SOME ASPECTS OF THE BIOLOGY AND CONTROL OF EARIAS HUEGELI Rog.

Being a Thesis presented by

JOHN WILLIAM TURNER B.Agr.Sc.

as part of the requirements

for the degree

Master of Agricultural Science

UNIVERSITY OF QUEENSLAND

1970

SUMMARY

Descriptions are given of the egg, larva, pupa and moth of Earias huegeli Rog. and of the moth of the other important economic species in Australia, Earias vitella (F.) as well as characters for use in the separation of the two species. The distribution and economic status of the two species are also given.

Studies were carried out on the biology of E. huegeli. These showed that no larvae emerged from eggs held at or below 13.0°C. The minimum temperature for development appeared to lie in the range of 13.0 to 16.2°C. The mean developmental period of eggs varied from 60.0 hours at 37.5°C. and 53 per cent. relative humidity to 372.3 hours at 16.2°C. and 57 per cent. relative humidity. Humidity differences produced large changes in the developmental period of eggs only at 37.5°C. where the mean period increased from 70.5 hours at 49.0 per cent. relative humidity to 120 hours at 0 per cent. relative humidity. High egg mortalities occurred when eggs were subjected to extremes of temperature and humidity. These were 0 per cent. relative humidity combined with 16.2 and 37.5°C., and 100 per cent. relative humidity combined with 16.2, 23.5 and 37.5°C.

The five larval instars were differentiated by the use of head capsule size ranges. The mean developmental periods of the larval instars were:- first instar, 3.5 days; second, 2.8 days; third, 3.1 days; fourth, 3.1

days; fifth 4.6 days. The mean maximum and minimum temperatures during the observation period were 24.7 and 22.6°C. respectively.

No pupation occurred below 15.5°C.; however, survival for protracted periods is possible at 12.5°C. The mean developmental period of larvae varied from 12.2 days at 36.0°C. to 53.3 days at 15.5°C.

Studies on larval feeding behaviour showed that squares and young bolls were preferred to the more mature bolls. Larvae fed on all parts of the squares and bolls and normally remained at the one feeding site unless forced to move by adverse conditions. Most squares and young bolls attacked by larvae were shed by the plant while larger damaged bolls were retained. Only a small percentage of the potential yield of the damaged bolls remained available owing to the losses from larval feeding, distortion of the bolls and to the entry of rotting organisms. Larvae were able to change feeding sites, the degree of success depending upon the age of the larvae and the availability of an alternative site. Larvae also fed in the terminals of the cotton plant. This feeding, which normally takes place before the production of squares, resulted in loss of apical dominance and the consequent production of a bushy plant.

Larvae normally pupated in cracks in the soil or in trash at the base of the plant.

No moths emerged from pupae held at or below 13.0°C. The mean pupal developmental period varied from 48.3 days at 16.2°C., to 7.6 days at 33.0°C. A mean developmental period of 73.6 days was recorded for pupae which were formed in early May and held under laboratory conditions during winter.

Moths could not emerge from pupae buried in the soil unless there was direct access to the surface. Laying moths, fed on sugar and water solutions, survived for an average of 8.6 days and laid an average of 105.9 eggs per moth. The mean lengths of life of fed and unfed, non-laying, virgin female moths were 40.2 and 14.1 days respectively. Egg laying commenced on the third day after emergence and continued during the whole life of the moth. Most eggs were laid at night. The density and length of plant hairs governed the choice of the laying site. More eggs were laid on the young tissues which have dense long hairs than on the older parts of the plant.

The shortest mean developmental period from egg to egg which was fully documented was 29.9 days at 36.0°C. while the longest mean period was 139.0 days at 16.2°C. The trend in the studies suggested that the actual maximum may be longer still.

In all, nine alternative hosts of E. huegeli were recorded. The most frequented host was Hibiscus trionum L. but other hosts appeared to play an

important part in the overwintering of the species.

Studies of the seasonal history of the insect showed the importance of H. trionum in the initiation and maintenance of populations of rough bollworms. Rainfall and competition for food were two factors which were shown to influence population levels of the insect on H. trionum. Low populations prevented the drawing of any conclusions about the influence of these factors on larvae feeding on cotton. The insect was shown to develop during the winter. The nature of these winter life cycles is discussed.

Eight parasites of E. huegeli were recorded. The percentage of insects parasitised was very low.

The LD_{50} levels of 20 insecticides were determined for E. huegeli moths. A comparison of DDT-endrin and DDT-parathion spray mixtures, applied to cotton throughout a growing season, showed DDT-endrin applied weekly to be the most efficacious approach to the control of the pest complex.

An approach to the control of E. huegeli is given, attention being paid to the interrelation of the agronomic and entomological factors involved in cotton production. Special emphasis is placed on the position of rough bollworm within the pest complex.

INTRODUCTION

Two species of rough bollworm are major pests of cotton in Queensland. Earias huegeli Rog. infests cotton in all the areas of the state where the crop is at present grown, while E. vitella (F.) has been recorded only in central and northern Queensland. In southern Queensland, E. huegeli is exceeded in importance as a cotton pest only by Heliothis armigera (Hubn.) and H. punctigera Wall. The common name "rough bollworm" is derived from the rough hairy appearance of the larvae.

The larvae of E. huegeli feed in both the terminals and fruit forms of the plant. Terminal attack is confined mainly to the early part of the season before fruit production commences and this damage results in the loss of apical dominance and the production of bushy vegetative plants which are difficult to machine harvest.

Larval feeding on fruit forms comprises the major economic damage to the cotton plant. Squares and small bolls which are damaged are normally shed by the plant, while larger damaged bolls are retained. The larvae will penetrate all except the mature fruit forms and feed internally for the whole of their development.

The actual physical damage caused by the larvae comprises only part of the economic damage.

Larvae often move from one fruit form to another and seldom eat out completely any of the fruit forms attacked. Distortion of fruit forms, as a result of attack, often makes a large proportion of the lint unavailable to machine harvesters, while the death of vital tissues in the fruit prevents the subsequent development of part of the boll. Another important consequence of larval damage, however, is the entry of rotting organisms into the fruit. These rots may cause partial or complete loss of the undamaged portions of the boll.

The larvae of E. huegeli are present in the cotton fields for the whole period of fruit form production and development - a period of approximately eleven weeks in southern Queensland. Although the numbers are comparatively low, even in cotton fields not treated with insecticide, the long period for which the crop is susceptible to damage, allows a very high cumulative total damage during the season.

As will be shown later, E. huegeli is a native of Australia and is not dependent on cotton for survival, in fact cotton is a secondary host. Thus in control of this species in cotton, the difficult situation is encountered of a native insect, well adapted to its environment and breeding on native plants.

Satisfactory control has been achieved by the

Plate 1. Commercial spraying rig used in insect control in the Brookstead district.

use of either DDT-endrin sprays or DDT-parathion sprays, but this control is dependent on regular application of the chemicals.

The present investigation was initiated to provide a better control of E. huegeli via a more thorough understanding of the insect. The first objective was to provide technical data on the life history and development of the insect, along with information on alternative hosts, parasites and behaviour. The second objective was to study the seasonal history of the insect by examining the seasonal occurrence and population fluctuations of the pest in southern Queensland. The third objective was the correlation of the information from these two fields, with data gathered on the control of the insect, to provide a background for future commercial control.

REVIEW OF LITERATURE

1. The Insect.

A. Description.

The moth of *E. huegeli* was originally described by Rogenhofer (1870) and an expanded description of the species was given by Hampson (1894) (p.133).

No detailed descriptions are available of other stages of the insect.

B. Distribution and Economic Status.

Earias is a wide spread genus found mainly on cotton and other Malvaceous plants. Europe, Africa, Asia, Australia and eastern Pacific were listed as areas of occurrence by Hargreaves (1948) who supplied a comprehensive list of the occurrence of the species of the genus on cotton throughout these areas. Hampson (1894) (p.133) listed the range of the genus *Earias* as Europe, Africa, Mauritius, Japan, China, India, Burma, Ceylon, Siam, Java and Australia. Pearson (1958) stated that the genus was confined to the Old World and Australia and he provided a detailed list of the distribution of the major economic species found in the genus. It is important to note that the genus has not been recorded from the Americas.

Hampson (1894) (p.133) recorded that *Earias huegeli* was present in Australia, Fiji, Tahiti, Gilbert Islands and the Marquesas. Pearson (1958)

stated E. huegeli was found in Australia and as far east as Tahiti and the Marquesas Islands. Hargreaves (1948) recorded E. huegeli as occurring in New Caledonia, New South Wales, northern Australia and Queensland. Froggatt (1922) stated that E. huegeli was to be found from Broken Hill to Darwin, in the Hawkesbury District, Moree, Tahiti, Gilbert Islands, Africa, the Marquesas Islands and Fiji. No reference was made to the source of his information that the species is present in Africa, and no supporting evidence could be found in literature for this contention. Cotes and Swinhoe (1887) (p.85) recorded E. huegeli as occurring in India and Australia, as did Rogenhofer (1870) and Kirby (1892) (p.281), but here again, there is no supporting evidence available to suggest the presence of this species in India.

Anon. (1906) recorded E. vitella on cotton at Chinchilla and Anon. (1907) stated that E. vitella was well recognised as a pest in southern Queensland. It is felt that, owing to lack of confirmation of this species occurring in this area, the species referred to is probably E. huegeli. No earlier references were found to the species on cotton in Queensland. Since the first recording, the insect has been regularly mentioned as a pest of cotton both in the Annual Reports of the Department of Agriculture and Stock (Queensland) and in the

Entomological Progress Reports (Aust.) in the Empire Cotton Growing Reviews, but, where no locality was given, the references are not quoted. Thus, E. huegeli appears to have been a pest of cotton from the earliest days of cotton growing in Queensland.

Anon. (1918) recorded E. huegeli as a pest of cotton at Vundala and Berludale. Tryon (1923) recorded E. huegeli damaging cotton at Pine Mountain. E. huegeli was listed as a pest by Ballard (1925) who commented that the insect was not a serious pest in the Callide Valley. Ballard (1926) recorded E. huegeli in the Callide Valley as did Wells (1930), but he added that it was only a minor pest. Atherton (1932) stated, however, that E. huegeli, which had not previously been regarded as a serious pest of cotton in Queensland, caused greater losses during the previous season than any other cotton pest, as it destroyed approximately 50 per cent. of the squares in many crops in the Callide Valley. Anon. (1934) recorded that the damage caused by E. huegeli in the Callide Valley had increased progressively during the three previous seasons. Anon. (1942) recorded E. huegeli as serious in the Callide Valley in autumn. Davis et al. (1963) recorded E. huegeli as occurring at Ayr, Millaroo and St. George. Passlow (1963) stated that E. huegeli is a major pest in both northern and southern Queensland, but that it was much less important in central

Queensland.

Passlow (personal communication 1968) stated that Davis et al. (1963) were not aware of the presence of Earias vitella in northern Queensland and possibly the references to E. huegeli in this paper should be to both E. huegeli and E. vitella.

Northern Australia was listed by Hargreaves (1948) as an area where E. huegeli occurred. Hill (1915) placed E. huegeli as a major pest of cotton in the Northern Territory. Li (personal communication, 1965) stated that E. huegeli represented a problem in cotton growing in the Northern Territory.

Newman (1924) stated that E. huegeli was present in the Ord River Area of Western Australia and the pest was again recorded in this area by Jenkin (1945) and by Richards (1964). Anon. (1963) recorded E. huegeli as present in Western Australia in the Ord River area and in Victoria.

Gurney (1924) recorded E. huegeli as being present in all the mainland states and the Northern Territory. He stated, that in New South Wales, the species was recorded on the coast from the Illawarra to the Tweed River and inland in the Riverina, Hunter River Valley, Moree, Broken Hill, etc. Wright (1965) rated E. huegeli along with Heliothis spp. as the most important cotton pests in New South Wales.

2. Life History and Habits.

Wright (1965) stated that rough bollworm was a serious pest of both buds and bolls but usually appeared as a stem-borer in cotton before the plants produced squares. Similar observations were made in the Ord River area of Western Australia (Richards, 1964). However, it was stated that there, the larvae entered either through the terminal bud or via a node. Terminal attack often resulted in the death of the upper few inches of stem and leaves, and usually these wilted or dead terminals were the first sign of rough bollworm infestation. Both Veitch (1938) and Passlow (1963) recorded terminal damage in Queensland. Veitch (1938), Passlow (1963), Richards (1964) and Wright (1965) all stated that the result of this damage was the production of an extremely vegetative plant.

Passlow (1963) pointed out that larval entry into squares caused them to fall, while damaged bolls remained on the plant where fungal rots usually completed the destruction. This loss of squares was confirmed by Richards (1964).

The duration of the larval stage was, according to Wright (1965), about two weeks in summer, while Richards (1964) stated the period as two or three weeks with the larvae passing through a number of instars. Froggatt (1924) recorded the

larval period as being 25 to 27 days.

Wright (1965) stated that pupation occurs on some parts of the plant, amongst debris on the ground or in a crack in the soil, while, according to Richards (1964), the usual site of pupation was between the bract and the boll. Both Veitch (1938) and Passlow (1963) claimed that larvae pupated anywhere on the plant.

The duration of the pupal stage has been placed at the following:-
Richards (1964), 8 to 11 days; Wright (1965), about 2 weeks. Froggatt (1924), who stated that the pupal period was 11 to 22 days, also noted that the pupal period was prolonged during winter.

Wright (1965) stated that egg laying began a few days after moth emergence and that eggs were laid mostly on young shoots, on buds, or on the peduncles or bracts of young bolls. Richards (1964) stated that eggs were deposited singly on the fruiting parts and foliage. Veitch (1938) observed that eggs were laid on the upper leaves and the stem.

The egg hatching time has been placed as follows:- Richards (1964), three to five days in the wet season; Wright (1965), three days; Froggatt (1924), six to seven days.

Wright (1965) placed the total length of life cycle at about 5 weeks, while Passlow (1963) stated

that the period between laying of the eggs and the emergence of the next generation varied under Queensland conditions, but usually occupied 4 to 6 weeks. Froggatt (1924) stated that from eggs laid in May (and held presumably under laboratory conditions), the length of life cycle was 79 to 85 days.

3. Alternative Hosts.

Gurney (1924) recorded species of Hibiscus as hosts of E. huegeli in New South Wales. Wright (1965) recorded Hibiscus, Abutilon and Sida as hosts in New South Wales but stressed that the most important alternative host was Hibiscus trionum L., the bladder ketmia. Richards (1964) stated that in the Ord River area native host plants of E. huegeli were plentiful, and one, Hibiscus ficulneus L., was particularly important. Anon (1934) stated that Melhania abyssinica Rich. was found to serve as a winter food plant of the insect.

It is interesting to note that all hosts of E. huegeli, except Melhania abyssinica (Sterculiaceae), recorded in Australia, belong to the order Malvaceae. Pearson (1958), in his listing of hosts of Earias spp. in Africa, recorded mainly Malvaceous hosts but also some hosts in the orders Tileaceae and Sterculiaceae.

4. Seasonal History.

Passlow (1963) commented that in north

Queensland E. huegeli attacked the crop throughout its growing life, while in south Queensland the period was shorter, being from January until the end of the season. However, in central Queensland, the pest was occasionally a problem in late sown crops. Froggatt (1924), writing about cotton in Queensland, stated that ratoon crops of cotton helped to carry over populations and that prolongation of the life cycle, due to lower temperatures, especially in the pupal stage, helped survival of the pest.

Gurney (1924) stated that the broods of caterpillars were irregular in occurrence. During the 1963-64 cotton season in the Namoi Region of New South Wales, Wright (1965), recorded that E. huegeli first appeared in December but numbers remained insignificant until late February when a build-up began with the peak being reached in April. Richards (1964) stated that rough bollworm was present throughout the year in the Ord River area, but it appeared to be particularly active during periods of dry weather.

5. Parasites.

A pentatomid predator was recorded by Riblec (1934) as reducing pest numbers in New Caledonia. Atherton (1932) recorded Tachinids and Braconids as parasites of E. huegeli in the Callide Valley.

6. Control.

In this review, all attempts at chemical control, other than with the modern insecticides, will not be included, as these control attempts have little relevance to the present discussion.

Trials by Passlow (1961) were conducted on cotton in central Queensland where populations of E. huegeli were low, and no conclusions are drawn as to the relative efficacy of chemicals applied, in control of E. huegeli.

Davis et al. (1963) conducted a series of trials on the control of cotton insect pests in different areas of Queensland and two of these trials were specifically aimed at rough bollworm. In one trial conducted at Millaroo, E. huegeli attack was severe throughout the growing season. Unsprayed plants were stunted and deformed. Treated plots, particularly where 0.05 per cent. endrin, applied at 100 gallons per acre was used, made heavy vegetative growth. Fruit form production showed that both DDT and endrin gave a reasonable control of boll feeding larvae. Endrin usage, however, gave better control of terminal damaging pests, principally E. huegeli.

Although the Earias species was quoted as E. huegeli, identification of moths from this area during the current work showed that E. vitella is

the major species and that E. huegeli is a less important species. It is therefore likely that, in this control trial, the principal species present was E. vitella.

Another trial of the same series was located at St. George. The number of eggs of Heliothis spp. was assessed and found to be low throughout the trial. Observation of the number of larvae in fallen fruit forms showed that, while H. punctigera caused damage particularly during January, E. huegeli populations were greater than those of Heliothis spp. and caused greater damage. The yield obtained from a mixture of 0.1 per cent. DDT, combined with 0.05 per cent. endrin, was 909 pounds of seed cotton. This yield was significantly higher than the yield of 512 pounds of seed cotton for DDT alone, 640 pounds for endrin alone, and 301 pounds in the untreated check.

A further trial of the same series, located at St. George, had a maximum Heliothis spp. egg count of 8.1 per 100 terminals, this being lower than that of the previous trial. High populations of E. huegeli were again encountered. Use of 0.1 per cent. DDT plus 0.05 per cent. endrin gave the highest yield of 909 pounds of seed cotton, while DDT alone gave a yield of 638 pounds of seed cotton, and endrin alone gave a yield of 848 pounds

of seed cotton, as compared with a yield of 471 pounds of seed cotton from the untreated check.

Two further trials of the same series were conducted at St. George, and, in these, Telodrin (Octachlorotetrahydromethanophthalan) (0.1 per cent.), azinphos ethyl (0.05 per cent.) and endrin (0.05 per cent.) were demonstrated to be the most efficacious chemicals for control of rough bollworm. It is interesting to note that parathion (0.015 per cent.) was significantly less efficacious than the previous three chemicals at both the 5 per cent. and 1 per cent. significance levels. Endrin subsequently became the standard recommendation of the Queensland Department of Primary Industries for control of E. huegeli.

Richards (1964) recommended the following basic spray programme for the protection of a normal wet season cotton crop, planted during November-December and harvested March-May. Three fortnightly applications of DDT at 1 lb. per acre, from commencement of general squaring of the crop, followed by nine weekly applications of DDT + endrin at ($\frac{1}{2}$ + $\frac{1}{4}$) lb. per acre. This schedule was aimed basically at Heliothis spp. and Earias spp., and entry of other pests required variations from this spray schedule.

Passlow (1963) commented that all cultural

practices which minimise pest build-up should be carried out. These included weed control and early elimination of crop residues after harvesting. He stated that stand-over and ratoon cotton provided sources of infestation and thus increased the chance of damage in the new crop.

Passlow (1963) further stated that chemical control of E. huegeli had, so far, not given satisfactory results. Some control was given by endrin, used at 0.5 lb. active constituent to the acre in sufficient water to wet the plants. The insecticide must be applied before pest populations become high, and repeated at least at fortnightly intervals, while the infestation continues.

Wright (1965) commented that, in the Namoi Region of New South Wales, although numbers of rough bollworm were usually small and appeared to cause insignificant damage in the early stages, if left untreated, they bred in the crop and many of the maturing bolls were later damaged. Frequent insecticide applications were therefore needed to maintain a deposit of insecticide on new growth, to kill moths and newly hatched larvae before the latter gained entry. The following sprays, applied at 10 day intervals, effectively reduced rough bollworm numbers. Carbaryl (13oz. active ingredient per acre) or azinphos ethyl (6oz. active ingredient

per acre) or endrin (4 oz. active incredient per acre). Bladder ketmia (Hibiscus trionum) was listed as an alternative host plant for rough bollworm, and it was recommended that this weed should be cleared from the area before cotton was planted and should be controlled during growth of the crop.

Work carried out by Passlow and Trudgian (1960) showed that, in central Queensland, the loss of fruit forms during the month after the first burst of squaring did not affect yields. However, the maturing of replacement fruit following removal during the second month was dependent on the length of the season and growing conditions. Under good growing conditions, replacement of fruit occurred, and was sometimes accompanied by increased yields. When poor early growth was followed by good growing conditions, removals during the second month did not affect yields; poor conditions late in the season, however, prevented plant recovery. Considerable risk was therefore associated with severe loss of fruit forms in rain-grown cotton, at any stage later than one month after the first burst of squaring.

Although conditions are different in southern Queensland and the cotton under discussion in this paper is grown under irrigation, a clear parallel can be drawn between the two areas as regards the effects of loss of fruit forms. However,

in southern Queensland the consequences are likely to be more severe, as the growing season is shorter.

NOTE: The paper on *E. huegeli* (Turner and Passlow, 1965) is not reviewed as it is based on the contents of this thesis.

