

THE SURVIVAL OF HELIOTHIS ARMIGER (HÜBNER)
(LEPIDOPTERA : NOCTUIDAE)
EGGS ON COTTON PLANTS IN RELATION TO SIMULATED RAIN AND
OVERHEAD IRRIGATION

Dissertation submitted to Rhodes University for the
degree of Master of Science.

by

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Irrigation in a cotton field,



the droplets and



eggs of Heliothis armiger.

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RÉSUMÉ

Crop pests are known to be adversely affected by rain. Because limited information on this aspect was available for Heliothis spp. occurring on cotton, this study was undertaken to examine the effect of water droplets from overhead irrigation and simulated rain on the survival of H. armiger eggs on cotton. Three aspects were examined: the effects of submersion, the physical impact of droplets on the eggs and the washing off of the eggs from cotton plants in the field.

The first two aspects were examined in terms of the structure and respiratory system of the eggs, confirming that H. armiger eggs are able to survive initial wetting in the field.

The wash-off of H. armiger eggs from cotton plants is explained in the light of the selection of oviposition sites by the moths, adhesion of the eggs to the plant parts and the dislodging and wash-off by water from simulated rain and overhead irrigation. The data are discussed in terms of the other mortality factors which occur in commercial cotton fields.

All in all, it was found that while overhead irrigation should be taken into account in surveys of H. armiger for pest management purposes, it does not offer a viable control strategy and should not be investigated further.

CHAPTER 1

INTRODUCTION

The Heliothis complex of bollworm species are important pests of cultivated cotton throughout the world (Hardwick 1965; Farrar & Bradley 1985). In South Africa Heliothis armiger (Hübner) is the key pest of cotton, and pest control strategies centre around it (Broodryk et al. 1974). Many integrated pest management programmes have been developed to combat Heliothis spp. and other cotton pests in many parts of the world (Dinkins et al. 1971; Adkisson 1972; Bottrell & Adkisson 1977; Henneberry et al. 1980; Waite 1983). Cultural control practices have received a great deal of attention, including, for example, the use of resistant varieties, uniform planting dates, cotton-free periods, early crop maturity, trap crops, fertilization, hand picking of pests and the destruction of host plants and infested plants, all playing prominent roles in the suppression of cotton pests (Adkisson 1958; Hayward 1972; Reed 1974; Bottrell & Adkisson 1977; Henneberry et al. 1980; Slosser 1980). However, the effect of overhead irrigation and rain on cotton pests has been largely ignored and is the subject of this study.

THE COTTON INDUSTRY IN SOUTH AFRICA

Cotton is the world's most important natural fibre crop, being cultivated on more than 30 million hectares of land in some 80 countries (Bottrell & Adkisson 1977) and is vital to the textile industry in South Africa. With an estimated producers' income of in excess of R100 million for the 1984/85 season, cotton ranks among the top five cultivated field crops in South Africa (Abstract of Agricultural Statistics 1985). With an annual shortfall of approximately 30% of domestic

requirements (Cotton Board 1984/85), the full potential of cotton production has not been realised locally.

Commercial cotton, Gossypium hirsutum (L.), family Malvaceae, belongs to the American Upland type (Prentice 1972) with the relatively smooth Acala cultivars dominant in South Africa. The more hairy types of cotton, such as the cultivar Rebel, contribute only about 2% of the cotton planted (Cotton Board 1984/85). About 80,000 - 90,000 ha of cotton are planted annually, of which about 45% is irrigated by overhead irrigation through conventional or self-driven centre-pivot systems (Cotton Board 1985).

WATER REQUIREMENTS OF THE GROWING COTTON PLANT

Successful cultivation of cotton depends largely on the correct quantity and timing of irrigation. The standard practice is to wet the ground to field capacity to a depth of about 1,8 m before planting, followed by a stress period of 6 weeks after plant emergence (De Kock 1977). The stress period stimulates the development of an effective root system, and prevents the development of excessive foliage, thus allowing for better penetration of pesticides in later insecticide applications. From the onset of the flowering period, regular irrigation is essential to prevent wilting. The most crucial water requirement is during the main flowering phase, between about 10 and 17 weeks after plant emergence (Metelerkamp & Cackett 1965; Dippenaar 1980; Grobbelaar 1986), the period central to this study. During this main flowering phase, which coincides with the main oviposition period of H. armiger on cotton, approximately 50 mm of water is needed weekly (Metelerkamp & Cackett 1965; Grobbelaar 1986). De Kock (1977) recommended an interval of 10 to 12 days between applications of irrigation.

HELIOTHIS ARMIGER CONTROL IN SOUTH AFRICA

Anneck & Moran (1982) and Moran (1983) identified H. armiger as the most important pest of crops in South Africa. This is supported by the fact that Bot et al. (1986) list 19 registered chemical groups of insecticides for the control of H. armiger on 27 different crops. On cotton 15 of these groups are registered to control H. armiger.

H. armiger can destroy 470 - 1 233 kg of seed cotton per ha (Basson & Pretorius 1978). Gledhill (1976) reported a similar loss of 1 350 kg/ha in Zimbabwe. These potential losses render pest control one of the major items in production costs. This varies between 11% and 19% of the total, that is 7 - 9 pesticide applications per season for irrigated cotton (Mumford & Van Hamburg 1985). To curtail these costs, a pest control strategy, based on integrated pest management (Van Hamburg 1981; Van Hamburg & Kfir 1982; Mumford & Van Hamburg 1985; Basson 1986) was implemented, and depending on the managerial skills of the producer, current pest control costs can now be reduced to below 10% (3 - 5 pesticide applications per season) of the total production costs.

EFFECT OF RAIN AND OVERHEAD IRRIGATION ON COTTON PESTS

Rain and overhead irrigation affect the population dynamics of pests. Miskimen (1970), Singh et al. (1974), Gross et al. (1976), Maelzer (1977), Samways (1979), Olcott-Reid et al. (1981) all reported a decline in insect populations following rain. Sharma & Pande (1985) showed that red spider mite populations were relatively susceptible to rain on smooth, non-hairy plant leaves, and Botha (1986) showed a 20% decline in red spider mite populations on cotton after overhead irrigation. With regard to the influence of

rain on Heliothis spp. on cotton, the available references are, however, vague. For example, Pearson & Darling (1958), Meng et al. (1961), Hardwick (1965) and Wu (1983), indicate that rainfall plays an important role in reducing the populations of Heliothis spp., either by disturbing their oviposition or by the physical dislodging and wash-off of the eggs from the plants. However, none of these authors quantified the loss of eggs in relation to the intensity of rainfall. Room (1976) was the first to examine this aspect more closely by exposing H. armiger and H. punctigera Wallengren eggs, oviposited on cotton, to simulated raindrops from a domestic garden sprinkler and shower rose. He concluded that between 30% and 50% of all eggs will be dislodged under "... any moderately heavy rain lasting more than 10 minutes." Mabbett (1983) found that under "heavy rainstorm" conditions 78 - 81% of eggs were washed off young plants. The observations of these authors all indicate that the physical forces exerted by water droplets on the eggs of Heliothis spp. reduce pest populations.

H. armiger populations, cotton plant development and water requirements of the plants show a close relationship (Fig. 1), and clearly indicated the need to quantify the effects of rain and overhead irrigation on the wash-off of H. armiger eggs from cotton plants.

THE CONTENTS AND SEQUENCE OF THE THESIS

The study was based on the hypotheses that:

- (i) The submersion of eggs in water during rain or overhead irrigation may affect egg respiration and perhaps kill the embryos.
- (ii) Features of H. armiger moths and the nature of oviposition substrates will influence the adhesion of eggs to cotton plants.

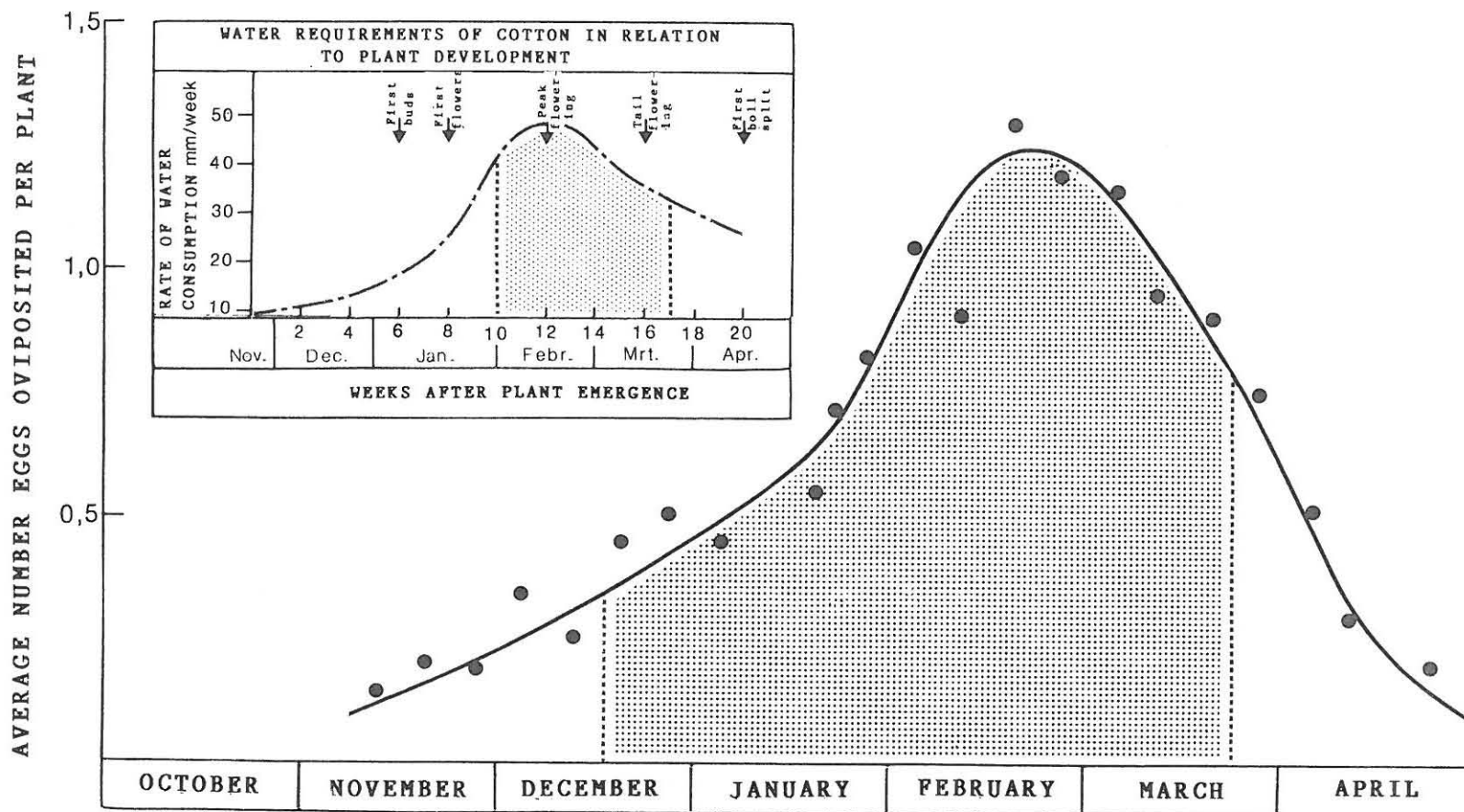


Fig. 1. Numbers of *Heliothis armiger* eggs in field cotton (main graph) and the water requirements (insert) of cotton in relation to the peak flowering period (shaded areas). The oviposition data represent average numbers of eggs per plant from 1971 to 1981 (Departmental Progress Reports, Project (A) I Pr. 110: Integrated cotton pest control, Plant Protection Research Institute). The insert shows water requirements, adapted from Grobbelaar (1986). The peak flowering periods in both graphs are those of Metelerkamp & Cackett (1965), Dippenaar (1980) and Grobbelaar (1986). The range in flowering periods in the main graph is wider than would be expected for any one season, and is due to planting dates which ranged from mid-October to mid-December. The planting date for the flowering period in the insert was mid-November.

(iii) The physical action of water droplets will dislodge and wash the eggs from the plants.

Chapter 2 deals with the techniques developed in the study. The culture and selection of H. armiger moths, to provide eggs which could be used in laboratory and field trials, is explained. A prerequisite for the field trials was to study fundamental aspects of the adhesion and wash-off of the eggs under controlled laboratory conditions. This entailed the design and construction of a laboratory irrigation simulator. Complete specifications are given since no suitable apparatus was available. In addition, the operation of two commercial overhead irrigation systems and a field rainfall simulator are described.

In order to study the action and physical characteristics of the droplets produced by the laboratory irrigation simulator and the commercial systems, the nature of the droplets are discussed in Chapter 3 in terms of their spray patterns and kinetic energy. These characteristics are related to droplet size, a simpler and more useful criterion in field studies than kinetic energy.

A general description of the biology of H. armiger, with emphasis on the morphological structure of the eggs in relation to egg respiration and oviposition behaviour of moths on cotton, is given in Chapter 4. This information is supported by laboratory experiments on egg respiration and field surveys of oviposition sites on cotton plants selected by field as well as laboratory-reared H. armiger moths.

Chapter 5 deals with the factors potentially influencing egg adhesion to cotton plants. These include factors relating to H. armiger, namely egg fertility, moth age, number of eggs laid per night per

moth and egg age, as well as external factors, including droplet sizes, periods that eggs were exposed to droplets to receive a 50 mm precipitation, angles at which droplets strike the eggs and the presence of hairs on cotton leaves. It was necessary to study these aspects in order to examine the physical wash-off of eggs from cotton plants by two commercial overhead irrigation systems and a rainfall simulator which are described in Chapter 6.

Finally, in Chapter 7 the results are discussed in terms of the overall survival of H. armiger egg populations. It is concluded that growers should take cognizance of the wash-off of H. armiger eggs when surveying for pests, but that irrigation cannot be employed as a control strategy and that the influence of irrigation on H. armiger survival does not deserve further research.

CHAPTER 2

GENERAL MATERIALS AND METHODS

In this chapter the methods used to culture H. armiger, and the selection of moths for oviposition experiments are described. Categories of oviposition sites and egg-marking techniques on field-grown cotton are given. Finally, the irrigation systems and simulators used are described. Further details of experiments are given in context. For statistical analyses the programs of the Directorate of Datametric Services, Department of Agriculture and Water Supply, were used.

REARING OF HELIOTHIS ARMIGER

A laboratory culture of H. armiger was started with larvae collected on cotton in the Transvaal, and has been maintained at the Plant Protection Research Institute in Pretoria since 1975 (that is for about 100 generations). The cultures were kept under temperature and humidity conditions of 25 - 27°C and 60 - 70% R.H. Natural photoperiods were maintained. Daylight from windows was supplemented by overhead fluorescent tubes. Semi-aseptic routines (Smith 1966) were adequate for keeping the cultures free of disease organisms.

About 15 male and 15 female moths (the greenish males are distinct from the brownish females) were placed in an oviposition cage, consisting of 5 litre Perspex jars with cloth-netting lids. The cages contained a layer of vermiculite and a Petri dish with some cotton wool, soaked in 7% sucrose solution in water for the moths to feed on. The females deposited their eggs after about three days on the lids of the cages. Larvae collected from the lids were reared singly in glass tubes on a Shorey & Hale (1965) diet in which kidney beans were

substituted for pinto beans. Pupae were removed from the tubes, and left to emerge in the oviposition cages.

MOTH SELECTION FOR OVIPOSITION EXPERIMENTS

Three days before eggs were needed for experiments, 25 newly-hatched females and 12 males from the culture were placed in two mating cages, and held in the laboratory. After 4 days individual females were transferred to 90 mm Perspex Petri dishes, with a layer of damp cotton wool and a mature cotton leaf to serve as an oviposition substrate, and left overnight. The eggs laid on the upper surface of 32 leaves were counted after removing clusters of eggs. The cotton variety Acala 1517/70 was used throughout as a standard host plant for laboratory as well as for field trials. The variety Rebel was only included for studies of plant characteristics. Alternatively, cotton leaves on moist cotton wool in trays were exposed to groups of 40 mated females and 12 males. The males were included in case some of the females needed to mate again. The trays were covered with plastic and ventilated. The leaves with eggs were randomly selected and exposed to the laboratory irrigation simulator (Appendix 1). In both cases the eggs from the controls and those remaining on the leaves after exposure were incubated to record fertility and larval development.

To obtain eggs from field populations of H. armiger, a black-light trap fitted to a large cage (Fig. 2) was used to collect live moths. The procedures described for collecting the eggs of individual moths were followed to collect eggs for exposure to the laboratory irrigation simulator.



Fig. 2. Black-light trap used to collect live Heliothis armiger moths in the field. The cage (1 x 1 x 1,8 m) was sited at the Hartebeespoort Research Station (Fig. 6), next to a cotton field at the peak flowering stage.

OVIPOSITION SITES IN FIELD COTTON

A flood-irrigated 1,5 ha cotton field on the Experimental Farm Hartebeespoort (Fig. 6) was surveyed in the 1982/83 and 1983/84 seasons to determine the distribution of natural populations of H. armiger eggs on individual cotton plants. Fifty healthy plants were randomly selected each week in the field from seven to sixteen weeks after planting and searched for H. armiger eggs. Plant heights were routinely recorded and the positions of the eggs grouped according to the oviposition sites illustrated in Fig. 3.

OVIPOSITION ZONES

OVIPOSITION SITES

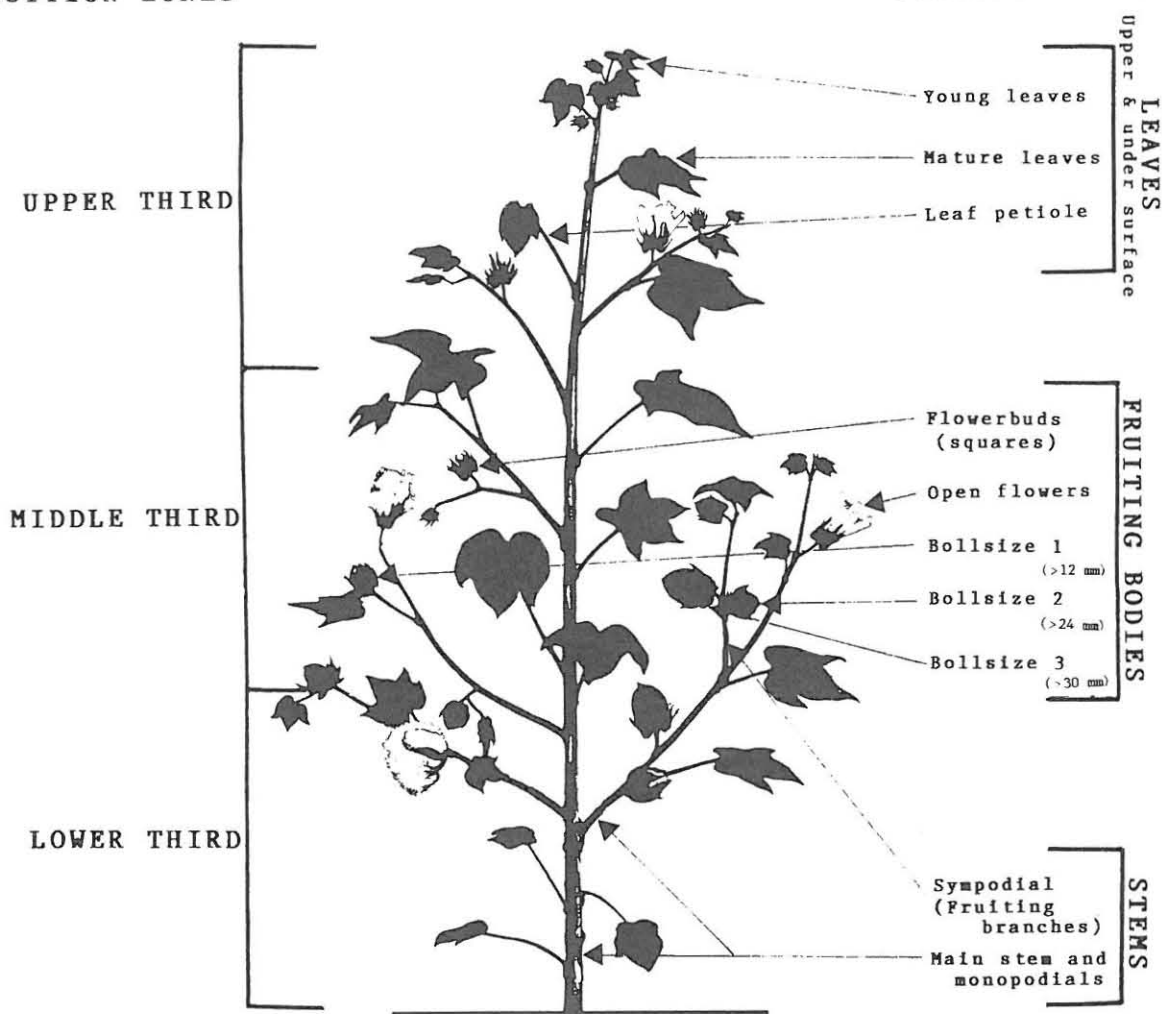


Fig. 3. Diagram of a cotton plant indicating oviposition sites for Heliothis armiger moths. "Fruiting bodies" is used in this study for all reproductive structures.

To infest plants with H. armiger eggs, 50 female and 20 4 - 5-day-old males from the laboratory culture were introduced into gauze-covered cages (Fig. 4) which were large enough to cover three mature plants for two successive nights as suggested by Johnson et al. (1975). The same categories of oviposition sites, described for naturally-laid eggs (Fig. 3) were used.



Fig. 4. Oviposition cage (1,5 x 1,5 x 1,8 m) used to "seed" field grown cotton with Heliothis armiger eggs in the observation areas in the irrigation and simulated rain experiments. The moths were released in the late afternoon in the cages to avoid stress due to high day temperatures (Hillhouse & Pitre 1976). To exclude rain during the oviposition period the tops of the cages were covered with plastic sheeting. See Figs 37 (Appendix 2), 38 (Appendix 3) and 39 (Appendix 4) for actual positions of the observation areas in experiments.

The locations of individual H. armiger eggs were marked and numbered with acrylic paint (Fig. 5), prior to each wash-off experiment.

IRRIGATION AND SIMULATED-RAINFALL SYSTEMS

A laboratory irrigation simulator (Appendix 1), a conventional overhead irrigation system (Appendix 2), a centre-pivot irrigation system (Appendix 3) and a rotating-boom rainfall simulator (Appendix 4) were evaluated in terms of their wash-off effect on H. armiger eggs from cotton plants. The exposure times to



Fig. 5. The method used for marking the positions of Heliothis armiger eggs on cotton plants. Egg positions were circled with acrylic paint (left) and provided with a reference number (right). Oviposition zones (Fig. 3) within plants were identified with different coloured paint.

the various systems were adjusted to allow for a precipitation of about 50 mm per application, in practice, according to Metelerkamp & Cackett 1965, Dippenaar 1980 and Grobbelaar 1986, the approximate weekly water needs of cotton during the main flowering period (Fig. 1). The precipitation was measured with commercial rain gauges, which were located in areas corresponding to the siting of the experimental plots. Details of the experimental sites are given in Fig. 6. The nature of the droplets produced by the irrigation systems and simulators are described in context in Chapter 3.

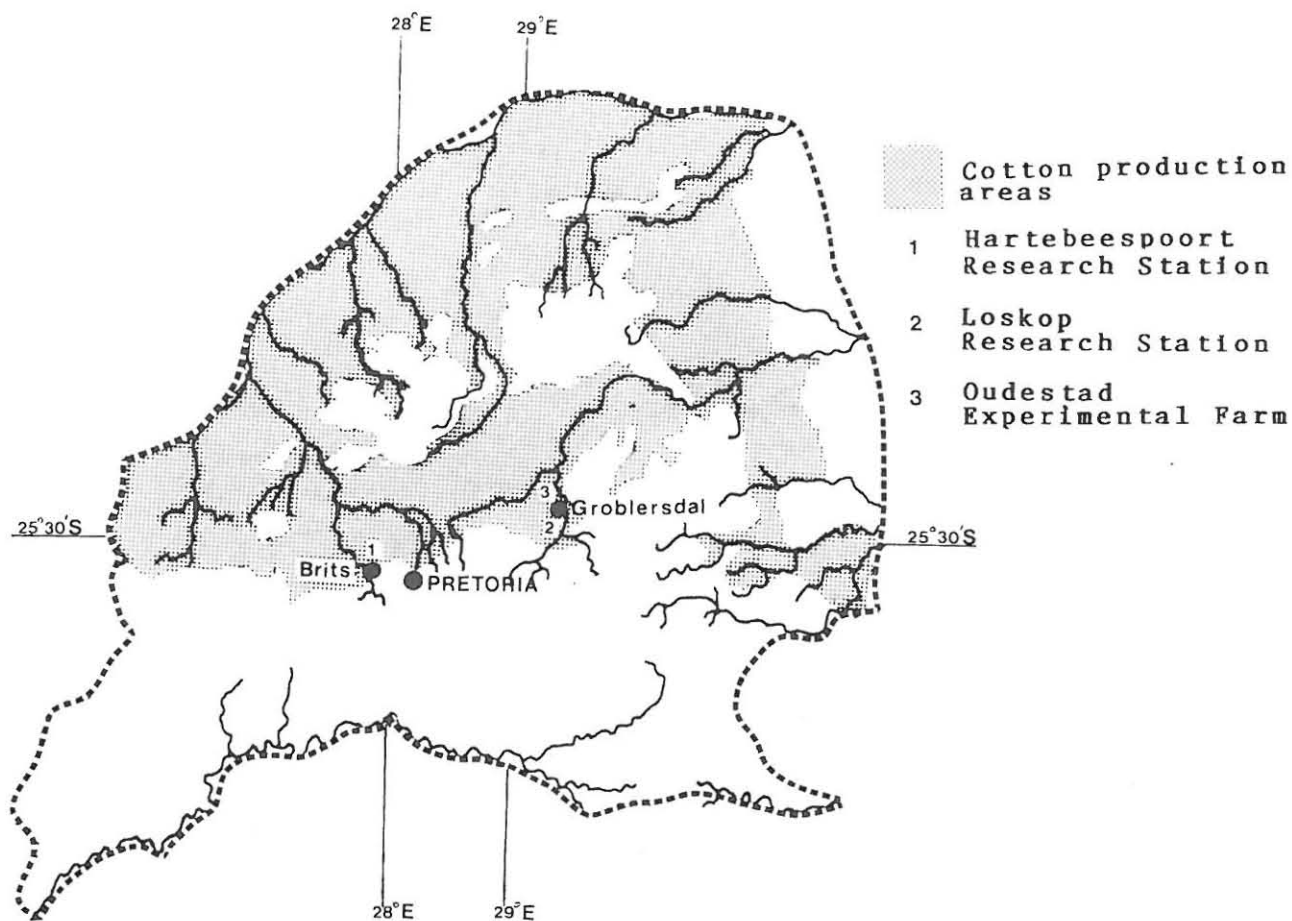


Fig. 6. The Transvaal, showing the cotton-production areas with a frost-free growing season of more than 200 days (Serfontein 1970), experimental sites and nearby towns. Oudestad is an Experimental farm of the Eastern Transvaal Co-operative, while Loskop and Hartebeespoort are Research Stations of the Department of Agriculture and Water Supply.

CHAPTER 3

DROPLET STUDIES

This chapter deals with the physical characteristics of the droplets from a laboratory irrigation simulator (Appendix 1), commercial irrigation systems (Appendices 2 and 3) and a field rainfall simulator (Appendix 4), studied in terms of spray patterns and their energy.

SPRAY PATTERNS

To measure droplet sizes, the absorbent filter paper technique (Laws & Parsons 1943; Morin et al. 1967) was employed. "Wye Valley" filter paper, dusted with powdered potassium permanganate was exposed to falling droplets. On the paper, the droplets cause distinct purple/brown stains. Laws & Parsons (1943), however, outlined several important shortcomings of this method, all of which influence blotch diameters. These are variation in the thickness of batches of filter paper, moisture of the filter paper and velocity of the droplets. Although the filter paper method is less accurate than the flour-pellet method (Burney 1968) or the oil-pan method (Gunn & Kinzer 1949) it was the only practical method under field conditions. The objections of Laws & Parsons (1943), were partially overcome by using a single batch of filter paper stored under constant temperature and humidity conditions (25°C, 40% R.H.).

To determine the spread factor of the droplets for the filter paper used, a laboratory apparatus, illustrated in Fig. 7, was built to collect droplets ranging from 1,9 to 4,6 mm diameter at free-falling heights of 0 - 3,0 m. The actual droplet sizes and blotch patterns obtained for some of the droplets are shown in Fig. 8. The splashing caused by the bigger droplets agrees with

the findings of Laws & Parsons (1943), but were ignored in the measurements of the droplets. The results of this experiment are presented in Fig. 9.

