability of an appropriate management procedure, it will provide a very sound basis for the assessment of pest management options.

OBJECTIVES

(i) To study the population dynamics of Heliothis on the Darling Downs and to quantify the significance of the major controlling influences (predators, parasites, pathogens, weather and host plant quality) on population changes within the species.

(ii) To assess the potential for an area-wide management approach to the suppression of Heliothis populations through the identification of ecological bottlenecks and the practical manipulation of the controlling factors.

RESULTS AND DISCUSSION

Survival of eggs and larvae of both agriculturally important Heliothis species (H.armigera and H.punctigera) was studied by continually observing the development of marked individuals on crops through to their time of pupation. The 23,000 individuals observed comprised 36 cohorts under natural conditions and 13 cohorts under manipulated conditions. These cohorts occurred on chickpeas, cotton, maize, mungbeans, pigeonpeas, sorghum, soybeans, and sunflower in both vegetative and reproductive growth stages.

A lifetable was constructed for each of these cohorts to identify the factors causing mortality, the Heliothis developmental stage affected, and to quantify the size of the mortality effect. The observed mortality of individuals within cohorts was also partitioned into five broad categories, namely parasitism, predation, disease, weather and host plant effects.

Life tables for Heliothis immatures

In considering the particular developmental stages of Heliothis, in all but 3 cases highest mortality as indicated by low survival rates and high kvalues (a measure of the intensity of mortality) occurred within the first instar larvae. In the 3 exceptional cases mortality of eggs was higher, but in all cases mortality affected the youngest developmental stages most severely. This indicates that the shape of the survival curve for Heliothis was similar on all crops studied, being of Slobodkin's Type IV (Slobodkin 1980).

Considerable variation occurred in Heliothis survival rates between crops under natural conditions -

	Egg Survival %			Instar I Survival %		
	min	max	mean	min	max	mean
Chickpea	27	52	35.0	0	37	17.8
Cotton	11	40	27.2	0	14	3.8
Maize	11	40	28.1	0	90	6.5
Mungbean		48	47.5		34	34.2
Pigeonpea	26	56	38.1	8	36	24.3
Sorghum	38	56	45.7	0	38	21.4
Soybean	31	91	54.0	1	31	18.0
Sunflower	33	76	42.1	3	40	24.3

and between different fields of a particular crop grown at different times during the season.

Numbers of survivors in each crop showed a linear decline with increasing physiological time from the white egg stage to the beginning of the second larval instar. Analysis showed there were no significant differences ($p>0.05$) between crops in the slopes of the fitted lines. However, while lines were therefore parallel, there were significant differences ($p<0.05$) between crops in the intercepts made by the lines.

Crop	Intercept for common slope	Adjusted Average Y	Sig*
Maize	1229.40	467.50	a
Cotton	1234.86	473.21	ab
Pigeonpea	1284.40	522.75	abc
Sorghum	1297.84	536.19	abcd
Sunflower	1338.15	576.50	bcd
Chickpea	1354.40	592.75	cd
Soybean	1367.48	605.84	cd
Mungbean	1391.15	629.50	d

* Sig = values for intercept and average Y followed by the same letter were not significantly different ($p>0.05$).

Clearly then, survival of <u>Heliothis</u> eggs to the start of the second larval instar was different, for example, on sunflower, chickpea and soybeans than on cotton or maize. Subsequent survival to the adult stage also varied between crops although data from the lifetables for these later developmental stages were insuffucient to allow meaningful analysis. Some changes in the ranked order of crops for survival through to pupation were evident -

Crop	Observed Survival to Pupation % min	max	mean
Maize	0	0	0.0 **
Cotton	0	0	0.0
Soybean	0	0	0.0
Pigeonpea	1	2	1.0
Sorghum	0	3	1.0
Sunflower	0	3	1.4
Mungbean	-	-	2.5
Chickpea	0	9	2.7

** Survival in these crops is, clearly, NOT zero otherwise Heliothis would not be a pest. This simply indicates that the cohort size was not large enough that survivors might occur under the encountered mortality factors.

That differences will occur in the numbers of moths arising from particular crop situations was amply demonstrated. This result supports both Firempong's (1988) conclusion that H.armigera employs a passive selection strategy in the selection of its host plants, and Real's (1980) hypothesis that a generalist herbivore should invest in plants whose contribution to fitness negatively covary.

Seasonal data for sunflower also showed that survival increased as the season progressed, although it was not clear whether this reflected improving weather conditions more suitable for survival, or a species effect as H.armigera increasingly dominated the species composition on the crop as each season progressed.