METHODS

1. The Insect.

A. Description.

Eggs, larvae, pupae and moths of *E. huegeli* were examined and descriptions were drawn up. It was not the intention in this section of the work to provide detailed descriptions of all the stages. Thus attention was paid mainly to the sexual differences of the pupae, to the aberrant colour forms of the moth and to the male and female genitalia. During examination of moths from central and north Queensland, it was discovered that what had previously been regarded as *Earias huegeli* in this state, was, in fact, both *E. huegeli* and *E. vitella*.

The pupae used for description were removed from the pupal cases and examined under a binocular stereoscopic microscope and illustrations were prepared to show the general structure and the external sexual characters of the male and female.

To prepare genitalia for examination, the abdomen of the moth was removed, boiled in ten per cent. potassium hydroxide for one minute and then washed in water. The genitalia were then dissected, cleared in clove oil, washed in xylol, washed in distilled water and mounted in de Faures medium. Illustrations were prepared to show the male genitalia of both *E. huegeli* and *E. vitella*. Dissections were

also made to examine the structure of the sexual organs of both the male and the female E. huegeli and illustrations of these were prepared.

B. Distribution and Economic Status.

Results given in this section were drawn from personal observations and from observations of other entomologists in the Queensland Department of Primary Industries who have had experience in cotton entomology. Observations on E. vitella were included to clarify the position with regard to these two species of rough bollworm.

2. Life History and Habits.

General observations recorded in this section were made on cotton growing at Hermitage Research Station, Department of Primary Industries, near Warwick, as well as on private farms in the Brookstead district, Lockyer Valley and Toowoomba district and at the Department of Primary Industries Laboratory, Toowoomba.

A. The Egg.

The eggs required for this series of experiments were obtained from mated moths, collected in the field and induced to lay under laboratory conditions. The moths were placed in four-pound honey jars covered with muslin, held in place by rubber bands. The jars were provisioned with a tube of sugar solution closed with cotton wool to

facilitate the moths' feeding. The moths oviposited principally on the muslin covers which were removed and replaced by fresh covers as the eggs were required. In all cases, the eggs were utilised while still attached to the muslin.

(a) Developmental Studies at Laboratory Temperature.

The eggs used in this experiment were removed from the oviposition jars at 9 a.m. daily. The daily supply of eggs was placed in small glass jars sealed lightly with screw top lids, the number of jars used depended upon the eggs available. The eggs were observed daily at 9 a.m. and the numbers of larvae which had emerged in each jar were recorded. The mean daily maximum and minimum temperatures during the period of observation were 25.0 and 22.8°C. respectively, with a range of 26.6 and 21.6°C.

(b) Developmental Studies at Controlled Temperatures.

The two controlled temperature experiments were carried out in a ten chamber multiple temperature incubator.

Eggs utilised in the first experiment were placed daily at 9 a.m. in small screw topped jars which were loosely closed. The following temperatures were employed in the experiment - 5.0, 8.7, 13.0, 16.2, 20.1, 23.5, 26.3, 29.4, 33.0 and 37.5°C. (all ± 0.5°C.). The humidity was not recorded but the

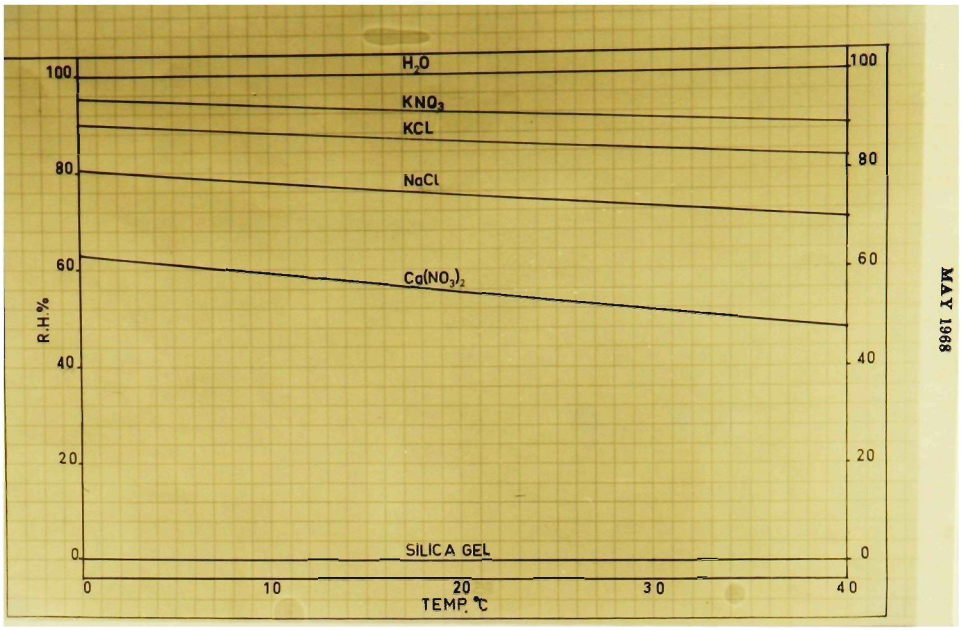


Figure 1. Relative humidities (per cent.) produced by humidity control agents at a range of temperatures (After Tsai, 1935).

Plate 2. Ten chamber multiple temperature incubator used in developmental studies.

range was such that condensation occurred at the lower temperatures, while the atmosphere of the chamber at higher temperatures appeared to be relatively dry.

In a second experiment, designed to remove this variable, eggs were placed at the following temperatures - 16.2, 23.5, 29.4 and 37.5°C., in combination with the range of relative humidities produced at these temperatures by water, anhydrous silica gel and saturated solutions of potassium chloride, potassium nitrate, sodium chloride and calcium nitrate. The relative humidities produced by these compounds at the temperatures utilised are shown in Fig. 1.

Eggs were removed from the oviposition jars every six hours and placed in small plastic tubes closed with a nylon cloth - these, in turn, were placed in larger plastic tubes, containing the humidity control agent, and the tubes were sealed tightly with plastic caps. Containers were not opened until 48 hours before the expected time of emergence of the larvae, and in all cases, no larvae had emerged at this time. Observations were then carried out every six hours. Containers were opened under still air conditions and were shaken lightly on resealing, to re-establish partially, the humidity regime.

B. The Larva.

(a) Instar Determinations.

Larval instars were determined by measurement of head capsule widths. These measurements were carried out using a binocular stereoscopic microscope with a calibrated eyepiece micrometer. The larvae were anaesthetised with carbon dioxide and placed on a microscope slide, the head being held in place during measurement by gentle pressure on a coverslip placed over the insect. Larvae employed in this study came either from laboratory bred specimens or from field collected material. Measurements were converted into centimetres and graphed. As clearly defined head capsule size ranges were shown, no statistical analyses were made.

A further series of measurements was made on eleven larvae which were bred from first instar larvae to pupation, to determine the duration of larval instars. These measurements confirmed the validity of the head capsule size range as shown in the first series of measurements.

(b) Duration of Larval Instars.

Larvae were reared to pupation on cotton squares using freshly emerged first instar larvae. The food supply was changed every second day. Head capsule widths were measured daily, using the method described in the previous section, and the measure-

ments recorded. Larvae were considered to have changed instars when head capsule width increased significantly. Larvae were held at room temperature, the mean daily maximum and minimum temperatures being 24.7 and 22.6°C. respectively.

(c) Larval Developmental Studies under Controlled Temperatures.

The ten chamber multi-temperature incubator was utilised in this experiment, to provide the following temperatures:- 12.5, 15.5, 19.0, 22.0, 25.0, 29.0 and 36.0°C. (all ± 0.5°C.).

Freshly emerged first instar larvae were placed individually in plastic tubes three quarters of an inch in diameter and two inches high, along with six germinated cotton seeds and the tubes covered with nylon cloth held in place by a rubber band. Variations of humidity with temperature in the different chambers were overcome by placing the tubes in airtight plastic butter boxes, containing a saturated solution of sodium chloride. This salt solution maintained the atmosphere at approximately 75 per cent. relative humidity and helped to sustain the quality of the food, especially in the chambers where the humidity was low.

The cotton seed used for food was first soaked in water for 24 hours, and then was removed and drained before being placed in a closed vessel

Plate 3. Cotton being grown under irrigation in the Brookstead District.

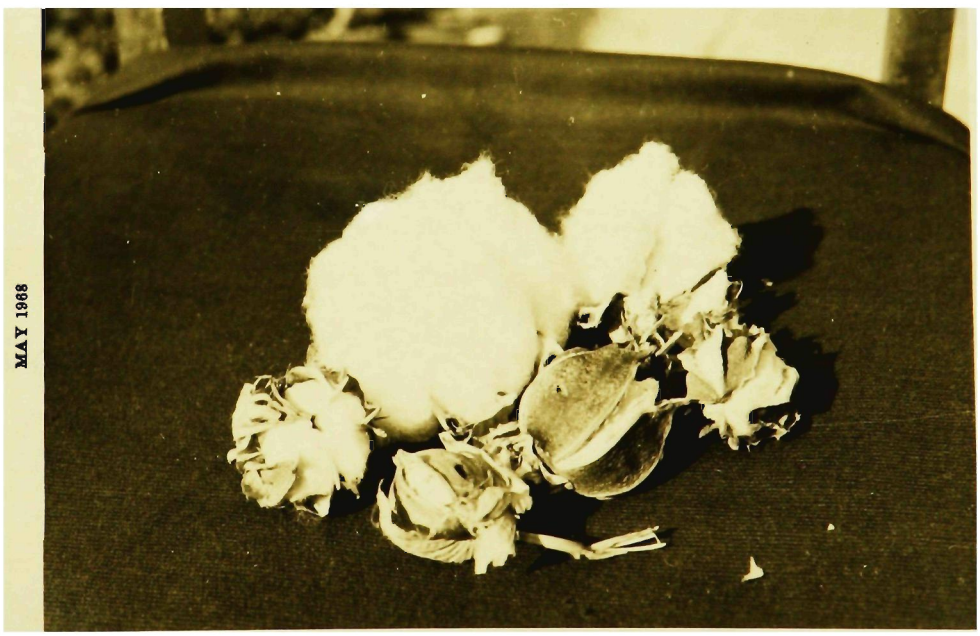


Plate 4. Loss of crop production as a consequence of rough bollworm attack - compare the production of the fully mature boll with the partial or complete loss of lint from the other bolls.

over a saturated solution of sodium chloride which maintained the atmosphere at 75 per cent. relative humidity. The seed was held in these containers for three days until partially germinated, then the seeds were dehusked. The food was changed three times per week.

A large percentage of the larvae died during the first instar but approximately 80 per cent. of those surviving completed larval development. The period from larval emergence to pupation was recorded.

(d) Larval Feeding Behaviour and Damage to the Cotton Plant.

Gauze covered cages 3 feet by 3 feet by 3 feet were used to cage single cotton plants in the field for these studies.

Observations of larval feeding behaviour involved the placing of three larvae on a plant which was checked for the presence of larvae when caged a fortnight before use, and on the day of larval placement. The larvae were observed twice weekly and any change in feeding site was recorded along with general observations.

The work on larval feeding behaviour was supported by general observations, made while this project was in progress.

Observations were also carried out on caged plants to determine the effects of larval feeding on

the fruit forms. Twenty cages were erected over plants in the field and all infested fruit was removed before the plants were heavily sprayed with parathion. A fortnight later, the plants were checked and any infested fruits removed. Ten caged plants served as controls; fruit forms of all sizes were tagged with small numbered jeweller's tags and the size of the fruit was rated visually. A similar procedure was adopted in the remaining cages, but, after classifying the size, first instar larvae or eggs were placed on the fruit. The cages were inspected twice weekly and both infested and fallen fruit were recorded.

C. The Pupa.

(a) Pupal Developmental Studies.

(i) Studies at Controlled Temperatures.

Pupae used in this study were obtained from field collected final instar larvae which pupated in the laboratory. Pupae were removed from the breeding containers every twelve hours and placed in the incubator in one and a half inch high plastic tubes covered with cloth, held in place by a rubber band. Approximately twenty pupae were placed at each of the following temperatures - 5.0, 8.7, 13.0, 16.2, 20.1, 23.5, 26.3, 29.4, 33.0 and 37.5 ^{o}C. In order to minimise humidity variations, the pupae were stored in sealed containers, along with a saturated

sodium chloride solution.

The pupae were observed every twelve hours and moth emergences and developmental periods of the pupae were recorded.

(ii) Studies at Laboratory Temperatures.

Final instar larvae were collected in the field and fed to maturity in small glass jars. The larvae were allowed to pupate in the jars and were held in these jars during the pupal stadia. Records were kept of date of pupation, date of moth emergence and the daily maximum and minimum temperatures.

D. The Moth.

(a) Moth Emergence from Pupae in the Soil.

Pupae were placed at the following sites - on the surface, in cracks, under the loose surface crust, and at 1 inch and 2 inches depth covered by loose, crumby soil. The areas of burial were covered by a cage and moths emerging were recorded. The soil in the area at Hermitage Research Station was a black self-mulching soil.

(b) Moth Longevity Studies.

(i) Longevity under Starvation Conditions.

Unmated moths were placed in clear plastic tubes within 24 hours of emergence and were not supplied with food. Daily observations were made and the dates of death were recorded. Records were kept also of daily maximum and minimum temperatures.

The means for the period were 20.1 and 14.4°C. respectively.

(ii) Longevity of Fed Laying Moths.

Great difficulty was experienced in all attempts to mate moths in captivity and only limited data were obtained in this section of the work.

Freshly emerged moths were placed in 2 feet by 2 feet by 3 feet wooden framed, gauze covered cages provisioned with a flowering cotton plant in a pot. The moths were held in these cages for two days before being removed to the laying cages. Laying cages were constructed from paper cups; a tube containing a sugar and water solution was inserted through a hole in the side, and the mouth of the cup was covered with muslin held in place by a rubber band. The moths were held singly in these containers. The containers were inspected daily and the length of life of the moth as well as the number of eggs laid each day, was recorded. The mean daily maximum and minimum temperatures during the period were 24.7 and 23.7°C.

3. Alternative Hosts.

A check was made for the presence of E. huegeli larvae on species of Malvaceae encountered and records were kept of the species on which larvae were found. During 1964 and 1965, a study was made of the growth and fruiting habits of a number of weeds in the family

Malvaceae, both on the Darling Downs and in the Lockyer Valley. Monthly inspections were carried out and records were kept of the growth stages of the plants.

The identifications of plant specimens collected during the studies on alternative hosts were carried out by the Queensland Government Botanist.

4. Seasonal History.

A. Field Population Studies.

Investigations and discussions before the commencement of this work suggested that populations of E. huegeli normally present on cotton plants were low and that Hibiscus trionum carried higher populations than the cotton plants. It was therefore decided to leave any naturally occurring H. trionum plants in the field and include the E. huegeli carried by these plants in the seasonal population study, as in all except large, weed free, cotton farms, the two plants appeared to comprise the major hosts. The Hermitage Research Station of the Department of Primary Industries, where the work was carried out, is located about five miles north-east of Warwick.

(a) Larval Population Studies.

Random samples of fruit forms were taken weekly from an area of unsprayed cotton and H. trionum

on Hermitage Research Station during the 1962-63, 1963-64, and 1964-65 cotton seasons. The samples of 200 cotton bolls, 200 cotton squares, and 200 H. trionum fruit forms were assessed in the laboratory for numbers of larvae present and numbers of damaged fruit forms.

(b) Light Trap Studies on Moth Activity.

The light source of the trap illustrated in the accompanying photograph was a 240 volt, 15 watt, General Electric B.L.B. Black Light Fluorescent Tube. This light trap was operated on the edge of the same two acre field, which served for the larval population study at the Hermitage Research Station.

The insects taken at the light trap were collected in four pound jars, part filled with 70 per cent. alcohol, and suspended below the funnel of the trap. The bottles were changed daily and the alcohol acted as a preservative allowing weekly collection and assessment of the moth catches. The moths were well preserved and readily identifiable after drying.

Records were kept of the numbers of E. huegeli moths taken daily in the trap.

(c) Meteorological Data.

The rainfall and temperature data utilised in the interpretation of the results were abstracted from the records of the weather station operated on Hermitage Research Station.

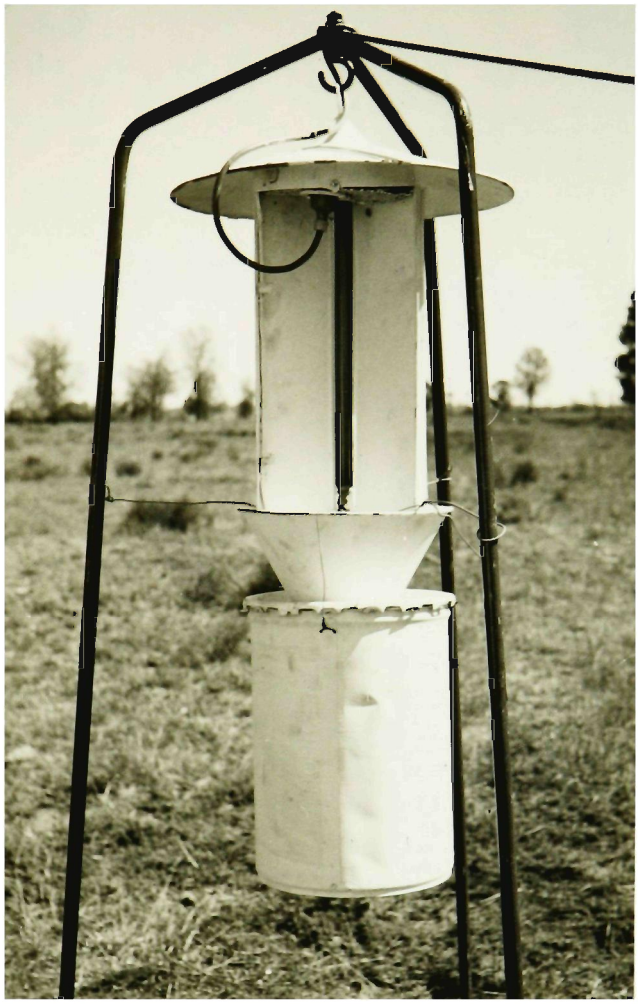


Plate 5. Light trap employed in studies of moth activity.

5. Parasites.

During the period 1963 to 1966 observations were made on all larvae and pupae brought back for breeding purposes to the laboratory in order to determine the occurrence of parasitism in the species. The majority of the material was collected from unsprayed cotton fields or from naturally growing Hibiscus trionum and all parasites emerging were collected for identification.

6. Control.

A. Topical Testing.

Moths used in these tests were reared from fourth or fifth instar larvae collected in the field in Hibiscus trionum fruit, which was gathered in large quantities and placed in cages 3 feet by 1 foot 6 inches by 1 foot 6 inches in the laboratory. Fresh food was added as required and the larvae fed and pupated in the cages.

The moths were allowed to emerge in the cages and were collected daily using an aspirator. The moths were held in glass jars and then were anaesthetised as they were needed using carbon dioxide, but were always used within fifteen minutes of being placed in the carbon dioxide atmosphere. Between anaesthetisation and use, the moths were held in a dish with a perforated false bottom through which carbon dioxide was passed.

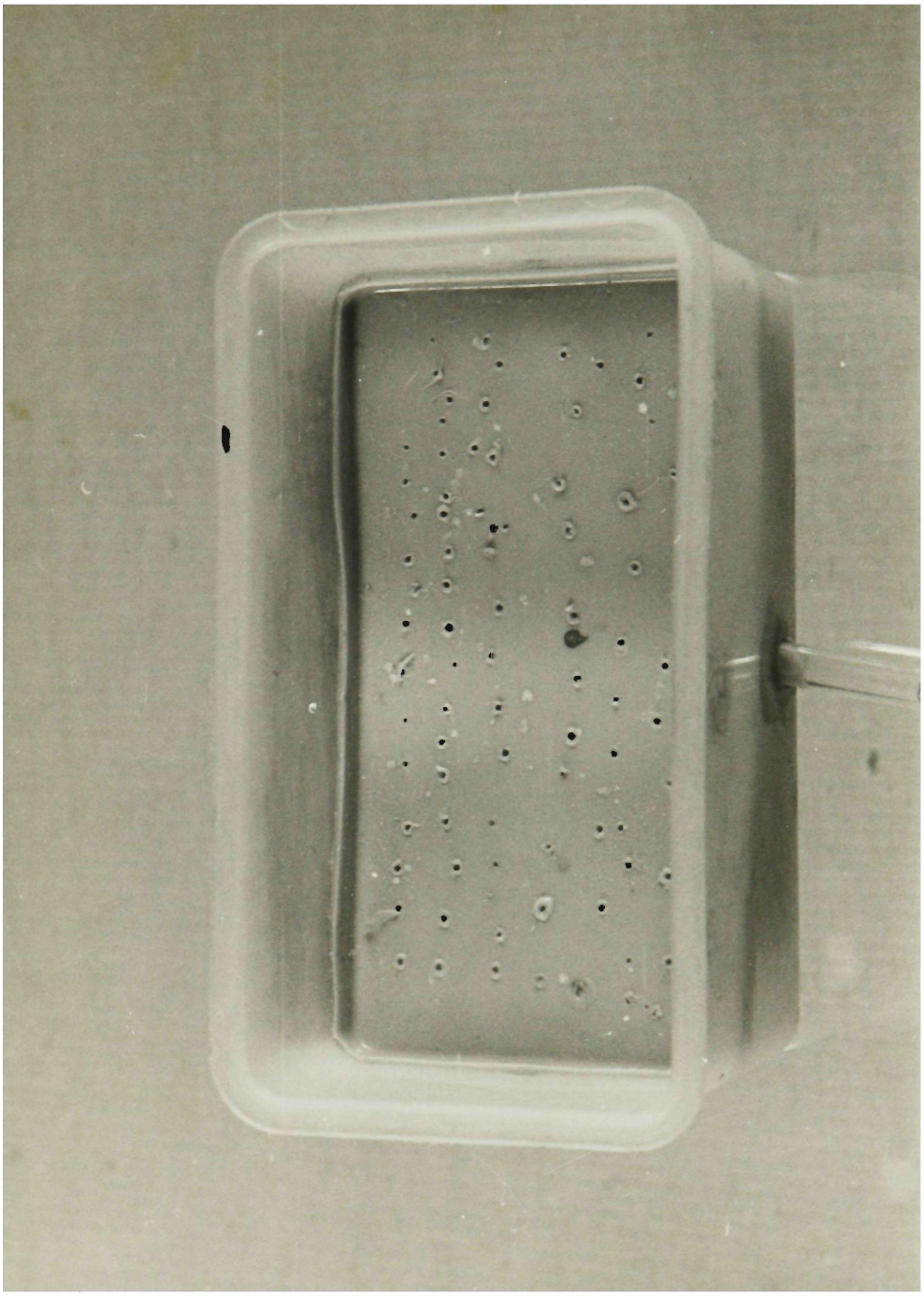


Plate 6. Container with a perforated bottom used for holding anaesthetised moths in a carbon dioxide atmosphere.