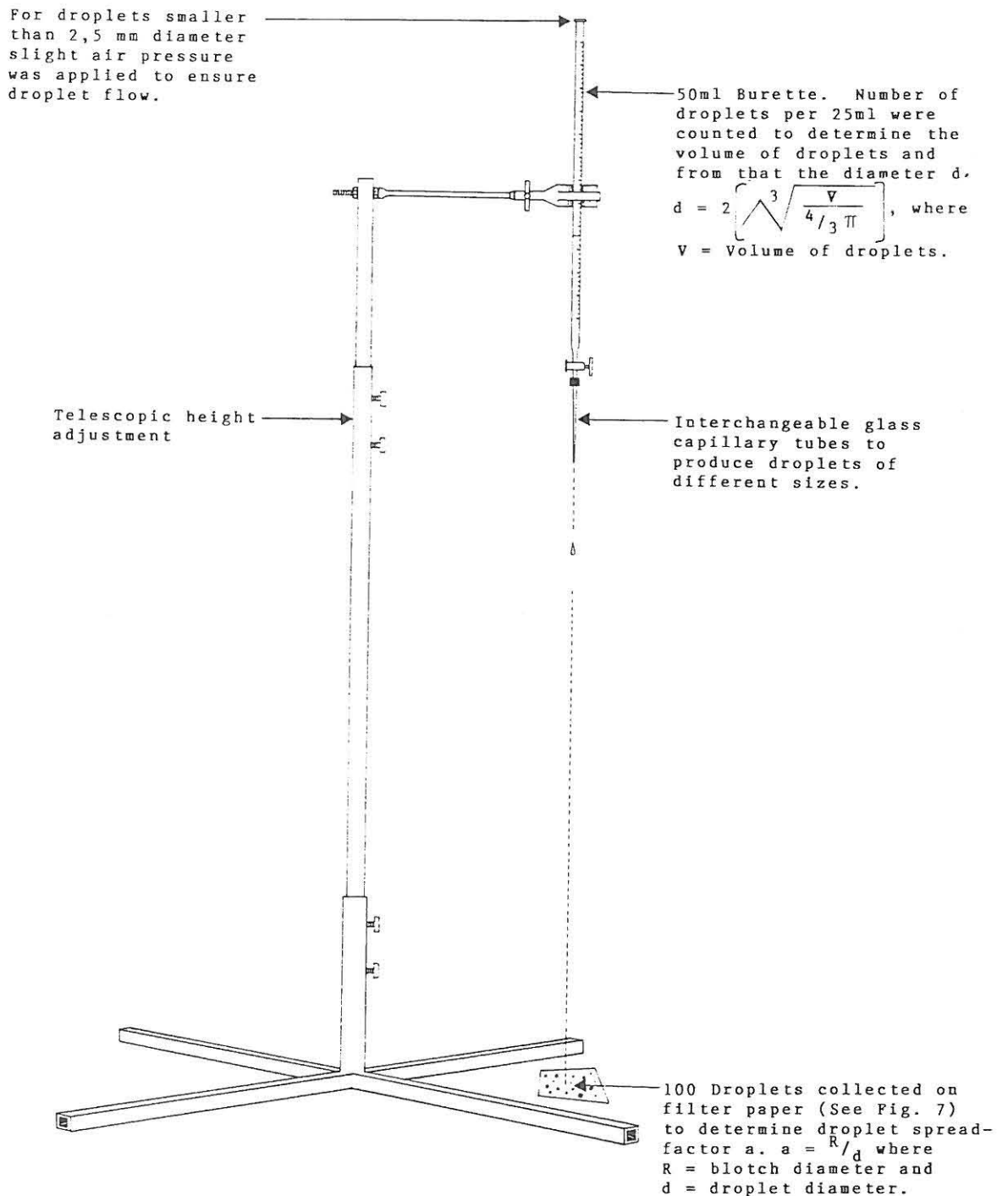


Fig. 7. Droplet tower to collect free-falling droplets at heights ranging from 0-3 m in still air and the procedure used to calculate the spread factor of droplets.

DROPLET SIZE (mm)	BLOTCHES		
	0m	1m	3m
 (1,9)	 (7,0)	 (8,2)	 (8,9)
 (3,8)	 (18,0)	 (18,5)	 (19,9)
 (4,2)	 (21,3)	 (23,0)	 (23,6)

Fig. 8. Photo copies of examples of actual blotches caused by free-falling water droplets from different heights collected on "Wye Valley" filter paper treated with powdered potassium permanganate. Figures in brackets indicate the corresponding average diameters (mm) of 100 droplets, using the droplet tower shown in Fig. 7.

From the data in Figs 8 and 9 it is apparent that the spread factor increases markedly, in a roughly linear way, as the sizes of droplets increase. However - and this is crucial in later discussions - the height from which the droplets fall had almost no effect on the amount of spread recorded. These results have

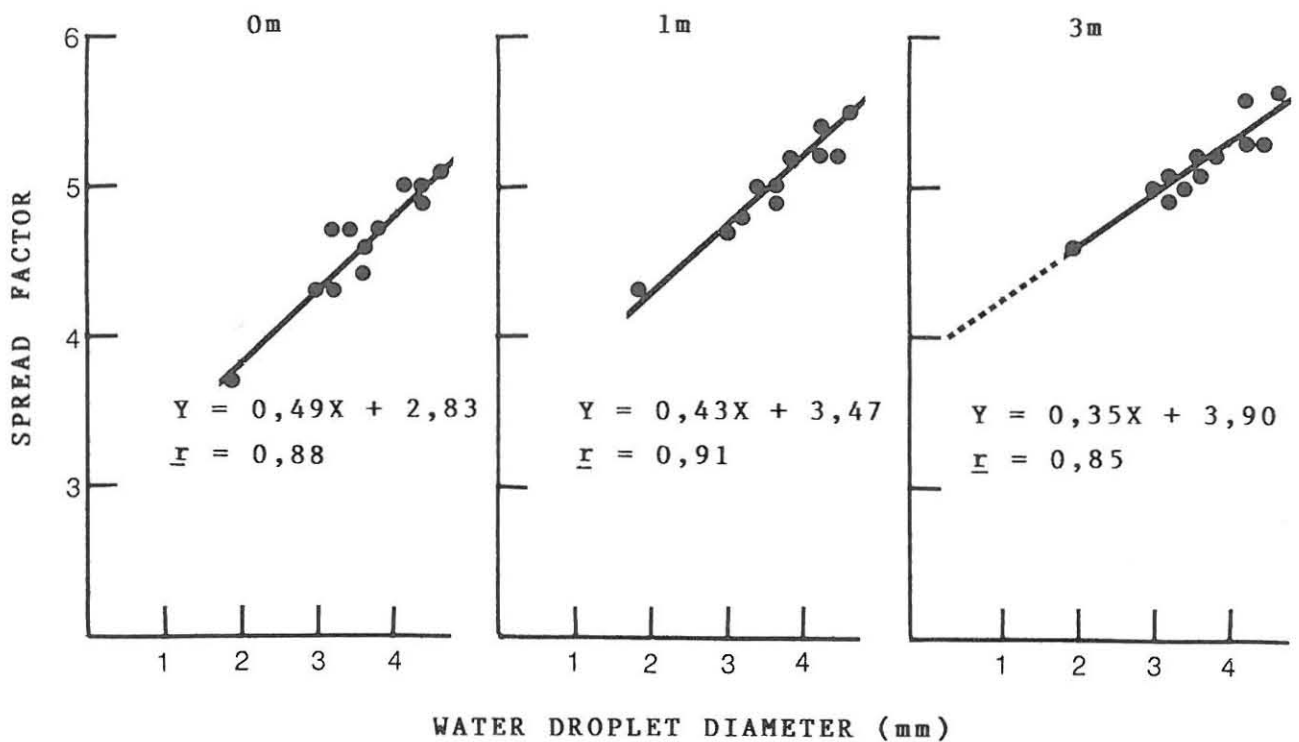


Fig. 9. Relationship between droplet size and spread factor of free-falling droplets collected on filter paper at different falling heights from the droplet tower shown in Fig. 7. The broken line for 3 m shows extrapolated values to accommodate droplets of 0,5 mm diameter encountered in field studies. $\underline{r}$ -values were computed for $p \leq 0,001$ $\geq 0,82$.

important implications for comparisons between different irrigation systems and rainfall: similar blotches point to similar droplet sizes, irrespective of the height from which they fell.

The size (diameter) and density (number per unit area) of droplets collected from a spray cloud constitutes a spray pattern, which is referred to in this study as the volume average diameter (v.a.d.) of Maas (1971). Other more commonly used criteria discussed by Maas (1971) were not considered, for example the volume

median diameter (v.m.d.) assumes an even distribution of large and small droplets about the median, and under-emphasizes the significance of the large number of smaller droplets. On the other hand, the numerical average diameter (n.a.d.), which is the mean of the number of droplets, over emphasizes the importance of the smaller droplets. The v.a.d. is, therefore, the only method which accommodates variation in both the number and volume of the droplets.

The v.a.d.'s of the spray patterns were computed by allocating the droplets to diameter classes, according to the method of Maas (1971). An example of the computation of the v.a.d. for a spray pattern is shown in Table 1. The droplet diameter shown, as for all the v.a.d. computations for the spray patterns studied were calculated from blotches representing the regression line for droplets falling from 3 m (Fig. 9), which approximates field situations.

The spray patterns, computed v.a.d. values and corresponding kinetic energy values (discussed later in this chapter) for the different systems used in this study are shown in Figs 10 to 13.

These spray patterns show very little difference between the range of sizes of blotches recorded for the conventional overhead irrigation system and the centre-pivot system. In the initial experiments on the wash-off of H. armiger eggs, the eggs under the centre-pivot system, were exposed to a much wider spectrum of droplet sizes than in the case of the conventional overhead irrigation system. This was unavoidable due to the positions of the sprinklers and the movement of the centre-pivot system (Appendix 3). However, the mean v.a.d.'s of droplets to which the eggs were exposed, were similar. Droplet sizes of natural rain and those from the rainfall simulator (Fig. 13) clearly

TABLE 1. Volume average diameter (v.a.d.) computed according to Maas (1971). Droplets were collected from the centre-pivot irrigation system during an experiment at the Oudestad Experimental Farm (Table 13, Replicate 3 - Appendix 3).

DROPLET CLASS	DROPLET DIAMETER (mm)	DROPLET NUMBER PER CLASS	RELATIVE VOLUME $\left(\frac{a}{\text{DROPLET DIAMETER}} \right)^3$ Class 1	PERCENTAGE OF TOTAL NUMBER OF DROPLETS $\left(\frac{b}{\Sigma b} \cdot 100 \right)$	TOTAL RELATIVE VOLUME (c.d)
	(a)	(b)	(c)	(d)	
1	0,5	413	1,0	34,4	34,4
2	0,8	261	4,1	21,7	89,0
3	0,9	190	5,8	15,8	91,6
4	1,0	150	8,0	12,5	100,0
5	1,2	75	13,8	6,2	85,6
6	1,5	61	27,0	5,1	137,7
7	1,6	24	32,8	2,0	65,6
8	1,8	18	46,7	1,5	70,1
9	2,0	9	64,0	0,8	51,2
TOTAL		1201		100	725,2

$$\text{v.a.d.} = 0,5 \sqrt[3]{\frac{c.d}{d}} = 0,5 \sqrt[3]{\frac{725,2}{100}} = 0,97 \text{ mm}$$

fall within similar ranges. The droplets from the laboratory irrigation simulator were within the range of sizes recorded for the other systems but were, on average, considerably smaller.

The physical nature of a spray pattern is also determined by the density of droplets. These densities (or number) of droplets are a key factor of the kinetic energy of spray patterns discussed below.

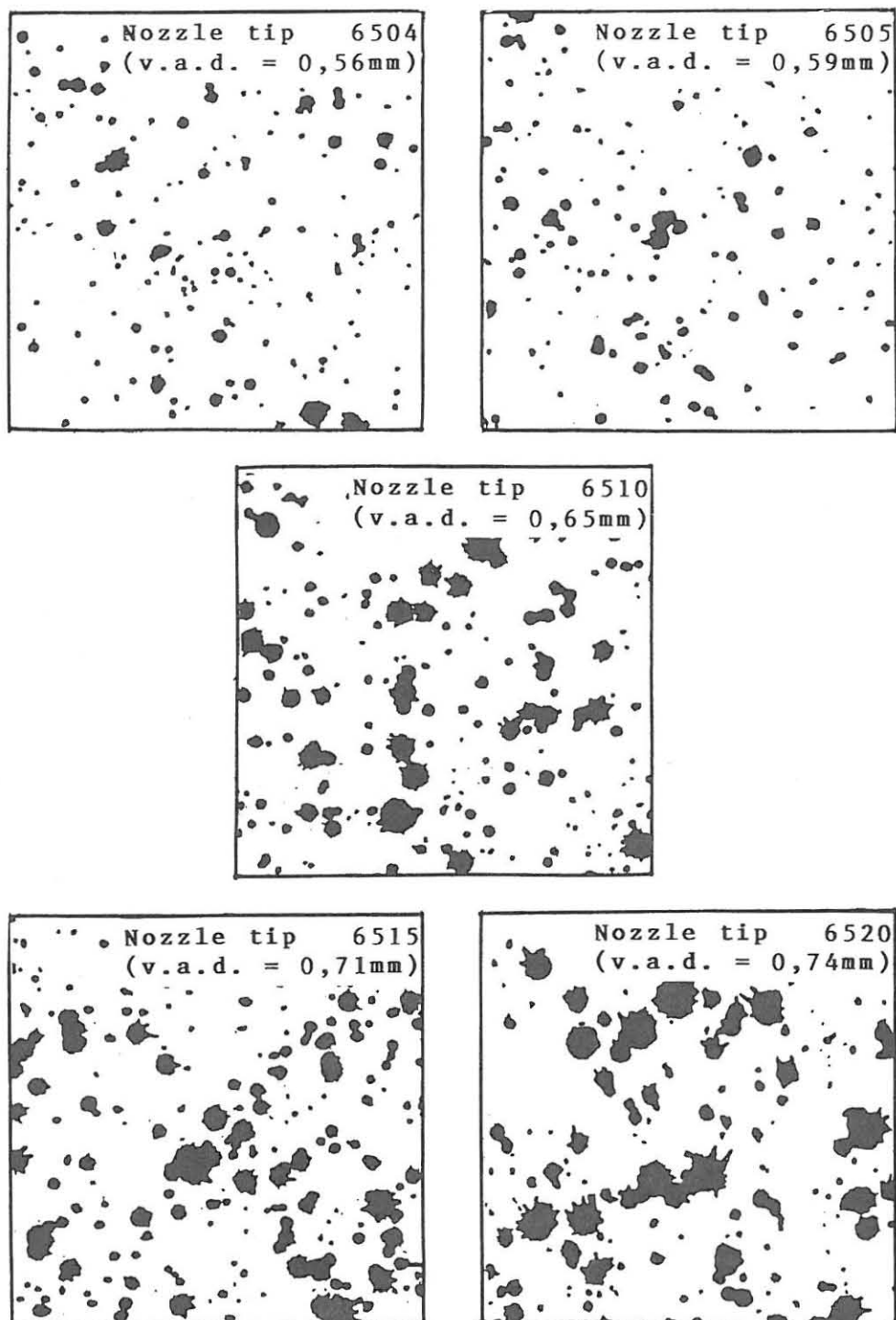


Fig. 10. Photocopies of examples of actual droplet blotches and calculated volume average diameter (v.a.d. - see text), collected from the laboratory irrigation simulator (Appendix 1) at position 2 on the turntable tray. These data were obtained from Table 11 - Appendix 1. The calculated kinetic energy values are based on the data from Morin *et al.* (1967) and the performance of the field rainfall simulator (Appendix 4). These values ranged from 40 - 65% of that of natural rain of similar intensity for the smallest to the largest droplets.

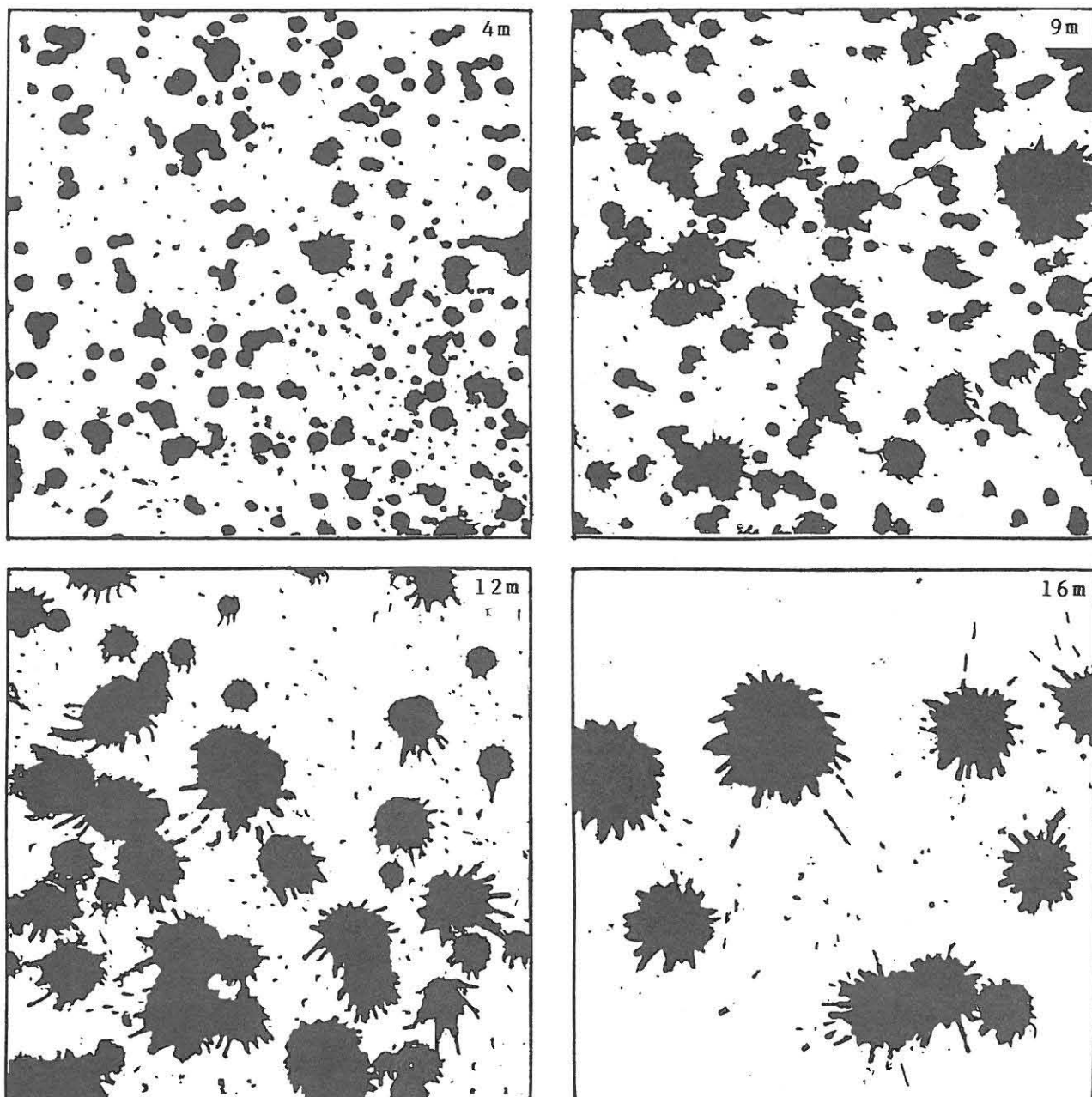


Fig. 11. Photocopies of examples of actual droplet blotches collected from the conventional irrigation system (Appendix 2), operated at an intensity of 7,3 mm/h. These data were obtained from Table 12, Replicate 6 - Appendix 2. Droplets were collected 1 m above ground level under windstill conditions at 1 m intervals from a sprinkler. The distances at which the droplets shown here were collected are given in the upper right hand corners. The calculated volume average diameter (v.a.d. - see text) of droplets for the total spray pattern was 1,17 mm. The observation areas for exposing Heliothis armiger eggs were 9 m from the sprinkler Fig. 37 - Appendix 2, with a droplet v.a.d. of 1,32 mm. The corresponding kinetic energy values for the total system ($EI_{30} = 214$ units) and the observation area ($EI_{30} = 310$ units) were 35% and 50% respectively of that of natural rain of similar intensity.

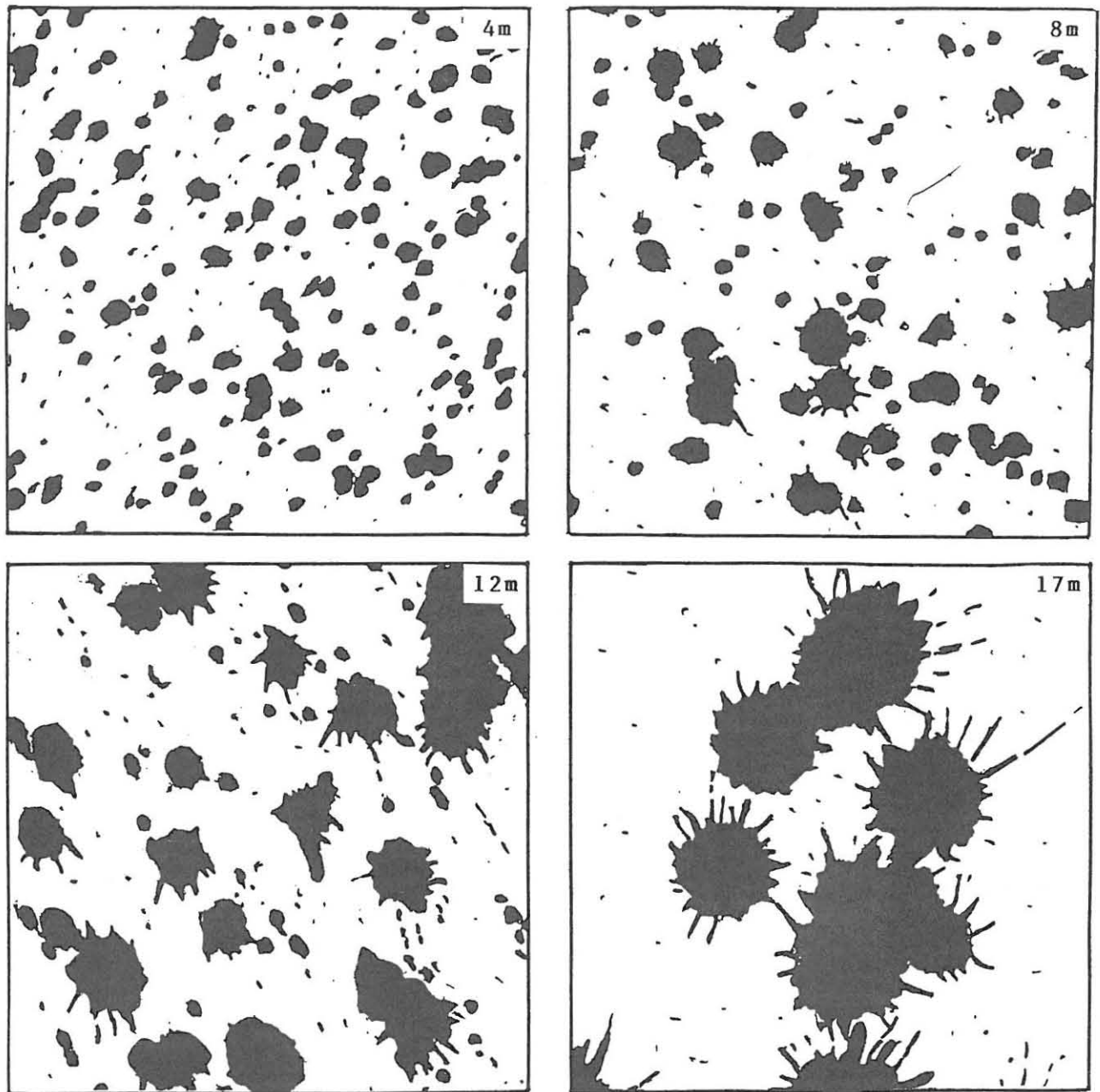
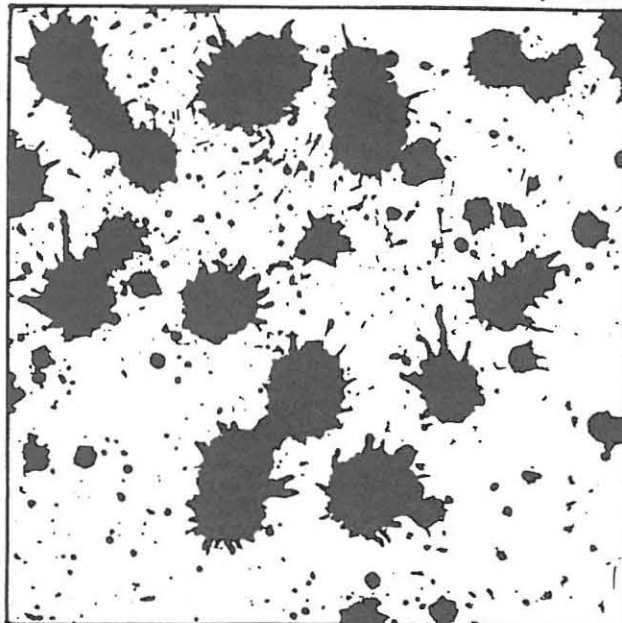


Fig. 12. Photocopies of examples of actual droplet blotches collected from the centre-pivot irrigation system (Appendix 3) operated at an intensity of 14 mm/h. These data were obtained from Table 13, Replicate 3 - Appendix 3. Droplets were collected under windstill conditions 1 m above ground level at 1 m intervals from the main water supply boom, in the observation area, Fig. 38 - Appendix 3. The distances at which the droplets shown here were collected are given in the upper right hand corners. The calculated volume average diameter (v.a.d. - see text) of the spray pattern in the observation area was 0,97 mm with a corresponding kinetic energy value ($EI_{30} = 275$ units) of 43% of that of natural rain of similar intensity.

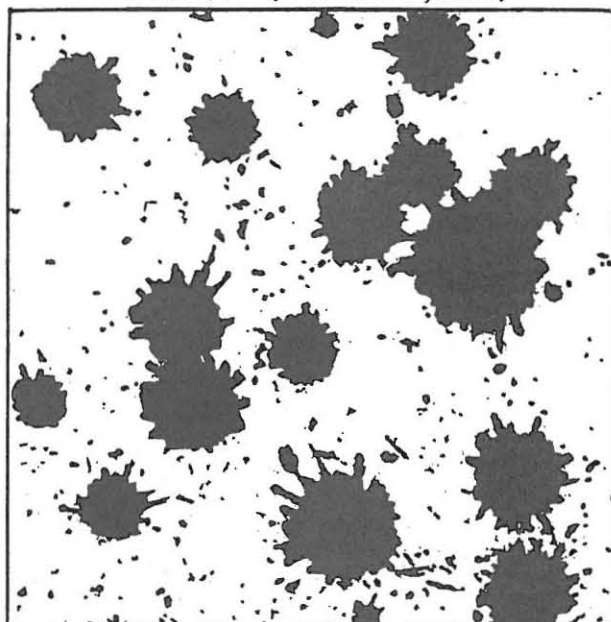
RAINFALL SIMULATOR (v.a.d. 0,94mm)



Kinetic energy 80%
of that of natural
rain. (Morin et. al
1967)

NATURAL RAIN

25mm/h (v.a.d. 1,2mm)



17,6mm/h (v.a.d. 0,98mm)

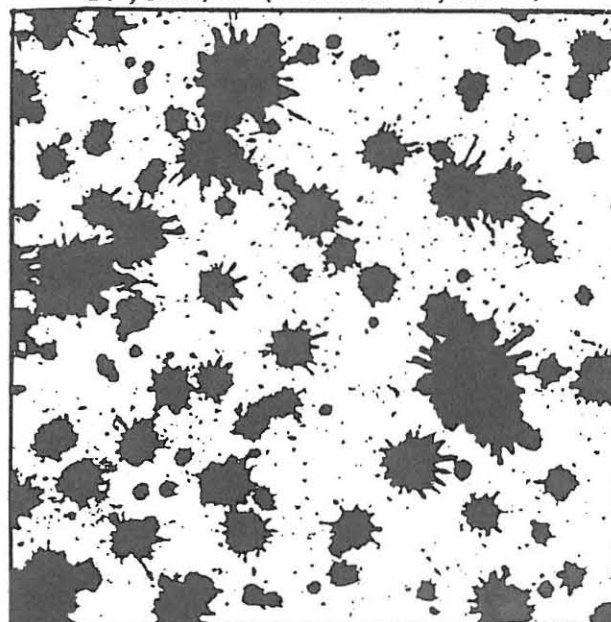


Fig. 13. Photocopies of examples of actual droplet blotches collected from the rainfall simulator (Appendix 4) operated at an intensity of 60 mm/h. These data were obtained from Table 14, Replicate 1 - Appendix 4. For interest and comparison blotches collected from rain at intensities of 25 and 17,6 mm/h are also shown.