The lifetables showed that dislodgement of eggs and disappearance of first instar larvae from plants accounted for the major decrease in Heliothis numbers. The causes of this mortality were generally not identifiable even though continual direct observation had been carried out. This implies that the role for natural enemies (parasites, predators and diseases) in reducing Heliothis numbers within generations was limited, placing importance on weather and host plant effects in limiting survival.

In a minor part of the work, field cages were used to produce cohorts of the separate Heliothis species on those crops which hosted both species. Data for survival of the separate species suggested no overall differences although there may be differences in the survival of particular developmental stages. Work on this aspect was inconclusive.

	Egg Survival%		Instar I Survival%		Survival % to Instar II		Survival % to Pupation	
Crop	H.a	H.p	H.a	H.p	H.a	H.p	H.a	H.p
Chickpea	18	45	0	0	0	0	0	0
Cotton	55	57	30	0	17	0	0	0
Sunflower	31	24	38	7	12	2	0	0

The roles of parasitism and disease

Fields of major crops within 2 specified 200 sq km areas were routinely sampled (the Area-Wide Survey) over 3 seasons for *Heliothis* infestation. A total of 17,040 medium to large larvae were collected during the sampling of 650 fields and incubated to assess levels of parasitism, disease incidence and *H.armigera* proportion.

Parasitism and diseases of insects are usually the most easily measured causes of mortality. Diseases can be treated merely as a special case of parasitism since, in general, the sort of sampling program that will measure parasitism will also measure disease.

These enemies were detected in most crops (data not presented) and tended to increase in occurrence following increasing *Heliothis* density. Peaks in activity levels of parasites and diseases were always asynchronous, reflecting their antagonistic modes of action. Chickpeas were confirmed as an early season "nursery" crop for *Heliothis* but action by these agents was negligible at this time (September to mid-October).

The most critical period in the life of a *Heliothis* individual is prior to the beginning of the second larval instar. At this time the individual is more subject to attack by predators, more sensitive to adverse environment, and more likely to be injured by mechanical agencies than at any other stage in its development. It is at this time then that the degree of subsequent infestation is largely decided. Consequently, while parasitism or disease may appear to be an important intra-generational mortality effect acting within a particular field, and may influence a decision to apply *Heliothis* control measures, any inter-generational effect on *Heliothis* population numbers is limited.

That *Heliothis* consistently presents a problem in crops demonstrates that, under present cultural practices, parasites and diseases are not providing aggressive *Heliothis* control. A lower attack rate can be caused simply by the abundant production of Heliothis projeny due to food availability, regardless of any possible effect of localized insecticide application programs on parasite populations. So while the actual number of affected individuals might increase as the season progresses, the percent affected declines.

The role of predation

Field cages involving the "predator-exclusion" technique were used to gauge the size of any predation component of Heliothis mortality. The occurrence of predation in most crops was successfully demonstrated, -

		Measured Mean % Stage Mortality due to Predation			
Crop	N*	Egg	LI	LII	LIII
Chickpea	1	36	7	-	-
Cotton	1	36	29	19	33
Maize	2	28	24	-	-
Pigeonpea	1	11	23	33	-
Sorghum	3	15	4	4	7
Soybean	3	15	24	15	-
Sunflower	2	12	40	14	33

* N = number of cohorts observed

although presence of the field cages in the crop did effect predator action in some situations. Survival rates usually improved dramatically inside the field cages, demonstrating a cage effect of weather amelioration. Predation rates were measured as the difference between mortality in open versus closed cages, in order overcome this problem.

Cages were not capable of excluding very small predators such as thrips (which probably attack Heliothis eggs). Populations of each predator species are also dynamic and so losses due to predation can be expected to fluctuate with time. Indicated predator mortality rates must therefore be treated as first estimates.

That predation was shown to act on the eggs and instar I larvae is important. However predation (along with egg parasitism) is not serving as a major limiting factor to the development of Heliothis cohorts in crops.

The role of weather

The direct effect of weather on survival is usually inferred from mathematical techniques, however such analyses are still incomplete at this time.

Laboratory experiments with both Heliothis species showed that dews and rainfall would not cause eggs or instar I larvae to drown under usual circumstances (LT_{50} 24-30 hours at 25°C).

Both these stages of both species also survived short exposures (15-30 minutes) to extreme combinations of high temperature (41-44-47-50°C) and relative humidity (10-30-60-75-95 %RH). Short exposures to elevated temperatures actually enhanced survival of the egg and instar I stages. The relationship between survival and time of exposure to the various combinations was complex, but indicated that other factors such as wind are required to produce significant mortality of young Heliothis.