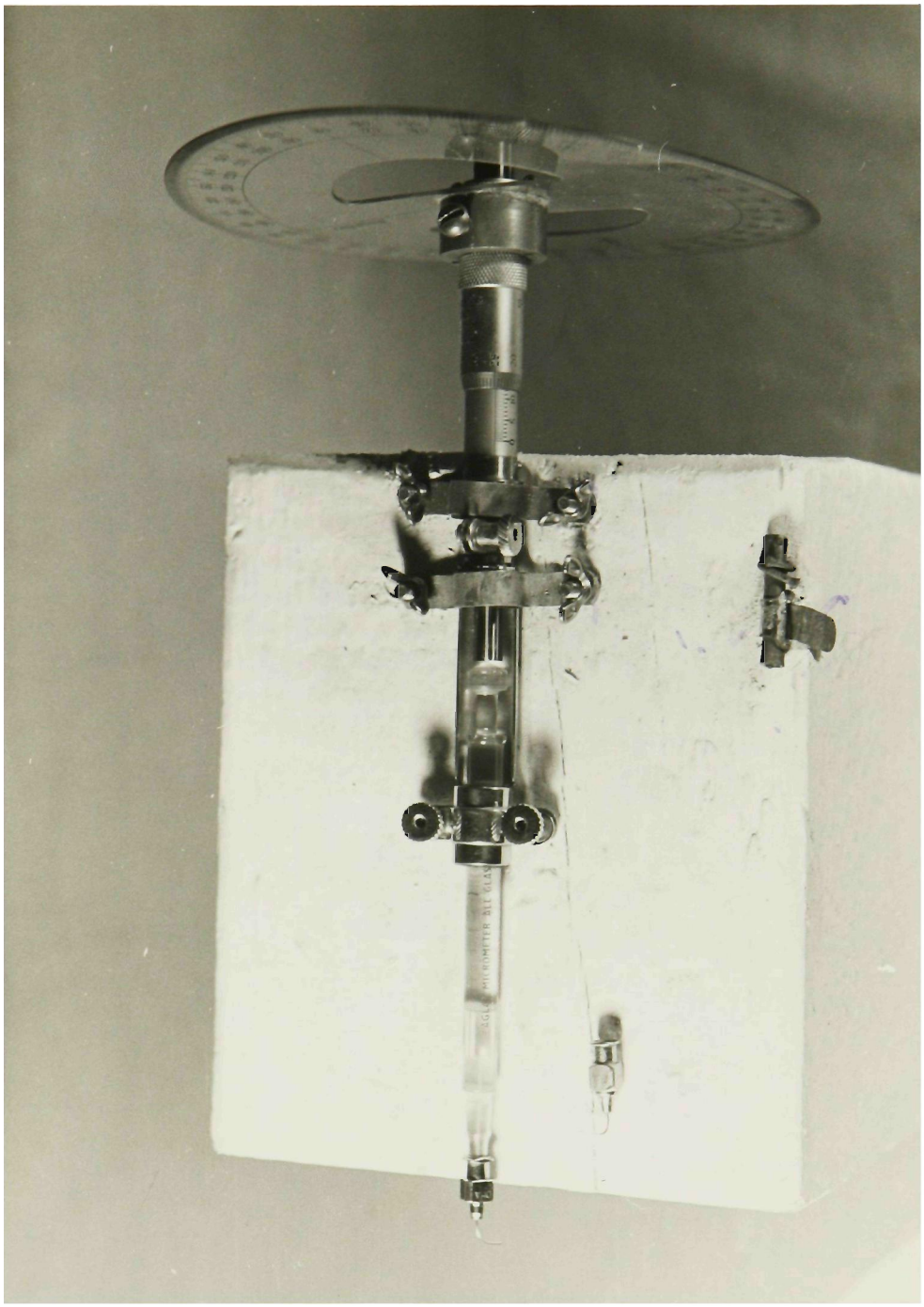


Plate 7. Agla micrometer syringe.

Insecticides used in these tests, with the exception of carbaryl, were dissolved in "Dioxane" which served as a carrier and "Shell Risella Oil" was added to serve as a spreading agent. In the case of carbaryl, glycol was used as a spreading agent. The ratio of carrier to spreader was 4 : 1 with both mixtures. All solutions were formulated from technical material.

The applications of insecticides were made using an Agla micrometer syringe fitted with a fine brass hypodermic needle, the tip of which had been ground flat. The apparatus was set up as shown in the accompanying photograph. The needle was bent at right angles and was placed on the syringe so that the tip was facing downward.

The moth to be treated was picked up by a wing using entomological forceps and held while 0.001 ml. of insecticide solution was placed on the needle tip, by advancing the micrometer. The insecticide was then placed on the moth by touching the ventral surface between the second and third pairs of coxae against the side of the needle, near the tip. This application technique was used with all moths treated. The dosage of insecticide applied was regulated by varying the concentrations of the solutions used.

The check treatment.moths were treated with

solvent and spreader in the same way as the treatment moths. Following treatment, the moths were held at 23.9°C. in 4 pound jars covered with muslin. A maximum of 20 moths was placed in each jar and they were inspected at 24 and 48 hours after treatment. The moths were classified as alive, dead and moribund, the latter being those moths which could no longer grip the sides of the bottle.

B. Cotton Schedule Spray Trial, 1965/66.

The trial was laid out as a 5 x 5 randomised block on Gatton Research Station using an area of evenly planted cotton, variety "Dixie King". The plot size used was four rows of plants each 120 feet long. The plots were separated laterally by four rows of cotton plants and at the ends by 6 feet of bare ground. The row spacing was 38 inches. Normal weed control cultivations were carried out and the cotton was hilled before irrigation. Regular flood irrigations were applied and sufficient moisture was present to maintain peak growth rates during the season.

Insecticide applications were made using a tractor-mounted boom spray with inter-row droppers protected by rigid guards. The insecticide was sprayed through five nozzles per row, one of these being mounted above the row and two on the droppers on either side. This placement of nozzles gave

complete insecticide coverage of the plant. Guards in front of the droppers protected the plant from physical damage and allowed the dropper nozzles to function efficiently without the interference of foliage. Following severe lodging of the crop in February, the droppers could not be used in their normal position but were moved into a horizontal position perpendicular to the boom. No further irrigations were carried out following lodging and yields are thus lower than could be expected.

Sprayings were carried out at a pressure of 75 pounds per square inch and at an average volume of 67.8 gallons per acre. Knapsack sprays were used on two occasions and the application rate in these instances was approximately 75 gallons per acre.

The following treatments were applied:-

1. DDT - endrin (weekly applications)
2. DDT - endrin (fortnightly applications)
3. DDT - parathion (fortnightly applications)
4. DDT - parathion (weekly applications)
5. Check; No insecticide.

Although the specification was made that the sprays should be made weekly and fortnightly if possible, it was necessary to make the application flexible to allow for extremely high insect populations in the crop. On these occasions, the

spraying interval was reduced.

The mean rates of application of insecticides during the season are as follows, all rates being active constituents:-

DDT - 0.62 lbs. per acre

endrin - 0.31 lbs. per acre

parathion - 0.23 lbs. per acre

dicofol - 0.62 lbs. per acre

Insecticide treatments were applied at the following dates as shown in Table I.

Table I

Dates of Application of Insecticide Treatments

Date	Weekly	Fortnightly	Method
November 29	x	x	Boom
December 10	x	x	Knapsack
17	x		Knapsack
23	x	x	Boom
30	x		"
January 6	x	x	"
13	x		"
18	x	x	"
22*	x		"
27+	x	x	"
February 3	x		"
10	x	x	"
16	x		"
28	x	x	"

* rain immediately after application.

+ dicofol included with treatment.

Fruit Form Production and Damage Assessments.-

During the trial two assessments were carried out. On January 4-5, ten random plants per plot were selected and on February 1 a similar assessment was made using 15 random plants per plot. The numbers of squares, squares damaged, bolls and bolls damaged per plant were assessed by visual observation and dissection on each of these two occasions. The numbers of Heliothis spp. and rough bollworm larvae found were recorded.

Yield Assessment.-

Harvesting was carried out using a single row machine harvester. Two separate harvests were made on April 5 and May 10 and yields were recorded as pounds of seed cotton from individual rows within the plots.

C. Cotton Schedule Spraying Trial 1966-67.

A trial was laid out and conducted on a similar basis to the one in 1965-66. The trial was designed to evaluate, under field conditions, some of the chemicals shown in the laboratory to be efficacious in killing E. huegeli moths. As E. huegeli was present in very low numbers and Heliothis populations were high, no information was gained on control of rough bollworm. Thus, the trial does not warrant further attention in this paper.

R E S U L T S

1. The Insect.

A. Description.

(a) The Egg.

The egg of Earias huegeli Rog. is almost spherical but has a slight ventral flattening. The dorsal surface is surmounted by two concentric rings of protuberances, the outer ring having 13 and the inner ring 5 to 7. The chorion has a basket-like texture with 26 ridges running from the dorsal to the ventral surface, interconnected by less prominent ridges. The patterning is more prominent on the dorsal and lateral surfaces than on the ventral surface, where the pattern grades to a stippling. The average diameter of an egg is approximately 0.47 mm.

The colour at oviposition is turquoise but a brown germ band develops, and the colour gradually changes to brown with a bluish tinge before hatching.

(b) The Larva.

Larvae of rough bollworm are slightly variable in colour patterning and also in the development of the colour patterns. It was noted that larvae growing slowly developed the darker colour patterns of the fourth and fifth instar, during the third instar. The shape of the colour

patterning did not vary; however, the intensity of the colours was extremely variable. Poor nutrition and slow growth tended to produce more intense browns on the normally brown areas.

The first instar larvae are basically greenish yellow and blend well with the colour of the plant. The gut contents are dark and visible. The head capsule is dark brown to black. Mandibles are brown. Prothoracic notal sclerite is brown and clearly visible. The anal plate is brown and pronounced. Larvae have a "hairy" appearance due to eight major setae per body segment.

During the second instar, the larvae darken and the colour patterns of brown and black appear with the basic body colour being an off-white. The sclerites on the body darken and the head capsule becomes black.

With the advent of the third instar, the patterning continues to darken while the first traces of the yellow colour patternings appear. The tubercles at the base of the setae begin to develop. The patterning on the thorax and first three abdominal segments is a confused pattern of brown on an off-white background with the yellow colourings confined to the apex of some of the tubercles. The brown markings on the remainder of the abdomen are confined to two indefinite lateral bands which fade

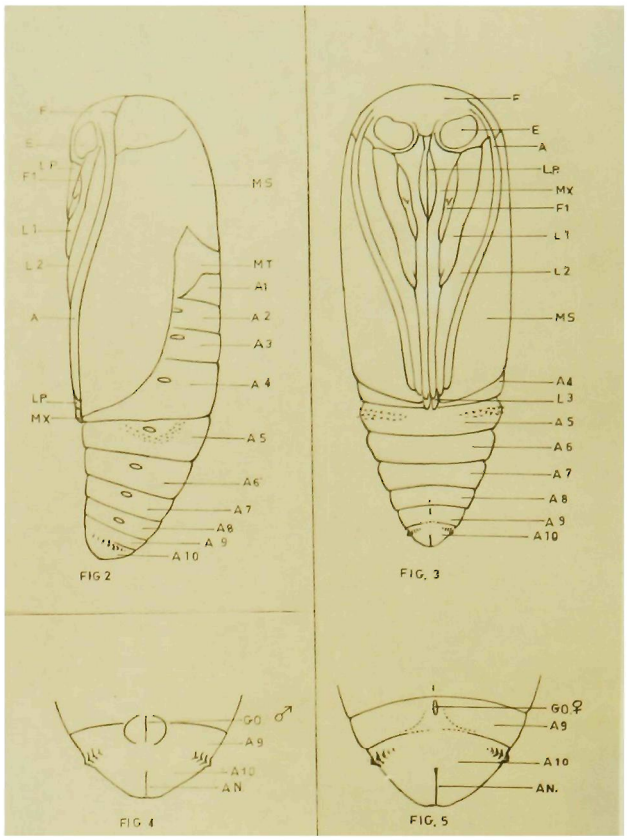
to extinction posteriorly. Some small spots of yellow colouring are located in the brown bands.

In the fourth and fifth instars, the browns become more intense, the yellows brighten and become more extensive, while the off-white background becomes more intense. The tubercles at the base of the setae become very pronounced. The brown on the posterior segments of the abdomen becomes more extensive to cover the majority of the lateral surfaces and extends also on to the dorsal surface, so that the off-white colouring dorsally is confined to a broad band which is dotted with small brown markings. This off-white colouring is not completely surrounded by the brown patterning.

(c) The Pupa.

The pupal case is grey to brown and elongate. The emergence portal at the anterior end is weakly sealed and is surmounted by a short, pointed structure (Plate 15).

The pupa, Figures 2, 3, 4 and 5, is normally less than 1 cm. in length, and is elongate, obtect and adecticous. The epicranial suture is weakly marked, the labial palps (L.P.) are one-third to one-quarter of the length of the maxilla; the maxilla (MX.) terminates approximately 0.2 mm. from the forewing tip (MS.). The mandibles are not clearly developed, the clypeus is small, compound



Figures 2 & 3. Lateral and ventral views of female pupae.

4. Details of male gonopore.

5. Details of female gonopore.

eyes (E.) are present. The antennae (A.) are long, ending just short of the mesothoracic legs (L.2).

The metathoracic wings (MT.) are covered by the mesothoracic wings (MS.) except on the dorsolateral surfaces. The femora of the prothoracic legs (F.1) are visible between the maxilla and the tibia and tarsus of the mesothoracic legs (L.2). The mesothoracic legs are visible below the apex of the maxilla and terminate slightly posterior to the forewing tip.

The fifth and sixth abdominal segments (A5 and A6) are movable at both the anterior and posterior junctions. The spiracles are visible on the second to eighth abdominal segments. The cuticle is clearly patterned on the dorsal abdominal surface but patterning is absent on the lateral and ventral surfaces. Spines on the fifth abdominal segment are more numerous ventrally. The tenth abdominal segment is more heavily sclerotised forming small lateral horns. The anus (AN.) is slit-like and is located on the tenth abdominal segment.

The location and shape of the male and female gonopores (GO.) are illustrated in Figures 4 and 5.

(d) <u>The Moth</u>.

The following is the description as listed in Hampson (1912):-

Earias huegeli

Earias huegeli, Rogenh. Verb. Zool. -bot.Ges. Wien, xx.p. 872 (1870);

Kirby, Cat. Lep. Het. p. 282.

Head, tegulae, and patagia white; thorax yellow-green with white dorsal streak; forelegs tinged with brown on inner side; abdomen white dorsally tinged with brown. Forewing white; a yellow-green fascia from base between discal and submedian folds to end of cell, then with its lower edge somewhat oblique and diffused to termen below vein 6; medial line represented by an oblique greenish striga on costal area or spot below costa and oblique striga on inner area or spots above and below vein; postmedial line green, maculate oblique from costa to discal fold, then inwardly oblique; subterminal line green, maculate, oblique from costa to vein 7; the termen and cilia at base green between veins 6 and 2. Hind wing semihyaline white, the termen tinged with brown from apex to vein 2. Underside of forewing white tinged with brown.

Ab. 1 Thorax and forewing with the green replaced by dull rufous; forewing with the costal area slightly tinged with rufous, the inner area strongly suffused with rufous and almost concolorous with the fascia.

Ab. 2 Forewing white tinged with rufous, the fascia almost obsolete. Hab. Queensland, Warwick (Turner),

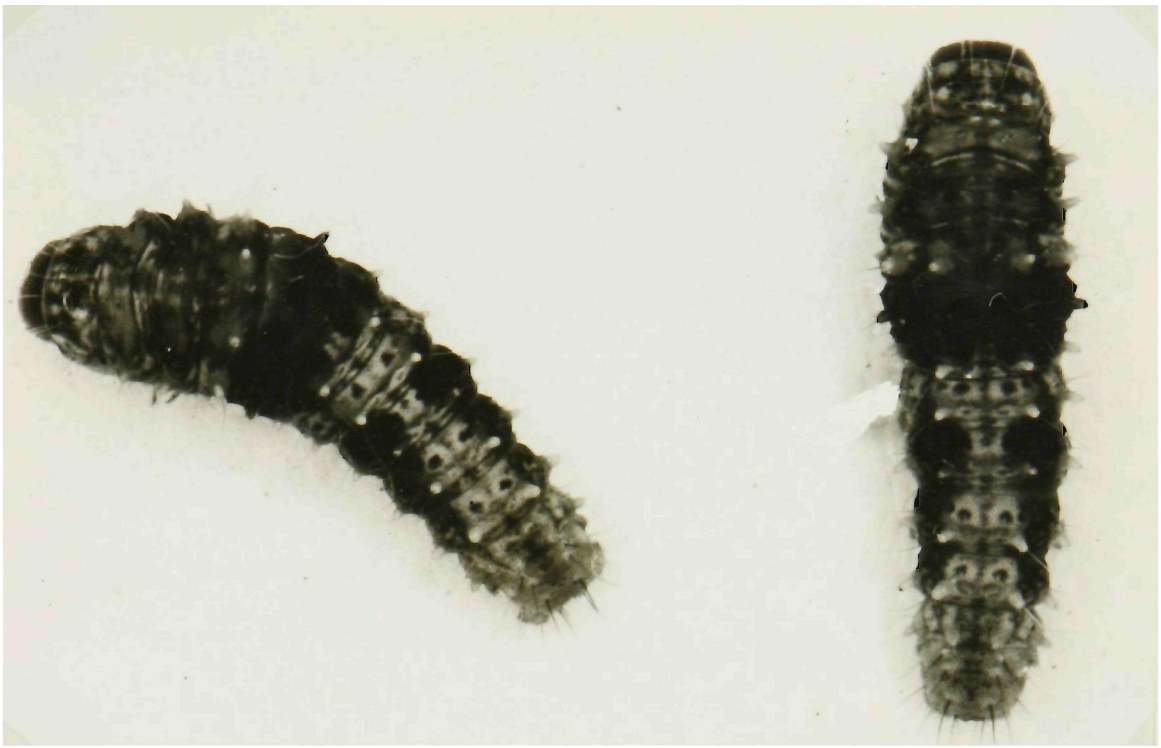


Plate 8. Larvae of E. huegeli

Plate 9. Larvae of E. vitella.

1 ♂; Moreton Bay (Diggles), 1 ♀; N. Australia, Port Darwin (Buckland), 1 ♀; N.S. Wales, Sydney (Raynor), 1 ♂, 1 ♀; Broken Hill (Lower), 1 ♂; Fiji (Matthew), 2 ♂, 1 ♀; Tahiti, Tauteia (Nicholl), 1 ♀; Gilbert Island, Apia (de la Garde), 1 ♀; Marquesas, Faton-Hiva I. (J.J. Walker), 1 ♀. Exp. 18-28 millim.

In specimens collected in Queensland, another variant exists in addition to the ones listed above.

Ab. 3 Forewings white tinged with green, the fascia almost obsolete.

It was noted during this work that the aberrant colour forms were more prevalent during the latter part of the cotton season than during the earlier part. No explanation is forthcoming as to the reason for this phenomenon.

The nomenclature used in the descriptions of male and female genitalia are based on Tuxen (1956) and Snodgrass (1935).

Female Genitalia.

The structure of the female genitalia is illustrated in Figure 6. The ostium bursae (O.B.), which is surrounded by a sclerotised area, leads via the ductus bursae (DU.BU.) to the corpus bursae (CRP.BU.). This sac is bluish in colour, with thick pliable walls which are pleated longitudinally. The corpus bursae opens via the ductus seminalis (DU.SML.)