KINETIC ENERGY

Later in this study the wash-off of H. armiger eggs from cotton by overhead irrigation systems and a field rainfall simulator are compared. For these comparisons it was necessary to determine the kinetic energy of droplets from each system.

Wischmeier & Smith (1958) determined the kinetic energy of natural rainstorms and their method was used by Burney (1968), for determining the kinetic energy of the Rocky Mountain Rainfall Simulator. This method was used in the present study to determine the kinetic energy of the spray delivery by the laboratory irrigation simulator, the conventional overhead irrigation system and the centre-pivot irrigation system. The method relies on the following information:

- (i) Droplet diameter.
- (ii) Droplet distribution, that is, arranging droplets according to their diameters in classes and the numbers of droplets per class.
- (iii) The mass of droplets in each class, expressed as a percentage of the total mass of droplets in all the classes. The mass of droplets was calculated from their volume by the formula $\frac{4}{3}\pi r^3 \times n$, where n = number of droplets in each class and with the specific gravity (S.G.) of water taken as unity.

The velocities of the different droplet size classes at and average plant height of 1 m were calculated according the methods of Laws (1941) and Gunn & Kinzer (1949) and are shown in Fig. 14.

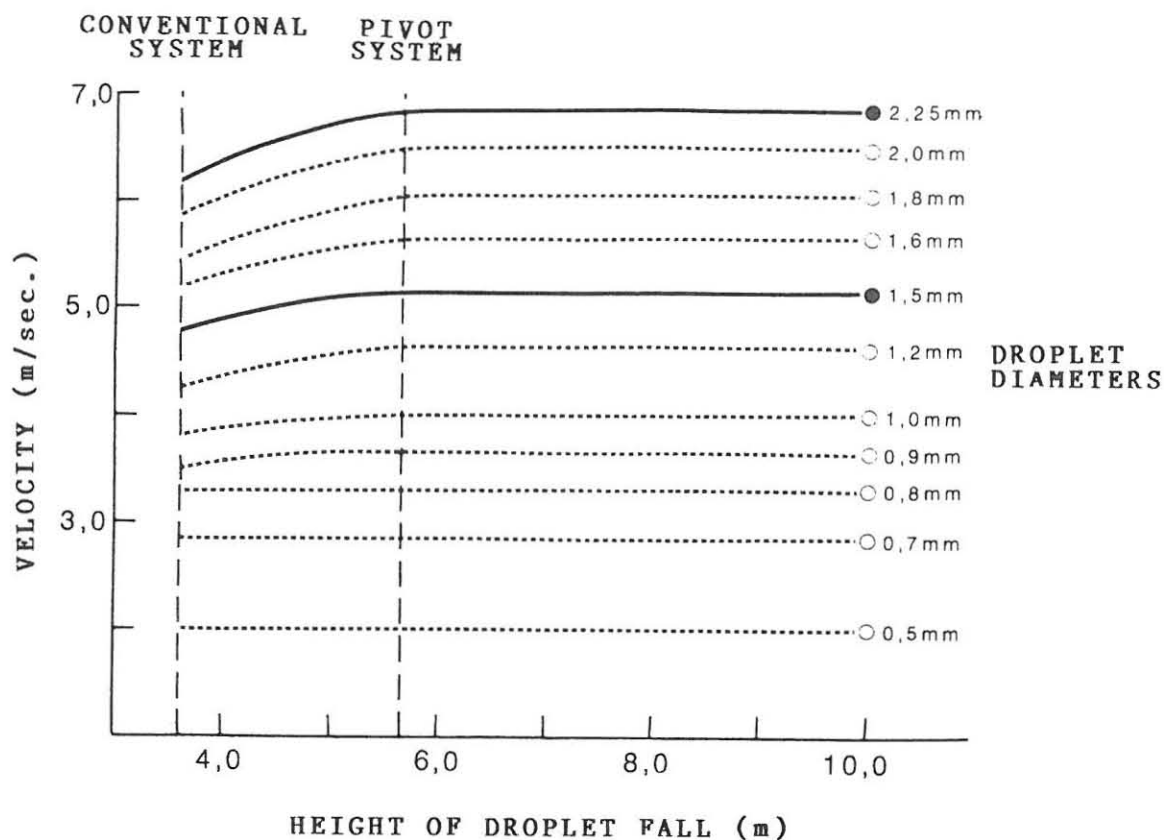


Fig. 14. Velocities of free-falling droplets in still air. The values for dotted lines were extrapolated according to Laws (1941) (closed circles) and from the values recorded for 10 m by Gunn & Kinzer (1949) (open circles). The actual falling height of droplets for the conventional- and pivot irrigation systems used are indicated by the vertical broken lines.

As in the case of the spread factor discussed earlier, the velocities of droplets too are determined by their size and not (within reasonable limits), by the falling distances. The effects of droplet size on terminal velocities are illustrated further in Fig. 15, in which adjustments for horizontal velocities were made. Despite the differences in the angles with which droplets from different irrigation systems strike the plants, terminal velocities vary negligibly, albeit consistently. The consistency of these results allow for the dynamics of droplets to be expressed in terms of kinetic energy.

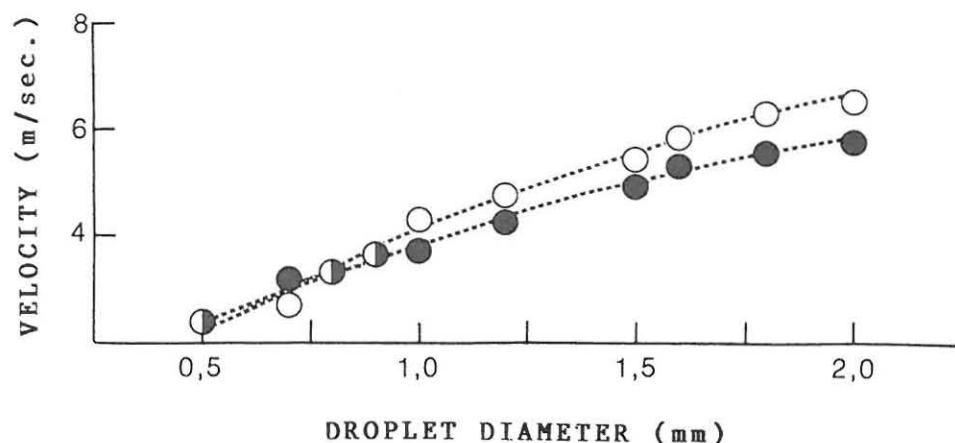


Fig. 15. Droplet velocities from the conventional overhead (closed circles) and pivot (open circles) irrigation systems for droplets of different sizes. The free-falling heights of droplets in still air were 3,7 and 5,7 m at an angle of incidence of 75° and 82° on the observation areas for the two systems respectively. The falling heights of the droplets for the two systems were the distance between the highest point of the sprays and 1 m above ground level, the approximate height of cotton plants used in the experiments.

The kinetic energy of each class of droplet diameter was calculated from the formula: $1/2 MV^2$ where

M = mass of mean droplet size per class and
V = velocity of mean droplet size at mean plant height.

The mass of 1 m^2 of water 1 mm deep is equivalent to 1 kg. This value may be distributed in each droplet diameter class as follows:

$$K.E._C = \frac{1 \times DW \times V^2}{100 \times 2} \text{ Joules/m}^2 \text{ per mm of rainfall}$$

Where $K.E._C$ = Kinetic energy of the droplet diameter class and

D.W. = Percentage by mass of droplets in each class.

The metric equation used for calculating rainfall energy in the Republic of South Africa is as follows:

$$E = 8,7308 \log I + 11,8975 \text{ (Wischmeier \& Smith 1958)}$$

Where E = Kinetic energy in Joules/m² per mm of rainfall and

I = Rainfall intensity in mm/h.

This equation, however, only indicates the kinetic energy of the rainstorm for a given duration. When calculating the rainfall factor R (Long term annual erosivity of rain at a locality), Wischmeier & Smith (1978) characterize the erosivity (EI_{30}) caused by a rainstorm by the equation:

$$EI_{30} = \frac{(210+89 \log I_{30}) \times \text{rainfall depth} \times I_{30}}{100}$$

Where EI_{30} = metric rainfall erosivity units; rainfall depth is expressed in cm and I_{30} in cm/h.

The equivalent equation in use in the Republic of South Africa (Directorate, Agricultural Engineering and Water Supply) is as follows:

$$EI_{30} = (8,7308 \log I + 11,8975) \times \text{rainfall depth} \times I_{30}$$

where I is expressed in mm/h, rainfall depth in mm and I_{30} in mm/h.

For comparing the dislodging of H. armiger eggs from cotton plants by the different systems, the computed EI_{30} value of Wischmeier & Smith (1978) was accepted as reliable indicator of the energy of water droplets when they strike H. armiger eggs on plants. This affords

the opportunity to relate the EI_{30} to a practical kinetic energy value, expressed as a percentage of that of natural rain of similar intensity. Table 2 shows an example of the computation of the EI_{30} of a spray pattern collected from the centre-pivot irrigation system described in Appendix 3 and is expressed in terms of natural rain in Figs 10 - 13.

TABLE 2. Computation of the kinetic energy at plant height of the centre-pivot irrigation system at an intensity of 49 mm/h. These data were obtained from Table 13, Replicate 3 - Appendix 3.

DROPLET DIAMETER CLASS	NUMBER OF DROPLETS PER CLASS	TOTAL MASS OF DROPLETS PER CLASS (mg)	% DROPLET MASS $(\frac{a}{\sum a} \cdot 100)$	VELOCITY (m/sec) (V^2)	KINETIC ENERGY (Metric ton) $(\frac{b \cdot V^2}{200})$
		(a)	(b)		(c)
0,5	413	27,03	4,76	2,08	0,103
0,8	261	69,96	12,32	3,30	0,671
0,9	190	72,50	12,77	3,71	0,879
1,0	150	78,52	13,83	4,07	1,146
1,2	75	67,84	11,95	4,69	1,314
1,5	61	107,77	18,98	5,30	2,666
1,6	24	51,46	9,06	5,70	1,472
1,8	18	54,95	9,68	6,16	1,837
2,0	9	37,69	6,64	6,46	1,386
TOTAL		567,72	99,99		11,474

$$EI_{30} \text{ of system} = \frac{\sum c \times (\text{Intensity})^2}{100} = \frac{11,474 \times 49 \times 49}{100} = 275 \text{ units}$$

The equivalent EI_{30} for rain at 49 mm intensity is

$$\frac{8,7308 \text{ Log } I + 11,8975 \times 49 \times 49}{100} = 640 \text{ units}$$

Thus the kinetic energy of the irrigation system is $\frac{275}{640} \times 100 = 43\%$ of rain at the same intensity.

To summarise, blotch patterns are a fair reflection of droplet sizes, their densities and their velocities (and therefore the kinetic energy). The kinetic energy, in turn, depends almost entirely upon droplet sizes. Thus, this simple procedure of recording blotches in the field is a reliable criterion for comparing different irrigation systems in terms of the more sophisticated - and impossible to measure - kinetic energy.

CHAPTER 4

BIOLOGY OF HELIOTHIS ARMIGER

This chapter deals with the salient features of the biology of H. armiger. Emphasis is placed on the morphology of the eggs in relation to their respiration under water, and oviposition behaviour of moths on cotton plants.

LIFE HISTORY

The moths (frontispiece) are typical noctuids, emerging during the early part of the night (Singh & Singh 1975; Roome 1975). Mating occurs in the early hours of the morning, from the second night after emergence (Roome 1975; Pearson & Darling 1958). The moths live for about two weeks (Taylor 1932; Pretorius 1976), depending on their food supply (Jones 1936; Jayaraj 1982), during which time multiple matings occur (Hardwick 1965). Each female is capable of laying 1 265 - 1 400 eggs (Pretorius 1976; Botes et al. 1985), with a maximum of 480 per night (Taylor 1932). Of these, about 70% are fertile (Botes et al. 1985). The incubation period of H. armiger eggs under optimal conditions is 3 - 4 days (Pretorius 1976), but can be as long as 14 days during cooler periods of the season (Jones 1936).

On cotton plants, the larval stage of H. armiger comprises 5 - 8 instars which feed almost exclusively on the buds, flowers and bolls (Pearson & Darling 1958; Reed 1965; Ismail & Swailem 1975; Ayad 1977; Bilapate et al. 1981; Ramos & Morallo - Rejesus 1981; Annecke & Moran 1982). The larvae reach maturity after 15 - 32 days, (Taylor 1932; Pretorius 1976; Botes et al. 1985), and pupate in shallow cells in the soil (Pearson & Darling 1958). The moths emerge in summer,

after a pupal stage of about 10 - 15 days, resulting in a complete life cycle of about 30 days (Pretorius 1976; Botes et al. 1985). Thus 3 - 4 generations occur per season, and the last generation overwinters (depending on locality) as diapausing pupae (Pearson & Darling 1958; Nel 1961).

MORPHOLOGY AND RESPIRATION OF HELIOTHIS ARMIGER EGGS

The eggs are circular, with a somewhat flattened base which imparts a dome-shaped appearance (Fig. 16A). Newly-laid eggs are cream coloured and shiny due to a thin film of secretion from the colleterial glands, which surrounds the individual eggs. This secretion acts as an adhesive to affix the eggs to the oviposition substrate. The function of the colleterial glands will be discussed in more detail in Chapter 5. As the eggs mature, the colour gradually changes to dark brown, and shortly before hatching the black head capsules of developing larvae can be seen through the chorions.

The egg sizes of Heliothis spp. range from 0,40 - 0,59 mm in diameter, and average 0,47 mm in height (Barber 1941; Pearson & Darling 1958). Egg sizes of H. armiger used in this study, (n = 60) were 0,44 - 0,58 mm in diameter (average 0,52 mm) and were 0,37 - 0,53 mm high (average 0,47 mm).

Longitudinal ridges radiate from near the micropyle, or the micropyle itself, to the base of the egg (Fig. 16A). The number of ridges varies from an average of 27 (Barber 1941) to 24 (Jones 1936). On most H. armiger eggs from laboratory cultures which were used in this study, there were 24 ridges, but these ranged from 21 - 25. Minute transverse ridges join the vertical ridges, imparting the appearance of a network (Fig. 16A).

On H. armiger eggs, a rosette-like structure bearing 3 - 4 micropyles with a diameter of 2,0 - 2,2 microns is situated apically on a small mound (Fig. 16B). The micropyles provide a way for the fertilizing sperm to enter the egg (Hinton 1970).

The unexpectedly low number of aeropyles (see below) found on the ridges of the chorion (Fig. 16C) are significant with regard to respiration. Generally, only one aeropylar opening was found on each longitudinal ridge. Occasionally two adjacent aeropyles were found, whilst some ridges lacked aeropyles. The aeropyles were arranged in a band, more or less one third of the distance from the apices of the eggs. The openings of the aeropyles varied between 1,1 and 1,4 microns in diameter, surrounded by a spongy area (Fig. 16D). It is estimated that a total of 25 - 30 aeropyles occur on each egg.

Before comparing the respiratory system in H. armiger eggs with those of other terrestrial insects, it is necessary to discuss the diverse respiratory systems which occur in terrestrial insect eggs. Hartley (1971) defines the respiratory efficiency of eggs as "... the ability of the egg to obtain oxygen from the environment", which relates to the structure of the eggs. The most comprehensive documentation on respiration in insect eggs is that of Hinton (1981). The chorion of terrestrial insect eggs is a complex structure, consisting of one or more layers of meshwork, each holding a layer of gas. The aeropyles described above, connect the internal gas layers to the ambient air.

According to Hinton (1981), the gas layers are incorporated either while the eggs are still in the common oviduct, as found in some phasmids and Diptera (Cyclorhapha), or the intra-chorionic air spaces may

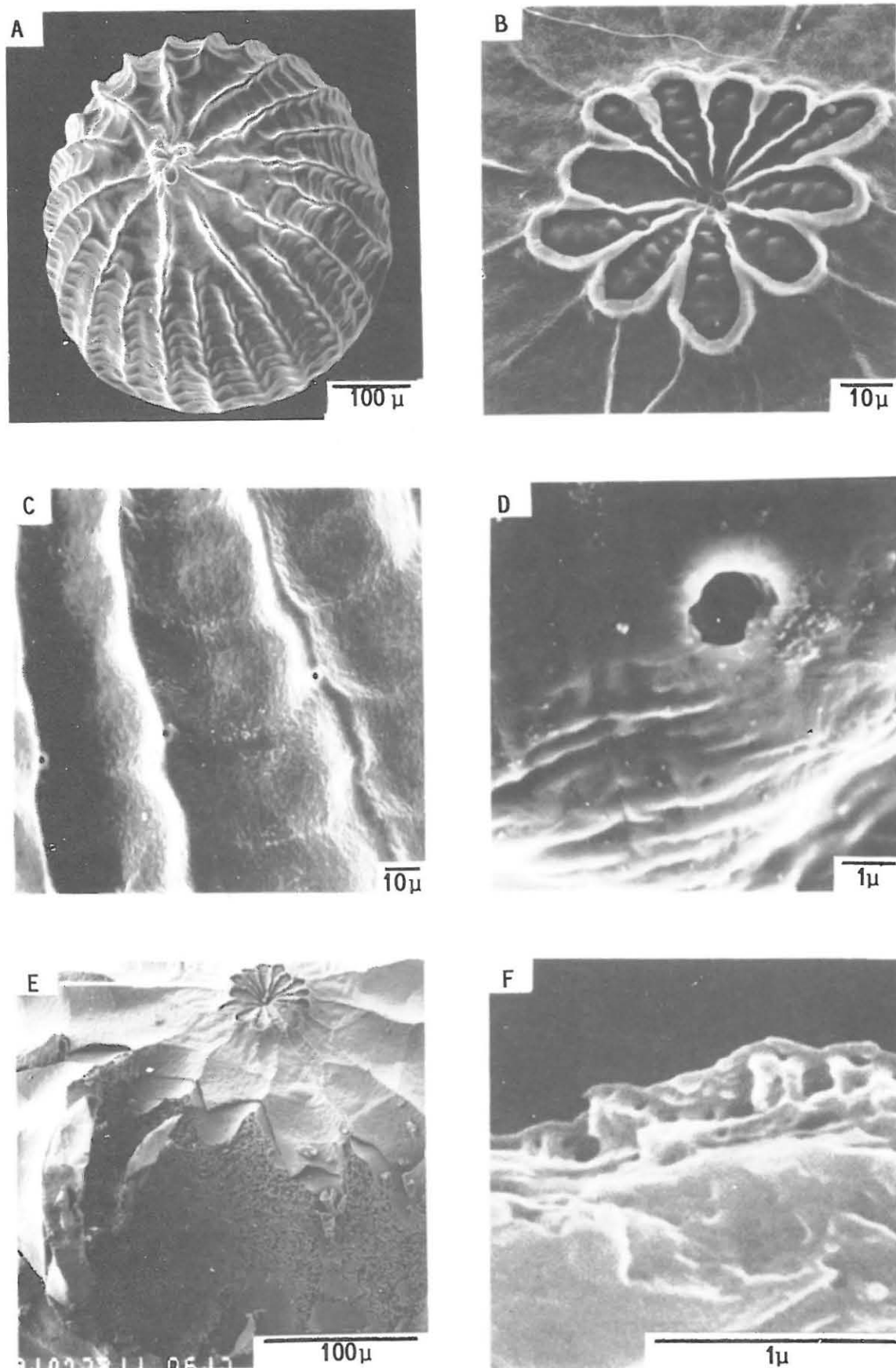


Fig. 16. *Heliothis armiger* eggs, showing longitudinal and transverse ridges (A); micropyles (B); aeropyles (C-D); inner surface of the chorion (E) and multiple layers of the chorion (F).

dry out and fill with air after the egg is laid, as has been found in some acridids, nepids and staphylinids. Hinton (1981) stated "In Lepidoptera, many of the less - specialized Ditrysia, the respiratory system of the chorion is essentially similar to that of many other groups of insects, in that there is a gas-filled space in the inner and lower part of the chorion. In the higher Ditrysia (to which H. armiger belongs), there is normally a space supported by vertical columns in the innermost part of the chorion. The shells of the higher Ditrysia contain a large number of very thin gas-containing layers between the surface and the innermost gas-containing layer." The inner gas layers are crucial to the survival of H. armiger and are discussed below.

The function of the **aeropyles** is to exchange gasses between the eggs and the atmosphere. The diameter of the aeropyles varies in size from about 10 microns in Antheraea pernyi Guer to 1 micron in Semiothisa signaria dispuncta Walker (Hinton 1981) and the spaces in the meshwork are about the same size. This provides an unimpeded pathway for the exchange of respiratory gasses between the atmosphere and the gas layers, thus permitting respiration of the developing embryo. Because the molecules of the respiratory gasses are much smaller than water molecules, the structure of the respiratory systems, are such that they resist the entry or loss of water at normal pressures, when oxygen is absorbed from the surrounding air or water.

It is not clear from the literature cited whether respiration can also take place through the **micropyles**, which serve to provide a way for the sperm cells to enter the eggs. Tuft (1950) showed that the micropyles and pseudo-micropyles in the cap area of the eggs of the reduviid Rhodnius prolixus (Ståhl) are important for respiration. Hinton (1981) in his review, however,

referred to these structures as aeropyles. The position is unclear and was not pursued in this study.

Another important feature of respiration in insect eggs is the presence of a thin and continuous film of air in the inner part of the chorion. This film of air can either be trapped at the open network of the inner surface of the shell, or, as it is in most insect egg shells, at the thin and continuous outer layer of the chorion. Very little is known about the permeability of the chorion to respiratory gasses between aeropyles. It may be that some eggs depend not only upon oxygen entering through the aeropyles, but also by diffusion through the chorion. Hinton (1981), found that in eggs of aquatic Ephemeroptera, Trichoptera and most primitive Diptera, layers of air in the shell are lacking and that no obvious provision is made for exchange of gasses. He suggests that in these insects respiration occurs through the entire shell by absorption of dissolved oxygen through spaces between the fibrils of the shell. These spaces are about $20\text{\AA}$ wide, enough to allow passage of respiratory gasses. This was tested by Tuft (1950), who showed that when the cap end (185 - 200 aeropyles and about 13 micropyles are situated in this area but nowhere else) of the egg of R. prolixus were blocked off with shellac, the eggs continued to absorb oxygen although the rate of uptake was reduced to about one tenth of the normal absorption. It can, therefore, be assumed that in the absence of free water, respiration of terrestrial eggs with layers of gas in the chorions will take place through the aeropyles (Hinton 1981). When under water respiration can also take place by means of gas diffusion.

The method of respiration, however, changes when the eggs are adapted to respire by means of a plastron (Hinton 1981). A plastron is simply a gas film or

bubble of constant volume covering the aeropyles and serves as a water-air interface. The film of gas is held in position by a system of water-repellent structures, which resist wetting in nature. A plastron thus makes it possible for eggs to respire in water, provided there is enough dissolved oxygen available. Anderson (1960) demonstrated that Calliphora erythrocephala (Meigen) (= Calliphora vicina Robineau-Desvoidy) eggs develop well in shallow water or moist air, but die in unaerated water. This illustrates the disadvantage of a plastron in environments where the oxygen pressure is below that within the egg tissue, when the plastron will extract as much oxygen from the tissue as from the surrounding environment.

An example of a terrestrial insect egg which relies on plastron respiration when submerged, is that of the silkworm Antheraea pernyi Guer (Hinton 1981). Hinton (1970), pointed out that the irregular surface of this insect's egg, the ragged holes at the openings of the aeropyles and the respiratory tubes leading to the inner layers serve to trap air over the aeropyles, and constitute the plastron.

On the other hand, the eggs of the moth Semiothisa signaria dispuncta Walker (Hinton 1981) do not respire by means of a plastron. According to Hinton (1970) the aeropyles of these eggs are much too small and few in number for effective plastron respiration, and the eggs would therefore not survive lengthy periods of submersion. It seems that for those terrestrial insect eggs that are not adapted for chorionic plastron respiration, all respiration under water relies on the reservoir of gasses trapped in the inner chorionic layers or by gas diffusion.

The structure of the eggs of H. armiger resembles that of S. signaria dispuncta with its low number of

aeropyles and their smaller size rather than A. pernyi, in which the aeropyles are more numerous, larger and impart a ragged surface to the shells. The structure of H. armiger eggs indicates that they must respire under water without the assistance of chorionic plastrons. Considering the findings of Hinton (1970), it appears that the number of aeropyles in H. armiger eggs (25 - 30) is far too low and further, their raised position on the crest of the longitudinal ridges probably render them unsuitable for plastron respiration. Hinton's views (1981) concerning eggs which resemble H. armiger are important: "The aeropyles of nearly all eggs tested have been found to be hydrofuge. They thus resist the entry of water, at least under low hydrostatic pressures. When the aeropyles are hydrofuge, a water-air interface is inevitably established across their openings, when they are covered by water, and they thus inevitably function as plastrons. However, in most of those eggs that lack a plastron the number of aeropyles is so few (my underlining) that the total water-air interface fresh-weight ratio is far too small for there to be plastron respiration of any significance." This provides further evidence that plastron respiration, if any, is insignificant in H. armiger. Hinton (1981) calculated that 0,103% of the surface area of eggs must be an air-water interface for plastron respiration. But, H. armiger eggs allow for an interface of only 0,004%, which renders plastron respiration extremely unlikely. It seems, therefore, that H. armiger eggs probably depend mainly on air trapped in suitably structured inner chorionic layers when submerged, or possibly by gas diffusion.

This poses the question what respiratory systems are involved, and what the survival rate of H. armiger eggs will be, under field conditions, when they may be submerged under water for several hours during rain or

overhead irrigation conditions, or if oxygen is supplemented in any way under these conditions.

A series of laboratory trials were conducted to examine the effect of water on H. armiger eggs. An analysis of the water used is shown in Table 3, and the experimental method adopted is described in Appendix 5.

TABLE 3. Analysis of the water used for submerging Heliothis armiger eggs. The pH was 8,6.

COMPONENT	CONCENTRATION (ppm)
F	0,0
NO ₂	0,0
NO ₃	0,0
CL	21,3
SO ₄	34,3
CO ₃	6,0
HCO ₃	46,0
Na	23,0
Mg	7,3
Ca	28,0

The survival rate of H. armiger eggs submerged for different periods in aerated, unaerated and de-oxygenated water is shown in Fig. 17.