Wind and rain are the only weather factors that involve a direct physical impact on Heliothis immatures and their host plants. Buffeting of the crop canopy by wind, and less frequently the washing effect of rain, may be the major controlling influences over the size of infestations of medium to large larvae. This supports the observation of cotton consultants that periods of sunny, still days give rise to larger than usual numbers of larvae on the crop.

The role of host plant effects

Whereas certain effects of host plants on Heliothis immatures were obvious during the life table studies, for example the exudation of gums from larval wounds to sunflowers and the higher losses of eggs from the waxy leaves of maize and sorghum plants, what was apparent was the myriad ways in which host plant effects might be expressed.

That such effects are involved in the loss of eggs and larvae from the plants is implicit. However, a full assessment of host plant effects was beyond the scope of this project.

Area-wide survey

Timings of observed peaks in larval densities within crops showed that, regardless of crop, peak densities closely followed peak moth catches in traps in both the irrigated and dryland area surveyed.

Larval densities, viewed seasonally, first peaked in chickpeas (October), secondly in reproductive maize and sunflower (mid to late December), and for a third time in soybean, sorghum and late sunflower (mid to late February). The availability of crops to support fourth generation larvae in late season was variable over the seasons studied.

Generally the H.armigera proportion within collected larvae increased as the season progressed. This followed the usual grower preference for planting recognized H.armigera hosts after December in the areas studied. Sunflowers proved the major host for second generation H.punctigera individuals from mid December through late January.

Pheromone trapping

Results from the pheromone trapping of adults showed certain similarities in the pattern of catches from all sites, indicating the developmental unity available to Heliothis over a large section of the Darling Downs.

However differences occurred in the apparent timings of peak trap catches between the 2 specified areas, reflecting differences in their heat accumulations. A small number of data "blips" may have indicated the influx of migratory moths, or the transit of relatively local moths looking for suitable feeding and ovipositional sites.

Area-wide management

The suitability of this strategy depends largely on the migratory behaviour of the pest, although migration was not directly addressed as an issue within this project. In some seasons on the Darling Downs, local emergence from overwintering is not the source of the early spring flights (see p.13).

Regardless of the origin of Heliothis moths giving rise to the F1 generation in early Spring, available areas of chickpeas and weeds usually provide ideal conditions for growth and development, with an absence of natural enemies. The attraction for area-wide management arises here because of the concentration of infestation in a much smaller area of cropping than that which is later available for F1 moths to oviposit F2 individuals.

While the action of present mortality factors is usually inadequate to maintain population suppression, a similar spatial concentration may occur with F4 and F5 individuals late in the season. This is less interesting however since numbers are usually low, these individuals will carry the highest insecticide resistance levels of the season, and any suppressing effect achieved will not neutralize the effect of immigration experienced at the beginning of the next season.

As the available evidence suggests that immigration is important in the establishment of early infestations (at least), especially for H.punctigera, greater inputs over longer periods of time will be essential to suppress the F1 Spring generation population.

Various tactics, including the practical manipulation of present mortality factors, are potentially useful in achieving the desired F1 control. Firstly, control of Heliothis on chickpeas and weeds by pesticide application is a possibility. This includes the potential for using weedicides to control the weeds on which Heliothis might develop, and the use of biological insecticides such as ELCAR or B.t. to dope standing crops with Heliothis diseases prior to their arrival. Secondly, the use of inundative release methodology using some artificially-reared natural enemy of Heliothis is attractive. Other current projects dealing with genetically engineering Heliothis NPV disease, and assessing trichogrammatid wasps for biocontrol potential make this approach even more feasible.

In September-October 1988, unseasonal hot weather following a mild winter disrupted the usual Heliothis ovipositional activity in chickpeas. Chickpeas were generally unattractive during the period of oviposition by moths from overwintered pupae, and a lack of alternative host material caused a decline in populations during the F1 generation. Heliothis did not recover from this initial setback, resulting in a "quiet" Heliothis year. This event supports the potential effectiveness of an area wide approach using control of F1 individuals.

Field collections of pupae

Natural pupal populations under field crops were sampled to investigate factors influencing pupal survival. Pupae of both species were distributed at similar depths. The mean pupal depth ± s.e. was 47.3 ± 1.1 mm in H.punctigera and 46.2 ± 0.6 mm in H.armigera. In both species, the mean depth of male pupae was significantly greater than that of female pupae. In the raingrown crops sampled, pupae were evenly distributed across the inter-row space. This is in contrast to irrigated crops where most pupae are located on the ridge near the plant row.