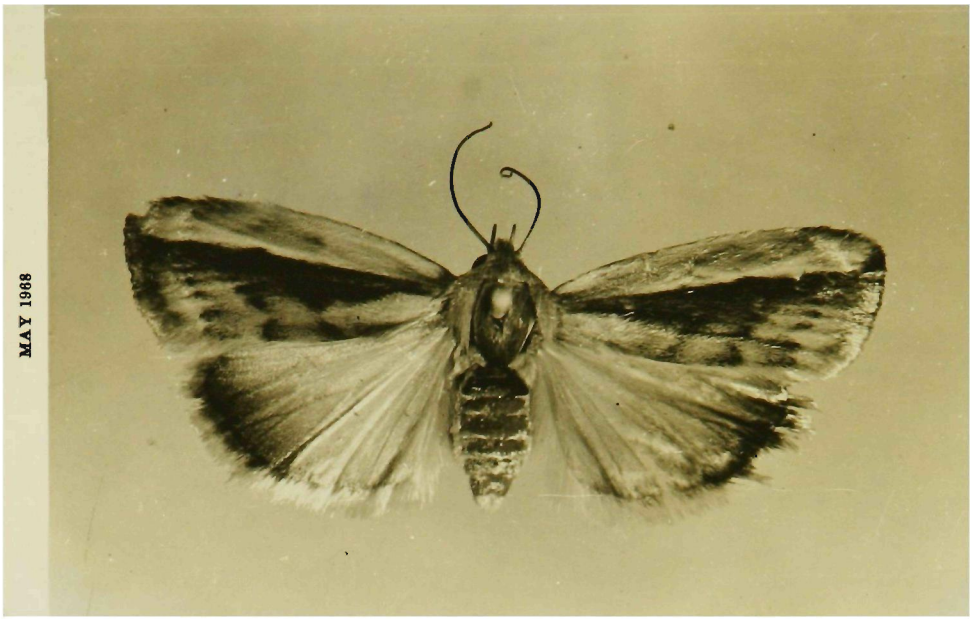


Plate 10. The moth of E. huegeli.

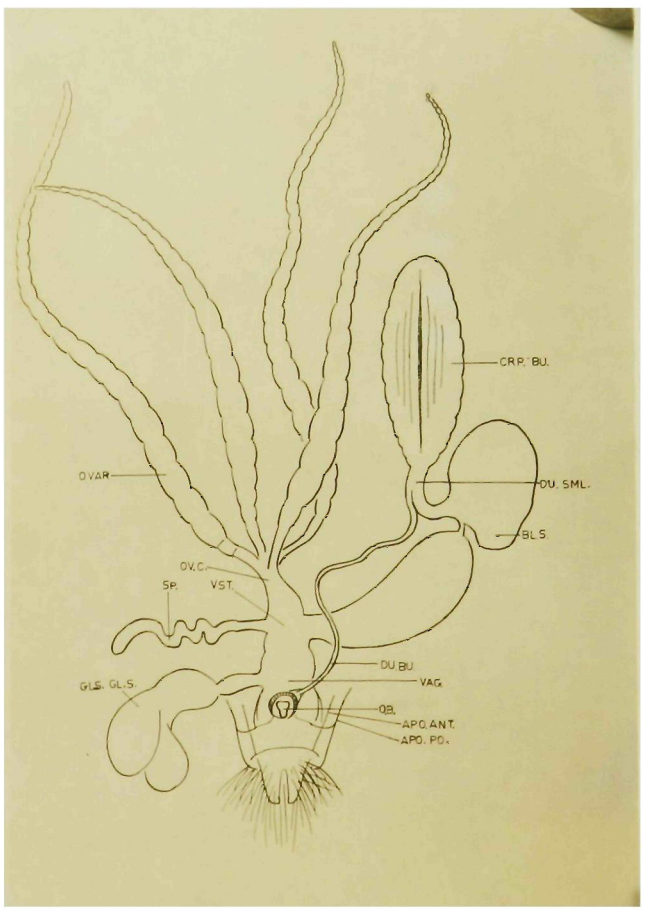


Figure 6. Female genitalia of E. huegeli.

to two thin walled sacs, the bulla seminalis (BL.S.), which in turn open into the vestibulum (VST.) opposite the spermatheca (SP.). The paired ovaries (OVAR.) open into the vestibulum via the oviductus communis (OV.C.). The sebaceous gland (GL.S.) feeds into the vagina (VAG.). The terminal segments are supported by the apophyses anteriores (APO.ANT.) and the apophyses posteriores (APO.POST.).

Male Genitalia.

The male genitalia of E. huegeli are illustrated in Figure 7. Details of the external genitalia are shown in Figure 8, while details of the aedeagus are shown in Figure 10. It will be noted that few of the parts of the external genitalia are named because of the doubtful status of the systems of nomenclature.

The testes (T.) are enveloped in a mantle to form a single structure. The paired vasa deferentia (V.D.) lead from the testes to the elongate vesiculae seminales (V.S.). The accessory glands (A.G.) feed into the vesiculae seminales. The ducts from the vesiculae seminales unite and feed into the ductus ejaculatorius (D.EJ.) which leads to the penis (P.). The ductus ejaculatorius is coiled loosely within the abdomen.

The external genitalia consist of the penis and the clasping organs. The penis is surrounded

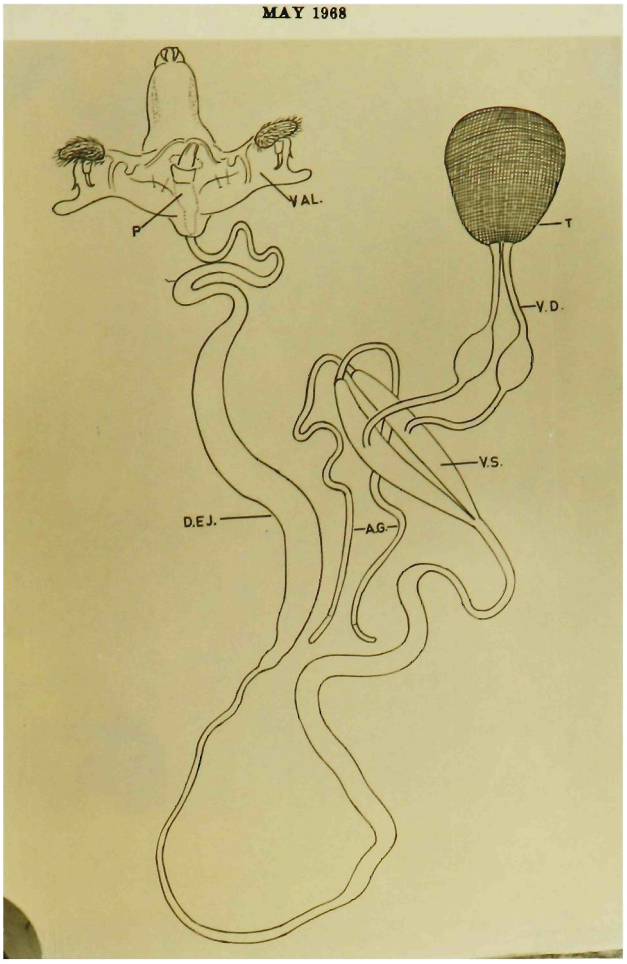


Figure 7. Male genitalia of E. huegeli.

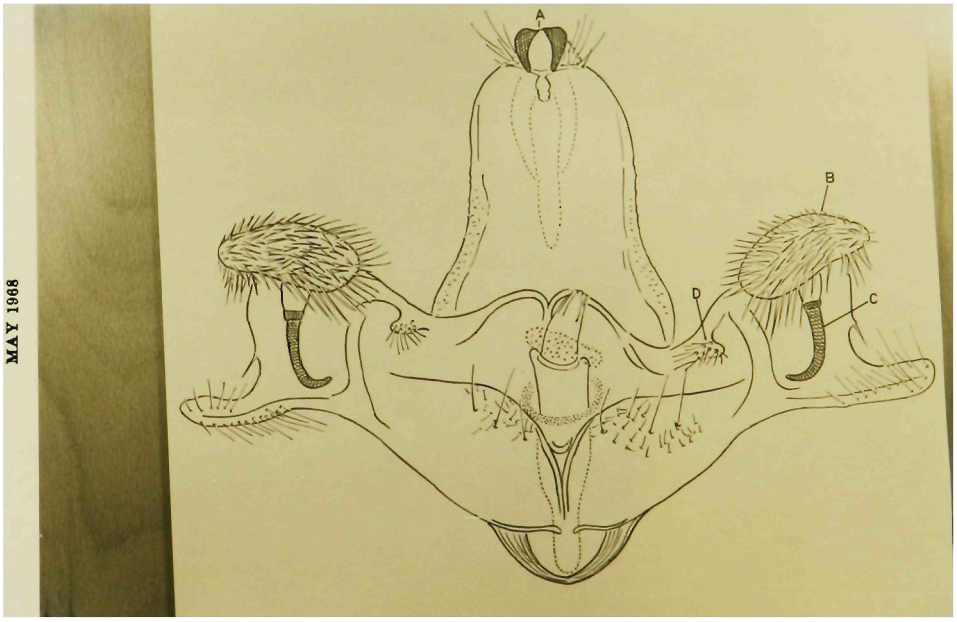


Figure 8. External genitalia of male E. huegeli moth.

dorsally by a fixed structure, and laterally by the paired hinged valvae (VAL.) which are shown in Figure 7 and 8 in an abnormally extended position.

B. Distribution and Economic Status.

E. huegeli is second only in importance to the Heliothis spp. as a pest of cotton in the three main cotton growing areas of southern Queensland, that is, Lockyer Valley, Brookstead and St. George. Passlow, (personal communications 1968) states that E. huegeli is a pest of little importance in the central Queensland cotton growing areas of Rockhampton and the Callide Valley. In northern Queensland, "rough bollworm" is a major pest on the Atherton Tablelands. However, examination of specimens forwarded from that area show that E. vitella, the northern rough bollworm, is the major species and E. huegeli the minor species. This is corroborated by field observation, Elder (personal communications 1967).

Additional localities are recorded in the section on alternative hosts. From the data gathered, it would appear that E. huegeli is present in most areas of Queensland.

C. Description and Distribution of E. vitella (F).

The following description of E. vitella is given by Hampson (1912):- Noctua fabia, Stoll, Pap. Exct. iv. pl. 355. f. H(1782); Hmpsn. Moths

Ind. ii. p. 133; Kirby, Cat. Lep. Het. P. 282.

Tinea vitella, Fabr. Ent. Syst. iii. 2, p. 293 (1794)

Aphusia speiplena, Wlk. xii, 770 (1857); Moore, Lep. Ceyl. iii. p. 490 Pl. 208. f. 6.

Micra partita, Wlk. xxxiii, 799 (1865).

Head, tegulae and patagia white, the tegulae and patagia tinged with flesh-colour; thorax yellow-green with white dorsal stripe; pectus and legs white, the fore tibiae and tarsi tinged with brown; abdomen white, dorsally slightly tinged with brown. Fore wing white tinged with flesh-colour, a yellow-green fascia from base between discal and submedian folds to end of cell, then with its lower edge somewhat oblique and diffused to termen below vein 6; cilia rufous at base between veins 6 and 3. Hind wing semihyaline white, the termen tinged with brownish ochreous from apex to vein 2. Underside of fore wing white tinged with brown.

Ab. 1 speiplena. Tegulae and patagia not tinged with flesh-colour, the latter slightly tinged with green; fore wing not tinged with flesh-colour, the green fascia widening to termen between veins 6 and 2 and with the cilia beyond it green, a short green streak on inner margin before middle, the terminal area slightly tinged with green towards apex and tornus.

Hab. Punjab. Wuzeerabad (Hearsey), 3 ♂, 1 ♀ type speiplena; Allahabad, 1 ♂; Caunpore (Betton), 1 ♂; Bombay, 2 ♂, 3 ♀; Bandra (Jayaker), 1 ♂; Madras, Gooty (Campbell), 1 ♂; Coimbatore (Walhouse), 1 ♂; Ceylon (Green), 1 ♂; Burma, Myingyan (Watson), 1 ♀; Andamans (Rogers), 1 ♂; Java (Horsfield), 1 ♂ type partita; Fiji (Matthew), 2 ♂. Exp. 22-28 millim. .

In Queensland species examined during this project, the following variants exist:-

Ab. 2. Head, tegula and patagia white tinged with flesh-colour. Dorsal thorax rufous, with white, tinged with flesh-colour bands on median dorsal and laterodorsal positions. Fascia mainly rufous with base and lower edge green.

Ab. 3. As Ab. 2 but with green tinge on rufous of thorax.

Ab. 4. As Ab. 2 but fascia rufous.

Ab. 5. Dorsal thorax green, with median dorsal and laterodorsal bands white tinged with flesh-colour. Termen at apical end of fascia rufous with rufous tinging extending obliquely from lower terminal angle of fascia to the upper edge.

Hargreaves (1948) listed E. vitella as being found in Burma, Ceylon, Fiji, Formosa, India, Indochina, Java, Micronesia, New Guinea, Northern Australia, Phillipines, Siam, and Tonga. Pearson (1958) stated that E. vitella was recorded from

Formosa to New Guinea but that the precise south-eastern limits were uncertain. Froggatt (1922) stated that E. vitella had a wide range over India, Ceylon, Burma, Andaman Island and Java and it was also recorded in Fiji. Lea (1928) recorded E. vitella on cotton in South Australia. Hill (1924) recorded E. vitella as present in the Northern Terrritory. Richards (1964) recorded E. vitella in the Ord River area of Western Australia, but placed it as a pest of minor importance.

Specimens of E. vitella were received during this project from Walkamin, South Yamba, and Nebo where the insect was infesting cotton and the species has been found in large numbers on Sida cordifolia L. at Millaroo.

Khan (1944) in discussing the Indian distribution of E. vitella, stated that the insect favours the more humid areas which do not have great ranges in temperature. In Queensland, E. vitella appears to fit into a similar pattern, with E. huegeli being more prevalent in the less humid areas. E. huegeli is the only species infesting cotton in southern Queensland. Sabine (personal communication, 1965) stated that, while E. huegeli was more prevalent in central coastal Queensland than E. vitella, neither species was of great importance in cotton. Elder (personal communication, 1965) stated that

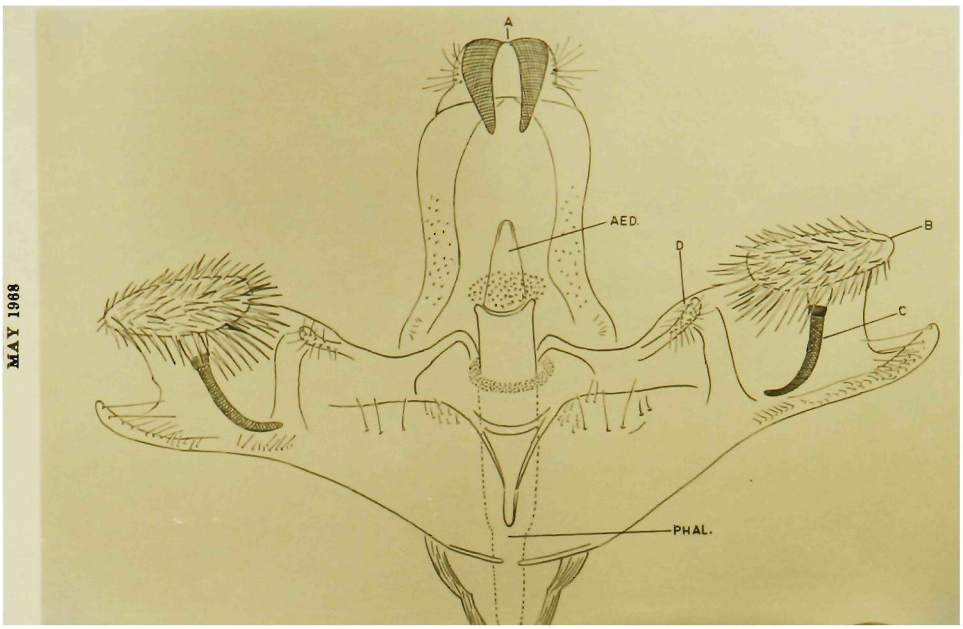


Figure 9. External genitalia of male E. vitella moth.

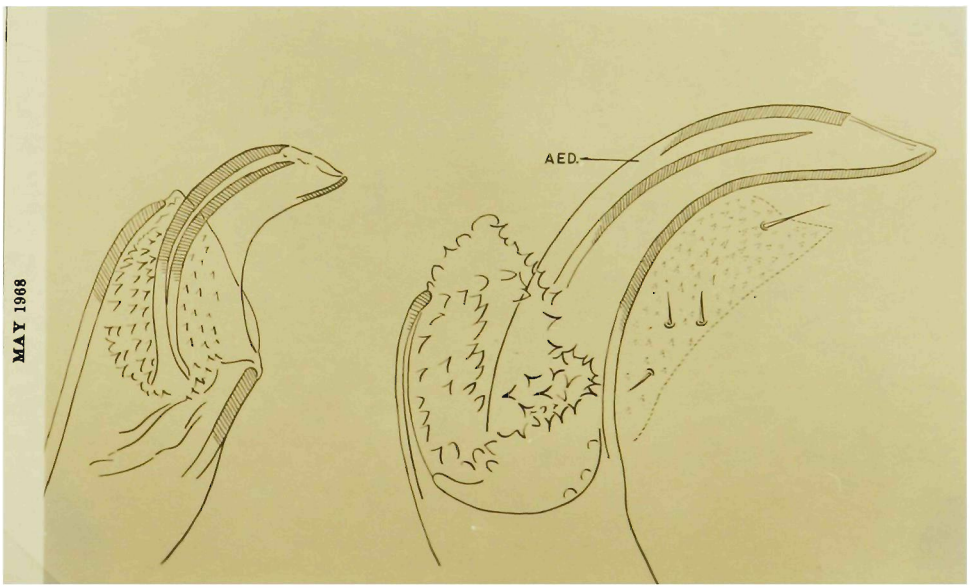


Figure 10. (Left) - Details of aedeagus of E. huegeli.

Figure 11. (Right) - Details of aedeagus of E. vitella.

E. vitella was the major species and *E. huegeli* was the minor species in northern Queensland.

D. Characters to Distinguish between *E. huegeli* and *E. vitella*.

The descriptions listed for the moths of the two species show clear differences in colouration and patterning.

The external genitalia of *E. vitella* are illustrated in Figure 9 and details of the aedeagus are illustrated in Figure 11. A comparison of Figure 9 and Figure 8 will show clearly the differences between *E. huegeli* and *E. vitella*. The pair of hooks marked **A** are larger and stronger in *E. vitella* than in *E. huegeli*, while the spined pad (B) in the case of *E. vitella* is larger and has more pronounced spines than that of *E. huegeli*. The hook (C) is also larger and stronger in *E. vitella* than in *E. huegeli*. The structure (D) is longer and narrower in *E. vitella* than in *E. huegeli*. **A** clear difference is evident in the length and shape of the aedeagus of the two species (Figures 10 and 11).

The final instar larva of *E. vitella* has a purplish body colour as compared with a brownish body colour in *E. huegeli*. There are two rows of yellow tubercules on the thorax and a single row on the abdomen of final instar of *E. vitella*, as compared with two rows on both the thorax and abdomen of

E. huegeli. The final instar larva of E. vitella has completely enclosed white areas on the dorsal surface of the abdomen. While off-white areas are present on the dorsal surface of the abdomen of the final instar larva of E. huegeli, these areas are not enclosed.

2. Life History and Habits.

A. The Egg.

(a) Developmental Studies at Laboratory Temperatures.

Observations were carried out on eggs held in the laboratory at ambient temperatures. The mean daily maximum and minimum temperatures during the period were 25.0 and 22.8°C. respectively with a range of 26.6 to 21.1°C. The time interval from laying to hatching is recorded in Table 2.

Table 2.

Time in Days from Laying to Hatching

Time (Days)	No. of larvae emerging at this time
3	3
4	48
5	152
6	32
Mean 4.9 days ± 0.04	

Thus under laboratory conditions the mean egg developmental period from laying to hatching is 4.9 days, with a range of 3 to 6 days. The temperature regime experienced in the laboratory is not unlike that encountered in the Darling Downs and Lockyer districts during parts of summer, although the range in the laboratory is not as great as that experienced in the field, particularly with regard to the maximum temperatures. Investigations were therefore carried out using both controlled temperatures and controlled temperature-humidity combinations, to ascertain the effects of the temperature extremes.

(b) Developmental Studies at Controlled Temperatures.

(i) Without Humidity Control: The intervals from laying to hatching of eggs held at seven controlled and constant temperatures (variation $\pm$ 0.5°C.), are illustrated in Figure 12. Eggs were placed at the following temperatures, 5.9, 8.7 and 13.0°C. but no larvae had emerged when the experiment was discontinued after two months. The eggs from these chambers were then held at room temperature for a week after removal, but no larval emergence occurred.