From these data it is clear that the viability of H. armiger eggs was not adversely affected by aerated water in contrast to eggs exposed to unaerated and de-oxygenated water, where significantly fewer eggs survived, after submersion for longer than 12 hours. This suggests that the survival of H. armiger eggs exposed to rain or to normal irrigation practices, would not be affected by submersion. The only effect of prolonged periods of rain or irrigation was to

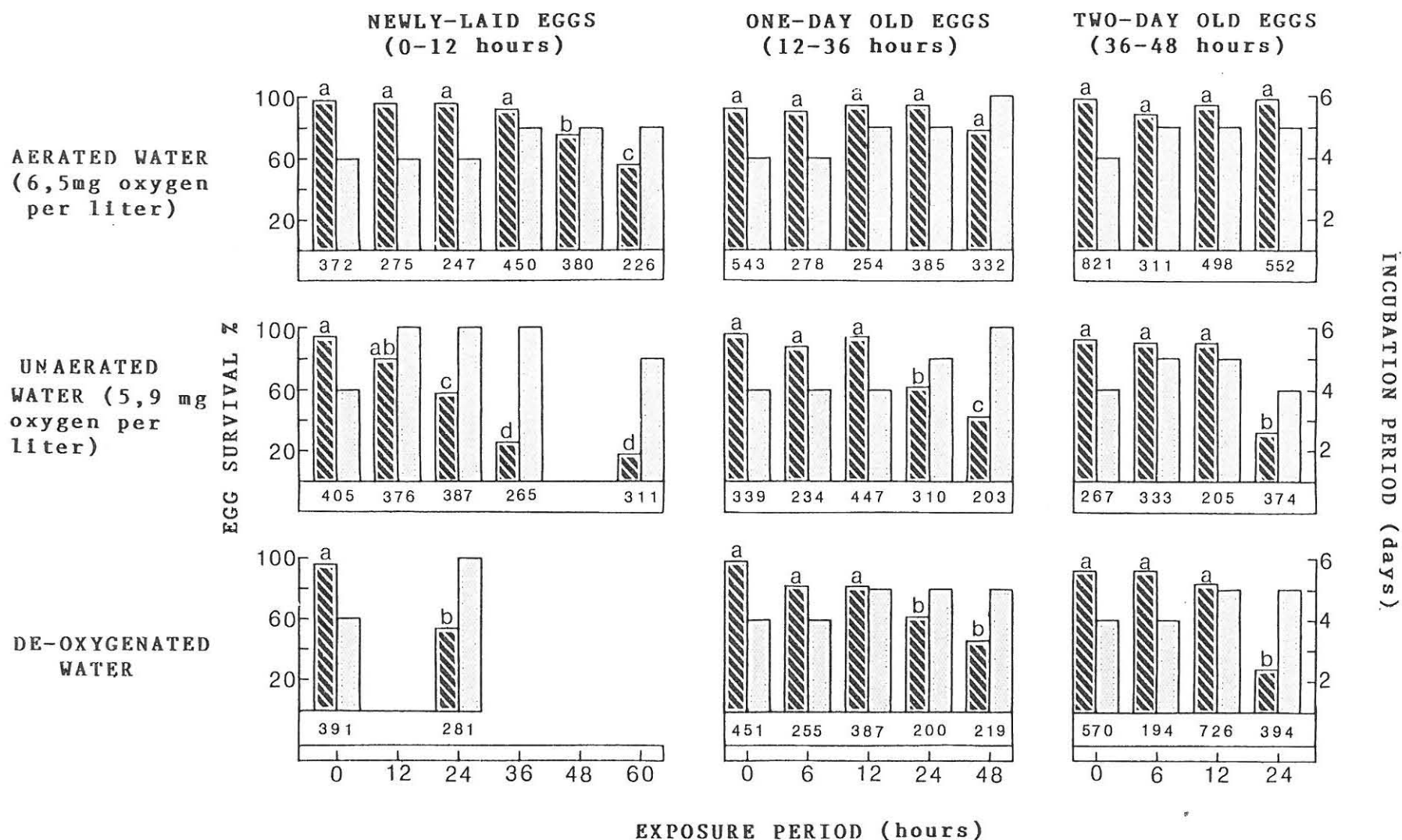


Fig. 17. Survival rate of *Heliothis armiger* eggs under water (dark bars) and number of days (light bars) for eggs to hatch. The numbers of eggs considered for each treatment are shown above the horizontal axis for each pair of bars. The same letters above each group of histogram bars show non-significant differences in chi-square values at the 95% confidence level.

retard the incubation period by one or two days. This delay could, however, also be ascribed to the lower ambient temperatures during rain or irrigation and requires further investigation. In the laboratory trials, all the larvae which emerged from the submerged eggs, fed and developed normally on the artificial diet. In well-aerated water, newly-laid H. armiger eggs developed normally and the results indicate that the oxygen requirements for the developing embryos were adequate for periods of up to 36 hours. When submerged for longer periods, a significant difference in the survival rate of the embryos was apparent. This trend was not observed for eggs a day or older when exposed. The larvae even emerged under water and were able to live for up to six hours under these conditions. These findings, however, contradict those of Hinton (1970) who concluded that eggs with the morphological characteristics, as described for H. armiger eggs, cannot survive for long periods under water.

This raises the question of what respiratory system(s) are involved to ensure the survival of submerged H. armiger eggs. Results obtained from the eggs submerged in unaerated and de-oxygenated water revealed a significant reduction in egg viability, when eggs were submerged for periods of 12 hours or more. This is due to an oxygen deficiency, and proves that the higher survival rate in aerated water resulted from oxygen uptake from the surrounding water.

The means by which the oxygen was supplemented, can now be interpreted from the available literature. As already pointed out, the possibility of plastron respiration in H. armiger is unlikely. The fact that no oxygen was extracted from the eggs into the surrounding de-oxygenated or unaerated water, as demonstrated by the similar viability of eggs (Fig. 17), points to a lack of plastron respiration through

either the aeropyles or micropyles. Judging by the findings of Anderson (1960), more of the eggs would have died had there been a plastron. The only alternative method of respiration in submerged H. armiger eggs, is through diffusion of oxygen through the chorion. Clearly this diffusion occurred only when the oxygen pressure in the surrounding water was higher than that in the egg. This is feasible under natural conditions, where rain and overhead irrigation water are rich in oxygen. Samples of water droplets collected during overhead irrigation revealed that the oxygen content of the water compared favourably with that of rain water.

An important feature of the survival rates of eggs submerged in water, in the absence of oxygen, is that the embryos could survive for up to 12 hours. This is in agreement with Hinton (1981), that sufficient oxygen is trapped in the meshwork of the chorion, as well as in the open network of the inner surface of the shell. Fig. 16E shows that the chorion of H. armiger eggs is well structured for trapping oxygen either in the open network of the inner surface, or in the meshwork of the egg shell (Fig. 16F), notwithstanding the low number of aeropyles (25-30 per egg) compared to the thousands on other Lepidoptera eggs (Hinton 1981). It was not possible in the submersion tests to determine when this oxygen uptake occurred, or to determine the critical period needed after oviposition for supplementing the reservoir of air.

In conclusion, it seems that survival of submerged H. armiger eggs depends firstly on the supplementation of dissolved oxygen from oxygen-rich water, by means of chorionic diffusion, and secondly, that egg survival under water also depends on an oxygen reservoir in the inner chorion of the eggs, extracted from the surrounding air, most probably through the aeropyles

after the eggs are laid. Clearly, the eggs of H. armiger are able to survive the temporary submersion which results from rain or overhead irrigation.

OVIPOSITION BEHAVIOUR

Many studies have been conducted on the oviposition behaviour of H. armiger and the factors which influence the oviposition patterns in relation to their host plants. In this section the oviposition incidence of H. armiger on cotton plant parts is described. This information was a prerequisite for the examination of the dislodging and removal of eggs from the plants by water droplets produced by different irrigation systems and simulated rain.

Several workers have found that H. armiger moths tend to oviposit preferentially on flowering cotton (Thomas & Dunnam 1931, Gaines 1932, 1933; Parsons & Ulliyett 1934; Jones 1936; Pearson & Darling 1958; Tunstall & Matthews 1965; Fye 1972; Johnson et al. 1975; Roome 1975). The physiological condition of the cotton plants is also known to have a significant influence on oviposition, with healthy vigorous plants more attractive to the moths (Thomas & Dunnam 1931; Gaines 1932, 1933; Fletcher, 1941). It was found that dryland cotton usually escapes H. armiger damage during droughts (Thomas & Dunnam 1931), with infestations restricted to irrigated fields (Parenchia et al. 1962). Heliothis moths prefer more hirsute (hairy) varieties of cotton to the glabrous (smooth) varieties for oviposition (Taylor 1932; Lukefahr & Shaver 1972; Stadelbacher & Scales 1973; Schuster & Anderson 1976). Climatic factors reduce oviposition in Heliothis spp. during dust storms, high winds, low temperatures or full moon phases (Nemec 1971; Agee et al. 1972).

Reports of studies on the distribution of eggs of

Heliothis spp. on cotton are inconsistent. Table 4 summarises the oviposition preference of Heliothis spp. on cotton in relation to plant morphology. Apart from preferences for certain parts of the plant, several authors also reported on oviposition preferences of Heliothis spp. in relation to the vertical distribution of eggs within plants. They all concluded that Heliothis spp. preferred to oviposit mainly in the upper third of the cotton plant. This preference coincides with the flowering stage of the plant, stimulating the moths to oviposit in the area where most of the flowers are (Beeden 1974; Patel et al. 1974; Johnson et al. 1975; Hillhouse & Pitre 1976; Jayaraj 1982; Mabbett 1983).

TABLE 4. Summary of the reported oviposition preferences for Heliothis spp. on cotton. Rating which were computed from the original data are marked with an asterisk.

POSITION ON PLANT	SPECIES	RATING	REFERENCE
Leaves (General)	<u>H. armiger</u>	44%	Parsons (1940)
	"	27%*	Matthews & Tunstall (1968)
	"	32%*	Beeden (1974)
	"	Mostly pre-flowering stage	Mabbett (1983)
	<u>H. zea</u> and <u>H. virescens</u>	41-55%	Farrar & Bradley (1985)
Upper surface of leaves	<u>H. armiger</u>	Mostly	Reed (1965)
	"	24%*	Matthews & Tunstall (1968)
	"	22%*	Beeden (1974)
	"	71%	Patel <u>et al.</u> (1974)
	"	51%	Jayaraj (1982)
	<u>H. zea</u>	20 - 40%	Wilson <u>et al.</u> (1980)

Under surface of leaves	<u>H. armiger</u>	3%*	Matthews & Tunstall (1968)
	"	9%*	Beeden (1974)
	"	34%	Patel <u>et al.</u> (1974)
	"	14%	Jayaraj (1982)
	<u>H. zea</u>	60 - 80%	Wilson <u>et al.</u> (1980)
Tender leaves	<u>H. armiger</u>	66%	Patel <u>et al.</u> (1974)
Medium aged leaves	"	26%	Patel <u>et al.</u> (1974)
Old leaves	"	7%	Patel <u>et al.</u> (1974)
Terminals	<u>H. zea</u> and <u>H. virescens</u>	8-55%	Farrar & Bradley (1985)
Stems (Mono podial + sympodial stems)	<u>H. armiger</u>	47%*	Matthews & Tunstall (1968)
	"	31%*	Beeden (1974)
	<u>H. zea</u>	0,5%	Wilson <u>et al.</u> (1980)
	<u>H. zea</u> and <u>H. virescens</u>	1-5%	Farrar & Bradley (1985)
Fruiting bodies (all reproductive structures)	<u>H. armiger</u>	13%*	Matthews & Tunstall (1968)
	"	31%*	Beeden (1974)
	"	32%	Jayaraj (1982)
	"	Mostly	Mabbett (1983)
	<u>H. zea</u>	Mostly	Hillhouse & Pitre (1976)
	"	0 - 25%	Wilson <u>et al.</u> (1980)
	<u>H. virescens</u>	Mostly	Johnson <u>et al.</u> (1975)
	<u>H. zea</u> and <u>H. virescens</u>	13-34%	Farrar & Bradley (1985)

Detailed studies of oviposition preferences of H. armiger on cotton plants - or any host plant for that matter - have not been conducted in South Africa, and available information is restricted to cursory references to this aspect by Taylor (1932) Parsons (1939, 1940) and Parsons & Ulliyett (1934).

In this study the distribution of H. armiger eggs found on individual cotton plants as outlined in Fig. 3 (Chapter 2) is shown in Table 5.

These data do not indicate preferences, but show that H. armiger mainly oviposit on leaves, notably the upper surfaces of young tender leaves (Fig. 18). Furthermore, most of the eggs were laid on the upper two thirds of the plant (Fig. 19). Significantly, the higher incidence of eggs on the upper two thirds revealed a

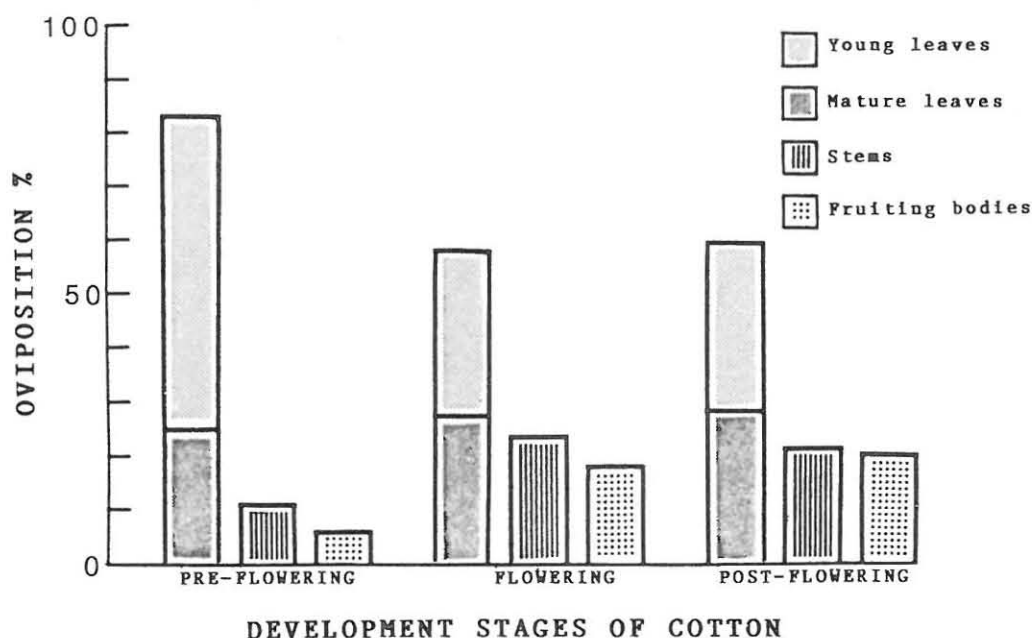


Fig. 18. Histograms showing the incidence of eggs of a natural Heliothis armiger population on cotton plants in the field in relation to plant development. These histograms are derived from the data in Table 5. The numbers of eggs laid on young leaves are shown as a proportion of eggs laid on all the leaves.

TABLE 5. Eggs laid by a natural Heliothis armiger population on cotton plants in the field, at three stages* of plant development. The oviposition sites of the eggs on the plants were recorded according the diagram in Fig. 3. The data are expressed as percentages and represent a total of 1 350 eggs on 500 cotton plants. The average numbers of eggs per plant recorded per survey are shown in Fig. 19.

OVIPOSITION SITES		PLANT STAGE AND OVIPOSITION ZONES											
		PRE-FLOWERING				FLOWERING				POST-FLOWERING			
		Top 1/3	Middle 1/3	Lower 1/3	Total	Top 1/3	Middle 1/3	Lower 1/3	Total	Top 1/3	Middle 1/3	Lower 1/3	Total
LEAVES	Young leaves (upper surface)	22,8	19,4	2,8	45,0	16,4	16,4	3,2	36,0	29,8	9,1	1,4	40,3
	Young leaves (under surface)	9,0	6,2	1,7	16,9	4,0	2,6	0,5	7,1	1,0	1,0	0,0	1,9
	Mature leaves (upper surface)	9,0	5,4	0,6	14,9	4,5	7,1	0,8	12,4	11,1	3,8	0,0	14,9
	Mature leaves (under surface)	3,9	2,0	0,0	5,9	0,8	1,9	0,3	2,9	1,0	0,5	0,0	1,4
STEMS	Leaf petioles	2,0	1,1	0,3	3,4	2,4	3,2	0,0	5,6	4,8	0,5	0,0	5,3
	Monopodial	2,2	3,7	0,0	5,9	6,6	3,4	0,0	10,1	1,0	3,8	0,0	4,8
	Sympodial	0,9	1,4	0,0	2,3	4,0	3,4	0,0	7,4	8,7	1,9	0,5	11,1
FRUITING BODIES	Flower buds	3,4	2,3	0,0	5,6	7,7	7,4	0,8	15,9	9,1	4,3	0,0	13,5
	Open flowers					1,3	0,0	0,0	1,3	0,0	0,0	0,0	0,0
	Bollsize 1					0,5	0,3	0,0	0,8	1,4	0,5	0,0	1,9
	Bollsize 2					0,5	0,0	0,0	0,5	0,5	0,0	0,5	1,0
	Bollsize 3									1,0	2,9	0,0	3,8
TOTAL		53,2	41,4	5,4		48,7	45,8	5,5		69,3	28,3	2,4	

*The stages were: Pre-flowering stage - from 6 to 8 weeks after plant emergence, representing the earliest period from the appearance of the squares to the appearance of the first flowers. Flowering stage - represents the ensuing period until peak flowering at about 12 weeks after plant emergence. Post-flowering stage - extends for about 20 weeks after plant emergence, and includes the tail end of the flowering period and the first appearance of ripe opened bolls.

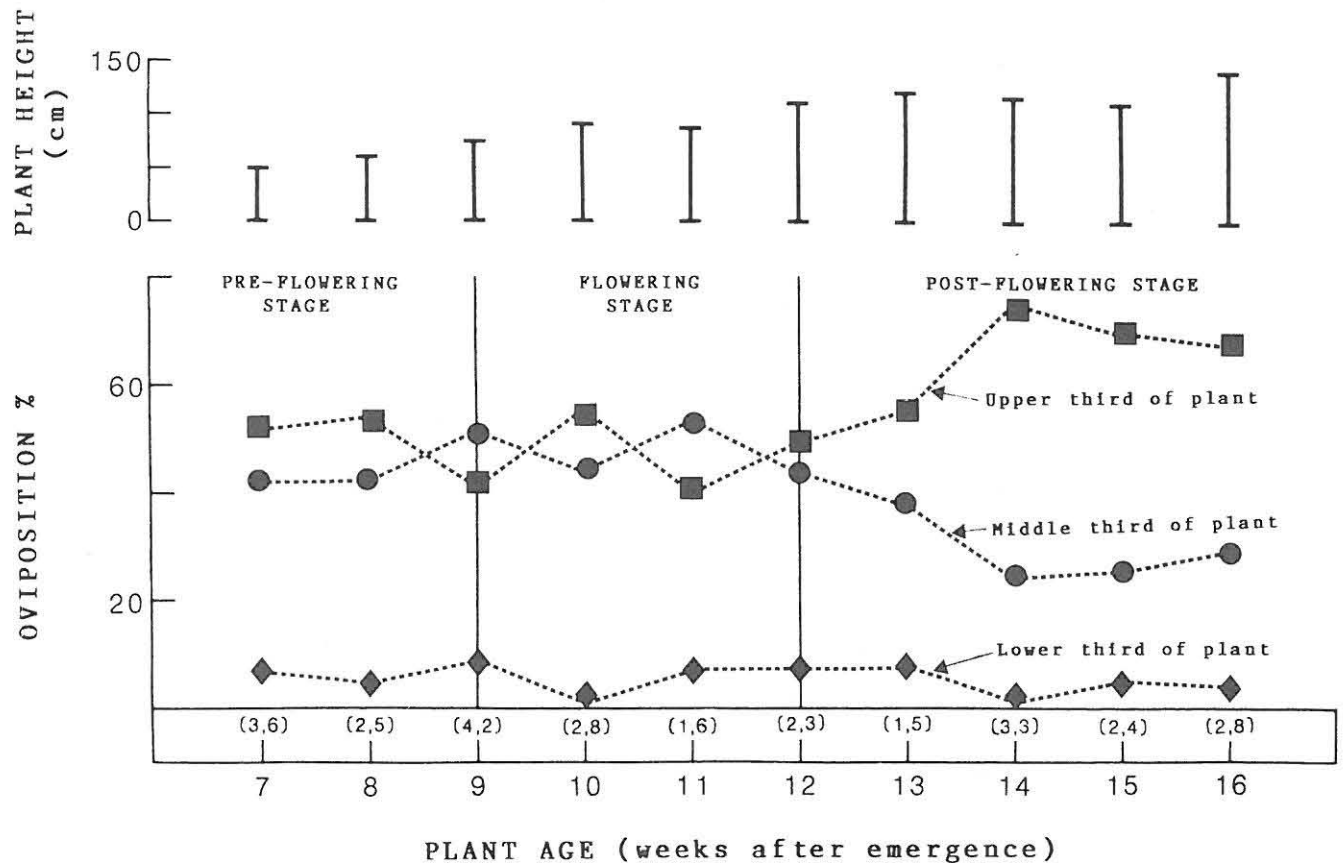


Fig. 19. The incidence of eggs of a natural *Heliothis armiger* population on height zones of cotton plants in the field during consecutive weeks after plant emergence. Figures in brackets above the horizontal axis indicate the average number of eggs recorded per plant. The data are derived from Table 5, except for weeks 15 and 16 which were collected during the 1982/83 season on cotton grown under similar conditions at the same locality. Fifty cotton plants were scouted for eggs each week. The upper graph shows the mean heights of the plants on each sampling date.

close relationship with the flowering of the plants. After peak flowering most eggs occurred on the upper third.

It appears that during the pre-flowering stage of the plant, the main period of leaf and stem formation, the

oviposition "preference" of the moths was for suitable oviposition surfaces, rather than height. The shift to the upper third of the plant after flowering, appears to be correlated with an increase in the availability of fruiting bodies in that third. Whether the fruiting bodies stimulate moths to oviposit in the upper third or whether they merely offer an additional, but not necessarily preferred, oviposition site is not known. Certainly most fruiting bodies (65 - 100% occur in the upper two thirds of the plant (Fye 1972), and offers a plausible explanation for this change in oviposition pattern.

On closer examination of the positions in which eggs were laid on the plant, it was found that on leaves most eggs were laid alongside veins or between the hairs which occur on the veins (Fig. 20). This secures the eggs more firmly to the substrate due to the anchoring effect of the ribs and hairs and perhaps by providing a larger surface substrate to which the eggs are fixed. On fruiting bodies, most of the eggs were laid on buds rather than on flowers or bolls (Table 5). On buds and flowers the eggs were laid mainly on the leaf-like bracteoles (outer calyx), with an occasional egg on the petals of flowers.

A dense cover of fine hairs occur on the stems, and particularly on young leaves at the growing tip before the leaves expand to spread the hairs over a much greater surface (Prentice 1972). These are favoured oviposition sites, but the eggs deposited on these hairs appear to be stuck loosely, almost perched on the hairs (Fig. 20), in contrast with the eggs on leaves and fruiting bodies.

With this knowledge on the morphology of H armiger eggs and their distribution on the host plants, it is now

possible to examine the effectiveness of the adhesion of the eggs.



Fig. 20. Preferred oviposition sites of Heliothis armiger on cotton (Variety Acala 1517/70). The photograph on the left depicts an egg alongside a vein on the upper surface of a leaf, and shows the support offered by the vein and hairs, enhancing adhesion. The photograph on the right shows an egg oviposited on the hairs on the main stem near a growing tip and illustrates that the oviposition site does not offer a secure substrate, with the egg stuck loosely on the hairs.

CHAPTER 5

EFFECTIVENESS OF ADHESION OF HELIOTHIS ARMIGER EGGS

Wash-off trials with the laboratory irrigation simulator (Appendix 1) revealed an exceptional variation in the effectiveness of the adhesion of individual H. armiger eggs to oviposition substrates. This chapter deals with the factors which influence this effectiveness, not so much for the sake of studying the factors per se, but rather to develop a standardised procedure for comparing irrigation systems in the field.

Factors relating to H. armiger include the cement secreted to glue the eggs, egg fertility, moth age, numbers of eggs laid per night and egg age. The external factors discussed include the nature of water droplets and characteristics of the host plant.

FACTORS RELATING TO HELIOTHIS ARMIGER

The colleterial glands of the female reproductive system secrete the cement that glues the eggs to plant surfaces, the "spumaline" of Hinton (1981). In Lepidoptera there are normally two glands that open through a short common duct into the vagina between the external orifice of the latter and the vestibulum (Hinton 1981). Each gland usually consists of a short or long distal tube that is widened proximally to form a reservoir. The size of the glands seems to be related to whether or not the eggs are glued to the substrate and the amount of secretion with which they are covered. The secretion that covers the eggs passes out of the cells through very fine intracellular canals that open through minute pores in the cuticular wall of the lumen of the gland.

Little is known of the chemical properties of the cement in the Lepidoptera, and nothing in Heliothis spp. Beament & Lal (1957) reported that in Pieris brassicae (L.), the cement in the colleterial glands is a viscous fluid consisting of a pale yellow matrix, with a large number of granules of the same colour. On exposure (after oviposition), the cement rapidly loses water and becomes more rubbery and darker. These authors indicated that the "hardening" is irreversible so that when eggs are exposed to water the cementing properties are retained, even though the cement is slightly hygroscopic. The hygroscopic nature of the cement (which covers the eggs) has a cushioning effect on reductions in ambient humidity, thus preventing desiccation and further, aids the translocation of water to the embryo.

The role of the cement, particularly the hygroscopic properties, in the adhesion/wash-off of H. armiger eggs from plants has not been investigated. Observations on H. armiger eggs oviposited on cotton leaves supports the findings of Beament & Lal (1957). When exposed under water at $24 \pm 1^{\circ}\text{C}$ for a period of 24 hours, the cement (which dried rapidly to remain as a glistening film over the eggs after laying) still stuck the eggs to the plants, but became more pliable, confirming the hygroscopic nature of the cement.

To investigate variation in egg adhesion within and between H. armiger moths, eggs of 47 individual four-day old moths from the laboratory culture were exposed to the laboratory irrigation simulator. The eggs of each moth were collected daily for three or four successive nights, and care was taken that each moth's eggs were always allotted to the same position on the turntable (Fig. 36 - Appendix 1). The wash-off data for the eggs, shown in Fig. 21, are for batches of fertile (90% or higher fertility rate) and infertile

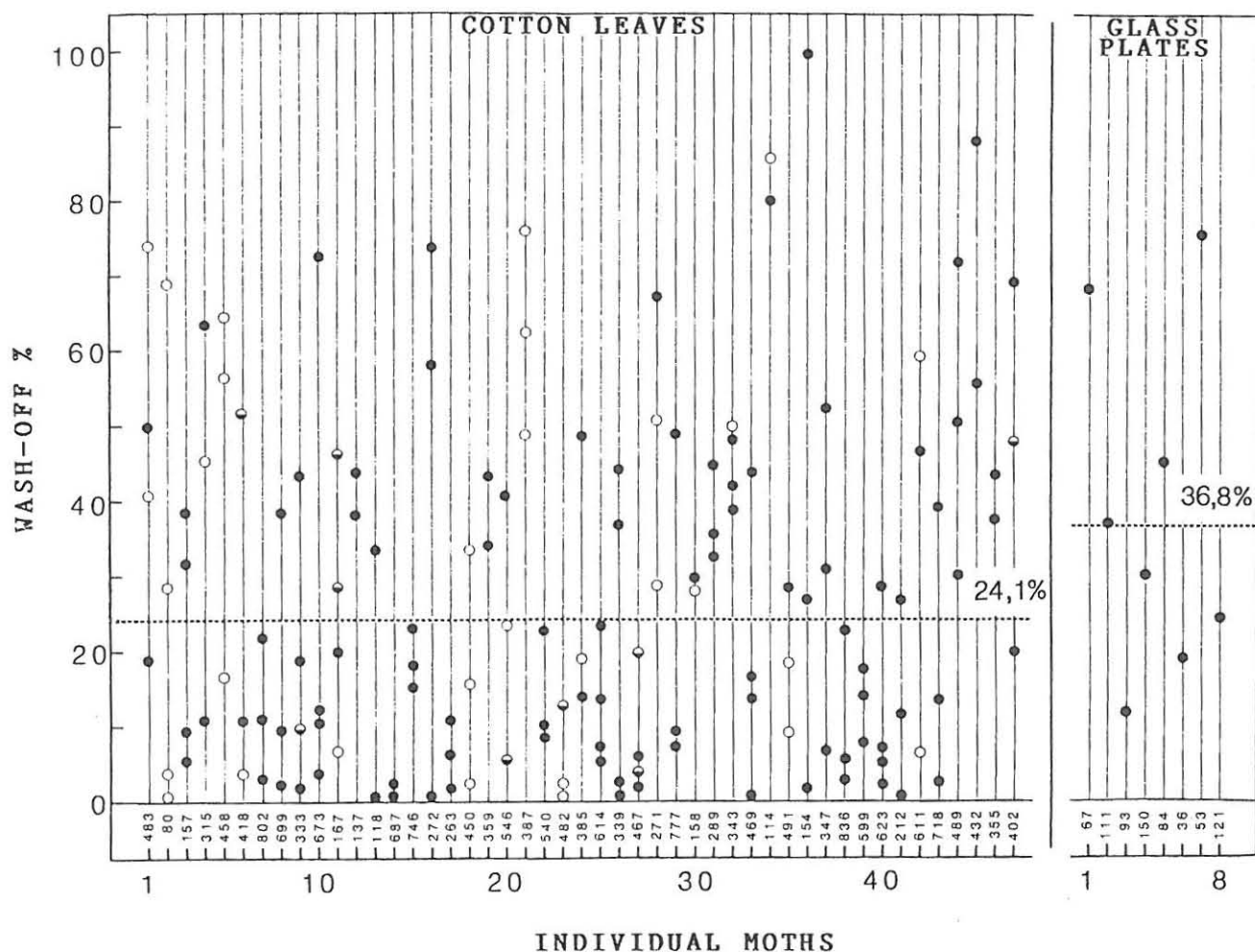


Fig. 21. Scatter diagram of the wash-off of laboratory-reared *Heliothis armiger* eggs oviposited on cotton leaves and glass plates. On cotton leaves the eggs oviposited by single moths were collected on successive days, as indicated by the number of circles, each representing a daily batch of eggs. On glass only one batch of eggs of eight single moths was collected. Each day's eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator fitted with nozzle tip number 6510 (Appendix 1). Open circles show infertile eggs, closed circles fertile eggs and half closed circles are intermediate values which ranged from 11 - 89% fertility. The dotted line shows the mean wash-off of eggs from the two surfaces. The number of eggs oviposited by each moth during the exposure period is shown above the horizontal axis. A total of 20 067 and 715 eggs were exposed on cotton leaves and glass plates respectively.