The average moth emergence (= pupal survival) was 37%. Unknown mortality averaged 9%, but at one site about 33% of pupae drowned when the field was severely waterlogged. Parasitism of prepupae and pupae was variable and averaged 37% (range 8.2-61.9%). Mortality from predators was low, averaging 6.5%, and the incidence of pathogens was negligible.

Effect of submersion in water on pupal survival

At 25°C, the submersion time to kill 50% of pupae was 49 h in H.punctigera and 34 h in H.armigera. Since pupae survive relatively long periods under water, drowning may not be an important mortality factor in the field except when prolonged waterlogging occurs.

Effect of soil moisture on pupal survival and moth emergence

The effect of soil moisture and simulated rainfall on pupal survival and moth emergence was investigated in field trials. No differences in pupal survival and moth emergence were recorded where soil moisture ranged from dry to very wet when prepupae tunnelled into the soil. Simulated rainfall after pupation, but before moth emergence, reduced survival by disrupting emergence tunnels and trapping moths in their tunnels. This effect was greater where prepupae tunnelled into dry soil than where they tunnelled into wet soil.

As well as the effect on pupal survival, soil moisture was found to influence pupal development. In one test, quiescence was induced, especially in H.armigera, in a treatment where the soil was dry and high temperatures were recorded. In a second test, there was a high incidence of autumnal diapause in treatments where the soil was moist and temperatures were lower. No diapause occurred in the dry soil treatment. It may be necessary to consider these aspects when developing population dynamics models for Heliothis spp. in Australia.

Pupal development in an open-air insectary

Cultures of H.punctigera and H.armigera were maintained continuously in an open-air insectary at Toowoomba. Duration of pupal development under fluctuating temperature conditions was investigated. Rate of development in both species was greater than that previously reported for constant temperature studies. In both species, the rate of development was significantly greater in females than in males.

Diapause and moth emergence in an insectary

The temporal incidence and duration of pupal diapause was determined in the cultures reared in an open-air insectary at Toowoomba. Spring diapause was recorded in H.punctigera during October and November. The incidence of spring diapause was significantly greater in males than in females. This was confirmed in a natural pupal population sampled under chickpea. Moths emerged from spring-diapausing pupae during early to mid-summer. Time of moth emergence was independent of time of entry into diapause. No spring diapause was recorded in H.armigera.

Autumnal diapause was recorded in both species, with a significantly greater incidence in H.armigera than in H.punctigera. There was a significantly greater incidence of autumnal diapause in males of both species.

As with spring diapause, moth emergence was independent of time of entry into diapause. Most moths emerged from autumnal diapause during spring, but a proportion of H.punctigera (48% in 1986 and 15% in 1987) remained in diapause through spring and emerged in summer. In spring, H.punctigera emerged before H.armigera, and females emerged before males of the same species.

Daylength and temperature were shown to have a major influence on the induction of diapause. Functions were developed to predict the incidence of spring and autumnal diapause in each species. Multiple linear regressions of daylength (expressed as time) and temperature satisfactorily explained a high proportion of the variation.

Threshold temperatures for diapause termination

Threshold temperatures for diapause termination were investigated in laboratory experiments. The theoretical lower developmental threshold temperature for diapause termination was 15.3°C in female H.punctigera, 16.1°C in female H.armigera and 16.5°C in male H.armigera. A developmental threshold was not determined in male H.punctigera because at the range of temperatures tested (15.1-20.2°C), the proportion of these pupae terminating diapause was low. On the basis of the limited data available on male H.punctigera, its temperature threshold is probably similar, or slightly below, that in female H.armigera.

Pupal survival under field cages

Survival of pupae produced in autumn, diapause incidence and spring moth emergence in H.punctigera and H.armigera were investigated under field cages at Kingsthorpe, 20 km west of Toowoomba, during 1986-88. In the absence of cultivation, and with predators and parasitoids excluded, survival of pupae (mostly overwintering) under pyramid cages was high (range 84.4-93.4%). More moths emerged from H.punctigera pupae (90.3%) than from H.armigera pupae (85.8%). Overall, 6.6% of eclosed moths were trapped in the soil and died.

In each year and in both species, the incidence of overwintering diapause increased from low levels in mid March to peak in late April or early May. The peak diapause levels in H.punctigera were significantly lower than those in H.armigera. In H.punctigera, diapause incidence was significantly greater in males than in females. Differences between sexes were not significant in H.armigera.

Daylength and temperature were important factors influencing the induction of diapause in both species. Multiple linear regressions incorporating daylength (expressed as time) and temperature explained approximately 79% of the variation in diapause incidence under field cages. These functions will be used to predict autumnal diapause incidence in each species.