The developmental periods are graphed against temperature in Figure 12. The developmental

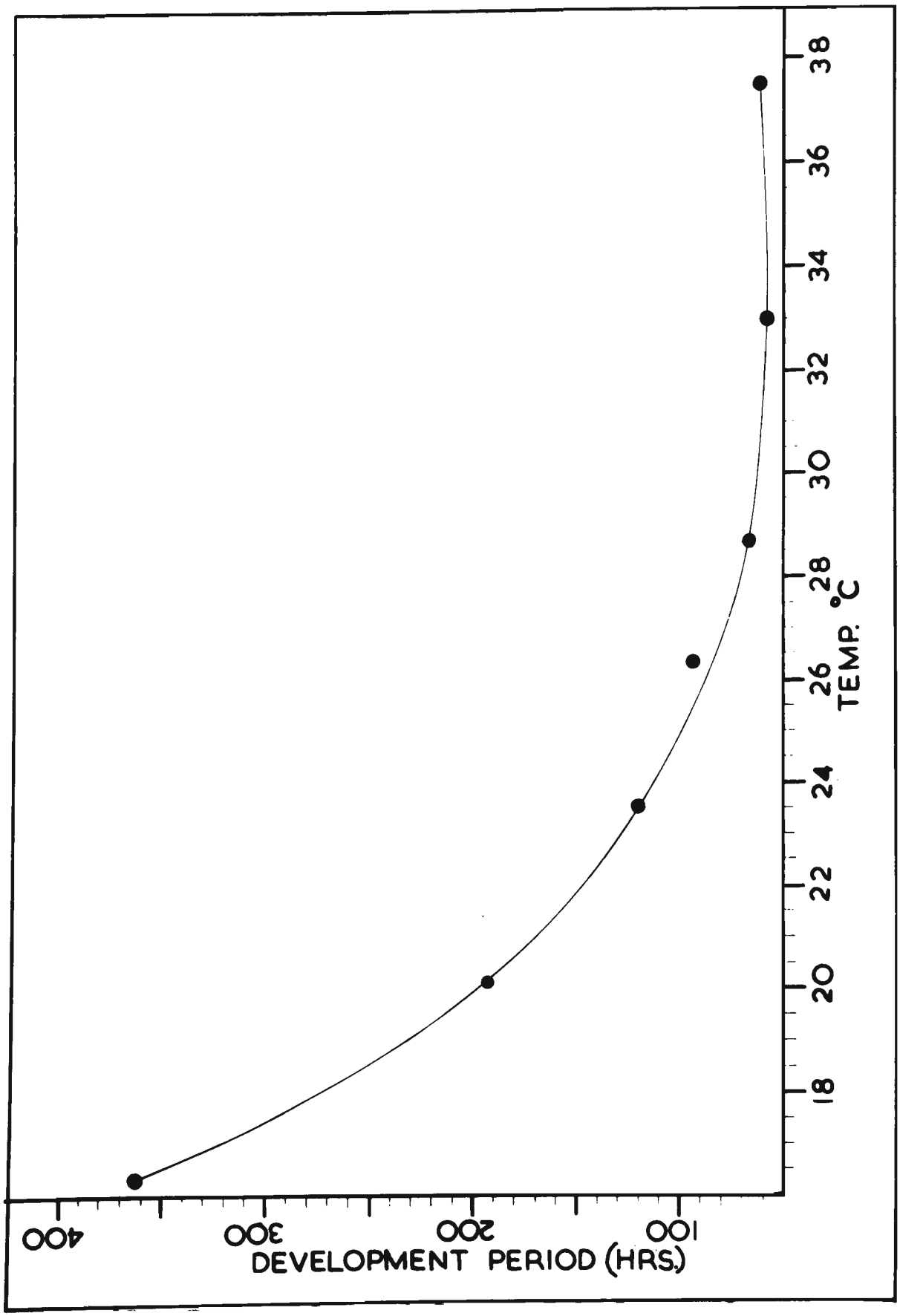


Figure 12 - Egg development period in hours at a range of controlled temperatures without controlled humidities.

periods lengthen with decreasing temperature. The minimum temperature allowing development of the eggs in this trial was 16.2°C. and at this temperature the mean developmental period was 363.9 hours. The minimum temperature allowing egg development is probably in the range 13.0 to 16.2°C.

The minimum mean period for development recorded in this experiment was 58.8 hours at 33.0°C. At 37.5°C. the mean developmental period was 3.5 hours greater than that at 33.0°C.

The incubator chambers were opened periodically and the humidity in the incubator chambers varied from 100 per cent. relative humidity (with free water being present) at 16.2°C., to a low humidity in the range 10 to 50 per cent. relative humidity at 37.5°C.

As will be shown in the experiment employing combinations of controlled humidities and temperatures, the developmental period of eggs is considerably lengthened at 0 per cent. relative humidity at 37.5°C. compared with the period required at 50 per cent. relative humidity at the same temperature. Thus in the experiment without controlled humidity, the increased developmental period at 37.5°C. may be a direct result of the deleterious effects of the low humidity regime in the incubator chamber.

Detailed observations of the egg laying habits of E. huegeli were made at a later date and

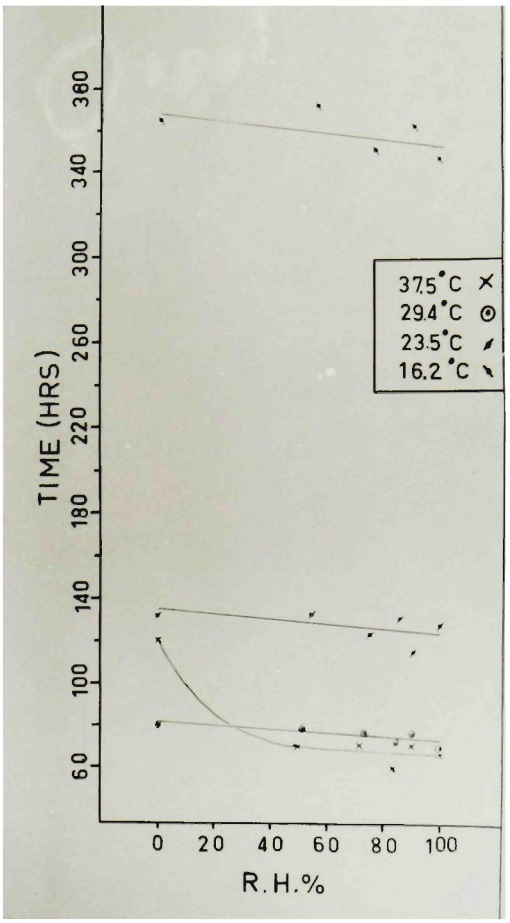


Figure 13. Developmental period (hours) of eggs held at a range of controlled temperatures and humidities.

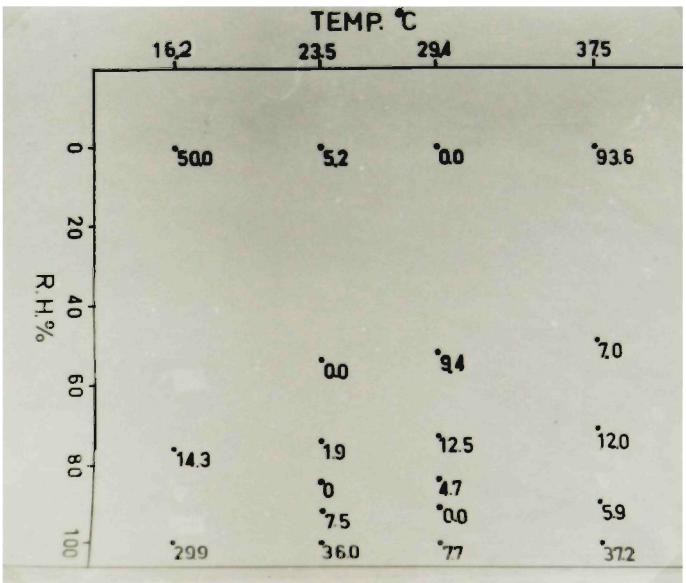


Figure 14. Percentage mortality of eggs held at range of temperatures and humidities.

showed that most eggs are laid between 5 p.m. and 11 p.m. The eggs used in this experiment were removed from the oviposition jars and placed in the incubator chamber at 9 a.m. daily. Consequently, a period of up to 16 hours elapsed during which egg development could proceed at room temperatures. This period provides an explanation for the discrepancies between the developmental periods recorded in this experiment and those recorded in the experiment with controlled temperature-humidity combinations.

(ii) With Controlled Humidities: A trial was laid out with a range of temperatures and humidities. Figure 13 illustrates the effects of temperature and humidity on the egg developmental period, while Figure 14 shows the mortality percentage at the different combinations used.

The mean developmental period showed a tendency to decrease with increasing humidity. However, this decrease was only slight, except at 37.5°C. where the mean developmental period was 120.0 hours at 0 per cent. relative humidity and 70.5 hours at 49.0 per cent. relative humidity. The eggs appear to be under severe dessication stress at the former temperature-humidity combination, as the resultant egg mortality was 93.6 per cent.

Although the length of the developmental

period shows this tendency to be shortened with increasing humidities, the mortalities as shown in Figure 14 are high at 100 per cent. relative humidity, with the exception of the eggs held at 29.4°C. where the mortality was 7.7 per cent. At 0 per cent. relative humidity, the mortalities were high only at 16.2 and 37.5°C. Thus the egg mortalities were high only at the temperature-humidity extremes, as can be seen from Figure 14. Temperature-humidity combinations approaching these extremes are possible under field conditions. The temperature combinations with 100 per cent. relative humidity are often experienced, while winds in conjunction with low humidities, would produce dessication conditions as severe as those produced in the laboratory, under still air conditions. Thus, a significant egg mortality may be present in the fields, as a result of temperature-humidity combinations.

B. The Larva.

(a) Instar Determination.

Head capsule sizes and the numbers of larvae recorded at each size are shown as a histogram in Figure 15. This histogram shows clearly the presence of 5 larval instars, coincident with the five groupings of head capsule widths. The presence of these five instars was confirmed by observation and measurement of larvae, during their whole developmental

period. Ranges set for the head capsule sizes of the larvae in each of the five instars are shown in Table 3.

Table 3.

Head Capsule Width Range (mm.) of Larval Instars.

Instar	Head Capsule Width (mm.)
1	0.25 to 0.35
2	0.36 to 0.52
3	0.53 to 0.83
4	0.84 to 1.25
5	1.26 to 1.68

The head capsule width of larvae of known instars in all cases fell within the range set in Table 3.

(b) Duration of Larval Instar.

In all the studies on larvae, the larval stadium was considered to end at the completion of construction of the pupal case, as any disturbance of the pupal case during the initial part of the prepupal period caused the larvae to attempt to fabricate a new case.

The developmental periods of the five larval instars and the total larval developmental period are recorded in Table 4.

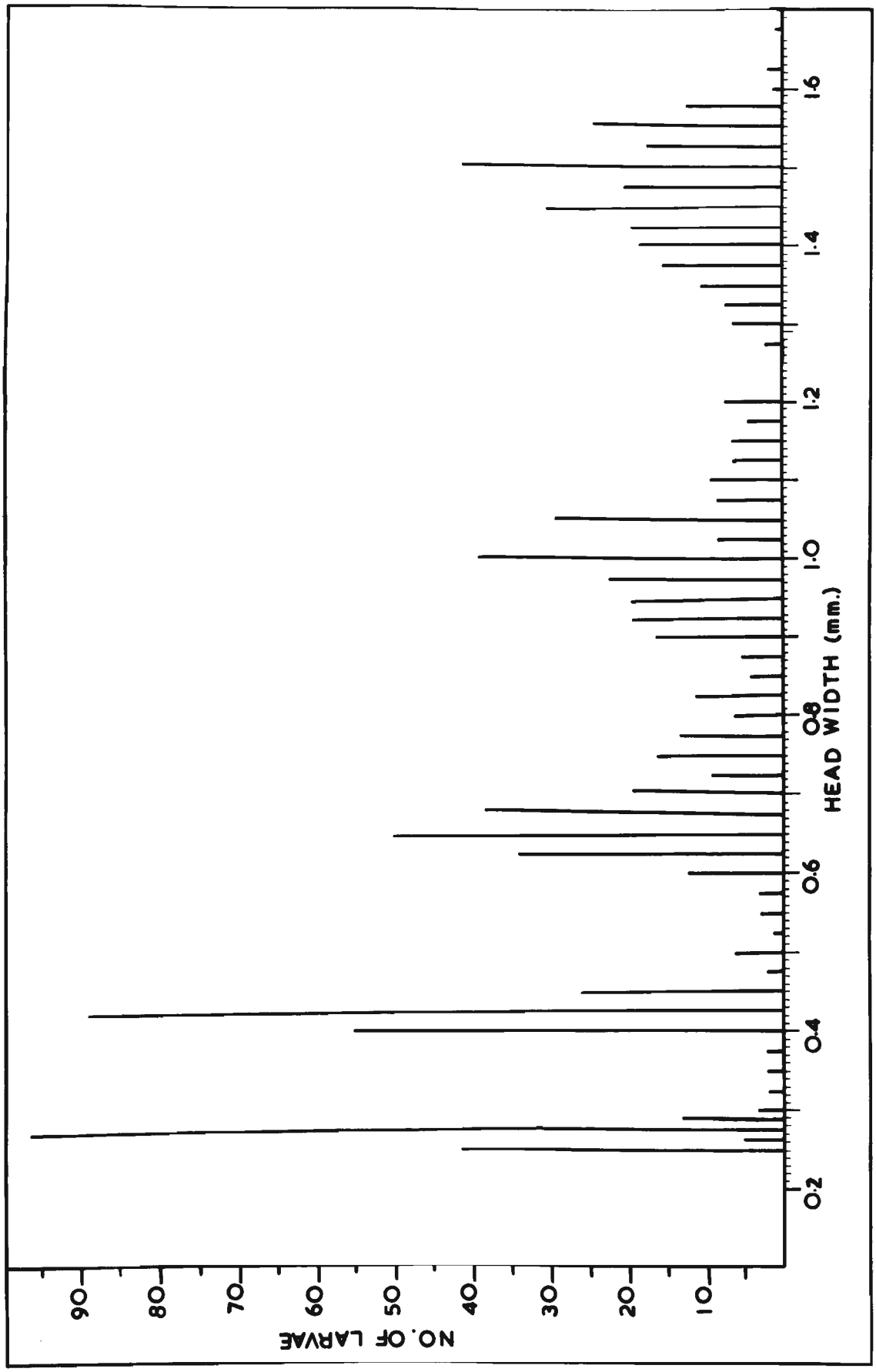


Figure 15.- Head capsule size and the number of larvae recorded at each size.

Table 4.

E. huegeli Larval Instar Developmental Periods in Days

	INSTAR					TOTAL
	First	Second	Third	Fourth	Fifth	
Time in Days	2	3	3	4	2	14
	2	2	2	4	4	14
	3	3	3	2	3	14
	4	3	2	3	3	15
	3	2	2	4	4	15
	4	2	4	2	6	18
	4	4	3	3	5	19
	4	4	3	2	6	19
	4	2	2	4	7	19
	4	4	6	1	5	20
	4	2	4	5	6	21
Mean	3.5 ± 0.2	2.8 ± 0.3	3.1 ± 0.4	3.1 ± 0.4	4.6 ± 0.5	17.1 ± 0.8

High mortalities were suffered during this work owing to the necessity of daily removal of larvae from the food, and the handling and anaesthesia incumbent upon head capsule measurement. The mean maximum and minimum temperatures during the period were 24.7 and 22.6°C. respectively. The mean larval developmental period under these conditions is 17.1 days, this period being comparable with the

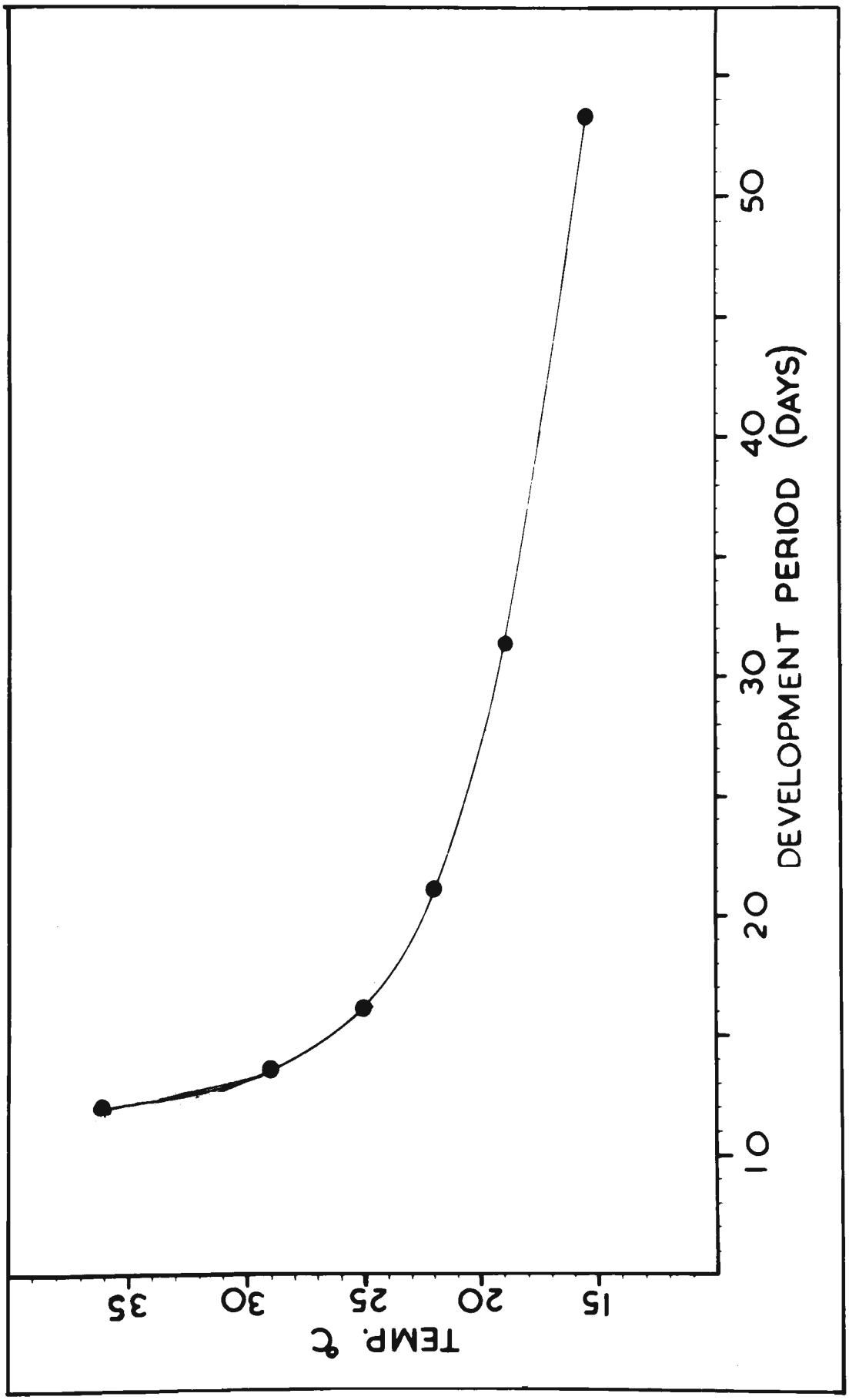


Figure 16 - Larval developmental period in days for larvae hold at a range of constant temperature

developmental period under a similar constant temperature regime in the following experiment.

The mean developmental periods of instars are as follows:-
First instar 3.5 days, second instar 2.8 days, third instar 3.1 days, fourth instar 3.1 days, fifth instar 4.6 days.

(c) Larval Developmental Studies at Controlled Constant Temperatures.

Studies were carried out to determine the effect of temperature on the developmental periods of larvae, held at a range of controlled constant temperatures. No pupation occurred with larvae held at temperatures below 15.5°C. However, as one larva held at 12.5°C. survived 82 days before dying during the third instar, the minimum temperature allowing development probably lies in the range 12.5 to 15.5°C.

The developmental period in days is graphed against temperature in Figure 16 and it shows a regular curve, passing through all points. The minimum mean developmental period recorded for larvae is 12.2 days at 36.0°C. However, the shape of the curve suggests that development is possible beyond this temperature and that the developmental period may decrease beyond this temperature. The longest mean developmental period recorded was 53.3 days at 15.5°C.

(d) Feeding Behaviour of the Larvae and Damage to Cotton Plants.

(i) Feeding Behaviour of Larvae.

Observations in the laboratory have shown that eggs are laid on any part of the plant, the only governing condition being the nature of the plant's hairs. A preference is shown for terminals and squares as oviposition sites, with a lesser preference for older parts of the plant. The location of the oviposition sites means that larvae frequently emerge from eggs, which are some distance away from a suitable feeding site. A period must therefore elapse between emergence and when the larvae reach permanent feeding sites. During this period, the newly emerged larvae have been observed to cause a limited amount of surface erosion. Examples of this type of erosion can be seen on the bracts of the squares; however, only very limited damage is caused to the plant by this type of feeding and it is probably of no economic importance. The larva, upon reaching the selected boll, square or terminal, tunnels its way into the tissue. Normally, only one larva is found per boll or square, but on occasions, a large boll may contain two or three larvae.

Field samplings have shown that more early instar larvae are to be found in squares and young

Plate 11. Rough bollworm damage to cotton square.

Plate 12. Rough bollworm damage to a young fruit. Note that boll had died.

bolls, than in the more mature bolls. It is probable, however, that this is not a preference expressed by the larvae but rather a result of the preferences of the moths for young tissues, with their dense plant hairs, as oviposition sites. In southern Queensland, little damage is caused to terminals by the pest. However, in central and northern Queensland, this type of damage is more important (Passlow and Elder, private communications, 1967).

Larvae found feeding in bolls come from two sources. Firstly, larvae which attack squares that subsequently develop into bolls and, secondly, from larvae attacking bolls directly.