(less than 10% fertility rate), the fertility norms maintained throughout this study). For comparison, the variation in the adhesion of eggs oviposited by single moths on a smooth glass surface, the wash-off data for eggs oviposited by eight moths are also included in Fig. 21. The results in Fig. 21 indicate a considerable variation in egg adhesion between the eggs from individual moths and also between moths of the same population. Arguably some of the variation in adhesion can be ascribed to differences in leaf surfaces as pointed out in Chapter 4, but the variation found with uniformly smooth glass surfaces points to variation in the adhesion itself. This raises the question whether the variation also occurs in field populations, or whether it was a result of inbreeding in the laboratory culture (Chapter 2). To test this possibility, H. armiger eggs collected from a field population of moths (Chapter 2), were used in a duplicated experiment. Over a period of four weeks, 123 moths (46 females and 77 males) were caught. For unknown reasons, only 23 of the females oviposited during the first night in captivity. The wash-off of these eggs is shown in Fig. 22, and the figures indicate a similar variability to that found for the eggs from the culture, but with a higher rate of wash-off (51,4%). A similar variability was found for the F1 progeny of these moths (Fig. 22). Although no statistically significant differences could be shown in the adhesion of the eggs from laboratory and field populations of H. armiger on cotton leaves, the differences are nevertheless considerable and require further investigation.

In order to accommodate this variation in adhesion, a series of experiments on the wash-off of H. armiger eggs was conducted on eggs collected from single and groups of moths (Chapter 2). The results are shown in Tables 15 to 18 (Appendix 6). From these data it is

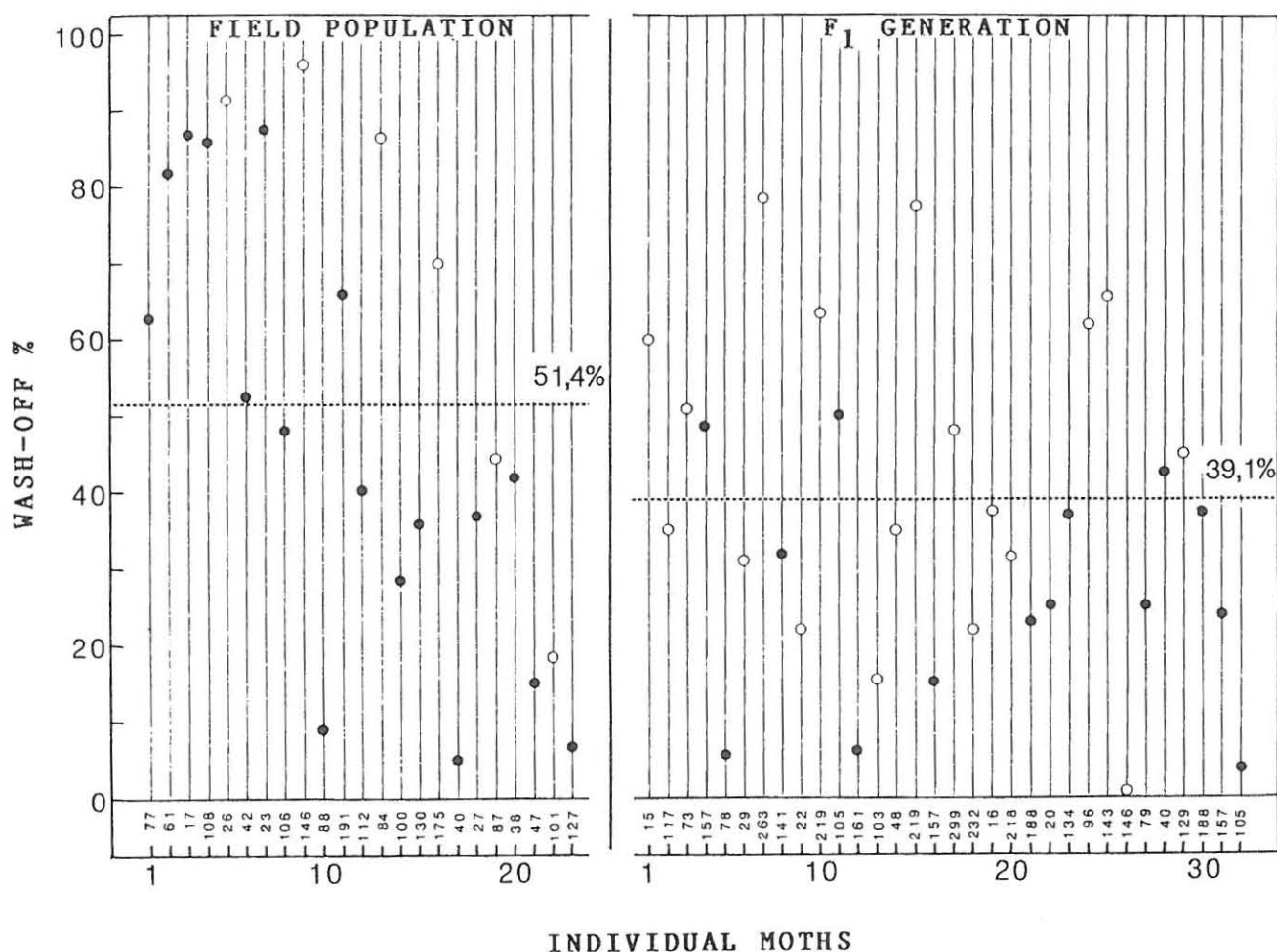


Fig. 22. Scatter diagram of the wash-off of Heliothis armiger eggs from cotton leaves. The eggs were collected from a field population caught in a black-light trap (Fig. 2) and their F₁ generation reared in the laboratory. Experimental procedures and figure outlay were the same as those described for the data shown in Fig. 21. The total number eggs exposed were 1 953 from the field collected moths and 4 097 for the F₁ generation.

clear that less variation was evident - but not eliminated, only hidden - when the eggs from groups of moths were used. This trend was maintained for different nozzle sizes as indicated by the variances obtained (Table 6). Furthermore, the fertility rates of the eggs improved when groups of moths were used (Tables 15 - 18). The differences in wash-off between

the two cotton varieties listed in Table 9 is a separate issue which is dealt with later in this chapter.

TABLE 6. Variances for wash-off data for Heliothis armiger eggs, oviposited by single and groups of moths, on two varieties of cotton leaves subjected to 50 mm precipitation from the laboratory irrigation simulator (Appendix 1) fitted with a range of nozzle sizes.

NOZZLE TIP		COTTON VARIETY	
NUMBER		Acala 1517/70	Rebel
6520	Single	48,66	17,46
	Group	27,05	7,41
6515	Single	31,21	5,92
	Group	2,19	3,43
6510	Single	192,92	30,75
	Group	12,70	14,97
6505	Single	4,41	2,72
	Group	6,52	4,34
6504	Single	64,98	8,00
	Group	1,13	1,81

All in all, the results indicate that groups of moths provided more consistent results (in terms of egg adhesion) than single moths. This is supported further by the numbers of moths required to provide a satisfactory level of confidence (Table 7); it follows that variation in the data was reduced by increasing the number of moths - and using representative samples of eggs by groups of moths - rather than collecting more eggs from individual moths.

TABLE 7. Numbers of single and groups of Heliothis armiger moths required to provide various levels of confidence for interpreting experiments on the adhesion of eggs. The data were derived from Tables 15 and 16 and were analysed according to the method of Southwood(1978) for determining the number of samples.

Level of accuracy	Single moths	Groups of moths
5%	1 297	603
10%	324	151
25%	52	25

Eggs that were not washed off were incubated to determine the effect of water droplets on the survival of the embryo. The development of larvae until pupation revealed that exposure to water droplets from the laboratory irrigation simulator had no obvious effect on the survival or development of H. armiger larvae.

The difference in egg fertility between batches of eggs oviposited by single H. armiger moths, raised the question whether egg fertility affected adhesion. This was examined by analysing the data in terms of fertile and infertile eggs (Fig. 23).

The pairs of histograms illustrate a consistent tendency for fertile eggs to adhere more firmly to cotton leaves, an improvement of 10 - 25% over infertile eggs. Significantly, however, the same order in variation was found for fertile and infertile groups, indicating that the variation in egg adhesion is independent of fertility. Whether the reduction in fertility of eggs is due to a lack of mating or fertilisation, or perhaps an inability to mate, is not

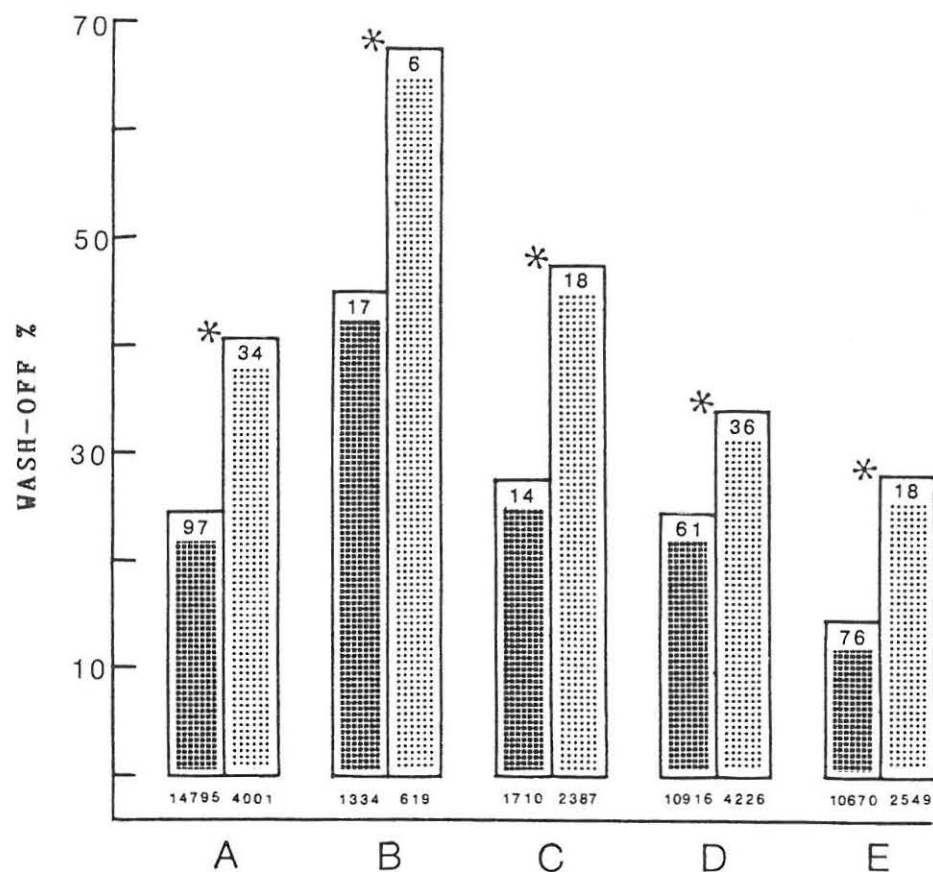


Fig. 23. The wash-off of batches of fertile (dark bars) and infertile (light bars) *Heliothis armiger* eggs. All eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator (Appendix 1). Figures above the horizontal axis show the numbers of eggs exposed, and the numbers of moths used are shown as inserts in the bars. The data are derived from various experiments as follows:

A = egg adhesion experiment (Fig. 21);
 B = field population (Fig. 22);
 C = F_1 generation of the field population (Fig. 22);
 D = single moths exposed to Acala 1517/70 (Table 15 - Appendix 6);
 E = Single moths exposed to Rebel (Table 17 - Appendix 6).

Asterisks above each pair of bars show significant differences in chi-square values at the 95% confidence level between fertile and infertile eggs.

known. Be that as it may, the wash-off per se of infertile eggs in the field had no effect on survival and the factors below are considered in relation to

fertile eggs only. The need to examine some of these factors were not anticipated and some of the data were obtained by re-analysing the experiments on egg adhesion, hence the fewer replicates in some cases.

The influence of moth age on the adhesion of H. armiger eggs is presented in Fig. 24. From these limited data it appears that the eggs of four-day old moths adhered significantly better to the cotton leaves than those of the older moths. Bearing in mind the variation in adhesion that exists between moths, the number of moths representing each age group were too low to arrive at a firm conclusion. Certainly no obvious differences are apparent between the data in Fig. 24 for eggs from groups of four-day old moths and those in Tables 15 and 16 (Appendix 6) for single and groups of moths of the same age. In this study moths of approximately the same age (4 - 6 days) were used; further research will be needed to determine the precise influence of moth age, covering a life span of up to 15 days (Taylor 1932), on the adhesion of eggs.

To investigate the effect of the numbers of eggs laid per night by H. armiger females on egg adhesion, batches of fertile eggs oviposited by single moths were analysed in terms of the numbers of eggs laid per female and the adhesion of the eggs. The batches were arranged in classes of 50, ranging from less than 50 eggs to more than 300 eggs per night (Fig. 25). From the results in Fig. 25 it is clear that batch size had very little effect on the adhesion of the eggs. The apparently improved adhesion of eggs in the highest class is probably an artefact; when moths are forced to lay large numbers of eggs on a leaf in the confines of a small cage, washing off of dislodged eggs is often prevented by other eggs. This clumping is irrelevant to the field situation, where the eggs are laid singly and sparsely. Note that these data on numbers of eggs

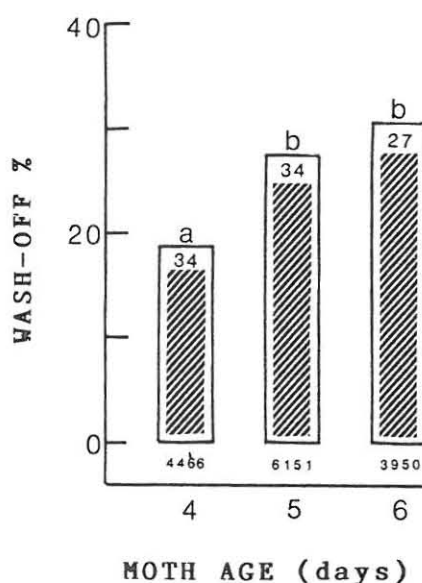


Fig. 24. The wash-off of newly-laid Heliothis armiger eggs oviposited by moths of different ages. The eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator (Appendix 1). The data are derived from fertile eggs oviposited by single moths (Fig. 21). The numbers of eggs considered for each treatment are shown above the horizontal axis, and the numbers of moths used are shown as inserts in the bars. The same letter above each bar shows non-significant differences in chi-square values at the 95% confidence level.

laid per night cannot be related to moth fecundity since the data were not analysed in terms of the numbers of eggs laid by females over their lifespan.

To determine the effect of egg age on the adhesion of H. armiger eggs to cotton leaves, eggs oviposited by groups of moths (Chapter 2) were removed daily from the oviposition cages. The eggs were aged in the laboratory with the cotton leaves held on dampened cotton wool and subjected to sprays from the laboratory irrigation simulator. The data are shown in Fig. 26.

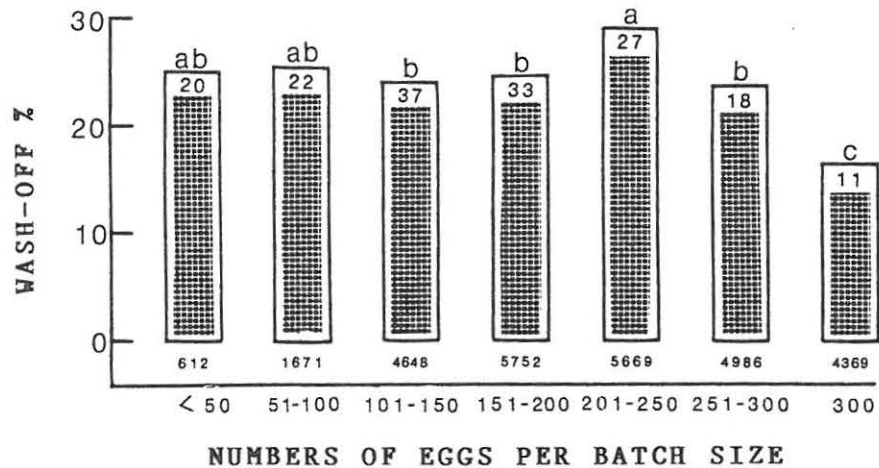


Fig. 25. The wash-off of different batch sizes of newly-laid Heliothis armiger eggs laid per moth per night. The eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator (Appendix 1). The data are derived from fertile eggs oviposited by single four-day old moths (Figs 21 and 29 (15° droplet impact angle only) and from Table 15 - Appendix 6). The numbers of eggs considered for each treatment are shown above the horizontal axis, and the numbers of moths used are shown as inserts in the bars. The same letter above each bar shows non-significant differences in chi-square values at the 95% confidence level.

From the results it is clear that the age of eggs had little effect on their adhesion, even up to about three days when the eggs were about to hatch, hence the low numbers recorded in Fig. 26 for the oldest category. What the effect will be in the field where the eggs are exposed to climatic extremes, and where the incubation period is up to 14 days (Jones 1936) remains to be examined.

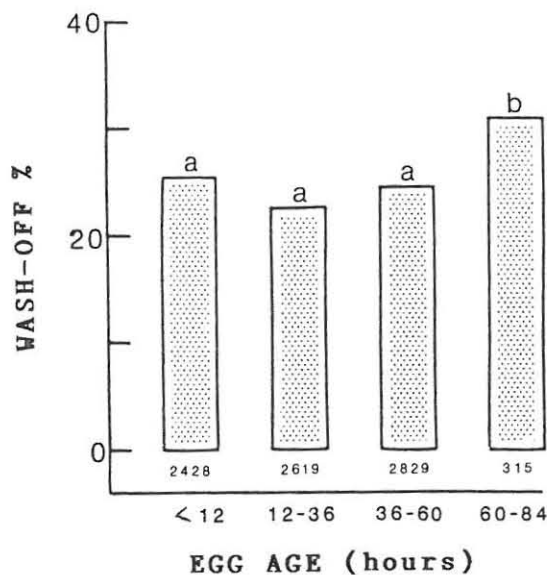


Fig. 26. The wash-off of fertile Heliothis armiger eggs of different ages, oviposited by four-day old moths. The eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator fitted with nozzle tip number 6510. (Appendix 1). The numbers of eggs considered for each treatment are shown above the horizontal axis. The same letter above each bar shows non-significant differences in chi-square values at the 95% confidence level.

EXTERNAL FACTORS

The size of the droplets from the laboratory irrigation simulator, the period that eggs were exposed and the impact angles of the droplets are discussed to provide a basis for examining the influence of the physical nature of the host plants on the adhesion of H. armiger eggs.

Data to determine the effect of **droplet sizes** of water (varied by using different nozzle tips fitted to the laboratory irrigation simulator) on the wash-off of H. armiger eggs from cotton leaves were derived from Tables 15 - 18 (Appendix 6). Although significant differences in wash-off were found between the different droplet sizes for eggs from single moths and groups of moths on the Acala 1517/70 variety (Fig. 27), the results were inconsistent and did not reveal any

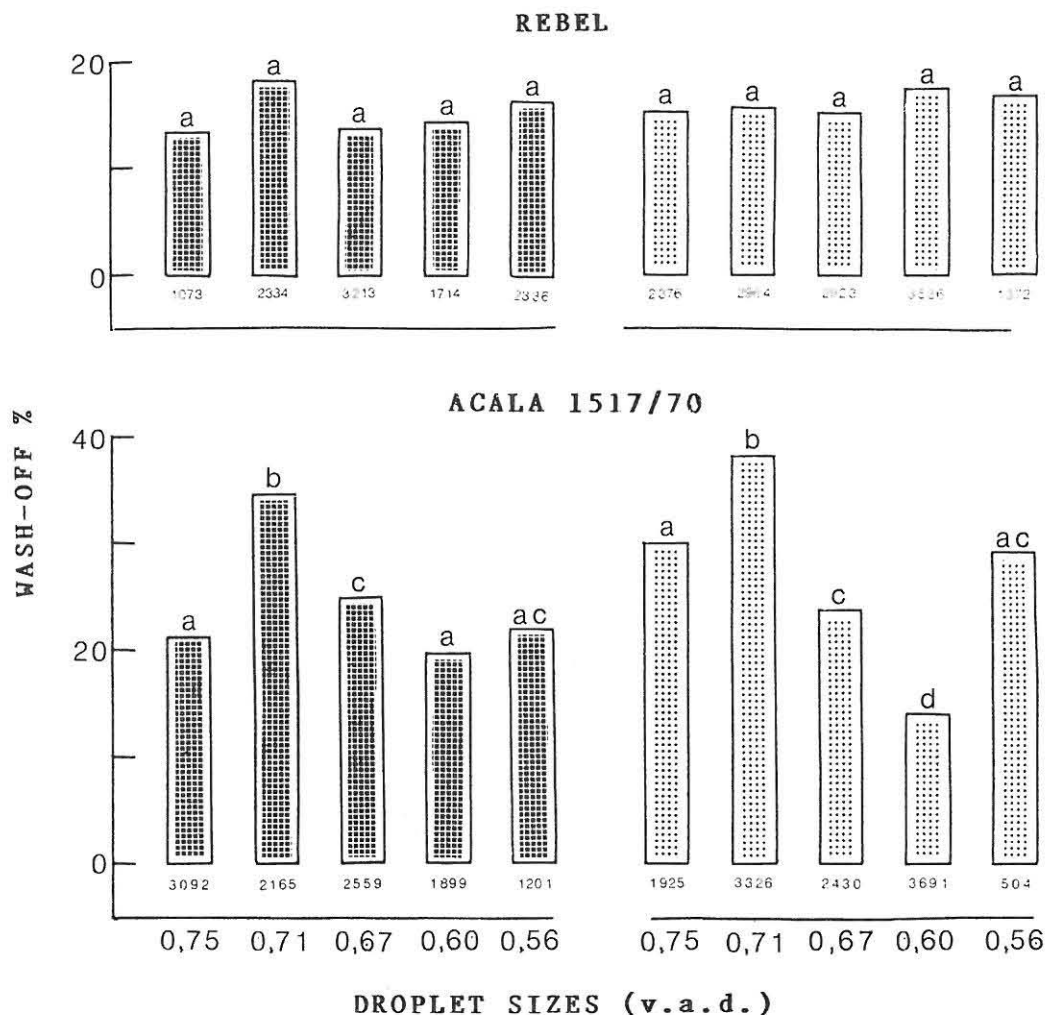


Fig. 27. The wash-off of newly-laid *Heliothis armiger* eggs by droplets of different sizes. The eggs were subjected to a 50 mm precipitation from the laboratory irrigation simulator fitted with a range of nozzles (Table 11 - Appendix 1). The data apply to fertile eggs and are derived from Tables 15 and 17 (Appendix 6) for the eggs laid by single moths (dark bars) and from Tables 16 and 18 (Appendix 6) for the eggs laid by groups of moths (light bars). The numbers of eggs considered for each treatment are shown above the horizontal axis. The same letter above each group of bars shows non-significant differences in chi-square values at the 95% confidence level.

trend in wash-off in relation to droplet sizes. There was, however, a tendency for nozzle tips no. 6515 (droplet size 0,70 - 0,72 mm) and 6505 (droplet size 0,59 - 0,61 mm) (Table 11 - Appendix 1) to wash off the

highest and lowest numbers of eggs respectively, for the eggs from both the single as well as the groups of moths. No explanation can be given for this tendency, and can only be ascribed to the performance of the nozzles, due to factors not related to droplet size. In contrast, the results obtained for eggs exposed on the cotton variety Rebel, no significant difference in the wash-off of the eggs between the different droplet sizes could be found.

Since the exposure period to receive a 50 mm precipitation differs for the three positions used on the turntable (Table 11 - Appendix 1) the wash-off caused by all the droplet sizes at each position on the turntable was evaluated. No significant differences for the three positions for single and groups of moths were found and the data are presented in Table 8.

TABLE 8. Significant differences in chi-square values (at the 95% confidence level) in the wash-off of newly-laid, fertile Heliothis armiger eggs from cotton leaves in relation to the position on the turntable of the laboratory irrigation simulator (Appendix 1). Four-day old moths were used to obtain eggs from single moths (light print) and groups of moths (bold print). Figures in parentheses show percentages wash-off. These data are derived from fertile eggs selected from Tables 15 and 16 (Appendix 6).

	POSITION ON TURNTABLE					
	1		2		3	
	(24,6)(25,9)		(23,6)(26,3)		(26,4)(25,7)	
1	-		NS	NS	NS	NS
2	-		-		NS	NS
3	-		-		-	

Because no significant differences in chi-square values at the 95% confidence level in wash-off for fertile

eggs were found for droplet sizes or positions on the turntable, all the data for single and groups of moths were pooled for examining the factors which follow.

The effects of the period of exposure to droplets on the dislodging and wash-off of H. armiger eggs from cotton leaves by a 50 mm precipitation applied during different exposure periods are shown in Fig. 28. From these results it is evident that varying the exposure periods from about one hour up to about 12 hours to produce a 50 mm precipitation did not influence the wash-off of eggs significantly. The inconsistent results for Acala 1517/70 are unexplained, but are not due to the exposure period.

It remains to determine the influence of the impact angles of droplets on the wash-off of the eggs. Under natural conditions a plethora of variables determine impact angles (e.g. wind, position of eggs on the plants, and of course, the impact angles of the droplets on striking the eggs). Clearly, the impact angle of droplets could only be manipulated and measured in the laboratory and was effected by tilting the turntable trays of the laboratory irrigation simulator (Appendix 1). Eggs from groups of moths were exposed on the trays tilted to angles from 15° to 75° and exposed to vertical sprays from the spray tower until 50 mm precipitation was recorded in the upright (Fig. 29) rain gauges. Tilting of the leaf surfaces reducing the area of exposed substrate and therefore the volume of water landing on the leaves. Note that this does not relate to the position of individual eggs in relation to the direction of the spray - the volume of water striking "egg areas", the surface area beneath eggs, would not be affected by the tilting of the leaves on the trays. By analogy, a mountain slope does

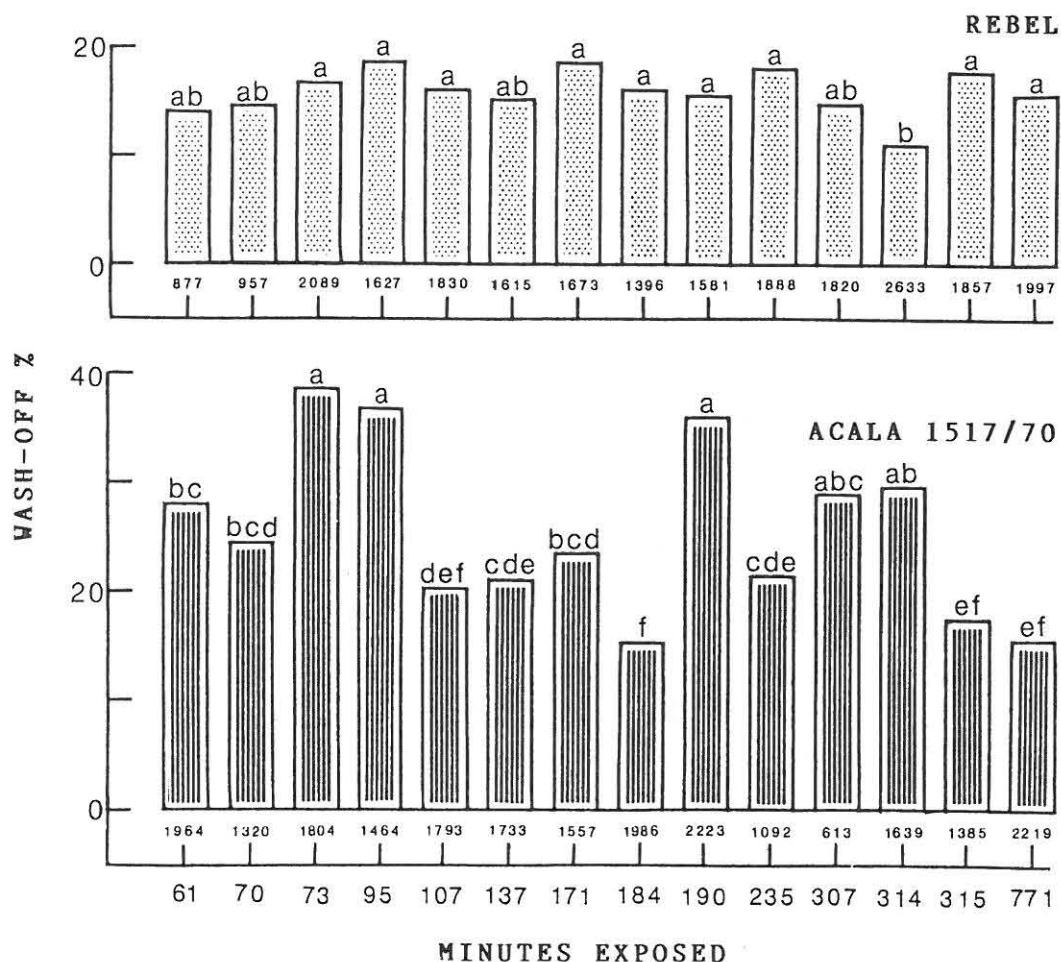


Fig. 28. The wash-off of newly-laid *Heliothis armiger* eggs from the cotton varieties Rebel (light bars) and Acala 1517/70 (dark bars), by a 50 mm precipitation applied over different periods. The eggs were subjected to droplets from the laboratory irrigation simulator fitted with a range of nozzles (Table 11 - Appendix 1). The data apply to fertile eggs and are derived from Tables 15 and 17 (Appendix 6) for the eggs laid by single moths and from Tables 16 and 18 (Appendix 6) for the eggs laid by groups of moths. The numbers of eggs considered for each treatment are shown above the horizontal axis. The same letter above each group of bars shows non-significant differences in chi-square values at the 95% confidence level.

not affect the amount of rain collected in a rain gauge, only the volume of rain per land-surface area.