Spring emergence from diapause

In each year, H.punctigera emerged from diapause before H.armigera. The time to 50% emergence was 13-16 days earlier in H.punctigera. Peak emergence periods were between early September and mid October in H.punctigera and between early October and early November in H.armigera. In both species, females emerged before males; 50% emergence of females was 11-16 days earlier than males in H.punctigera and 3-8 days earlier in H.armigera. The time of emergence after 30 June increased as pupal depth increased. In H.punctigera, a small proportion (<5%) of overwintering pupae did not emerge until summer.

Spring emergence of diapausing pupae placed at 25 and 50 mm depth in artificial burrows was investigated at Kingsthorpe and Emerald. At Kingsthorpe, these emergence patterns were compared with emergence patterns under field cages and male moth captures in pheromone traps. Emergence at Emerald was completed before emergence started at Kingsthorpe.

In 1986 and 1987, asynchrony between local emergence of overwintering pupae and pheromone trap captures at Kingsthorpe indicated that local populations were not the source of the major spring flights of either species on the Darling Downs. The origin of these spring moth populations is uncertain. In 1988, there was apparent synchrony between local emergence from overwintering and pheromone trap captures. Moth numbers trapped at the Kingsthorpe site were lower in 1988 than in 1986 and 1987, further suggesting that immigration was less important in 1988.

Various models which could be used to predict spring moth emergence were evaluated. A simple cumulative heat unit model developed from the emergence data from the artificial burrows satisfactorily predicted spring emergence under cages on the Darling Downs. Validation of a spring emergence model developed in the Namoi Valley for *H.armigera* (Cunningham *et al* 1979) was also carried out.

ACHIEVEMENT OF RESEARCH RELATIVE TO OBJECTIVES

Our study represented one section in a collaborative program involving researchers from QDPI, CSIRO, UNE and UQ, aimed at improving our understanding of the *Heliothis* life system.

The first objective was successfully achieved, the second objective came to less successful fruition.

Crop sampling for immatures and pheromone trapping for adults defined the seasonal phenology and abundance of *Heliothis*. Detailed studies quantified important mortality factors affecting the immature stages of *Heliothis* spp. in the Darling Downs agroecosystem. The considerable variation in survival rates between crops and between fields of a particular crop grown at different times during the season demonstrate the dynamism in the numbers of *Heliothis* generated in this region.

These data facilitated the preliminary assessment of the area-wide management approach. This strategy essentially aims to suppress seasonal pest numbers to low levels throughout an entire ecosystem, by a radical reduction of the first spring generation using a range of techniques; mass release of parasites and predators, application of pathogens, autocidal techniques and destruction of spring hosts.

Although some mortality effects, for example weather, are difficult to predict, natural events in Spring 1988 support the practicality of using the area-wide management strategy of F1 generation control.

The concept of area-wide suppression where and when the population is small and localized deserves more careful consideration and much further research. Inevitably, the decision to move in this direction will be a political one.

RECOMMENDATIONS FOR FUTURE RESEARCH

The *Heliothis* life system is complex and demanding of a well-coordinated, multidisciplinary research effort to clarify intra- and interregional population dynamics. Such an approach is expensive but is more likely to produce worthwhile results than any fragmented effort.

Within cropping systems, mortality of *Heliothis* during the egg and early instars is usually very high, but subsequent mortality is low. The more important mortality factors are weather (over which we have no control) and host plant effects. Although predation, parasitoids and pathogens may, in some situations, be important mortality factors, they are generally unreliable and ineffective in providing economic control.

As our reliance on insecticides for Heliothis management on a crop by crop basis must be reduced, alternative management tools need to be developed. Research areas indicated by our study which offer prospects for control include the evaluation of biocontrol agents for inundative and/or augmentative release, the enhancement of pathogenic activity in disease organisms suitable for biological insecticide formulations, and continuing development of plant varieties with improved insect-resistant characteristics (although we should broaden our awareness of what suitable resistance characteristics might be).

While predators can have a very great impact on low-density Lepidopteran populations, parasitoids are the first choice as biocontrol agents as they are generally the easier to mass produce and their target usually the more specific. Work is already underway to evaluate egg parasites for inundative release programs, where they will be used as biological insecticides to obtain high levels of Heliothis egg mortality.