Larvae feed either completely within the fruit form or with the final abdominal segment exposed. Faeces are normally deposited outside the tunnel entrance by the larva, which backs out partially to defecate but frequently much of the faeces is deposited within the excavation.

Larvae placed on cotton plants which had no fresh growth and no fruit forms, were able to survive and grow by feeding on the leaves. Larvae are often too big to be able to feed internally in the fruit of some native hosts, and these larvae can survive with most of the body outside the fruit.

A change in the feeding site appeared in all

Plate 13. Boll damaged by E. huegeli.

cases to be a matter of necessity. Conditions observed to necessitate a change in the feeding site were:- entry of rotting organisms into the fruit form, shedding of the fruit form by the cotton plant, and exhaustion of food in the fruit form. In all of these instances, larvae attempted to make their way to a new feeding site, the success of these efforts being dependent on the size of the larvae and the distance the larvae were required to travel. Greater larval size and shorter distances gave a higher percentage of success.

During the study, larvae were observed to change fruit forms following the entry of rotting organisms or the exhaustion of food when feeding on small squares. These changes involved relatively short distances. Larvae which were shed in a fruit form or in the corolla of a flower, had greater distances to move. Final instars, placed on the ground a foot from the base of the plant, were able to return to the plant in less than 15 minutes. The return to the plant was not made by chance, as the larvae returned in an almost straight line and appeared to use vision as the guiding mechanism.

(ii) Larval Damage to Fruit Forms.

Larvae attacking squares enter the squares from any point. Larvae penetrating the petals often feed for a period on the stamens, stigma, and pollen,

Table 5.

Fruit Form Shedding by Cotton Plants.

	Time in Weeks from Infestation to Shedding	SSS		SS		S		MS		SB		YB		B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
	0.5	3	11.5												
	1.0	2	7.7			5	19.2	3	16.6	11	44.0				
Infested	2.0	3	11.5	6	22.2	6	23.0	4	22.2	1	4.0				
	2.5	9	34.5	9	11.1	5	19.2	5	27.7	3	12.0	8	33.3		
Fruits	3.0	5	19.2	10	37.0	10	38.4	1	5.5						
	3.5	2	7.7					3	16.6	1	4.0	2	8.4		
Falling	4.0	1	3.8												
	4.5									1	4.0				
	5.0									1	4.0				
Total Infested Fruit Falling.		25	96.0	25	92.5	26	100.0	16	88.6	18	72.0	10	41.7	0	0
Infested Fruit Falling.		1	3.8	2	7.7	0	0	2	11.1	7	28.0	14	58.2	22	100.0
Total Infested Fruit.		26		27		26		18		25		24		22	
Non Infested Fruit Falling		6	33.3	6	33.3	2	50.0	2	50.0	4	40.0	3	17.6		0
Non Infested Fruit not Falling.		12	66.6	12	66.6	2	50.0	2	50.0	6	60.0	14	82.4	9	100.0
Total Non Infested Fruit.		18		18		4		4		10		17		9	
Mean Time in Weeks for Fruit Fall of Infested Fruit.		2.3 ± 0.2		2.6 ± 0.1		2.3 ± 0.1		2.3 ± 0.2		1.9 ± 0.3		2.7 ± 0.1		No fall.	

SSS Squares 1/3" long.
SS " 1/3" - 2/3" long.
S " 2/3" - 1" long.
MS Mature squares 1" long - flowering.
SB Young boll not filling calyx.
YB Boll approximately 1" in diameter.
B Boll > 1" diameter.

before penetration of the ovary through its apex occurs. Larvae frequently do not penetrate the ovary quickly enough and are shed along with the corolla.

The larvae, having successfully penetrated the ovary, feed internally on the tissue, concentrating mainly on the embryonic seeds. In many cases, the larvae cause a physiological reaction similar to the plant's reaction to moisture stress, resulting in the shedding of damaged squares.

Table 5 summarises the effects of larval feeding on fruit fall. It will be seen that larval feeding contributed to the shedding of squares and the smaller bolls. The percentage shedding of damaged and undamaged fruit forms of various sizes is respectively:- squares less than 1/3 inch long - 96.0 and 33.3; squares 1/3 inch to 2/3 inch long - 92.5 and 33.3; squares 2/3 inch to 1 inch long - 100.0 and 50.0; squares 1 inch long until flowering - 88.6 and 50.0; small bolls (i.e. do not fill the calyx) - 72.0 and 40.0; young bolls about 1 inch in diameter - 41.7 and 17.6; bolls greater than 1 inch in diameter - no fall in either category.

Thus, most of the damaged squares are shed by the plant. Squares not seriously damaged were retained, although deformed bolls were produced. Although no measurements were made, observations

suggest this deforming reduces yields.

Fewer bolls than squares were shed. Boll shedding decreases with increasing boll size and ceases when bolls are greater than 1 inch in diameter. The mean period of time between infestation and shedding of squares varied from 2.3 to 2.6 weeks. The expected mean developmental period of larvae during February-March, when this study was carried out, was in the range 2.6 to 3.8 weeks. Many larvae would thus be shed with the squares. However, these larvae are predominantly mid and late instars and thus, the majority would regain the plant. Some larvae were observed to leave the squares before the latter were shed.

The mean period of time between infestation and shedding of bolls was in the range 1.9 to 2.7 weeks, and thus, with the larvae in the bolls, there exists a situation similar to that seen with larvae in the squares.

Larvae present in bolls either enter the bolls directly or are larvae which have been carried through from the square stage. Larvae penetrate the boll wall at the apex above the calyx, through the calyx, under the shelter of the calyx, and also through the bracts. The preferred food source in the bolls, as with squares, is the developing seed. However, quantities of lint forming tissues are

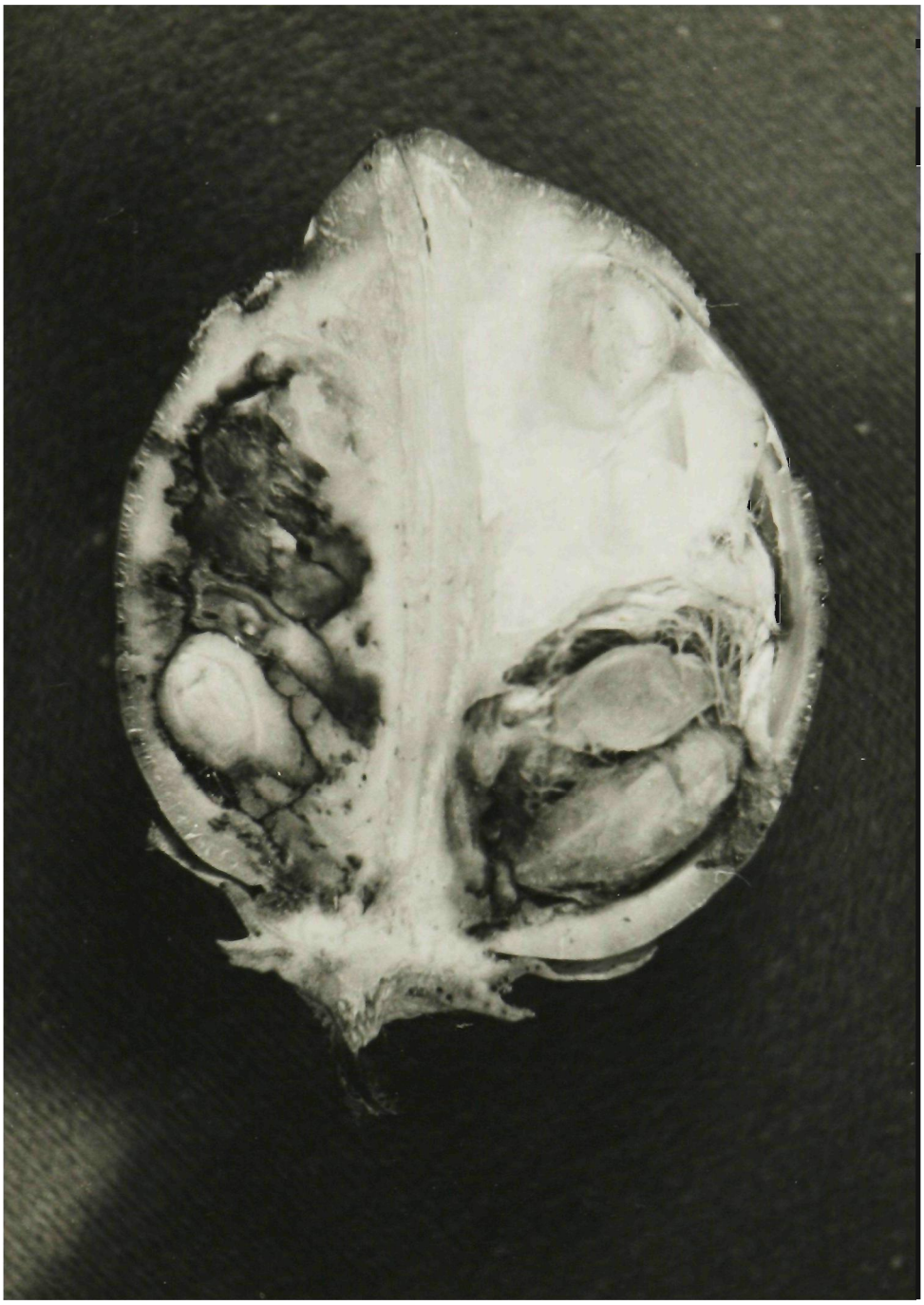


Plate 14. Showing extent of damage to bolls by boll rotting organism following larval damage.

also consumed.

The actual amount of tissue consumed by the larvae is small compared with the resultant economic loss incurred. The physical damage caused by the tunneling results either in the entry of boll rotting organisms or the distortion of the boll, so that it is unable to open fully at maturity. The larvae may damage only one or two locks of the cotton boll. The subsequent entry of fungi or bacteria into the damaged area can destroy the remaining tissues of the boll. Larval damage, causing the boll to become distorted, can prevent the natural opening of the boll to its fullest extent thus making a percentage of the undamaged lint unavailable to the mechanical harvester. Also, partial damage to a lock often results in the failure of the remaining lint to mature.

In summary, high percentages of damaged squares and of damaged young bolls are lost, while damaged fruit forms retained by the plants yield only up to 50 per cent. of their potential maximum yield.

(iii) Larval Damage to the Cotton Plant.

Larvae, as noted earlier, will feed on young plants before squaring commences, by tunnelling in the terminals. Entry occurs at either the apex or any point in the meristematic tissues but is commonly

Plate 15. Pupal case of E. huegeli.

associated with a leaf node. Larval development is usually completed in the terminal, although under adverse conditions, new feeding sites are sought.

Larval attack on cotton terminals varies in intensity from district to district. Terminal damage by E. huegeli is more significant in the Lockyer Valley than it is on the Darling Downs. No explanation can be offered for this discrepancy.

(e) Pupation.

Pupation occurs normally when the fifth instar is fully developed. However, under starvation conditions, the fifth instar larva can pupate before reaching its full size. The moth produced from a prematurely pupating larva is smaller than the moth of a fully grown larva.

Pupation on the Darling Downs and in the Lockyer Valley occurs mostly in the soil, with very few pupae being found on plants. The larvae choose sites such as in trash, under clods in the soil and in cracks in the ground, as pupation sites. In north Queensland, the majority of larvae pupate on the plant (personal communications, Elder 1965) and the same situation exists in central Queensland.

Larvae which pupated in cages or jars, chose sites where the surface was rougher or where two surfaces formed an angle. The main requirement

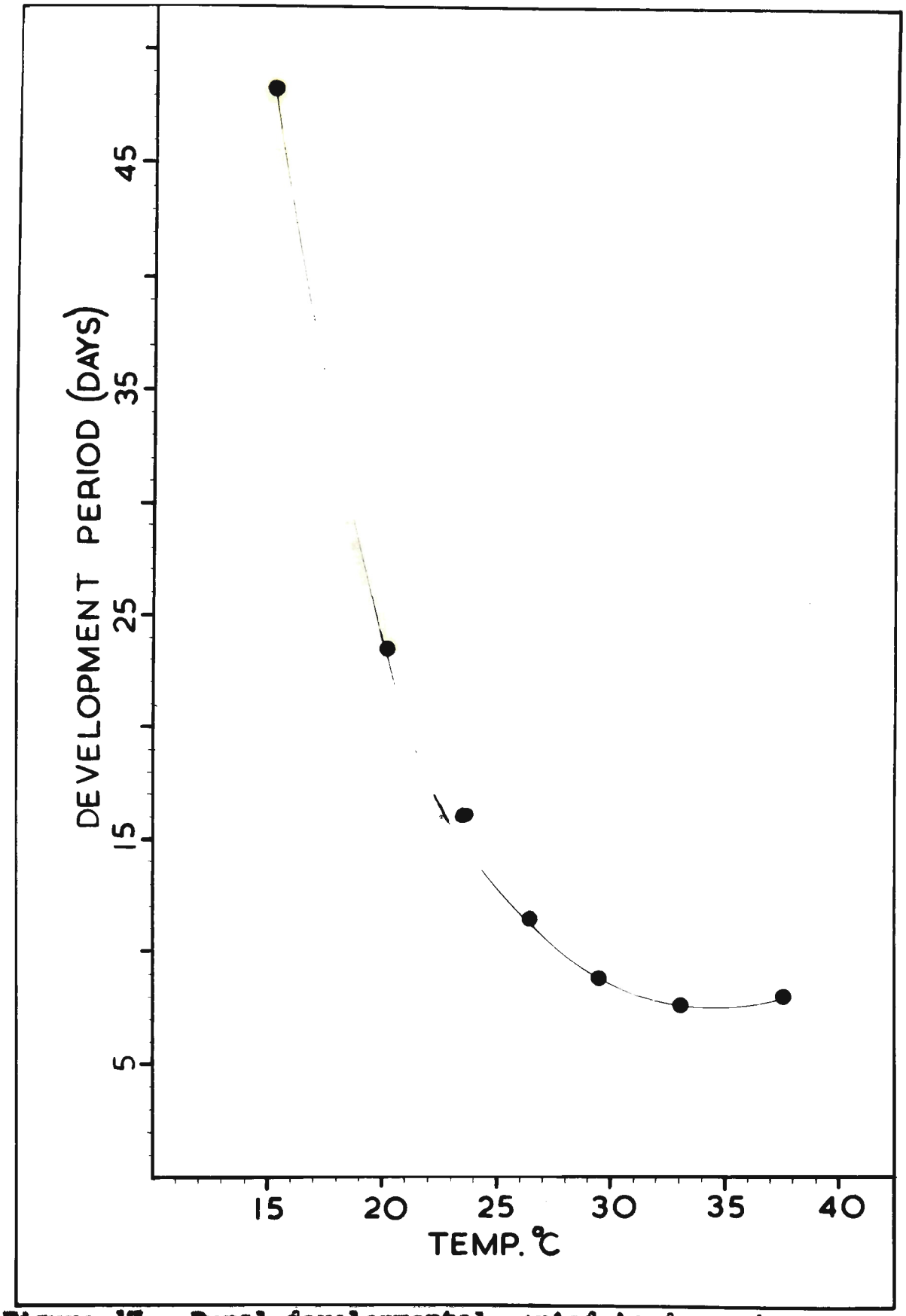


Figure 17.- Pupal developmental period in days at a range of controlled temperatures.

appeared to be sufficient traction to allow the construction of the pupal case. Fully grown larvae were observed searching the ground for a pupation site and rejecting a number of the sites examined, before a suitable site was selected.

After constructing the pupal case of a silk-like material, the larva contracts in length and ceases activity during this prepupal stage. If the pupal case is removed during the initial part of the prepupal stage, the larva will attempt to fabricate a new case.

C. The Pupa.

(a) Pupal Developmental Studies.

(i) Studies at Controlled Temperatures.

The developmental periods of pupae held at constant controlled temperatures in the incubator are shown in Figure 17.

The longest mean pupal stadium was recorded at 16.2°C. where an average of 48.3 days is required to complete development. No moths emerged from pupae held at 13.0, 8.7 and 5.0°C. and thus, it is likely that the minimum temperature for development lies in the range from 13.0 to 16.2°C.

The optimum temperature for development, as shown by the graph, lies in the range 33.0 to 35.0°C. At 37:5°C: the mean developmental period is 8.1 days, compared with 7.6 days at 33.0°C.

(ii) Studies at Laboratory Temperatures.

The results shown in Table 6 illustrate clearly the lengthening of the pupal stadia with the onset of winter. This progressive increase can be seen to apply to insects pupating during the periods shown in the table. The variation of mean length of the pupal stadia is from 10.6 days for insects pupating during the period February 4 - 14, to 73.3 days for those pupating during May 1 - 13. It will be noted that the mean maximum pupal period recorded is longer than that recorded under constant temperatures. The daily maximum and minimum temperatures in the laboratory during May, June and July were 18.6 to 10.3°C. respectively. From results obtained in the constant temperature experiment, development must have occurred either at an average temperature below 16.2°C. or in a stop-go fashion above and below the critical temperature for development, to produce a mean developmental period of 73.3 days.

Table 6.

Mean Pupal Period (days) of Insects Pupating at Different Times and the Mean Maximum and Minimum Laboratory Temperatures during the Interval February to August, 1963.

Time of Pupation	Mean Pupal Period of Insects Pupating at this Time (days)	No. of Pupae observed	Mean Temp during Interval (°C.)	
			Max.	Min.
Feb. 4 - 14	10.6 ± 0.3	21	24.8	22.8
Feb. 16 - 27	11.3 ± 0.2	37	25.0	22.9
March 1 - 17		0	24.7	22.6
March 18 - 30	15.6 ± 0.4	31	24.4	21.9
April 1 - 12	29.5 ± 6.5	8	23.5	19.3
April 14 - 29	48.4 ± 4.8	28	21.4	18.1
May 1 - 13	73.3 ± 3.4	17	19.5	15.1
May 15 - 31		0	19.5	14.6
June		0	18.1	11.8
July		0	18.5	10.3
August		0	19.5	13.6

D. The Moth.

(a) Moth Emergence from Pupae in the Soil.

The percentages of moths emerging from pupae placed in various positions in and on the soil are recorded in Table 7.

Table 7.

Percentage of Moths Emerging from Pupae Placed in and on the Soil.

Position	Percentage Emerging
Soil Surface	100
In Cracks	90
Under Crust	90
1" Depth	0
2" Depth	0

Following the shedding of the pupal skin, the moth breaks through the lightly sealed anterior end of the pupal case by expanding the body. The moth then works its way out using peristaltic movements and, to a limited extent, its legs. The moth can emerge successfully only if there is free space in front of the anterior end of the pupal case, as it does not have the ability to force its way up through the soil or past other solid structures. The results shown in Table 7 clearly illustrate this fact. Moths emerged from pupae placed on the soil surface, in cracks, and under the light soil crust, but in all these cases, there was free passage available. In contrast, no moths emerged to the surface from pupae buried at 1" and 2". Laboratory experiments where pupae were placed in a crumb structured soil which allowed limited free spaces,

showed that, while the moths emerged from buried pupae, they were unable to force an exit from the free space into which they initially emerged.

Observations of larvae in the field selecting their pupation site in soil cracks and under trash, showed that a criterion for selection was ready access to the surface.

(b) Moth Lengevity Studies.

Recorded in Table 8, is the length of life of moths held under starvation conditions, in single containers in the laboratory. Table 9 records the length of life and egg laying records of eight moths held in the laboratory, while Table 10 shows the length of life of male and female moths, one group of which was fed while the other was not fed.

Table 8.

Moth Longevity (in Days) under Starvation Conditions.

Length of Life (Days)	2	7	9	10	12	13	14	16	17	18	19	22	23	25
No. of Moths	1	1	1	4	5	1	3	3	2	3	1	1	1	1
Average Length of Life 14.2 days ± 0.9														

Table 9.

Longevity (Days) and Egg Laying Records of Moths.

Days After Emergence	3	4	5	6	7	8	9	10	11	Total Eggs Laid	Length of Life of Moth (Days)
	29	27	17	27	28	39	25	0	1	193	11
No. of	11	14	30	8						63	9
Eggs		16	26	18	15	1				76	9
Laid	19	20	24	21	4	6				94	10
on	2	5	21	18	8	9				63	9
Day	33	34	10	41	50					168	8
	37	59								96	5
	1	3	16	32	42					94	8
	132	178	144	165	147	55	25	0	1	MEAN 105.9 ±17.1	MEAN 8.6 ±0.6

Table 10.

Longevity (Days) of Male and Non-laying Female Moths under Feeding and Starvation Regimes.

	FED	STARVED
Male	38.1 ± 6.5	13.9 ± 2.0
Female	40.2 ± 4.4	14.1 ± 2.4

Results recorded in Table 10 show the length of life of unfed and unmated male and female moths to be 13.9 and 14.1 days respectively. The observations recorded in Table 8 for unsexed moths

held singly under starvation conditions show a mean length of adult life of 14.2 days. Unmated moths which were fed sugar and water solutions survived for longer periods - an average of 40.2 days in the case of females and 38.1 days in the case of males.

Field observations have shown that moths feed on nectar and other floral secretions and also gather water from drops of dew on the plants. The laboratory experiments, summarised above, show the benefits that moths gain in terms of increased length of life from feeding on a sugar and water solution. Moths held in containers congregate around the feeding tube and feed readily.