From the histograms shown in Fig. 29 it is apparent that only at the highest level of tilting (75°) was there any marked decline in the wash-off of eggs, notwithstanding a progressive decrease in the volume of water recorded. In other words, the tilting of the leaves (and thereby changing the impact angles) compensated for the lower precipitation, rather like the higher rates of soil erosion which occur on hillsides compared to flat lands. It seems as if droplets striking the eggs sideways impart a "pushing" effect which enhances dislodging. The graphs inserted in Fig. 29 illustrate the concept further by a reciprocal analysis. Insert I illustrates the wash-off of H. armiger obtained for different precipitations and and Insert II shows the increment, over the expected wash-off, that is when the calculated precipitation per area (shown in the main graph) is substituted in Insert I. Note that the higher wash-off rates which result from the tilting of the oviposition substrates in relation to spray direction is not to be confused with the increased kinetic energy of droplets driven sideways by wind (Rogers et al. 1967). This aspect is dealt with in the Discussion.

Since hairy cotton varieties are more attractive to H. armiger moths for oviposition, the presence of hairs (trichomes) especially those on the upper leaf surface - the most favoured oviposition site on cotton (Table 5) were examined in relation to adhesion of the eggs. A moderately hairy variety "Rebel" was compared to the widely used, more smooth variety "Acala 1517/70" (A.I. Greeff, Research Institute for Tobacco and Cotton, personal communication) in this study. Both these varieties are recommended for the areas in which the experiments were done. Table 9 lists the salient morphological features of each of the varieties. Fig. 30 shows the larger number of hairs on the upper surface of Rebel leaves which were compared to Acala

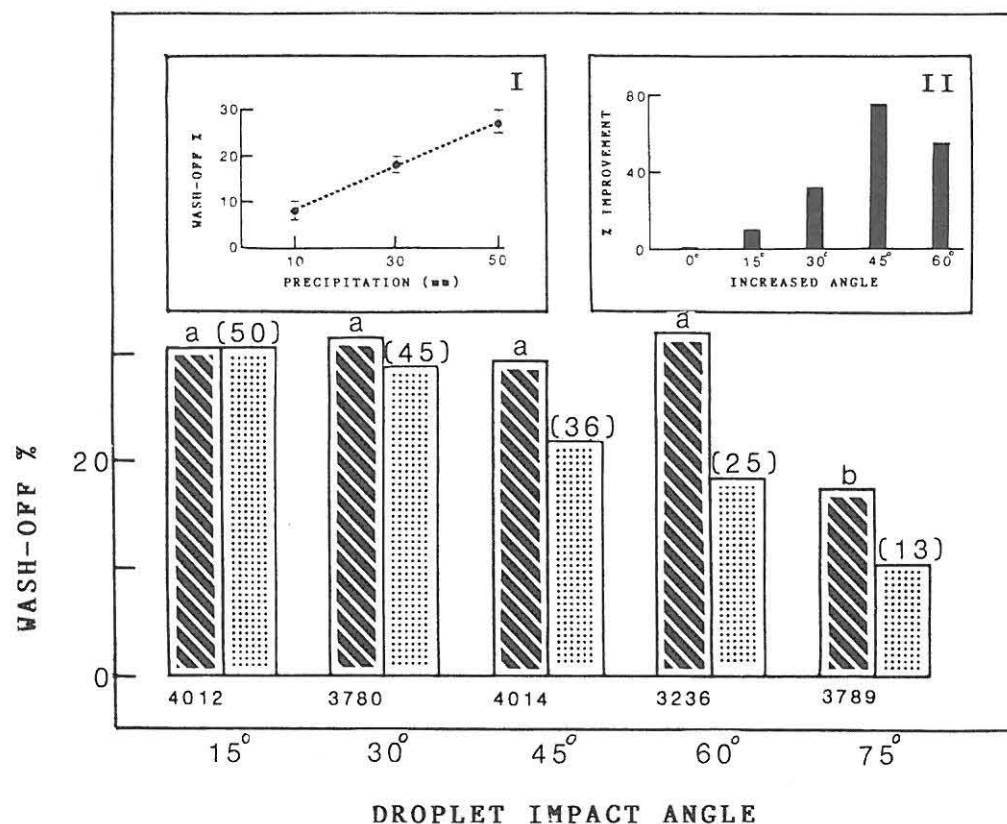


Fig. 29. The wash-off of newly-laid *Heliothis armiger* eggs oviposited by four-day old moths on cotton leaves by droplets from the laboratory irrigation simulator striking the eggs at various angles. The eggs, exposed on the turntable (Fig. 37 - Appendix 1) were tilted in relation to the vertical sprays from the spray tower, fitted with nozzle tip number 6510, until 50 mm precipitation was recorded in the rain gauges. The dark bars show the actual percentage wash-off of eggs. The same letter above each dark bar shows non-significant differences in chi-square values for exposure angles at the 95% confidence level. The numbers of eggs considered for each treatment are shown above the horizontal axis. Figures in parentheses above the light-shaded bars show the calculated precipitation (mm) received per leaf area at each angle of exposure (see text). The light shaded bars show the corresponding expected percentage wash-off of eggs for these precipitations, and are based on the graph in Insert I. Insert I shows the wash-off of eggs with increasing precipitation. Each point on the graph represents the mean and ranges for three replicates. The line was fitted by eye. Insert II is derived from the main graph and Insert I shows the improved wash-off resulting from droplets striking the eggs at greater angles.

1517/70 used in these experiments. All the leaves used, were collected from field-grown plants.

TABLE 9. Main morphological differences between the cotton varieties Acala 1517/70 and Rebel, with emphasis on leaf hairs.

MORPHOLOGICAL CHARACTER	VARIETY	
	Acala 1517/70	Rebel
Plant height (mature)	100 - 150 cm	60 - 90 cm
Growth pattern	Open, pinetree like	Short, compact cylinder like
Bollsize (mature)	3,7 cm average	Smaller than Acala
Hairiness (Fig. 30)	Regarded as a smooth variety	Moderately hairy variety
Trichomes (hairs) on upper surface of mature leaves:		
*Main and secon- dary veins. (Trichome pattern mainly open and branched into 3-4 hairs) Fig. 30 - Upper four photo- graphs	78 (57 - 94)	190 (125 - 270)
**Minor veins (Trichome pattern mainly unbranched hairs) Fig. 30 - lower pair of photographs	0	160 (44 - 360)
* Average number of trichomes counted per 4,5 cm² per 20 leaves. ** Average number of trichomes counted on the total leaf surface per 20 leaves. Figures in paren- theses indicate ranges in number.		

ACALA 1517/70

REBEL

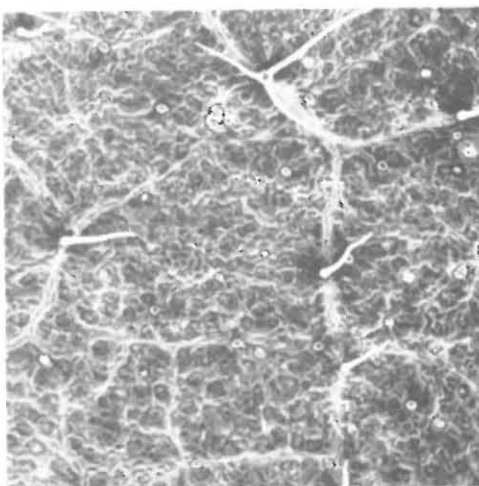
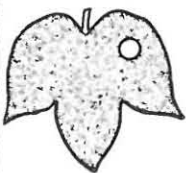
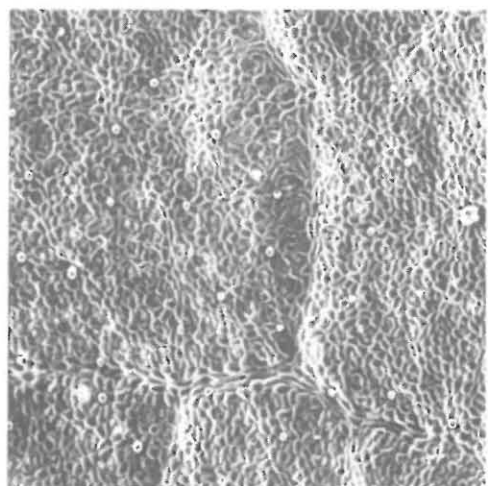
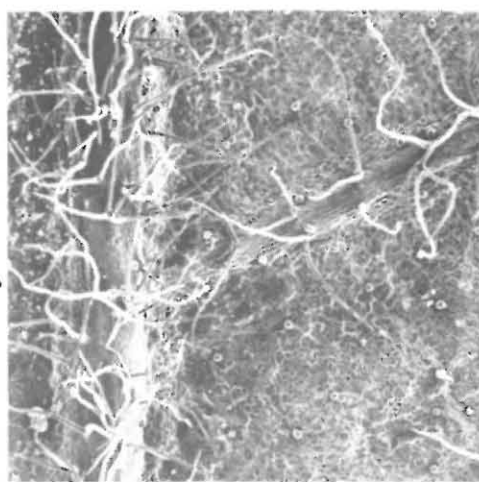
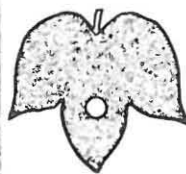
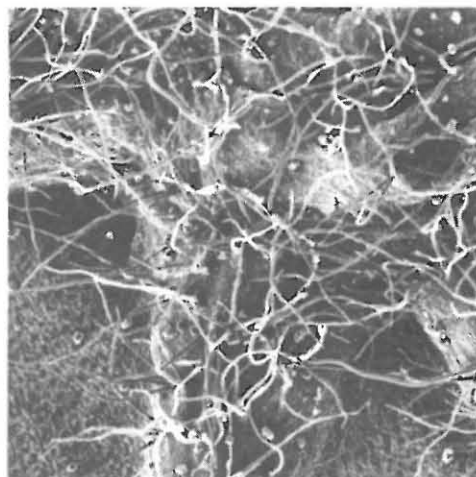


Fig. 30 Differences in hairiness on the upper surface of mature cotton leaves of the cotton varieties Acala 1517/70 and Rebel used in this study. The circled areas on the inserts between the photographs indicate the approximate areas enlarged ten times.

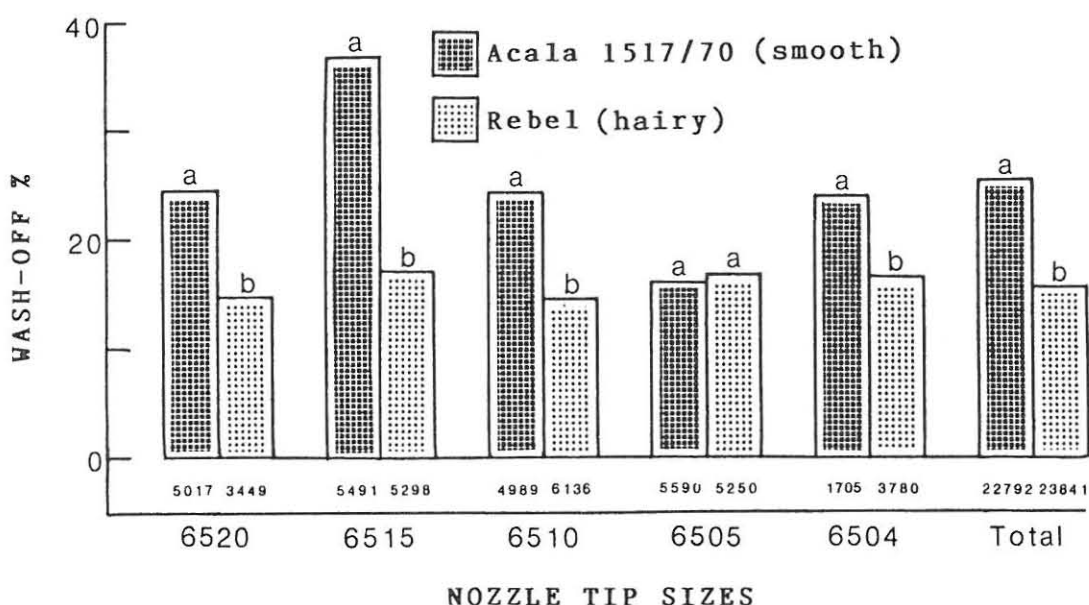


Fig. 31. The wash-off of newly-laid *Heliothis armiger* eggs from the upper surfaces of leaves of a smooth (dark bars) and a hairy (light bars) cotton variety, by a 50 mm precipitation from the laboratory irrigation simulator (Appendix 1). The data apply to fertile eggs and are derived from Tables 15 and 17 (Appendix 6) for eggs laid by single moths and from Tables 16 and 18 (Appendix 6) laid by groups of moths. The numbers of eggs considered for each treatment are shown above the horizontal axis. The same letter above each pair of bars show non-significant differences in chi-square values at the 95% confidence level.

The wash-off results presented in Fig. 31 are pooled for eggs laid by single and groups of moths. The data, except for nozzle tip 6505, reveal a clear tendency that fewer eggs were washed off from the hairy variety Rebel. This was probably due to an initial supporting effect of the hairs (thus resisting dislodging) as well as impeding the washing off of dislodged eggs by trapping them. This trapping may explain the smaller variation in the numbers of eggs lost from the hairy cultivar, than from the more smooth variety.

To summarise, the following characteristics of the adhesion of H. armiger eggs have been illustrated.

- (i) Of the factors relating to H. armiger, increased egg fertility reduced wash-off of the eggs and variation in the results was lessened by using groups of moths rather than single moths. Moth age, number of eggs laid per night per moth and egg age had no effect.
- (ii) An increase in the impact angles from the vertical with which droplets strike oviposition substrates enhanced wash-off. The size of droplets and exposure periods had no effect.
- (iii) More hairy leaf surfaces retained the eggs better.

It is within these parameters that the wash-off of the eggs in the field due to further factors is investigated in the next chapter.

CHAPTER 6

WASH-OFF OF HELIOTHIS ARMIGER EGGS FROM COTTON PLANTS.

This chapter deals with the wash-off effect of overhead irrigation and simulated rain on H. armiger eggs oviposited on field-grown cotton. An evaluation of the systems is followed by a discussion of the wash-off of the eggs in terms of plant oviposition zones, plant parts (Fig. 3) and the precipitation applied.

Two overhead irrigation systems were tested, namely, a conventional overhead irrigation system (Appendix 2) and a centre-pivot irrigation system (Appendix 3) and compared with a rotating-boom field rainfall simulator (Appendix 4). The general materials and methods are described in Chapter 2. The systems are compared by an analysis of wash-off data for eggs oviposited by laboratory reared populations of H. armiger. The results are shown in Tables 19 - 22 (Appendix 6). To evaluate the systems the total wash-off of eggs are expressed as percentages of all eggs oviposited on cotton plants and are shown in Fig. 32. From these data it is evident that there was no significant difference in wash-off by the different systems, notwithstanding the differences in droplet sizes, kinetic energy (Chapter 3) and the period necessary to apply 50 mm precipitation.

The slightly higher wash-off rates recorded for the conventional (1983/84) and the centre-pivot systems can be ascribed to the effect of wind, which ranged from 10 - 15 km/h, during the irrigation period (Table 12, Replicate 4 - Appendix 2 and Table 13, Replicate 2 - Appendix 3).

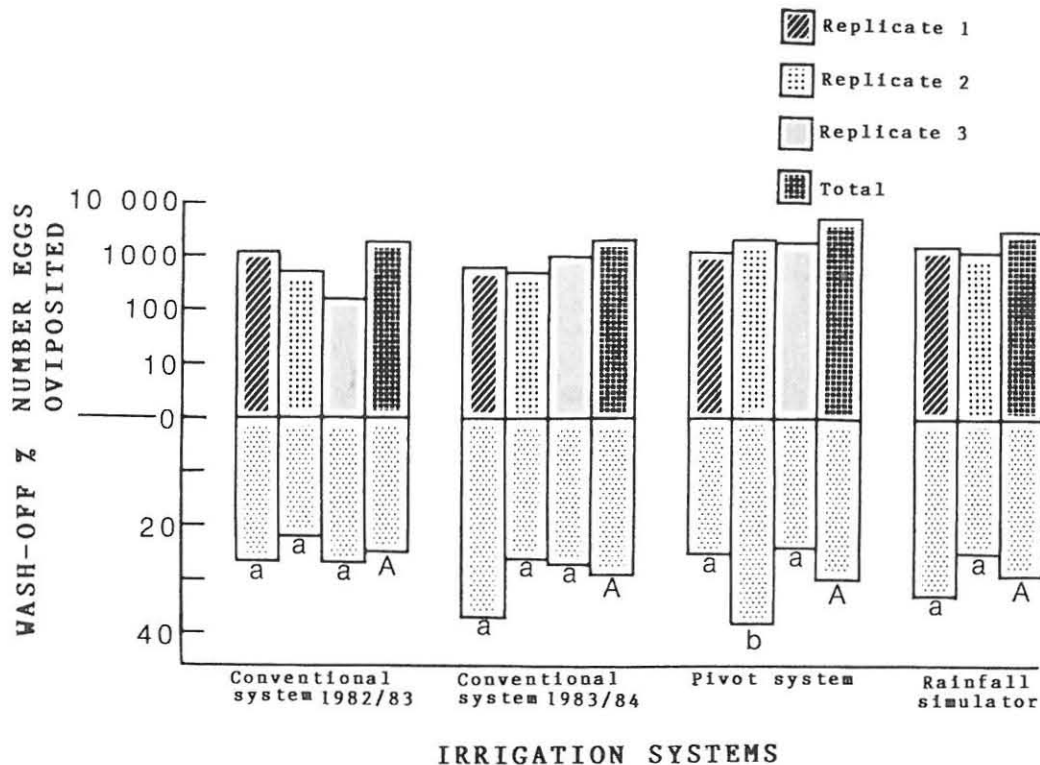


Fig. 32. The numbers of *Heliothis armiger* eggs oviposited on field-grown cotton by caged moths (upper bars), and the percentages of eggs washed off (lower bars). A 50 mm precipitation was applied by the different irrigation systems. Replicates is shown in the Figure. The same lower-case lettering under lower bars for replicates and upper-case lettering for totals show non-significant differences in chi-square values at the 95% confidence level. The data are derived from Table 23 - Appendix 6.

For further detailed comparison of the systems, the wash-off of eggs oviposited in the different oviposition zones of the plants were analysed. These data are shown in Fig. 33, and reveal that no significant differences in the wash-off of eggs from the different zones were detectable. This result was somewhat unexpected; one would expect eggs towards the middle of the plant to be more protected, but it seems that the run-off (rinsing) effect of droplets may be as effective as the direct action of droplets. In practice this means that all the eggs on the plant, regardless of whether they are in the upper or lower parts of the plant, are equally prone to washing off.

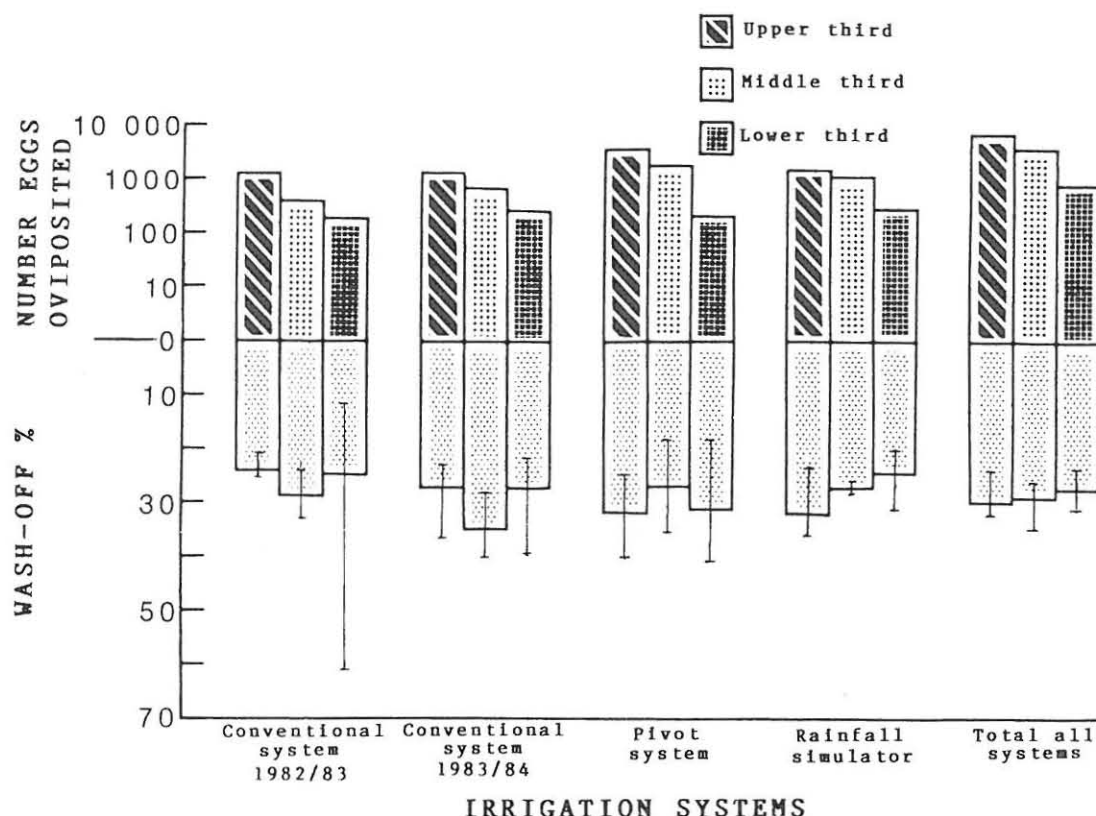


Fig. 33. The numbers of *Heliothis armiger* eggs oviposited in the different oviposition zones (Fig. 3) of field-grown cotton plants (upper bars) and the percentage wash-off (lower bars) after a 50 mm precipitation was applied by the different irrigation systems. The bars represent two replicates for the field rainfall simulator and three for the other systems. Means and ranges in wash-off for replicates are shown. The data are derived from Tables 19 - 22 (Appendix 6).

With the knowledge that eggs from different oviposition zones were equally liable to be washed off by all the systems, it was possible to analyse the data in terms of the wash-off from the different oviposition sites described in Chapter 2. The data given in Fig. 34 shows that most of the *H. armiger* eggs were oviposited on cotton leaves, notably mature leaves, a consequence of caging the moths - normally most eggs probably are laid on younger leaves. There were no clear preferences for plant stems or fruiting bodies. The wash-off data, however, revealed that fewer eggs were washed off from leaves, than from the other plant parts. This trend was observed in all the experiments,

albeit not statistically significantly in all cases. Also, eggs oviposited on plant stems tended to be washed off more easily than those oviposited on the fruiting bodies. This trend too was not statistically significant.

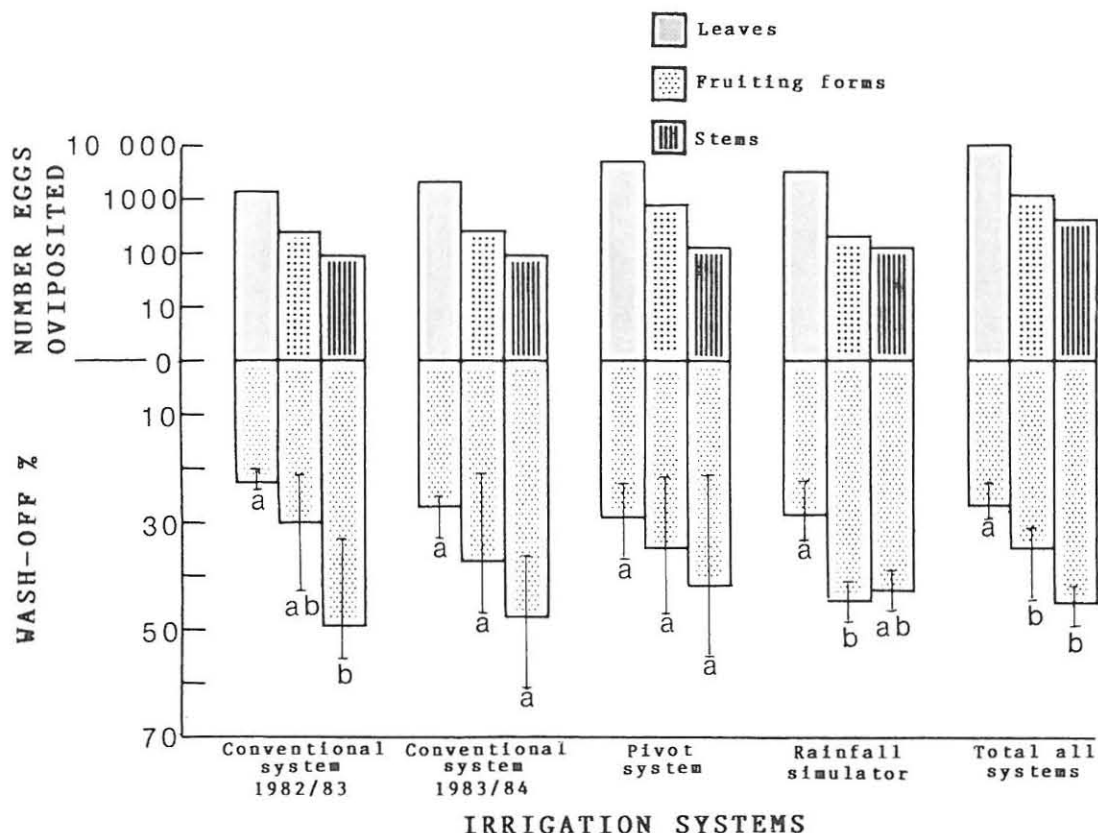


Fig. 34. The numbers of *Heliothis armiger* eggs oviposited on different oviposition sites (Fig. 2) on field-grown cotton plants (upper bars) and the percentage wash-off (lower bars) after a 50 mm precipitation was applied by the different irrigation systems. The bars represent two replicates for the field rainfall simulator and three for the other systems. Means and ranges for systems are shown. The same letters under each group of lower bars show non-significant differences in chi-square values at the 95% confidence level. The data are derived from Tables 19 - 22 (Appendix 6).

A more detailed analysis of the wash-off of eggs from leaves is shown in Table 10. These data, as expected, revealed that more eggs were washed off from the upper surfaces of leaves than from the lower surfaces. However, 13 - 25% of the eggs on the lower surfaces of mature as well as young leaves were washed off.

Furthermore, more eggs were washed off from the upper side of young leaves than from mature leaves. Note that the hairs are more dense on the younger than the older leaves (the number of hairs does not increase with growth (Prentice 1972)). In view of the fact that the laboratory studies (Chapter 5) showed that the hairs impede wash-off this result was unexpected; perhaps it is due to a "perching" of the eggs on the hairs rather than between them (Fig. 20). When the eggs are perched in this way, the surface area in contact with the substrate was relatively small. Similarly, the dense hairs covering the stems (including leaf petioles) of the plants resulted in poor adhesion. Logically, eggs laid on the tips of the bracts (Chapter 4) were invariably washed off, presumably again due to poor contact between the eggs and the substrate.

The wash-off of eggs from cotton plants in relation to increased precipitation is shown in Fig. 35. The data indicate that the majority of the washed off eggs (40%) were washed off during the first 10 mm of precipitation, perhaps almost immediately with the first few millimeters. However, the first reading was taken at 10 mm and the graph (Fig. 35) cannot be extrapolated to include lower values. After 10 mm a consistent trend in wash-off, at a rate of about 5% for every additional 10 mm applied, was found. Wind, as indicated by the open circles in Fig. 35, appeared to increase the wash-off considerably. This is considered in terms of kinetic energy in the Discussion.

TABLE 10. Significant differences (indicated by asterisks) in chi-square values at the 95% confidence level in the percentage wash-off of H. armiger eggs found between different pairs of leaf surfaces after 50 mm precipitation was applied by the different irrigation systems tested. Data are derived from Tables 19 - 22 (Appendix 6).