The use of Microplitis (and even exotic parasitoids) has been suggested, due to the recognised ability of this wasp to decimate populations of medium sized (fourth instar) larvae in certain crops, even under heavy insecticide regimens. Whereas this parasitoid may be unsuitable for control programs in cotton, it would be suitable for inundative release in other crops (e.g. sunflower) where damage occurring prior to death at the medium sized larval stage is not so economically important. Such parasitoids can play an important role in overall population management through intergenerational effects, as well as for intragenerational reductions in pest numbers in these more economically tolerant crops.

The sporadic importance of pathogens, in particular virus (NPV), in reducing Heliothis infestations was evident during our study, but further work is needed before placing increased reliance on these agents.

Various host plant effects were observed during the study which highlighted the potential value in pursuing host plant resistance.

The need to have a better understanding of Heliothis ecology was the catalyst for our project. While our knowledge is greatly improved, further research will be necessary before the area-wide suppression of Heliothis can be properly tested. The advantages of such an approach are clear. A study of adult movement is one area warranting specialist attention as it could be crucial in determining the success of any future area-wide management approach.

LIST OF PUBLICATIONS

Titmarsh,I. and Murray,D. 1986. *Heliothis* research on the Darling Downs. *The Australian Cottongrower* 7,36-37.

Murray,D.A.H. and Titmarsh,I.J. 1988. Population dynamics of *Heliothis* on the Darling Downs. *Proceedings of the Australian Sunflower Association 7th Workshop*, Moama, N.S.W. 47-49.

Murray,D.A.H. 1988. Survival of *Heliothis* spp. pupae in field cages on the Darling Downs. *Proceedings of the 1988 Australian Cotton Conference*, Surfers Paradise, Queensland. 95-100.

Titmarsh,I. 1988. Survival of *Heliothis* eggs and larvae on Darling Downs crops. *Proceedings of the 1988 Australian Cotton Conference*, Surfers Paradise, Queensland. 101-105.

Murray,D.A.H. 1989. Predatory role of *Agrypnus* sp. (Elateridae) larvae in field crops. *Proceedings of a Soil-dwelling Invertebrates Workshop*, Brisbane. 3pp.

Murray,D.A.H. (1990) Survival of *Helicoverpa punctigera* (Wallengren) and *H.armigera* (Hubner) (Lepidoptera: Noctuidae) pupae submerged in water. *Journal of the Australian Entomological Society*. (in press).

Murray,D.A.H. (submitted to journal) Effect of soil moisture and simulated rainfall on pupal survival and moth emergence of *Helicoverpa punctigera* (Wallengren) and *H.armigera* (Hubner) (Lepidoptera: Noctuidae). *Journal of the Australian Entomological Society*.

Murray,D.A.H. and Wilson,A.G.L. (submitted to Editor). Methods for studying diapause. in *Handbook of Methods in Heliothis Research* M.P. Zalucki Editor (in preparation).

Titmarsh,I.J., Zalucki,M.P., Room,P.M., Evans,M., Gregg,P.C. and Murray, D.A.H. (submitted to Editor). Estimating the abundance of adults and immatures. in *Handbook of Methods in Heliothis Research* M.P. Zalucki Editor (in preparation).

Room,P.M., Titmarsh,I.J., Murray,D.A.H. and Zalucki,M.P. (submitted to Editor). Life-tables for *Heliothis*. in *Handbook of Methods in Heliothis Research* M.P. Zalucki Editor (in preparation).

Copies of published articles are attached.

Several publications are at various stages of preparation. Details of proposed publications are –

Murray,D.A.H. The incidence of pupal diapause in *Heliothis punctigera* Wallengren and *H.armigera* (Hubner) in southeast Queensland.

Murray,D.A.H. Comparison of *Heliothis armigera* (Hubner) moth emergence patterns under sunflower, maize and sorghum.

Murray,D.A.H. Overwinter survival of *Heliothis punctigera* Wallengren and *H.armigera* (Hubner) in southeast Queensland.

Murray,D.A.H. Distribution and abundance of *Heliothis punctigera* Wallengren and *H.armigera* in southeast Queensland.

Murray,D.A.H. Thermal requirements for diapause termination in *Heliothis punctigera* Wallengren and *H.armigera*.

Murray,D.A.H. Prediction of spring emergence in *Heliothis punctigera* and *H.armigera* in southeast Queensland.

Murray,D.A.H. and Titmarsh, I.J. A model for population dynamics of *Heliothis* species in Darling Downs agricultural systems.

Titmarsh, I.J. Lifetables for *Heliothis* spp. infesting major crops grown on the Darling Downs.

Titmarsh, I.J. Analysis of *Heliothis* spp. lifetables.

Titmarsh, I.J. Survival of *H.armigera* and *H.punctigera* eggs submerged in water.