Studies with laying moths which were fed (Table 9), have shown that the mean length of life of these moths is 8.6 days with a range of 5 to 11 days. The mean egg production was 105.9 eggs with a range of 63 eggs to 193 eggs. Egg laying commenced on the third day after emergence and continued for up to a further 8 days. There was no constant pattern in the number of eggs laid per day.

(c) Observations on Moth Behaviour.

(i) General Observations.

E. Huegeli moths are sluggish during the day and are found resting on the terminals and top growth of the plant. When disturbed, the moths fly with an irregular darting flight pattern and tend to remain

about one or two feet above the plants; if flying above bare ground, the same behaviour can be observed. A moth which has been disturbed several times becomes much more sensitive to approaches.

Special conditions seem to be required for mating, as no success could be obtained in mating moths held in small containers such as bottles and small cages in the laboratory, or in cages 3 feet by 3 feet by 2 feet in the field. Cages were provisioned with sugar and water solutions and flowering cotton plants, but these appeared to have no influence on the small percentage of moths which were mated.

(ii) Oviposition Times.

The number of eggs removed and the time of removal are recorded in Table 11.

Table 11.

Number of Eggs Laid During Various Periods of the Day.

Period	No. of Eggs
11 p.m. - 5 a.m.	165
5 a.m. -11 a.m.	0
11 a.m. - 5 p.m.	15
5 p.m. -11 p.m.	1276

Results in Table 11 show clearly that the moth is nocturnal in its laying habits, the majority of the eggs being laid during the period 5 p.m. to

11 p.m. The behaviour of the moths in the field confirms these observations.

(iii) Oviposition Sites.

The location of one hundred and ninety-four eggs laid by laboratory bred and mated moths on caged cotton plants, was observed in order to investigate whether oviposition site preferences existed with E. huegeli.

Eggs were found on all parts of the plant with the exception of the lower main stem; however, the distribution was clearly governed by the length and density of plant hairs. For oviposition, the moths chose areas of long hairs in preference to areas of short hairs, and preferred areas of dense hairs, but a high density of hairs appeared to compensate for the shortness of hairs. Although no eggs were found on sites without plant hairs, they were laid on most of the parts of the plant which had hairs. When young growth was present, most of the eggs were located there, with the young leaves and fruit forms attracting equal attention. Here again the preference is governed by the nature of the plant hairs. Large bolls were not preferred by the ovipositing moths to mature foliage.

E. huegeli moths require stimulation from plant hairs to lay and the more satisfactory the

stimulation is, the more the site is preferred.

Observations in the laboratory show that moths will not lay on a smooth cloth surface, but will lay freely on muslin and other cloths which have protruding fibres.

E. Effects of Temperature on the Total Life History.

Studies carried out into the effects of a range of temperatures on the eggs, larvae and pupae, showed the sensitivity of the insect to these temperatures especially as expressed by the developmental period. The lengthening of the developmental period at and near the minimum temperature allowing development, is of great interest in the understanding of the insect's seasonal history, while the effects of temperatures in the range of the normal temperatures experienced in the field, provide a basis for the understanding of the length of generations throughout the season.

Table 12 gives the developmental periods of eggs, larvae and pupae at a range of constant controlled temperatures. The figures are taken directly from experimental results and, where these results are not available, the figures have been extracted from the graphs.

The shortest mean period recorded for the completion of the egg to egg cycle was 25.9 days at

36.0°C. Indications are that the developmental period may be slightly less, but no valid figure is available for the length of the larval period. The longest mean developmental period, egg to egg, which is fully documented, is 139.0 days at 16.2°C. However, results suggest that the true maximum period could be far greater than this. For example at 12.5°C. a larva survived for 82 days, before dying during the third instar. Also the longest mean pupal period recorded was 73.3 days for pupae held in the laboratory (Table 6). The range of mean maximum and minimum temperatures during this period was 18.6 and 10.3°C. respectively.

Table 12.

Developmental Period (Days) at Specified Temperatures.

Temp. °C.	Egg	Larva	Pupa	Moth	Total
37.5	2.6		8.1	Egg	
36.0	2.5	12.2	8.2	Laying	25.9
33.0	2.4	12.6	7.6	From	25.6
29.4	2.7	13.3	8.8	Third	27.8
26.3	3.9	15.2	11.4	Day	33.5
23.3	4.9	18.7	16.1	After	42.7
20.1	7.9	26.7	23.6	Moth	61.2
16.2	15.1	50.9	48.3	Emergence	139.0
15.5		53.3			

3. Alternative Hosts.

The following are the recordings of hosts other than cotton, made during the period, giving species, date of collection and locality.

Hibiscus trionum L.

Recordings were so frequent that distribution only will be given. E. huegeli larvae were found on this species from October until the first frost in the area. Distribution- Gatton Research Station, Forest Hill, Flagstone Creek, Toowoomba, Drayton, Ramsay, Nobby, Warwick, Hermitage Research Station via Warwick, Mt. Russell, Brookstead, Pittsworth, Oakey, Dalby, Kingaroy, Nanango, Wooroolin, Tingoora and Booie.

Abutilon tubulosum Hook.

Mt. Russell 15.V. 1963.

Abutilon oxycarpum f. acutatum F. v. M.

Mt. Russell 15.V. 1963.

Hibiscus heterophyllus Vent.

Wutul 3.111. 1963.

Marlborough July, 1964.

Pavonia hastata Cav.

Kingaroy 19.11.1964.

Toowoomba March, 1964.

April, 1964.

February, 1965.

March, 1965.

Plate 16. Hibiscus trionum L. showing details of a twig.

Malvastrum spicatum Gray.

Stoneleigh via Pittsworth 20.IV. 1964.

Biloela 6.VII. 1965.

Bowenville 31.V. 1966.

Sida sp.

Barkly Tableland 25.IV. 1965.

Sida cordifolia L.

Millaroo Research Station 11.VI. 1965.

Hibiscus rosasinesis L.

Brisbane, June 1968.

The survey for alternative hosts was confined to the family Malvaceae and yielded ten hosts of the pest. As E. huegeli is a native insect, it was thought desirable to investigate the relative importance of these known hosts as breeding sites throughout the year. Table 13 summarises the results of observation made during 1964-65 on the growth and fruiting habits of four of the host species.

Alternative hosts of E. huegeli on the Darling Downs can be divided into two broad groupings on the basis of preferred growing sites. The first group consists of those plants which are found growing on disturbed ground and on the flat areas of the region. Hibiscus trionum L. is the most commonly occurring species in this category and plays a major role during summer as a host of the

pest. H. trionum, a summer growing annual, whose main requirement for successful growth is a low level of competition from other plants, occurs either in areas of poor pasture or on disturbed areas of ground such as ploughed fields and roadsides. The fruiting period of H. trionum is from October until the first frost in April or May and, for the whole of this period, larvae may be found on the plants. The population of larvae carried by the plant is often very high and H. trionum appears to be a favoured site for build-up of E. huegeli population, before the cotton plants commence fruiting, as well as a breeding site for moths reinfesting the cotton fields during the fruiting season.

Malvastrum spicatum is also found on the flat, open Downs areas but does not appear to be as important a host during summer as H. trionum but, owing to its fruiting habits, does supply a possible source of food during autumn and winter.

The second group of hosts in the Darling Downs area are the Malvaceous weeds found in the wooded residual hills of the Eastern Downs. These areas are frost free except under extreme conditions. This means that even frost susceptible Malvaceae may survive as perennials and therefore could provide food for E. huegeli throughout the winter period, as well as a part of the summer period. Abutilon

Table 13.

Growth and Fruiting Habits of Some of the Alternate Hosts of E. huegeli in the years 1964-65 as observed in Southern Queensland.

Month	Plant			
	Hibiscus trionum L.	Pavonia hastata Cav.	Malvastrum spicatum Gray.	Abutilon oxycarpum F. v. M.
January	Fruiting	Fruiting	Fruiting	Fruiting
February	"	"	"	"
March	"	"	"	"
April	" End of fruiting during April or	" End of growth	"	"
May	" May at first frost	" at first frost	"	"
June	No fruit or live plants	No fruiting or growth	"	"
July	" " " " "	" " " "	"	"
August	" " " " "	" " " "	Plants eaten by cattle	No leaves or fruit
September	1st plants late September if weather warm	" " " "	Plants eaten by cattle	" " " "
October	Fruiting	Growth and fruiting	Plants eaten by cattle	Fruiting
November	"	" " "	Fruiting	"
December	"	" " "	"	"
Classification	ANNUAL	PERENNIAL	PERENNIAL	PERENNIAL

oxycarpum f. acutatum and Malvastrum spicatum are two species which are common in this type of country and which will produce flowers and fruit during the autumn-winter period.

There is not a complete separation of species into plants occupying one or the other of these two areas and overlap of species such as Malvastrum spicatum frequently occurs.

The role of the alternative hosts in the seasonal history of E. huegeli will be discussed in more detail in the appropriate section.

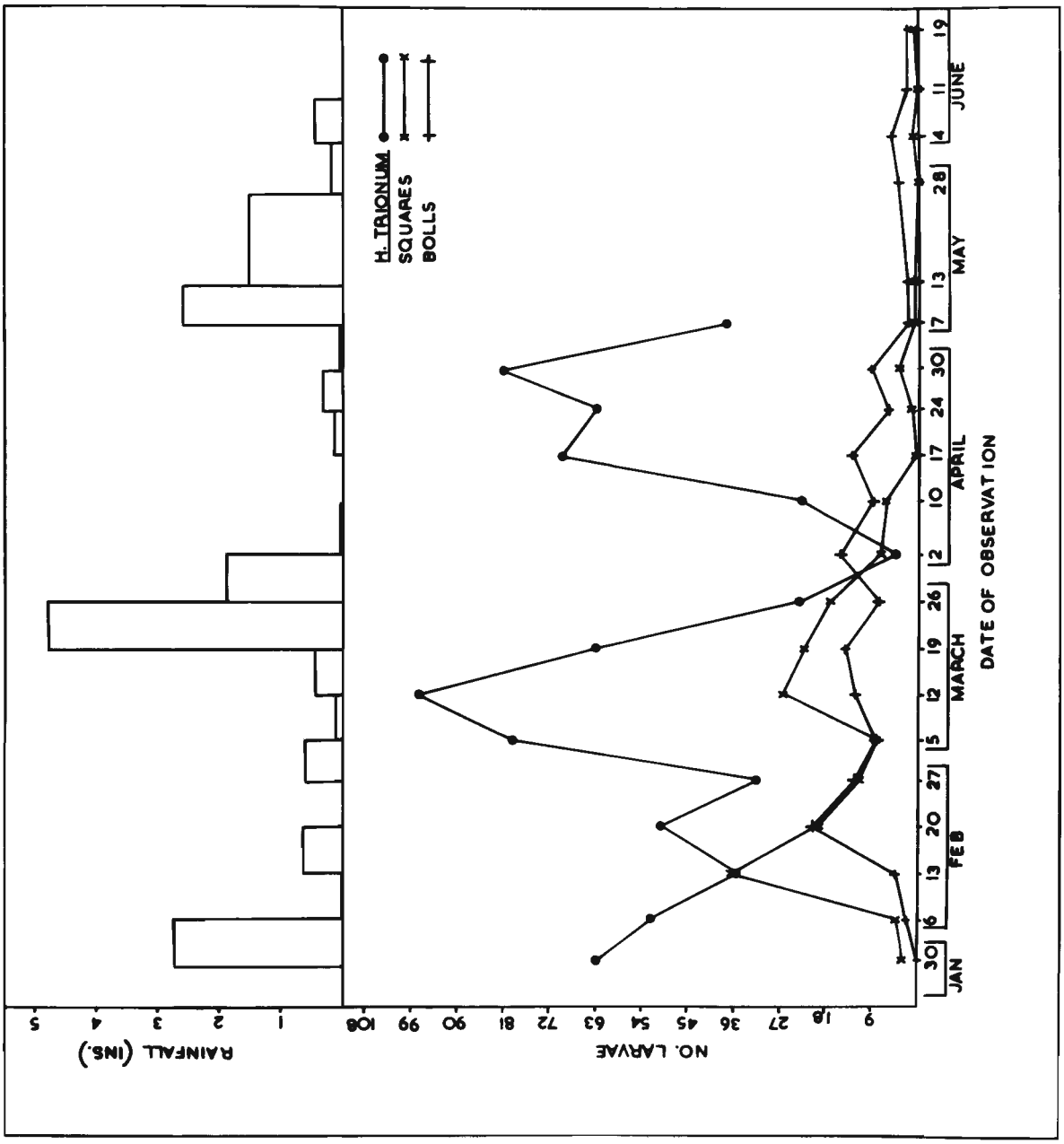


Figure 18 - Larval Numbers in 200 Cotton Squares and Dolle and 100 Hibisous trionun Fruits at weekly Intervals during the 1962-63 Cotton season along with the Rainfall Recorded during this period

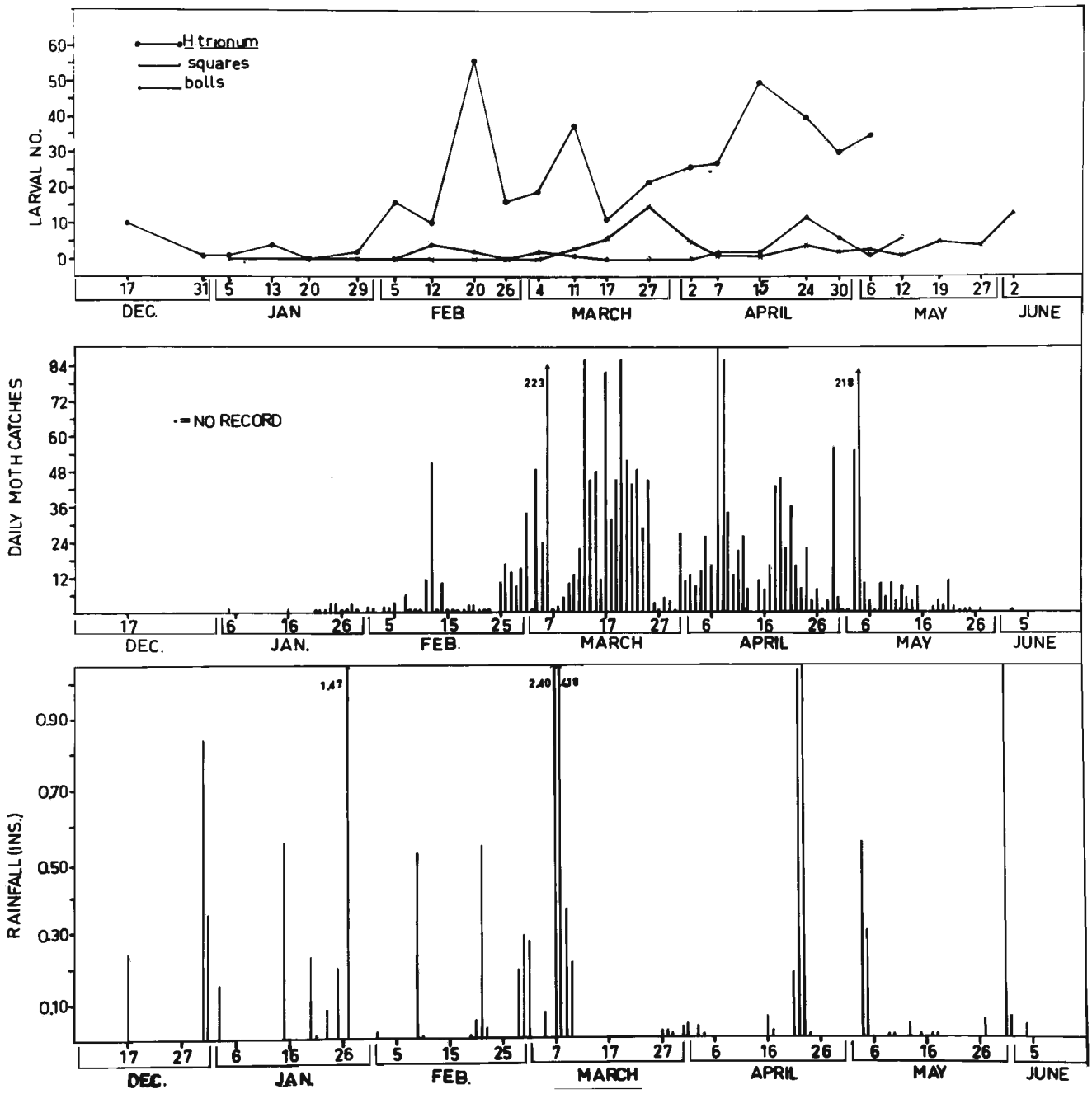


Figure 19. Number of larvae in 200 cotton squares, cotton bolls and 200 H. trionum fruit forms at weekly intervals along with daily light trap moth takes and daily rainfall during the 1963-64 cotton season at Hermitage Research Station.

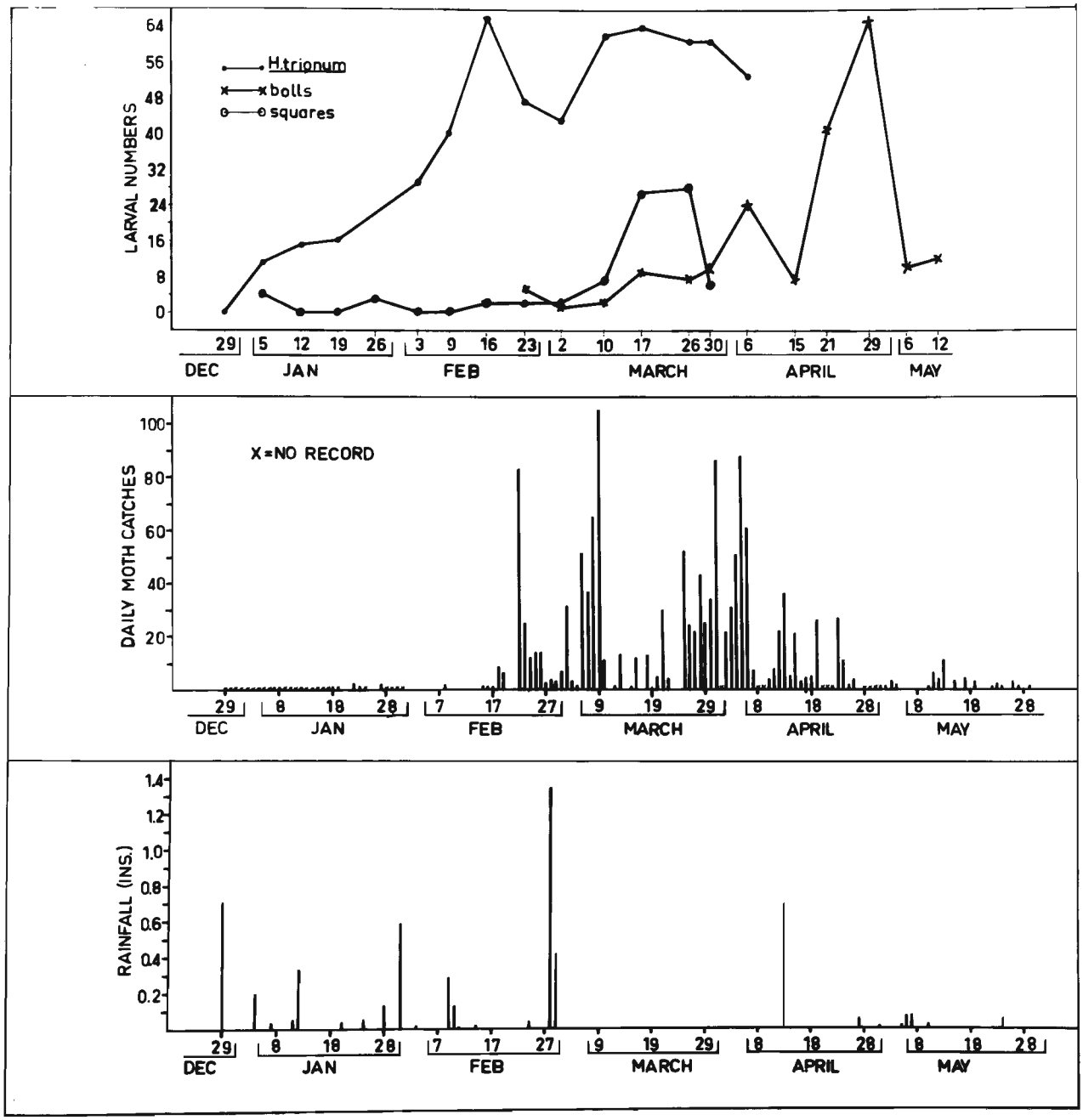


Figure 20. Number of larvae in 200 cotton squares, 200 cotton bolls and 200 H. trionum fruit forms at weekly intervals along with daily light trap moth takes and daily rainfall during the 1964-65 cotton season at Hermitage Research Station.

4. Seasonal History.

A. Field Population Studies.

Population data gathered during the studies are shown in Figures 18, 19 and 20, along with the rainfalls during these periods. The graphs illustrate the fluctuations in populations which occur in the field during the cotton season. Larvae were present on Hibiscus trionum before cotton squares became available in both the 1963-64 and 1964-65 cotton seasons, while no figures are available for the period before January 30, 1963 - the starting date of the experiment. The first sampling was not made from H. trionum until the fruits were freely available from plants in the field and as the establishment of this species was delayed by post planting cultivations, E. huegeli is potentially able to breed on H. trionum from a much earlier date than that shown. The earliest recording of E. huegeli larvae is October 23 at Forest Hill, on H. trionum during 1963. Here, larvae were infesting approximately 25 per cent of the fruit on plants about 1 foot high and carrying a substantial crop of fruit. The size range of larvae was from the second to the fourth instar. The earliest recording of E. huegeli on H. trionum from the Darling Downs was November 5, 1964 at Brookstead. H. trionum fruits from late-September in the Lockyer Valley and from mid-October on the Darling Downs, the

growth in both districts being dependent on temperature. E. huegeli may infest this host from the time when the first fruit forms are available.