PLANT PART	CONVENTIONAL IRRIGATION SYSTEM				CENTRE-PIVOT SYSTEM		FIELD RAINFALL SIMULATOR		TOTAL ALL SYSTEMS	
	1982/83		1983/84							
	% WASHED OFF	SIGNIFICANCE	% WASHED OFF	SIGNIFICANCE	% WASHED OFF	SIGNIFICANCE	% WASHED OFF	SIGNIFICANCE	% WASHED OFF	SIGNIFICANCE
Mature leaves (upper surface)	26,7	NS	29,0	NS	32,5	*	39,6	*	32,6	*
Mature leaves (under surface)	20,3		22,0		20,8		16,3		19,7	
Young leaves (upper surface)	22,7	NS	35,2	NS	41,3	*	43,4	*	40,3	*
Young leaves (under surface)	15,2		24,6		15,6		13,6		16,1	
Mature leaves (upper surface)	26,7	NS	29,0	NS	32,5	*	39,6	NS	32,6	*
Young leaves (upper surface)	22,7		35,2		41,3		43,4		40,3	
Mature leaves (under surface)	20,3	NS	22,0	NS	20,8	NS	16,3	NS	19,7	NS
Young leaves (under surface)	15,2		24,6		15,6		13,6		16,1	

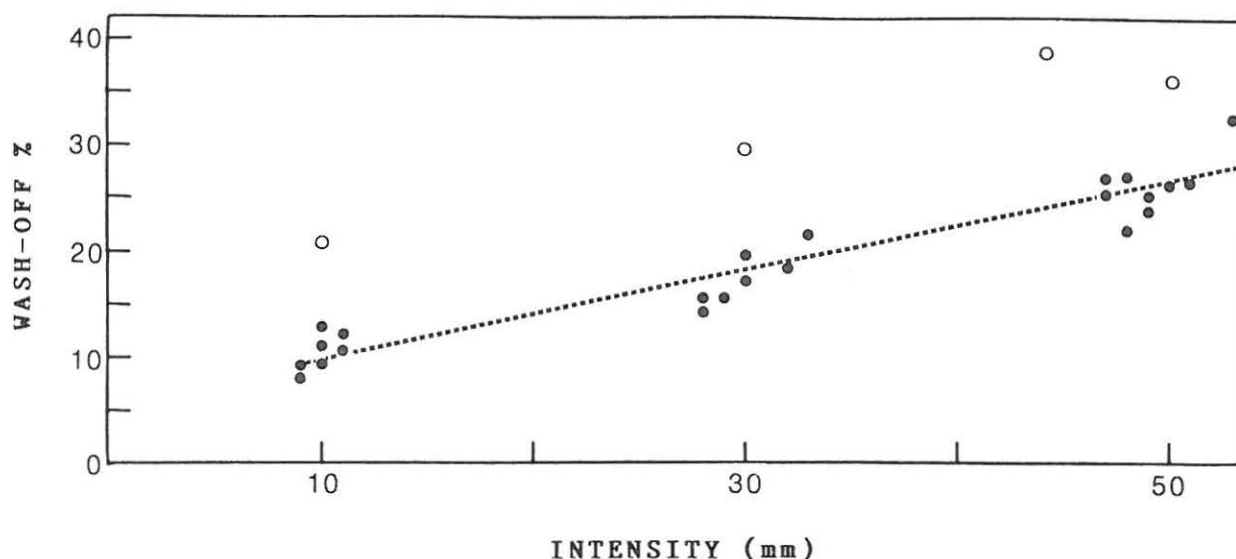


Fig. 35. Percentage Heliothis armiger eggs washed off from cotton with increasing precipitation. The circles are replicates and show the combined replicates of the different irrigation systems at intensities of approximately 10, 30 and 50 mm. Closed circles indicate windspeeds of less than 3,5 km/h during the application period, while windspeeds up to 15 km/h were recorded during applications indicated by the open circles. The broken line, fitted by eye for closed circles, shows the expected wash-off during a 50 mm precipitation at windspeeds less than 3,5 km/h. The data are derived from Table 23 (Appendix 6).

To evaluate the wash-off of eggs of a field population of H. armiger, a cotton field at the Hartebeespoort Research Station was routinely surveyed for suitable numbers of egg which were found on two occasions during the latter half of the 1983/84 season. Plants were randomly selected, and the eggs marked as explained in Chapter 2. A 50 mm precipitation was then applied by a conventional irrigation system. During the first experiment, an unusually high infestation of 4,5 eggs per plant (225 eggs/50 plants) occurred, while during the second experiment, a much lower - more normal - level of 0,48 eggs per plant (108 eggs/225 plants) was recorded. The wash-off data of these two experiments

are shown in Tables 24 and 25 (Appendix 6). These data show an unexpectedly high wash-off rate of 75% for the high egg population, a much higher wash-off rate (about 40-45% in this case) than the 30% recorded for the eggs of laboratory reared moths. This increase was due to an extraordinarily high initial wash-off rate, perhaps by very little water, similar to the results shown in Fig. 35, before 10 mm was applied. The remaining eggs on the plant followed the familiar expected wash-off trend. For the lower egg population the wash-off was in the expected range of 25 - 30%.

Clearly, the nature of the oviposition site (such as hairiness and position on the leaves, but not oviposition zones) plays some part in wash-off, as does the amount of precipitation and wind. However, the irrigation systems all had similar effects. In the field, of course, a multitude of factors can influence the adhesion and wash-off of eggs. Interactions between some of these factors are drawn together in the Discussion.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

The purpose of this study was to investigate the effect of water droplets from simulated rain and from overhead irrigation on H. armiger eggs oviposited on cotton.

During rain or overhead irrigation, H. armiger eggs on cotton plants are subjected to a bombardment of droplets striking the plant. The survival of the eggs depends upon whether they can resist dislodging, physical damage and drowning when submerged under water for prolonged periods. All three of these aspects were studied in the laboratory, the first also in the field. Finally, the data are evaluated in terms of other natural mortality factors and the possibility of implementing overhead irrigation as a cultural control method in an integrated pest management system is discussed.

RESPIRATION AND SURVIVAL

The electron microscopic investigation of the structure of the eggs revealed that the respiratory system of H. armiger eggs enables the eggs to resist drowning, so that the eggs can survive for prolonged periods under water, even when low in oxygen content. Under field conditions eggs are periodically submerged under water droplets which accumulate on the plants. Under such conditions the eggs are usually covered by a thin film of oxygen-rich water (Hinton 1970), in which the oxygen is continuously replenished, thus ensuring egg survival. The successful hatching of eggs following exposure to falling droplets in laboratory studies, show that eggs are able to withstand the physical impact of falling droplets. This confirms the findings

of Hinton (1970) who states that the forces exerted by the falling droplets are virtually instantaneous and unable to cause any physical damage, or drowning, the high hydroscopic pressures notwithstanding.

Water droplets, however, dislodge and wash some eggs from plants, the central theme of this study. For the purpose of this discussion, the eggs were considered dead once they were washed off.

PRACTICAL CONSIDERATIONS

Of the many factors examined, including those relating to H. armiger itself as well as external factors, only three were found to have a significant influence on the wash-off of H. armiger eggs from plants. These are

- (i) infertility of the eggs,
- (ii) the hairiness of cotton plant parts and
- (iii) the nature of overhead irrigation and simulated rain.

Egg fertility cannot be manipulated, and can therefore be ruled out as a control strategy. Hairiness of plants and overhead irrigation on the other hand, are important in practice.

Several authors reported that the presence of hairs on cotton plant parts is an important feature affecting cotton pests. Kamel & Elkassaby (1965) and Tunstall & Matthews (1965) reported that jassids, red spider mites and aphid populations are suppressed in hairy cotton varieties. On the other hand, on smooth cotton varieties there is reduced oviposition by Heliothis spp. (Lukefahr et al. 1975).

The degree of hairiness, however, is dictated by the

conflicting interests of the spinning industry (which prefers smooth varieties) and the need to curtail potentially destructive jassid populations (Parnell et al. 1949). The advantage of a slightly better wash-off of H. armiger eggs obtained with smoother varieties (Chapter 5) is of secondary importance compared to the risk of stimulating other pests - especially when viewed in the light of the relatively minor impact of irrigation on H. armiger populations explained later.

To assess overhead irrigation as a cultural control method for H. armiger, kinetic energy - a function of droplet size and velocity - and the factors influencing kinetic energy, must be viewed in relation to the wash-off of H. armiger eggs. Droplet size had little effect on egg wash-off, and the different systems tested washed off about the same numbers of eggs, despite the differences in the kinetic energy of the droplets. Although different models of irrigation systems were not compared, a wide range of nozzles was tested in the laboratory. In practice this means that modifications to droplet size will not improve wash-off. Rogers et al. (1967) found that wind increases kinetic energy and may explain the higher (8%) wash-off found under windy conditions in this study. Wind, of course, cannot be tailored to irrigation requirements and thus has no practical usefulness. Whether all the improvement in wash-off can be ascribed to increased kinetic energy is questionable, since the angles at which droplets strike eggs, as found in the laboratory experiments, also improve wash-off. However, impact angles were not measured in the field and statements about their role would be premature.

On examining the wash-off of eggs from the plants in the field, it was found that eggs may be washed off, irrespective of the oviposition site, some more quickly than others. The numbers of eggs washed from plants is

therefore not only dependent on adhesion as found in this study, but also on the amount of precipitation. It was found that about 30% of H. armiger eggs on cotton plants were washed-off by a 50 mm precipitation, more or less the standard application rate in cotton production. Importantly, most of the eggs (about 40% of all the eggs washed-off) were washed-off by about the first 10 mm of the precipitation (Fig. 35, Chapter 6). Standard irrigation practices therefore, influenced the survival of H. armiger eggs, and must be accounted for in pest control strategies.

The relative importance of mortality factors affecting the egg stage of pests has been the subject of many different interpretations (Thompson 1928; Box 1932; Tucker 1934; Morris 1957). Small fluctuations in the total mortality affecting the egg and early larval stages could, however, have very marked effects on pest population levels (Pickles 1936; Morris 1957; Morris 1965; Van Hamburg & Hassell 1984). The importance of any mortality factor must be evaluated in terms of the total mortality.

To evaluate the effect of overhead irrigation on H. armiger population levels on cotton, and its possible implementation as a cultural control method, egg parasitism and egg inviability (Cilliers & Pretorius 1976; Van Hamburg 1981) are important factors affecting the egg stage. Unpublished data supplied by Dr H. van Hamburg of the Plant Protection Research Institute indicate an average egg parasitism of 26,6% and egg inviability of 18,1% at about the time and place the field trials for this study were done. These figures conveniently illustrate the interactions among the different mortality factors, but bear in mind that each of the mortality factors is known to vary enormously. Assuming that predators are inactive

or other mortality factors play no role, the survival rate, taking into account the egg parasitism and egg inviability given above and a 30% wash-off by overhead irrigation will be as follows (after Van Hamburg & Hassell 1984):

$$\begin{aligned}\text{Survival rate} &= 1 \times 0,734 \times 0,819 \times 0,70 \\ &= 0,42\end{aligned}$$

Without irrigation this would be 0,6, a reduction in wash-off from 30% to 18%.

Clearly, the effect of irrigation on the survival of H. armiger eggs is unpredictable due to its dependence upon other mortality factors. Furthermore, the overall affect will be less than 3% in the above example - even this is an overestimate, since other mortality factors, notably predation are known to occur (Bottrell & Adkisson 1977) - if irrigation cycles of 10 to 12 days, the regimes currently in general use, are followed. According to Reinders (1986), the required water needs of a 10 - 12 day cycle, can be spread over more than one day at intensities not lower than 25 mm per irrigation. This will utilise the improved wash-off obtained by the first 10 mm applied (Fig. 35), but even so, the overall wash-off mortality will only be increased to about 4,5%.

Therefore, it is unlikely that the large numbers of eggs which are washed off initially when fields are irrigated can be utilised in pest management programmes and more viable management strategies can be achieved by encouraging other mortality factors (Broodryk 1980; King et al. 1985a; King et al. 1985b; Nyambo 1985; Smith 1986).

Nevertheless, the immediate impact of irrigation is

considerable - 30% in the above example, but, as explained in Chapter 6, sometimes as high as 75%. This has an important bearing on the timing of surveys which are routinely carried out for pest management decision making, and undoubtedly deserves further attention, if not in respect of H. armiger eggs (which are no longer the key stage on which sprays are based (Van Hamburg & Kfir 1982; Kfir & Van Hamburg 1983; Basson 1986), but merely a useful indicator of the potential larval population), certainly the larvae and even other pests which may be washed off to a greater or lesser degree. Obviously, surveys carried out shortly after irrigation or rain will be skewed towards an underestimate of the numbers of H. armiger larvae (the stage on which decisions are based) and eggs present on the plants. This is in keeping with current recommendations that cotton fields should be re-surveyed if 10 mm or more rain occur shortly after a survey (Basson 1986). The most reliable time for conducting surveys will be at least 3 to 4 days following irrigation, to allow the eggs to hatch, but perhaps more conveniently between irrigation cycles. In this way the direct benefits which may accrue from the irrigation will be utilised and further, more reliable estimates of the pest population(s) will be obtained.

There are a number of other factors that may affect wash-off, and thus egg survival but did not need to be investigated to develop the techniques used in this study. Examples are the adhesion of eggs laid by migratory moths, the survival of eggs after being washed off, the application of pesticides and soluble fertilizers through overhead irrigation systems and the effect water droplets may have on the survival of parasites and predators, to name only a few.

To summarise, irrigation must be taken into account in

the planning of surveys for cotton pests, but has little or no direct effect on H. armiger egg populations. Irrigation should not be adopted as a control strategy for H. armiger, and further research into this aspect will be wasted effort.

SUMMARY

The influence of rain and overhead irrigation on populations of H. armiger eggs on cotton was studied in the laboratory with the aid of an irrigation simulator and in the field by comparing the wash-off of the eggs caused by a rainfall simulator and the overhead irrigation systems which are in general use in cotton production. The possibility of adapting irrigation practices to reduce populations of H. armiger to economically acceptable levels was evaluated.

H. armiger eggs do not drown when they are temporarily submerged under water droplets during irrigation. This is achieved by a well-developed respiratory system which relies on about 25 aeropyles to absorb air which is then trapped in inner chorionic layers. Furthermore, the eggs are not damaged by the impact of water droplets. The water does, however, wash the eggs from the plants, the central theme of the study.

Variations in droplet sizes (a convenient quantitative measure of the kinetic energy of the droplets) had no significant effect of the wash-off of the eggs. Therefore, the nozzles fitted to irrigation systems cannot be modified to improve wash-off. Increases in the impact angles with which droplets strike oviposition substrates improved the wash-off obtained in laboratory trials. Under field conditions the impact angles depend not only upon the trajectory of droplets, but also upon many other factors such as the tilting of leaves and wind. Such factors cannot be manipulated and were not pursued. Increases in the precipitation applied through irrigation (but not the duration of the irrigation period) was the only physical feature found to significantly improve the wash-off of H. armiger eggs. This hardly lends itself to manipulation since the amount of water applied

depends on the requirements of the plants and the logistics of irrigation practices.

A number of features of H. armiger, including moth age, number of eggs laid per moth per night and the age of the eggs were found to have little or no affect on the numbers of eggs washed-off. These aspects were not studied for their own sake, but to develop suitable techniques for assessing the adhesion and wash-off of the eggs; over a wider range of the variables they may well be significant. For the same reason many other factors of academic interest which may affect wash-off were ignored. Reductions in the proportions of viable eggs significantly improved the wash-off of the eggs, another feature which cannot conceivably be manipulated and, besides, fall into the category of "other mortality" discussed below.

The characteristics of cotton plants influence both the selection of oviposition sites by H. armiger moths and the adhesion of the eggs. Leaves were clearly preferred over other plant parts, but for evaluating the influence of irrigation, whole plants were considered. The hairs on cotton leaves served to anchor H. armiger eggs while on other parts of the plants they tended to disturb the adhesion of the eggs; the net result was that more H. armiger eggs were washed-off from smooth cotton varieties than from hairy ones. While this offers a tempting avenue for reducing the numbers of H. armiger in cotton, it is thwarted by the more important potential stimulation of jassid populations on smooth cotton varieties. Most of the eggs were laid in the upper third of the plants. Somewhat unexpectedly, equal proportions of the H. armiger eggs were washed-off by irrigation irrespective of the height in the plants at which they were laid.

About 30% of H. armiger eggs were washed off by

standard irrigation applications of about 50 mm. This is a gross overestimate for two important reasons. Firstly, the significance of mortality caused by irrigation reduces with increases in other mortality factors; egg parasitism, for example, is considerable in H. armiger populations. Secondly, cotton fields are irrigated only every 10 to 12 days. The overall effect of irrigation was 4.5% in a documented example. It is concluded that modifications to irrigation practices as a pest control strategy are not viable.

Nevertheless, individual irrigation applications can sometimes markedly reduce the numbers of H. armiger eggs in cotton fields. This is crucial for the timing of the surveys on which spray programmes are based. The surveys should be conducted at least 4 days after irrigation. The direct benefits of eggs washed off will be exploited and, perhaps more importantly, the eggs not washed off will have hatched. Thus, larval counts - on which spray programmes are based - will be a truer reflection of the status of H. armiger in cotton fields.

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APPENDIX 1

LABORATORY IRRIGATION SIMULATOR

A laboratory apparatus was designed and built by the author to simulate the water droplets of rain or overhead irrigation systems for use under controlled conditions in a glasshouse. The apparatus (Fig. 36) consisted of three major components, namely a water supply, a spray tower with nozzles and a turntable.

The water supply was from a 50 litre reservoir, incorporated in the system to stabilise the supply pressure. A 0,75 kw centrifugal pump (delivery range 1 - 5 kl/h at pressure heads of 32 and 25 m respectively) delivered the water to the spray tower at pressures ranged up to 400 KPa.

The spray tower consisted of a 3 m metal stand, fitted with leveling screws and a 1 m cross bar adjustable for height. A nylon water hose of 2,0 cm diameter, fitted with a pressure regulator and meter (adjustable from 0 - 400 KPa), connected the reservoir to the spray nozzles. The spray nozzles were manufactured by Spraying Systems (Spraying Systems Co. [n.d.]) were brass 'Unijet' type with flat spray tips, designed to produce flat spray patterns tapered at the edges to provide a fairly uniform distribution of droplets. To produce droplets of different diameters tip numbers 6520, 6515, 6510, 6505 and 6504 were used - the first two numbers refer to the spray angle at a pressure of 300 KPa, and the last pair the maximum output in litres/min at 200 KPa. Nozzle tip 6510 was used unless specified otherwise. At 50 KPa, the recommended operating pressure for the apparatus, the apex of the spray cone was 35° , and the output ranged from 0,64 litre/min for spray tip number 6504 to 3,2 litre/min

for tip number 6520. The spray cone angle must not be confused with the droplet impact angles discussed in Chapter 5.

The rotating turntable comprised ten 0,75 m x 0,21 m expanded metal trays, radiating from the centre bearing and could be tilted to any angle. The turntable was belt driven by an electric motor and rotating speed was varied by means of a rheostat connected in series.

The spray tower and turntable were positioned at right angles to each other (Fig. 36), 2 m apart so that the flat sprays overlapped the ends of the trays, thereby eliminating the tapered edges of the flat spray patterns. Impact angles of the droplets were varied by tilting the trays. The operating specifications used for the experiments are shown in Fig. 36. To calibrate the system in terms of the volume of water sprayed, six laboratory-made rain gauges with 9 cm diameter openings were fixed to two trays in positions corresponding to the exposure positions and perpendicular to the spray. The rest of the trays were set at an angle of 15° to eliminate the accumulation of water on the leaves (oviposition substrates) used. This setting also reduced the exposed surface by about 4%, so that, although 50 mm were recorded in the rain gauges, only about 48 mm landed on the exposed leaves (this is explained further in Chapter 5). These differences, however, were regarded as insignificant and ignored. The performance of the apparatus is shown in Table 11, and the physical characteristics of the spray patterns in Fig. 10 (Chapter 3).

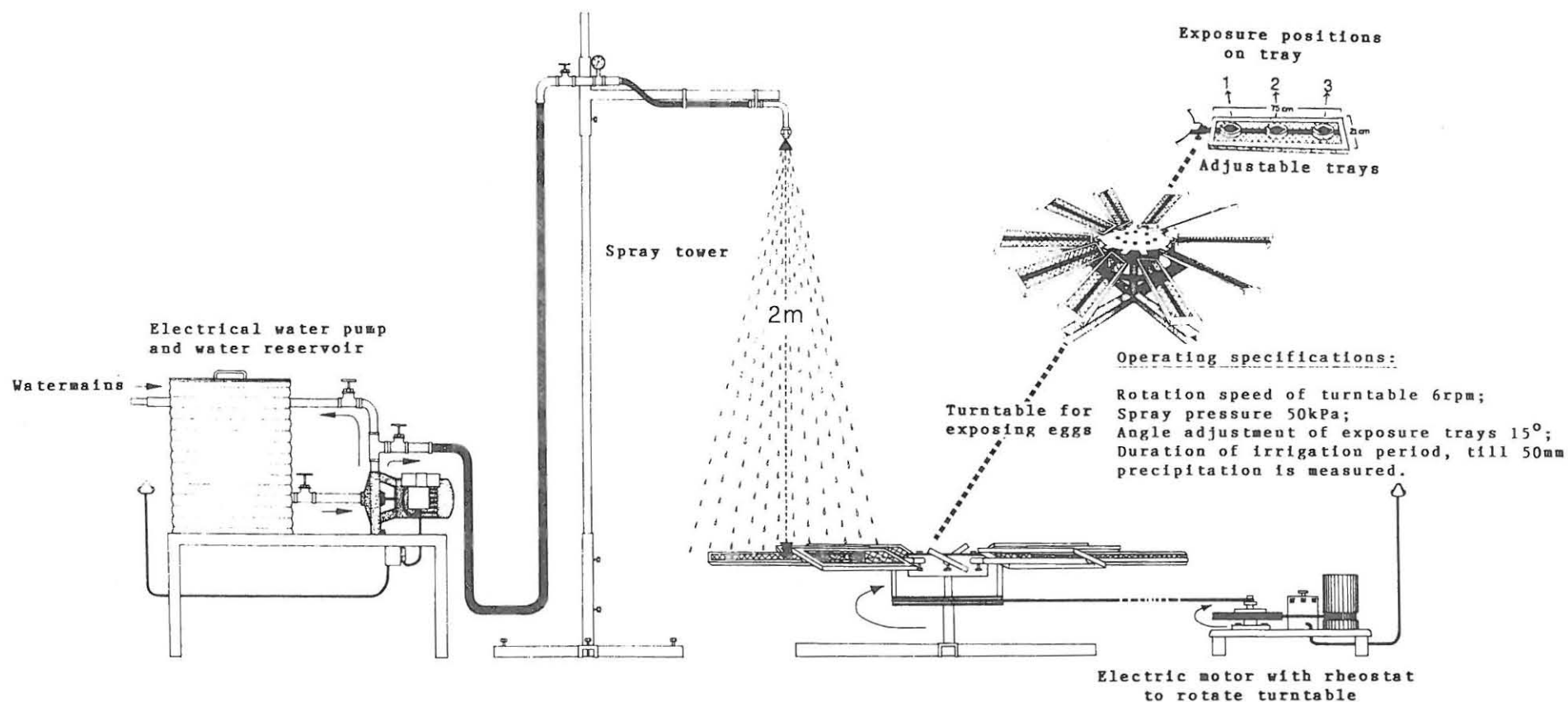


Fig. 36. Laboratory irrigation simulator.

1. The spray tower was fixed and fitted with levelling screws, height adjustment and a flow regulator. The delivery through the spray nozzles was calibrated by means of a pressure gauge.
2. The turn table consisted of ten trays which could be tilted in relation to the droplets from the spray tower. Two trays were fitted with 3 rain gauges each to measure precipitation.

TABLE 11. Performance of the laboratory irrigation simulator. The data represent the mean of eight replicates. Standard errors are given for times needed to deliver a 50 mm precipitation. The operating specifications are shown in Fig. 36. Volume average diameter (v.a.d.) of droplet sizes are explained in Chapter 3.

SPRAY TIP NUMBER	POSITION ON TRAYS								
	1			2			3		
	Volume delivered (mm/h)	Time to deliver 50 mm (min)	Droplet size (v.a.d.) (mm)	Volume delivered (mm/h)	Time to deliver 50 mm (min)	Droplet size (v.a.d.) (mm)	Volume delivered (mm/h)	Time to deliver 50 mm (min)	Droplet size (v.a.d.) (mm)
6520	21,1	137 ± 7,2	0,76	50,0	61 ± 1,7	0,75	44,1	70 ± 2,9	0,74
6515	16,2	190 ± 9,5	0,72	42,2	73 ± 2,5	0,70	31,3	95 ± 2,5	0,71
6510	9,6	314 ± 4,6	0,67	28,5	107 ± 2,1	0,68	19,2	171 ± 16,0	0,65
6505	3,8	771 ± 13,1	0,61	16,7	184 ± 3,6	0,61	10,0	315 ± 21,6	0,59
6504				13,4	235 ± 11,5	0,56	9,7	305 ± 20,8	0,56

APPENDIX 2

CONVENTIONAL OVERHEAD IRRIGATION SYSTEM USED FOR DETERMINING THE WASH-OFF OF HELIOTHIS ARMIGER EGGS FROM COTTON PLANTS

A conventional system (Fig. 37) consisting of an electrically driven centrifugal pump, with a delivery capacity of up to 9,0 mm/hour/120 spray nozzles was used at both of the experimental stations. Standard Rain Bird 14070 W sprinklers (Rainbird Sprinkler Corporation 1982), fitted with 4,37 mm nozzle tips mounted on 1,3 m x 20 mm galvanised pipe uprights were connected to the main water supply by draglines (50 m x 20 mm water hoses). The sprinklers were in two rows, spaced 12 m apart in a cotton field.

The system was operated at a delivery rate of 6,5 - 8,0 mm/h. The irrigation was turned off after 10, 30 and 50 mm precipitation was obtained to record wash-off of H. armiger eggs. The operating specifications and performance of the systems for each experiment at the two localities are shown in Table 12.

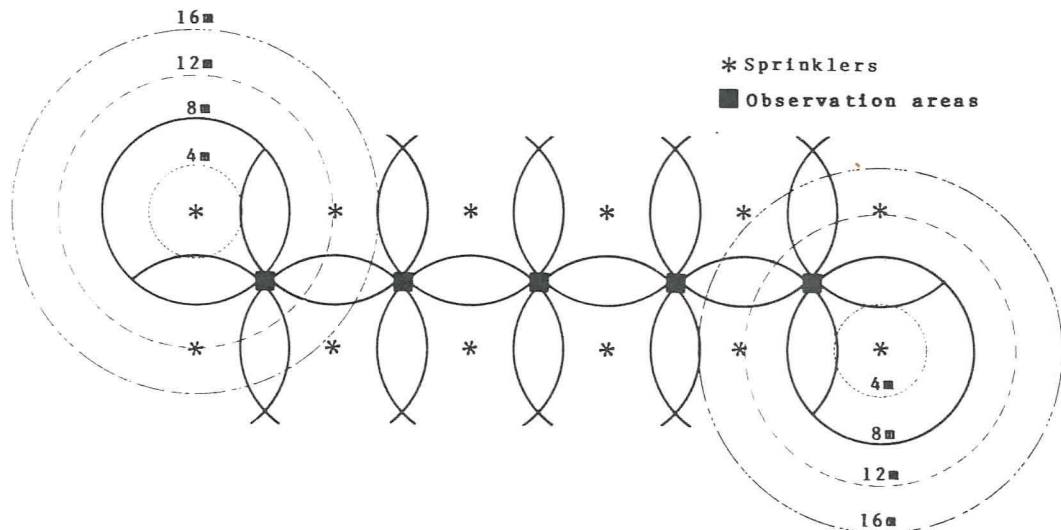


Fig. 37. Conventional overhead-irrigation system. The photograph illustrates a section of the system in operation at the Hartebeespoort Research Station. Two commercial rain gauges were placed in each observation area for measuring the precipitation. The position of the observation areas in relation to sprinklers are illustrated in the diagram, and show the landing positions of droplets under wind still conditions. Droplets landed on the observation areas were mainly 8 - 9 m from the sprinklers. See Fig. 11 (Chapter 3) for spray patterns and actual droplet blotches collected at various distances from the sprinklers.

TABLE 12. Environmental conditions and performance of the conventional overhead irrigation systems during exposure of Heliothis armiger eggs.