Titmarsh, I.J. Survival of *H.armigera* and *H.punctigera* larvae submerged in water.

Titmarsh, I.J. The incidence and abundance of *H.armigera* and *H.punctigera* and their natural enemies in two agricultural systems (irrigated and raingrown) on the Darling Downs.

Titmarsh, I.J. Calculations of temperature-driven development for *Heliothis* species on the Darling Downs.

Titmarsh, I.J. Precision of a common technique used for fast assessment of larval densities over a range of major crops.

Titmarsh, I.J. The survival of *H.armigera* and *H.punctigera* eggs exposed to a range of temperature and relative humidity combinations.

Titmarsh, I.J. The potential for *H.armigera* and *H.punctigera* eggs affected by a range of temperature and relative humidity combinations to be re-hydrated.

Titmarsh, I.J. The survival of *H.armigera* and *H.punctigera* larvae exposed to a range of temperature and relative humidity combinations.

Presentations were made at field days and grower meetings on several occasions, as well as newspaper releases about relevant research findings.

Two seminars were presented jointly by D. Murray and I. Titmarsh -

17 September 1985. The role of stage survival to the population dynamics of Heliothis spp. on the Darling Downs. Entomology Department, University of Queensland, Brisbane.

14 August 1987. Ecological studies for better Heliothis control. Entomology Branch, Queensland Department of Primary Industries, Brisbane.

I. Titmarsh presented a student talk on Heliothis ecology to 4th year Queensland Agricultural College students on 4th October 1989.

D. Murray presented a seminar entitled 'Pupal survival studies for interpretation of Heliothis population dynamics' on 10 October 1989 at Entomology Department, University of Queensland, Brisbane.

I. Titmarsh will present a seminar entitled "Survival of Heliothis immatures on Darling Downs crops" at Entomology Department, University of Queensland, on 23rd March 1990.

David Murray
Senior Entomologist

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Entomologist

Heliothis Research On The Darling Downs

I. Titmarsh and D. Murray, Queensland Department of Primary Industries, Toowoomba

Entomologists enjoy conferences and workshops as much as any other directed-interest group and during a workshop on *Heliothis* ecology last July, as often happens in gatherings such as these, some chickens came home to roost.

Convenor Tom Passlow (Director, Entomology Branch, Q.D.P.I.), was fast to point out that, given massive increases in areas planted to crops in recent decades and major agricultural expansion into inland regions, we now have a continuum of host plants over a vast area of eastern Australia. Thus large areas of economic host material are available to *Heliothis* infestation from early spring to late autumn.

Although progress has undoubtedly been made in rationalising *Heliothis* control, our management of these amazingly damaging insects continues to rely on insecticides even though this reliance has become more realistically based. Tom profferred two questions — "Is progress in *Heliothis* control being made sufficiently rapidly?" and "Are the most attractive areas for advancing our knowledge in *Heliothis* control being covered?"

MANAGING HELIOTHIS

In a soon-to-be-published critical review of the technical literature on past *Heliothis* research (Zalucki *et al* in press), virtually all management-control papers related to particular crop situations (e.g. *Heliothis* in cotton, *Heliothis* in sorghum, etc.). Few addressed the much bigger issue of managing *Heliothis* in a broad ecological sense.

Chicken 1: This highlighted large gaps in our knowledge of the basic biology and population dynamics of the two important *Heliothis* species, *H. armigera* and *H. punctigera*, and **Chicken 2:** within a likely scenario of further expansion in acreages planted to susceptible crops and anticipated insecticide resistance problems while dependence on chemicals continues, the absence of effective alternative control techniques courts disaster.

Entomologists have recognised being at the end-of-the-line with the concept of *Heliothis* management based on individual crops in isolation. A more realistic approach is researching the overall "lifestyle" or ecology of the species, considering crops and insecticides only for their effect on *Heliothis* population size — the reverse of considering the size of any *Heliothis* effect on individual crop yield.

Professor Rhondda Jones (Zoology Department, James Cook University of North Queensland), discussed several research directions necessary to provide the information on which comparisons of *Heliothis* populations can be based. These involved the study of —

- Seasonal abundance of *H. armigera* and *H. punctigera* and local variation in densities of their immature stages on different crops. Meaning how many of them are on what, where and when.

- Variation in factors affecting survival of populations of immatures. This defines crops, areas, times and conditions that are favourable to survival allowing infestation of later crops and lists active mortality agents — the absence or low efficacy of which may be artificially enhanced (e.g. through the inundative release of parasites, etc.).

- How *Heliothis* species survive adverse seasons. Implicit here is their entry and exit from diapause (a state of arrested development) which effectively times their seasonal activity and can determine whether they are major pests or mere nuisance value in certain areas.

- Mobility and migration. Whereas anomalies in seasonal abundance data when compared to light or pheromone catches of moths can indicate the occurrence of *Heliothis* migration, this aspect seeks to answer the importance of migrants to local population dynamics and find how far they have come.

What has all this got to do with the Darling Downs? Well with the exception of the mobility and migration consideration which requires super-expensive radar systems and other sophisticated equipment, a new *Heliothis* population dynamics study which embraces the other three areas of concern now has one complete season's data for two regions on the Downs.

For seasonal abundance, crop fields in the irrigated area between Cecil Plains-Brookstead and the dryland area around Mt. Maria were sampled for medium to large *Heliothis* grubs which were collected and returned to the laboratory. These yielded data on levels of parasitism, disease incidence and the proportion of any infestation that was *H. armigera*. Results from crops hosting both *H. armigera* and *H. punctigera* (chickpea, soybean, sunflower) show that —

- the impact of natural enemies on egg and caterpillar stages in early season is negligible;
- the *H. armigera* proportion within infestations tends to increase over the season;
- disease incidence decreases and parasitism levels increase as the season progresses.

PUPATION TIME

Egg and larval survival were studied through marking "cohorts" of individuals (i.e. groups of eggs laid on the same night) and then continually observing them as they developed on plants up to the time that they pupated in the soil. Although data analysis is incomplete, it was obvious that considerable differences exist between crops in *Heliothis* numbers surviving to pupation.

As has been shown in North Queensland tobacco (Titmarsh 1985), mortality hit the egg and smallest caterpillars hardest but factors responsible could not be identified from direct observation. This means that predation by other insects and weather are important in causing death. Just how important each is can be determined in coming seasons by manipulating the experimental technique and carefully measuring weather conditions so that accurate mathematical equations can be prepared.

In light of these results it is possible that *Heliothis* mortality could be supplemented in early season through "doping" crops with disease organisms or by inundative releases of egg or larval parasites into crops. This may be of particular use in chickpea where the data support the suspicion that this crop can act as a *Heliothis* source for infestation of later crops.

Preliminary studies on pupae showed that survival to the moth stage of large caterpillars allowed to pupate in the ground within cages was high at about 75%. However, about a fifth of these moths were trapped underground by the crusted soil surface and subsequently died.

Similar survival was recorded for pupae from under crops of sunflower, maize and sorghum but moth emergence was 2 to 3 days earlier from under sunflower where soil temperatures are higher due to less shading effect of the foliage. Drowning of pupae during irrigation or by thunderstorms can probably now be ignored since 48 hours of complete submersion in rainwater could kill only half of the tested pupae — so only prolonged periods of wet weather could be expected to have any effect.

High levels of parasitism were recorded in pupae excavated from fields of sunflower and sorghum with the overall pupal survival rate being about 20%. Activity of predators and diseases was low.

TYPICAL DIAPAUSE PATTERN

Some pupae (22%) of *H. punctigera* were found to enter diapause during October and November and required longer times to develop, though most emerged in January. This was a surprise! Both species showed typical autumn diapause patterns, a small proportion of individuals entering diapause in mid-March with most entering diapause by late May. By studying spring emergence times of these individuals we can gauge whether early season populations consist mainly of emerged local moths or of immigrants to the region.

So what? From the point of view of *Heliothis* management, the most important question is "How important are migrants to local population dynamics and how far have the migrants come?" (Jones 1986). If local work proves the answer to be "critically important and a very long way," control will be restricted to finding ways to increase local mortality rates or to discourage prospective immigrants.

If *Heliothis* are both generated and move relatively locally, we can also interfere with source populations to limit the size of successive generations — a strategy of regional management. This concept is currently being discussed with some enthusiasm in the technical literature under the name Area Wide Management.

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Jones, R. E. (1985). Spatio-temporal dynamics of *Heliothis* populations in Australia. Proceedings *Heliothis* Ecology Workshop, Brisbane.

Titmarsh, I. J. (1985). Population dynamics of *Heliothis* spp. on tobacco in far North Queensland. M.Sc. Thesis, James Cook University. 266pp.

Zalucki, M. P., Dagleish, G., Firempong, S. and Twine, P. J. (in press). The biology and ecology of *Heliothis armigera* (Hubner) and *Heliothis punctigera* Wallengren (Lepidoptera:Noctuidae) in Australia: What do we know? Aust. J. Zool.