CHARACTERISTIC	LOSKOP RESEARCH STATION (1982/83)			HARTEBESPOORT RESEARCH STATION (1983/84)				
	REPLICATES			REPLICATES				
	1	2	3	4	5	6	7	8
Plant age (weeks after emergence)	13	14	15	12	13	14	11	16
Average plant height (cm)	105	118	114	108	102	107	79	110
Intensity (mm/h)	6,3	6,7	7,0	7,9	6,6	7,3	6,5	7,9
Irrigation period (hours/min)	8'	7'8"	6'15"	6'20"	7'10"	6'35"	7'25"	6'20"
Precipitation (mm)	50	48	51	50	47	48	48	50
Windspeed range (km/h)	0-3,6	0-3,6	0-3,6	0-10	0-3,6	0-3,6	0-3,6	0-3,6
Average temperature (°C)	29,3	35,0	31,5	25,9	33,5	32,2	30,1	29,5

APPENDIX 3

CENTRE-PIVOT IRRIGATION SYSTEM USED FOR DETERMINING THE WASH-OFF OF HELIOTHIS ARMIGER EGGS FROM COTTON PLANTS

The system (Fig. 38) consisted of five electrically-driven towers on wheels which supported the main water-supply boom and was designed to irrigate a 30 ha circle. At an operating pressure of 464 KPa a pump delivery of 30 litre/sec was delivered. By selecting the rotation speed of the system a 50 mm precipitation on the experimental area was obtained over a period of about 3 hours 20 min. The main water supply boom was fitted with Rain Bird 30 H sprinklers (Rainbird Sprinkler Corporation 1982). The nozzles varied in size and spread, to ensure a uniform distribution of droplets as is normal in practice, progressively less water being discharged towards the end of the system due to the slower speed. The system could not be stopped once in operation and results were obtainable only for the full (50 mm) precipitation. The section selected for observation was located between the third and fourth driving towers from the centre. The experimental layout is shown in Fig. 38 and the precipitation was recorded as described in Appendix 2. The operating specifications and performance of the system for each experiment conducted at the Oudestad Experimental Farm are shown in Table 13.

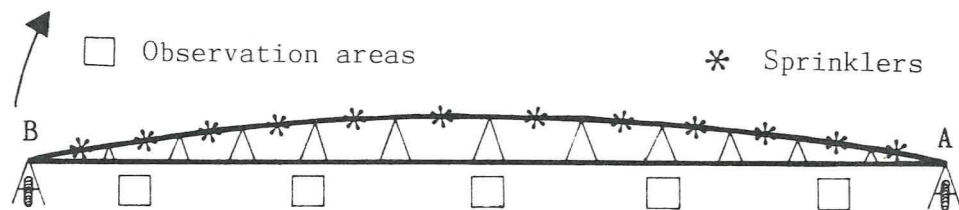


Fig. 38. Valley Model 4271 centre-pivot irrigation system. The photograph illustrates the system in operation at the Oudestad Experimental Farm. The diagram represents observation areas in a section between two driving towers. Nozzle tip and spreader sizes ranged from 5,14/3,56 mm (nearest the pivot) to 5,53/3,16 mm from point A to point B. See Fig. 12 (Chapter 3) for spray patterns and actual droplet blotches collected at various distances from a sprinkler.

TABLE 13. Environmental conditions and performance of the centre-pivot irrigation system during exposure of Heliothis armiger eggs.

Characteristic	Replicates		
	1	2	3
Plant age (weeks after emergence)	13 - 14	14 - 15	15 - 16
Average plant height (cm)	83	87	85
Intensity (mm/h)	14.1	13.6	14.0
Irrigation period (hours/min)	3'20"	3'15"	3'30"
Precipitation applied (mm)	47	44	49
Windspeed range (km/h)	0 - 3,6	0 - 15,0	0 - 3,6
Average temperature (°C)	29,6	29,8	31,3

APPENDIX 4

ROTATING-BOOM FIELD RAINFALL SIMULATOR USED FOR DETERMINING THE WASH-OFF OF HELIOTHIS ARMIGER EGGS FROM COTTON PLANTS

A rotating-boom rainfall simulator (Swanson 1965) was used to simulate rain on field-grown cotton. The simulator Fig. 39, consisted of ten 7,93 m booms, each with 15 nozzles, arranged to ensure an even distribution of the droplets. H 1/2 U 80/100 Veejet nozzles manufactured by Spraying Systems (Spraying Systems Co. [n.d.]) were fitted. The booms were rotated at 3,5 - 4,0 revolutions per min. and the nozzles sprayed vertically downwards from 2,74 m above ground.

This system produces droplets with energies (explained in Chapter 3) about 80% of that of natural rainfall when operated at an operating pressure of 40 KPa. (Morin et al. 1967). This amounts to 63 mm of rainfall/h., the intensity measured during the experiments. This can be classed as a heavy rainstorm, but short of a deluge. The system was turned off after 10, 30 and 50 mm precipitation was obtained to record the wash-off of H. armiger eggs. Precipitation was recorded as described in Chapter 2. The operating specifications and performance of the system for each experiment conducted at the Hartebeespoort Research Station is shown in Table 14.

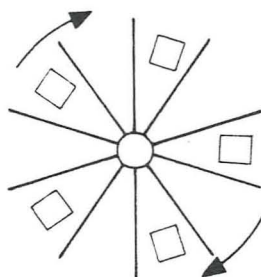


Fig. 39. Rotating-boom rainfall simulator in operation at the Hartebeespoort Research Station. The simulator was supplied by the Directorate of Agricultural Engineering and Water Supply. The diagram illustrates the siting of the observation areas (blue cages in the photograph) under the booms. See Fig. 13 (Chapter 3) for spray patterns and actual droplet blotches collected at the observation areas.

TABLE 14. Environmental conditions and performance of the rotating-boom field rainfall simulator during exposure of Heliothis armiger eggs.

Characteristic	Replicates	
	1	2
Plant age (weeks after emergence)	15	16
Average plant height (cm)	100	110
Intensity (mm/h)	60,0	62,5
Irrigation period (min)	53	47
Precipitation applied	53	49
Windspeed range (km/h)	0 - 3,6	0 - 3,6
Average temperature (°C)	27,4	31,6

APPENDIX 5

CHAMBER FOR SUBMERGING HELIOTHIS ARMIGER EGGS IN WATER WITH DIFFERENT OXYGEN CONTENTS

Newly-laid H. armiger eggs from the culture, oviposited on 4cm² organdi netting were submerged in tap water as illustrated and described in Fig. 40. The oxygen content of the water for the different treatments was determined by means of the rank oxygen electrode method (Johnson 1972). Daily records of eggs hatched were kept and the larvae placed on artificial diet.

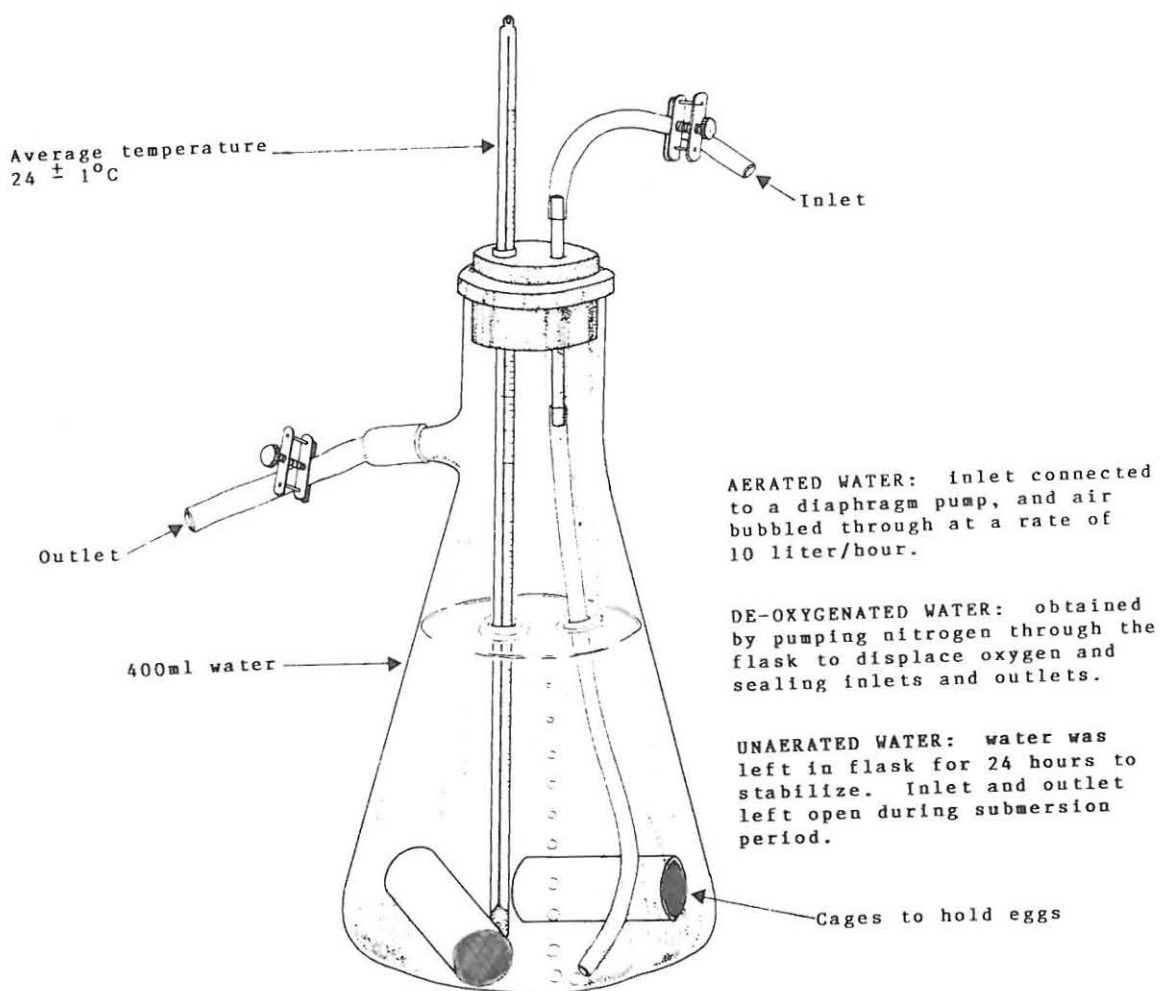


Fig. 40. 500 ml Buchner flask adapted as an exposure chamber for submersion of Heliothis armiger eggs.

APPENDIX 6

WASH-OFF DATA FOR HELIOTHIS ARMIGER EGGS OVIPOSITED ON
COTTON IN LABORATORY AND FIELD EXPERIMENTS

TABLE 15. Wash-off of newly-laid Heliothis armiger eggs from the upper surfaces of cotton leaves (variety Acala 1517/70). The eggs were laid by single four-day old laboratory-reared moths. Fifty mm precipitation was applied with the laboratory irrigation simulator (Appendix 1) fitted with a range of nozzle tips. Each value represents the pooled total number of eggs exposed and washed off for eight single moths. Figures in parentheses show the ranges recorded. A total number of 112 moths was used.

NOZZLE TIP NUMBER	POSITIONS OF EGGS ON TRAYS											
	1				2				3			
	NUMBERS OF EGGS		% WASHED OFF FERTILE		NUMBERS OF EGGS		% WASHED OFF FERTILE		NUMBERS OF EGGS		% WASHED OFF FERTILE	
	EXPOSED / WASHED-OFF		WASHED OFF	FERTILE	EXPOSED / WASHED OFF		WASHED OFF	FERTILE	EXPOSED / WASHED OFF		WASHED OFF	FERTILE
6520	1277	116	13,0 (7-72)	84 (0-100)	1314	351	26,7 (6-50)	87 (0-100)	1291	202	15,6 (0-38)	86 (0-98)
6515	1263	458	36,3 (5-81)	94 (0-100)	1132	515	45,5 (10-85)	88 (0-100)	1118	514	46,0 (35-74)	60 (0-98)
6510	1068	532	49,8 (6-94)	70 (0-100)	1332	76	5,7 (2-18)	79 (0-98)	1104	113	10,2 (1-75)	87 (0-99)
6505	1702	404	23,7 (0-39)	51 (0-97)	1551	400	25,8 (0-53)	57 (0-100)	1271	247	19,4 (9-71)	21 (0-100)
6504	NO EXPOSURE				1145	335	29,3 (13-94)	73 (0-100)	805	245	30,4 (3-87)	79 (0-100)
TOTAL	5310	1560	29,3	72	6474	1667	25,9	75	5589	1321	23,6	66

TABLE 16. Wash-off of newly-laid Heliothis armiger eggs from the upper surfaces of cotton leaves (variety Acala 1517/70). The eggs were laid by groups of four-day old laboratory-reared moths. Fifty mm precipitation was applied with the laboratory irrigation simulator (Appendix 1) fitted with a range of nozzle tips. Eggs from groups of 40 moths were exposed to each nozzle tip. The eggs were divided into eight batches (replicates) for each of the three positions on the turntable and the data were pooled. Figures in parentheses show the ranges recorded. A total of 200 moths was used.

NOZZLE TIP NUMBER	POSITIONS OF EGGS ON TRAYS											
	1				2				3			
	NUMBERS OF EGGS		% WASHED OFF		NUMBERS OF EGGS		% WASHED OFF		NUMBERS OF EGGS		% WASHED OFF	
	EXPOSED / WASHED OFF		FERTILE		EXPOSED / WASHED OFF		FERTILE		EXPOSED / WASHED OFF		FERTILE	
6520	608	214	35,2 (10-60)	92 (82-99)	688	208	30,2 (3-41)	94 (92-100)	629	156	24,8 (14-71)	96 (91-100)
6515	1199	476	39,7 (15-76)	94 (90-99)	1020	380	37,3 (8-71)	92 (76-100)	1107	410	37,0 (20-79)	95 (90-99)
6510	973	204	21,0 (3-56)	93 (89-100)	825	223	28,1 (1-47)	92 (88-97)	632	152	24,0 (4-70)	91 (82-100)
6505	1245	148	11,9 (5-36)	98 (92-100)	1167	153	13,1 (7-24)	97 (95-100)	1279	215	16,8 (14-50)	98 (94-100)
6504	NO EXPOSURE				323	96	29,7 (2-77)	89 (82-100)	181	51	28,2 (12-43)	81 (61-100)
TOTAL	4025	1042	25,9	95	4023	1060	26,3	94	3828	984	25,7	94

NOZZLE TIP NUMBER	POSITIONS OF EGGS ON TRAYS															
	1				2				3				TOTAL			
	NUMBERS OF EGGS		% WASHED OFF	% FERTILE	NUMBERS OF EGGS		% WASHED OFF	% FERTILE	NUMBERS OF EGGS		% WASHED OFF	% FERTILE	NUMBERS OF EGGS		% WASHED OFF	% FERTILE
	EXPOSED / WASHED OFF				EXPOSED / WASHED OFF				EXPOSED / WASHED OFF				EXPOSED / WASHED OFF			
6520	1274	218	17,1 (1-54)	65 (0-100)	1042	156	15,8 (15-82)	53 (0-98)	1033	251	24,3 (0-38)	60 (0-100)	3349	625	18,6	61
6515	1030	216	21,0 (16-66)	88 (0-100)	979	240	24,5 (6-60)	93 (0-100)	746	130	17,4 (0-91)	84 (0-100)	2755	586	21,2	89
6510	1645	195	11,9 (0-26)	91 (0-100)	1428	288	20,2 (3-44)	71 (0-100)	1005	157	15,6 (0-67)	69 (0-100)	4078	640	15,7	79
6505	1022	180	17,6 (0-18)	69 (0-100)	965	69	7,2 (0-25)	71 (15-100)	954	140	14,7 (2-36)	78 (0-100)	2941	389	13,2	73
6504	NO EXPOSURE				1217	315	25,9 (8-37)	100 (93-100)	1119	158	14,1 (0-36)	99 (94-100)	2336	473	20,2	99
TOTAL	4971	809	16,3	80	5631	1068	19,0	79	4857	836	17,2	78	15459	2713	17,5	79

TABLE 18. Wash-off of newly-laid *Heliothis armiger* eggs from the upper surfaces of cotton leaves (variety Rebel). The eggs were laid by groups of four-day old laboratory-reared moths. Fifty mm pre-precipitation was applied with the laboratory irrigation simulator (Appendix 1) fitted with a range of nozzle tips. Eggs from groups of 40 moths were exposed to each nozzle tip. The eggs were divided into eight batches (replicates) for each of the three positions on the turntable and the data were pooled. Figures in parentheses show the ranges recorded. A total of 200 moths was used.

NOZZLE TIP NUMBER	POSITIONS OF EGGS ON TRAYS											
	1				2				3			
	NUMBERS OF EGGS		% WASHED OFF FERTILE		NUMBERS OF EGGS		% WASHED OFF FERTILE		NUMBERS OF EGGS		% WASHED OFF FERTILE	
	EXPOSED /	WASHED OFF			EXPOSED /	WASHED OFF			EXPOSED /	WASHED OFF		
6520	849	153	18,0 (6-36)	97 (88-99)	809	113	14,0 (2-40)	94 (88-97)	718	92	12,8 (3-37)	93 (91-99)
6515	702	105	15,0 (10-41)	94 (89-97)	1191	170	14,3 (2-32)	96 (89-98)	1071	191	17,8 (4-41)	99 (94-100)
6510	1145	130	11,4 (9-20)	98 (91-100)	862	145	16,3 (12-27)	90 (76-96)	916	173	18,9 (6-22)	96 (95-99)
6505	1317	211	16,0 (5-24)	93 (88-96)	1106	188	17,0 (4-30)	91 (88-94)	1113	223	20,0 (2-56)	89 (83-96)
6504	NO EXPOSURE				671	120	17,9 (11-32)	98 (92-98)	701	112	16,0 (3-32)	96 (94-97)
TOTAL	4013	599	14,9	94	4639	736	15,9	94	4519	791	17,5	94

TABLE 19. Numbers of *Heliothis armiger* eggs laid and the percentages washed off from the different oviposition sites and zones (Fig. 3) of field-grown cotton by a 50 mm precipitation from the conventional overhead irrigation system (Appendix 2). The experiments were conducted at the Loskop Research Station (Table 12, Replicates 1, 2 and 3 - Appendix 2) and the data represent the combined results of three replicates. Percentages were not computed for egg counts lower than 10 per oviposition site, but are incorporated in the "total" percentages.

OVIPOSITION SITES	OVIPOSITION ZONES							
	UPPER THIRD		MIDDLE THIRD		LOWER THIRD		TOTAL	
	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF
Monopodial stems	2	?	9	?	11	54,5	22	45,5
Sympodial stems	39	48,7	9	?	8	?	56	48,2
Mature leaves (upper surface)	325	22,5	74	43,2	50	30,0	449	26,7
Mature leaves (under surface)	448	20,9	139	20,1	29	10,3	616	20,3
Young leaves (upper surface)	198	23,2	42	23,8	42	19,0	282	22,7
Young leaves (under surface)	66	15,2	11	9,1	2	?	79	15,2
Leaf petioles	15	60,0	2	?	1	?	18	55,6
Flower buds (squares)	51	25,5	4	?	0	?	55	25,8
Open flowers	28	50,0	1	?	2	?	31	51,6
Bollsize 1	21	28,6	6	?	0	?	27	33,3
Bollsize 2	8	?	12	66,7	1	?	21	57,1
Bollsize 3	18	27,8	73	26,0	33	12,1	124	22,6
Total	1219	24,0	382	29,3	179	24,6	1780	25,1

TABLE 20. Numbers of *Heliothis armiger* eggs laid and the percentages washed off from the different oviposition sites and zones (Fig. 3) of field-grown cotton by a 50 mm precipitation from the conventional overhead irrigation system (Appendix 2). The experiments were conducted at the Hartebeespoort Research Station (Table 12, Replicates 4, 5 and 6 - Appendix 2) and the data represent the combined results of three replicates. Percentages were not computed for egg counts lower than 10 per oviposition site, but are incorporated in the "total" percentages.

OVIPOSITION SITES	OVIPOSITION ZONES							
	UPPER THIRD		MIDDLE THIRD		LOWER THIRD		TOTAL	
	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF
Monopodial stems	20	30,0	22	36,4	11	54,4	53	37,7
Sympodial stems	23	73,9	12	33,3	2	?	37	59,5
Mature leaves (upper surface)	502	27,7	248	31,5	103	29,1	853	29,0
Mature leaves (under surface)	394	20,6	138	23,2	90	26,7	622	22,0
Young leaves (upper surface)	186	25,8	119	51,3	30	30,0	335	35,2
Young leaves (under surface)	83	30,1	24	12,5	7	?	114	24,6
Leaf petioles	3	?	3	?	0	?	6	?
Flower buds (squares)	49	30,6	36	36,1	7	?	92	30,4
Open flowers	11	63,6	29	41,4	0	?	40	47,5
Bollsize 1	18	50,0	50	42,0	0	?	68	44,1
Bollsize 2	2	?	17	35,3	9	?	28	32,1
Bollsize 3	0	-	15	40,0	2	?	17	35,3
Total	1219	27,1	713	34,5	261	27,6	2265	29,5

TABLE 21. Numbers of Heliothis armiger eggs laid and the percentages washed off from the different oviposition sites and zones (Fig. 3) of field-grown cotton by a 50 mm precipitation from the centre-pivot irrigation system (Appendix 3). The experiments were conducted at the Oudestad Experimental Farm (Table 13 - Appendix 3) and the data represent the combined results of three replicates. Percentages were not computed for egg counts lower than 10 per oviposition site, but are incorporated in the "total" percentages.

OVIPOSITION SITES	OVIPOSITION ZONES							
	UPPER THIRD		MIDDLE THIRD		LOWER THIRD		TOTAL	
	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF
Monopodial stems	76	46,1	16	6,3	0	?	92	45,7
Sympodial stems	15	20,0	6	?	0	?	21	28,6
Mature leaves (upper surface)	1378	37,4	588	31,8	59	18,6	2025	32,5
Mature leaves (under surface)	1109	26,1	480	9,2	28	10,7	1617	20,8
Young leaves (upper surface)	668	39,4	192	49,0	28	35,7	888	41,3
Young leaves (under surface)	261	16,5	56	14,3	9	?	326	15,6
Leaf petioles	1	?	0	?	0	?	1	?
Flower buds (squares)	86	23,3	44	36,4	19	78,7	149	34,2
Open flowers	146	41,1	91	37,4	1	?	238	39,5
Bollsize 1	29	27,6	112	24,1	0	?	141	24,8
Bollsize 2	3	?	73	39,7	39	25,6	115	36,5
Bollsize 3	0	?	24	16,7	47	48,9	71	38,0
Total	3772	31,6	1682	26,6	230	31,3	5684	30,1

TABLE 22. Numbers of Heliothis armiger eggs laid and the percentages washed off from the different oviposition sites and zones (Fig. 3) of field-grown cotton by a 50 mm precipitation from the rotating-boom field rainfall simulator (Appendix 4). The experiments were conducted at the Hartebeespoort Research Station (Table 14 - Appendix 5) and the data represent the combined results of two replicates. Percentages were not computed for egg counts lower than 10 per oviposition site, but are incorporated in the "total" percentages.

OVIPOSITION SITES	OVIPOSITION ZONES							
	UPPER THIRD		MIDDLE THIRD		LOWER THIRD		TOTAL	
	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF
Monopodial stems	29	69,0	41	22,0	30	30,0	100	38,0
Sympodial stems	5	?	13	76,9	0	?	18	72,2
Mature leaves (upper surface)	396	43,7	395	35,4	56	39,3	847	39,6
Mature leaves (under surface)	461	17,8	465	16,7	71	7,0	997	16,3
Young leaves (upper surface)	368	42,9	92	48,9	13	23,1	473	43,4
Young leaves (under surface)	245	15,1	54	7,4	2	?	301	13,6
Leaf petioles	0	?	1	?	0	?	1	?
Flower buds (squares)	40	47,5	84	39,3	7	?	131	42,0
Open flowers	0	?	19	26,3	3	?	22	31,8
Bollsize 1	0	?	12	0,0	8	?	20	10,0
Bollsize 2	0	?	0	?	0	?	0	?
Bollsize 3	0	?	0	?	0	?	0	?
Total	1544	31,9	1176	27,3	190	23,2	2910	29,5

TABLE 23. Numbers of *Heliothis armiger* eggs laid and the percentages washed off from the different oviposition zones (Fig. 3) of field-grown cotton with increasing precipitation from the irrigation systems and the rotating-boom field rainfall simulator. The data for each replicate represents the wash-off of eggs laid by 250 moths on 15 plants. This table is a break-down of the results shown in Tables 19 - 22 and a recombination of data for the different systems.

SYSTEM	REPLICATE	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF											
			UPPER THIRD			MIDDLE THIRD			LOWER THIRD			TOTAL		
			10 mm	30 mm	50 mm	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm
CONVENTIONAL IRRIGATION SYSTEM 1982/83	1	1105	8,6	17,4	25,2	11,0	23,0	33,0	7,5	16,0	22,6	8,9	18,2	26,3
	2	516	4,1	13,4	22,1	12,8	20,6	25,5	3,6	12,8	14,6	8,1	15,3	22,1
	3	159	9,0	14,0	21,0	9,8	14,6	24,4	33,0	55,0	61,0	11,9	14,0	26,4
	Totals /Means	1780	7,5	16,1	24,0	11,5	21,2	29,3	8,9	19,0	24,6	9,0	17,5	25,1
CONVENTIONAL IRRIGATION SYSTEM 1983/84	4	639	19,5	28,0	36,5	23,7	33,8	40,2	15,7	24,5	30,4	20,3	29,4	36,8
	5	538	9,1	14,4	26,2	8,4	15,9	28,6	7,3	12,9	21,8	8,4	14,7	26,2
	6	1088	9,3	14,4	23,5	15,4	24,3	34,8	14,3	25,7	40,0	10,9	17,2	26,8
	Totals /Means	2265	11,8	17,7	27,1	19,3	27,8	37,3	11,5	19,2	27,6	14,2	21,2	30,5
CENTRE-PIVOT SYSTEM	1	1229	-	-	26,0	-	-	24,4	-	-	18,3	-	-	25,1
	2	2264	-	-	40,4	-	-	35,7	-	-	24,0	-	-	38,7
	3	2191	-	-	24,8	-	-	18,6	-	-	40,8	-	-	24,0
	Totals /Means	5684	-	-	31,6	-	-	26,6	-	-	31,3	-	-	30,1
FIELD RAINFALL SIMULATOR	1	1656	21,3	30,5	36,2	11,3	20,6	27,0	20,0	20,0	31,4	17,8	26,6	32,8
	2	1254	10,1	18,9	23,6	12,3	21,8	27,6	7,5	12,5	20,0	10,8	19,6	25,1
	Totals /Means	2910	17,4	26,6	31,9	11,8	21,2	27,3	12,1	15,3	24,2	14,8	23,6	29,5
	Totals /Means All Systems	12639	12,6	20,6	29,7	13,0	22,2	28,5	11,0	17,9	27,2	12,7	20,9	29,1

TABLE 24. Numbers of Heliothis armiger eggs laid by field populations and the percentages washed off from the different oviposition sites and zones (Fig. 3) of field-grown cotton by a 50 mm precipitation from the conventional overhead irrigation system (Appendix 2). The experiments were conducted at the Hartebeespoort Research Station (Table 12, Replicates 7 and 8 - Appendix 2). Replicates 7 and 8 represent the numbers of eggs oviposited on 50 and 225 plants respectively. Percentages were not computed for egg counts lower than 10 per oviposition site, but are incorporated in the "total" percentages.

AVERAGE NUMBERS OF EGGS OVIPOSITED PER PLANT	OVIPOSITION SITES	OVIPOSITION ZONES							
		UPPER THIRD		MIDDLE THIRD		LOWER THIRD		TOTAL	
		NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF
4,5 (Replicate 7)	Leaves	111	80,2	73	86,3	5	?	189	83,1
	Fruiting bodies	6	?	9	?	1	?	16	75
	Stems	8	?	12	50,0	0	?	20	55
	Total	125	77,6	94	72,3	6	83,3	225	75,5
0,48 (Replicate 8)	Leaves	40	20,0	21	19,1	3	?	64	20,3
	Fruiting bodies	15	33,3	8	?	0	?	23	34,8
	Stems	15	40,0	5	?	1	?	21	41,1
	Total	70	31,4	34	29,4	4	25,0	108	30,6

TABLE 25. Numbers of Heliothis armiger eggs laid by field populations and the percentages washed off from the different oviposition zones (Fig. 3) of field-grown cotton with increasing precipitation from the conventional overhead irrigation system (Appendix 2). The experiments were conducted at the Hartebeespoort Research Station (Table 12, Replicates 7 and 8 - Appendix 2). Replicates 7 and 8 represent the numbers of eggs oviposited on 50 and 225 plants respectively.

AVERAGE NUMBERS OF EGGS OVIPOSITED PER PLANT	NUMBERS OF EGGS OVIPOSITED	% WASHED OFF											
		UPPER THIRD			MIDDLE THIRD			LOWER THIRD			TOTAL		
		10 mm	30 mm	50 mm	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm
4,5 (Replicate 7)	225	50,3	66,7	77,6	56,1	61,9	72,3	50,0	66,7	83,3	51,6	64,4	75,5
0,48 (Replicate 8)	108	10,6	19,3	31,4	11,4	16,2	29,4	5,2	14,7	25,0	8,3	17,6	30,6