Hibiscus trionum thus plays an important role in the establishment of rough bollworm in cotton fields where the weed is present. The initial build-up of population in H. trionum is followed by a later infestation of the cotton fruit forms. H. trionum, however, continues to carry a higher percentage of rough bollworms throughout most of its fruiting period than does cotton. The percentage infestation present in cotton exceeded that present in H. trionum on only one occasion during the three seasons of sampling.

The percentage of cotton fruit forms infested remained low throughout most of the period recorded. The maximum infestations in cotton during the 1962-63, 1963-64 and 1964-65 seasons were 18.0 7.5 and 33.0 per cent. respectively while the mean weekly infestations were:- Squares 3.8, 1.4 and 3.1 per cent.; bolls 4.1, 1.7 and 8.2 per cent. respectively. H. trionum, however, carried during the 1962-63, 1963-64 and 1964-65 seasons maximum populations of 48.5, 27.5 and 33.5 per cent. respectively, and mean populations of 21.0, 11.5 and 20.1 per cent. respectively.

Thus, a clear preference exists on the part

of the insects for H. trionum and this plant, when available, is selected as an oviposition site.

Population levels, as illustrated in the graphs, are subject to some controlling factors. The results gathered do not show any apparent relationship to weather factors such as temperature, humidity and hours of sunlight. However, there appears to be some relationship to rainfall. As a general rule, rain reduces populations of larvae while dry weather favours a steady high population. The graphs show instances of large falls in larval numbers during weeks when heavy rain fell but falls of seven inches during the period March 7 - 10, 1964, were accompanied by a rise in population from 28.5 to 39.5 per cent. of H. trionum fruit forms infested. Such inconsistencies suggested that some other factor such as disease dispersed by rain may operate in conjunction with rain, and that the presence or absence of this second factor decides the population's fate. Periods of dry weather during 1965 coincided with a more stable population level than was experienced in the two previous seasons.

Another factor which appears to contribute to the control of the populations present on H. trionum is competition for food. It will be seen from the graphs that sharp depressions in populations occurred after the following samplings:- March 12,

1963; April 30, 1963; March 11, 1964 and April 15, 1964 and the samples at these dates had 80.5, 69.5, 79.0 and 96.0 per cent. respectively of the fruit forms damaged. Further sharp drops occurred after the following samplings:- January 30, 1963, February 20, 1963, February 20, 1964 and February 16, 1965 when the samples had 31.5, 38.0 and 42.0 per cent. respectively of fruit forms damaged.

The high percentage of damaged bolls, present in the first group of samplings listed, would reduce the chances of young larvae finding an unoccupied or undamaged boll to serve as a feeding site. The general conditions of the H. trionum plants at these periods of high population and damage were such that it appears unlikely that they would become less attractive to ovipositing moths, thus causing a shift in populations from H. trionum to cotton. No large shifts of population accompanied the over population of the H. trionum. On each of the occasions where a sharp fall in population followed high larval numbers, and a consequent high percentage damage to H. trionum, population levels did not rise until the shedding of mature and damaged fruit and the production of new fruit brought about a lowering in the percentage of damaged fruit.

Some further factor appears to operate in population control, as the high moth takes in the

light trap did not produce correspondingly high larval numbers infesting the plants. The factor or factors would thus appear to operate against eggs or early instar larvae.

Population levels present in cotton remain low throughout most seasons and so do not illustrate as clearly the fluctuations evident with H. trionum. The percentage damage to cotton squares rarely exceeded 20.0 per cent. owing to the shedding of seriously damaged squares by the cotton plant. Boll damage, on the other hand, is cumulative, and during the seasons, was frequently greater than 50.0 per cent. and on occasions exceeded 90.0 per cent. The percentage boll damage recorded, is lower on many occasions than the actual boll damage in the field, as sampling was aimed at a measurement of the population of larvae and thus in sampling, mature bolls and bolls damaged by rots were avoided. The damage to cotton fruit was caused by both Heliothis spp. and rough bollworm.

The highest population recorded on cotton during the three seasons was during April, 1965, when 33.0 per cent. of the bolls sampled were infested. This higher than average population in cotton, was during a period of dry weather when no alternative food source was available, the cotton having ceased to produce squares and the Hibiscus trionum having died, two consequences of the dry weather.

The following moths were recorded in the light trap at Hermitage Research Station but are not shown in the graphs.

1964	July 3	1	1965	June 17	2
	July 15	1		June 18	1
	October 3	1		June 19	3
	October 8	3			
	October 13	3			

Table 14.

Mean Hourly Screen Temperatures (°C.) at Hermitage Research Station (Via Warwick) during 1963 and 1964.

	1963	1964
January	21.8	23.1
February	22.9	21.3
March	20.6	19.7
April	16.6	16.1
May	13.6	12.3
June	9.3	8.5
July	6.9	7.8
August	10.1	8.1
September	12.2	13.5
October	15.6	14.5
November	18.0	18.8
December	20.1	19.7

An E. huegeli moth was collected at a light in Toowoomba on August 10, 1967.

Hibiscus trionum L. commences fruiting in warmer areas in southern Queensland during late September and may be immediately attacked by rough bollworm. From this time onwards, H. trionum remains the major summer host of E. huegeli until the plants are killed by the first frosts. Rough bollworms may survive during the summer period on this host alone in the absence of cotton and other host weeds. Hosts of E. huegeli which fruit during the summer are Pavonia hastata Cav., Malvastrum spicatum Gray, Hibiscus heterophyllus Vent., Abutilon oxycarpum f. acutatum F. v M. and Abutilon tubulosum Hook. Rough bollworm breeds through summer on the above listed range of hosts and during autumn with the first frosts, only on plants which are located in sheltered areas and so survive. H. trionum is not a winter growing species.

Table 13 gives the growth habits of M. spicatum and A. oxycarpum. These two species provide a potential source of food during the winter for E. huegeli larvae, which have been found on the former in April, May and August while the latter was recorded as infested during May. The mean hourly screen temperatures recorded at Hermitage Research Station are shown in Table 14 and a comparison of these temperatures with the larval developmental periods shown in Table 12, indicates the slow development of

larvae which would take place during the winter.

To illustrate the nature of the development, consider a larva developing from an egg laid in mid-May, on an available host, under conditions similar to those recorded at Hermitage Research Station. The mean hourly screen temperatures during May to September, 1964, were lower than the temperatures allowing development of eggs, larvae or pupae in the incubator. However, these field temperatures did allow development as is witnessed by the recording of a rough bollworm moth in the light trap in July, 1964. The longest mean developmental period from egg to moth, under laboratory conditions, is 139 days and evidence suggests the period could be even longer (Table 12). This would allow a single generation to span the winter with moths emerging in spring, as weather conditions became warmer and the rate of development increased.

The maximum pupal developmental period recorded in the laboratory from insects pupating during May, was 73.3 days, the mean maximum and minimum temperatures recorded during this period being 18.7 and 12.6°C. respectively. These temperatures are higher than the prevailing field temperatures during winter at Hermitage, and, as pupal development has been shown to occur at these field temperatures (as shown by the moth recordings

during June, July and August), the developmental period of rough bollworms pupating in May can be expected to be greater. The lengthening of the pupal period during autumn and winter under similar conditions, should be such that pupae from larvae completing development in May, will not emerge until the following spring. Thus, two alternatives exist for the overwintering of rough bollworm in southern Queensland, firstly through larval development through the early part of the winter followed by pupation, or through a lengthening of the pupal period to span the whole winter.

Winter temperatures are higher in central Queensland and observations in the Callide Valley during August, 1965, showed larvae feeding on Malvastrum spicatum Gray, and on standover cotton.

Thus, it would appear that the insect breeds during the winter in this area, but the length of the life cycle could be expected to be less than that in southern Queensland.

5. Parasites.

The following is a record of all parasites collected. The identifications were carried out by the Commonwealth Institute of Entomology. The following comment was attached to the identification of Diplazon laetatorius F. by the C.I.E., "Parasite of an aphidivorous Syrphid" and thus may be a false record.

Pupal Parasites.

Warwick	13/3/63	Turner	Brachymeria hyalarctae Cam. Chalcidae
Warwick	March, 65	"	"
Warwick	"	"	Genus and Species indeterminable by C.I.E. Ichneumonidae.
Warwick	17/5/63	"	Irabatha sp. Ichneumonidae

Larval Parasites.

Warwick	17/5/63	"	Diplazon laetatorius F. Ichneumonidae
Warwick	20/5/63	"	Apantales sp. (Ater group) Braconidae
Warwick	1/5/63	"	Strobliomyia plebia Mall. Tachinidae
Warwick	10/4/63	"	"
Warwick	1/5/64	"	"

A total of less than twenty parasites belonging to four species was collected, having emerged from larvae in the Toowoomba laboratory. During the period of collection, over ten thousand

larvae were raised to adults in the laboratory. This extremely low rate of larval parasitism would not constitute a significant factor in the dynamics of the insect. The percentage of the field collected pupae (approximately 10), held in the laboratory, which were parasitised, was much higher. Many of the pupal cases observed on the plants were damaged by what appeared to be parasite emergence holes. The percentage of E. huegeli pupating on the plants in southern Queensland is low and pupation in the soil and in trash may offer greater protection against parasitism.

Table 15.

The LD_{50} of a Range of Insecticides Expressed as Microgrammes Per Moth

Chemical	LD_{50}			
	Dead		Dead + Moribund	
	Estimate	Fiducial Limits (95%)	Estimate	Fiducial Limits (95%)
Bidrin	0.006		0.004	
parathion	0.011	0.005- 0.016	0.009	0.004- 0.013
methidathion	0.017		0.018	
fenitrothion	0.017		0.018	
azinphos-ethyl	0.076	0.032- 0.135	0.063	0.006-.0.123
endrin	0.102	0.077- 0.415	0.105	0.067- 0.417
promecarb	0.137		0.137	
chlorfenvinphos	0.137		0.178	
dieldrin	0.155		0.125	
carbaryl	0.194		0.130	
dimethoate	0.338		0.335	
trichlorphon	0.856		-	
maldison	0.866		0.834	
DDD	1.642		1.944	
DDT	2.396	0.885- 4.835	2.307	1.728- 2.960
aldrin	2.439		0.664	
DDT + toxaphene (1 + 1)	3.674	1.141-11.833	3.365	
toxaphene			3.840	2.803-12.73
heptachlor	5.321		5.321	
Strobane	12.157	5.543-37.086	5.013	3.057-11.31

6. Control.

A. Laboratory Topical Testing.

This section of the work suffered, owing to a high mortality in the control populations, the cause of which could not be detected. The mortalities in the controls at 24 hours post treatment were frequently in the range of 20 to 30 per cent. During the log probit analysis of the figures, the computer often did not give limits, owing to the nature of the programming. These results, however, do give a measure of the efficacy of a range of chemicals against E. huegeli.

The LD_{50} values of the chemicals tested are given in Table 15 along with limits where these are available. A wide variation in the levels of LD_{50} was shown, ranging from 0.006 microgrammes per moth for Bidrin (Dimethyl phosphate of 3-hydroxy-N, N-dimethyl-cis-crotonamide) to 12.157 for Strobane ($C_{10}H_{11}Cl_7$). Mevinphos appears to have an LD_{50} lower than that shown for Bidrin, however, the testing was halted before this level was determined.

B. Cotton Schedule Spraying Trial, 1965/66.

Each plot in the trial was sampled on two occasions (January 4-5 and February 1) and all the bolls and squares on each of 10 and 15 plants respectively were examined. The number of sound and of damaged bolls and squares on each was recorded,

along with the numbers of Heliothis spp. larvae and E. huegeli larvae.

The percentages of damaged fruit forms at the first and second samplings are recorded in Table 16 and 17 respectively, while the total fruit production is recorded in Table 19.

At the first sampling there were no differences in damage to the total fruit (bolls and squares) in treated plots at the 1 per cent. significance level. However, at the 5 per cent. level both weekly applications gave equivalent protection while DDT-endrin (weekly) was significantly better than both of the fortnightly applications (Table 16).

The second sampling (Table 17) showed DDT-endrin (weekly) to be equal to DDT-parathion (weekly) at the 5 per cent. significance level. DDT-endrin (weekly), however, is significantly more efficacious than both of the fortnightly treatments.

It will be noted in Table 19, that the average number of bolls per plant was greater in the treated plots throughout the trial and that, while the average numbers of squares per plot were equal at the first sampling in both treated and check plots, the number of squares in the check plot greatly exceeded the numbers in the treated plots, at the second sampling.

Insect numbers as shown in Table 20 were low throughout the trial but, at both samplings, the number of Heliothis spp. were greater than the numbers of E. huegeli present. Observations, however, show that the numbers of E. huegeli rose during the latter part of February before spraying ceased. It is not possible to proportion blame for the damage, but the populations of both Heliothis spp. and rough bollworm were typical of those encountered in the Lockyer Valley, both in size and time of occurrence.

In Table 18, the yields, given as pounds of seed cotton per acre, are shown. The treated plots all gave a significantly greater yield at the first pick than the non-treated plots. It is interesting to note that the non-treated plots gave the highest yield at second pick. The total yields obtained, showed that DDT-endrin applied weekly, was significantly more efficacious at the 5 per cent. level than all other treatments.

As both chemical mixtures will give a high level of control, it is relevant to consider the economics of their usage, as it should be the prime consideration in commercial control.

The total cost per acre of the insecticides used in the trial is as follows, the costs being calculated at the 1966/67 Queensland Cotton Marketing Board's contract price to growers:-

DDT-endrin weekly, $21.29; DDT-endrin fortnightly, $12.16; DDT-parathion weekly, $14.05; DDT-parathion fortnightly, $8.02.

Although the DDT-endrin sprays were slightly more expensive, the increased yields as shown in Table 18 compensated for the extra expense.

The trial was carried out on arbitary spraying schedules with differences only between December 10 and February 16. Such rigid schedules cannot be recommended, and in the normal farm situation, where observations at more regular intervals than weekly are practicable, a schedule based on a combination of "weekly" and "fortnightly" applications must obviously give maximum return for the minimum cost.

Table 16.

Percentage of Damaged Fruit Forms at First Sampling January 4 - 5

Treatment	Squares		Bolls		Total	
	Trans. Means.	Equiv. Means.	Trans. Means.	Equiv. Means.	Trans. Means.	Equiv. Means.
DDT-endrin (weekly)	0.253	6.3	0.188	3.5	0.239	5.6
DDT-endrin (fortnightly)	0.361	9.7	0.314	9.5	0.315	9.6
DDT-parathion (weekly)	0.291	8.2	0.181	3.2	0.273	7.3
DDT-parathion (fortnightly)	0.337	10.9	0.213	4.5	0.313	9.5
Check	0.587	30.7	0.790	50.5	0.613	33.1
Necess. 5%	0.068		0.095		0.054	
Diff. for Signif. 1%	0.094		0.131		0.074	

Table 17.

Percentage of Damaged Fruit Forms at Second Sampling February 1.

Treatment	Squares		Bolls		Total	
	Trans. Means.	Equiv. Means.	Trans. Means.	Equiv. Means.	Trans. Means.	Equiv. Means.
DDT-endrin (weekly)	0.163	2.6	0.227	5.1	0.216	4.6
DDT-endrin (fortnightly)	0.204	4.1	0.363	12.6	0.339	11.1
DDT-parathion (weekly)	0.146	2.1	0.308	9.2	0.289	8.1
DDT-parathion (fortnightly)	0.146	2.1	0.418	16.5	0.400	15.2
Check	0.597	31.6	0.656	37.2	0.616	33.4
Necess. 5%	0.245		0.073		0.103	
Diff. for Signif. 1%	0.337		0.100		0.141	

Table 18.

Yield (Pounds/acre) of Seed Cotton.

Treatment	First Pick	Second Pick	Total Yield
DDT-endrin (weekly)	2997.6	365.0	3362.6
DDT-endrin (fortnightly)	2725.0	371.1	3069.3
DDT-parathion (weekly)	2855.8	310.6	3166.3
DDT-parathion (fortnightly)	2656.6	336.0	2992.6
Check	925.6	637.3	1562.9
Necess. 5%	168.8	88.6	154.3
Diff. for Signif. 1%	232.6	122.1	212.7

Table 19.

Fruit Form Production of Cotton Plants. Average No. of Fruit Forms/plant.

Treatment	Sample I Jan. 4-5			Sample II Feb. 1		
	Av. No. Squares/ plant	Av. No. Bolls/ plant	Av.Total Fruit/ plant	Av. No. Squares/ plant	Av. No. Bolls/ plant	Av.Total Fruit/ plant
DDT-endrin (weekly)	16.26	5.10	21.36	2.13	9.58	11.71
DDT-endrin (fortnightly)	15.66	5.00	20.66	2.00	10.00	12.00
DDT-parathion (weekly)	17.64	5.26	22.90	2.33	10.00	12.33
DDT-parathion (fortnightly)	18.16	5.20	23.36	1.33	10.61	11.94
Check	17.38	2.40	19.78	11.6	4.80	16.46

Table 20.

Numbers of Insect Larvae Found per Treatment (From 30 Plants at First Sampling and 45 Plants at Second Sampling.

	Treatment				
	DDT-endrin (weekly)	DDT-endrin (fortnightly)	DDT-para-thion (weekly)	DDT-para-thion (fortnightly)	Check
First Sample Jan. 4-5					
Heliothis spp.	7	10	4	16	27
E. huegeli	1	1	0	2	2
Second Sample Feb. 1					
Heliothis spp.	0	0	0	0	15
E. huegeli	1	2	0	1	4

C. Cotton Schedule Spraying Trial, 1966/67.

A trial was laid out during 1966/67 to study the efficacy, in the field, of insecticides shown in the laboratory to give control of E. huegeli. Because of high populations of Heliothis spp. and very low populations of E. huegeli the results obtained gave no information as to the control of the rough bollworm. The design of the trial was a 13 x 3 randomised block and the procedures were as for the 1965/66 trial.

D I S C U S S I O N

1. The Insect.

A. Description.

No further comment need be made at this stage, as it was necessary to expand the descriptions of the moth from literature in the results section, and no detailed descriptions of any of the other stages of the insect were found in literature.

B. Distribution.

The results of this work have augmented the knowledge of the distribution of this species, and the recognition of the presence of the northern rough bollworm E. vitella casts some doubt on some of the past records of occurrence of E. huegeli in northern Queensland.

2. Life History and Habits.

A. The Egg.

Under controlled temperature conditions, the mean egg hatching time varied from 2.4 to 15.1 days. Periods recorded previously by Froggatt (1924), of 6 to 7 days, Richards (1964), of 3 to 5 days and Wright (1964), of 3 days, all fall within the range recorded during the present studies. As the length of the egg developmental period is dependent on temperature, the variations in the above three records reviewed probably result from variations in the ambient temperature.

B. The Larva.

No reference to the number of larval instars was found in literature, except for Richards (1964), who stated that the larvae pass through a number of instars.

Froggatt (1942) recorded the larval period as being 25 to 27 days, Wright (1965) stated about two weeks, while Richards (1964), stated the period as being two to three weeks.

Under controlled temperature conditions, the larval developmental period varies from 12.2 days at 36.0°C to 53.3 days at 15.5°C. and, here again, the periods reviewed fall within these ranges, their length having depended on the ambient temperatures at which the larvae were held.

The nature of the physical damage recorded by Veitch (1938), Passlow (1963), Richards (1964), Wright (1964, 1965) agrees fully with the observations made during this study. It is important, however, to note that the relative importance of terminal feeding and boll feeding varies. Richards (1964) and Wright (1965) both stated that terminal feeding precedes boll attack. Observations made during the present study show that terminal feeding is much more widespread in the Lockyer Valley and is of greater importance than it is in the cotton growing areas on the Darling Downs. No explanation can be offered for this

apparent discrepancy in behaviour, which also occurs in the selection of pupation sites. As is recorded in the results section, larvae pupate either on the plants, in the trash or in the soil; however, few pupae are located on the plants in southern Queensland. This agrees with the observations of Wright (1965), but contrasts sharply with the observations of Richards (1964), Passlow (1963) and Veitch (1938). Thus the behaviour of the larvae varies from area to area.

C. The Pupa.

The pupal developmental periods, recorded from literature, fall within the range recorded in the laboratory under constant temperatures and the variations within the figures reviewed are to be expected owing to differences in the temperatures under which the pupae were held. Studies during this project confirm Froggatt's (1924) statement that an elongation of the pupal period occurs during the winter.

D. The Moth.

Wright (1965) stated that egg laying begins after a few days, whereas in the studies for this project, no eggs were laid until the third day after moth emergence. Observations made confirm those of Veitch (1938), Richards (1964), and Wright (1964) concerning the location of eggs, but it is

necessary to extend the listing of locations to include most parts of the plant, where the hair structure is suitable to provide the stimulus for oviposition. The majority of eggs are laid on the young parts of the plant, owing to the more favourable hair arrangements in these areas.

E. Total Length of Life Cycle.

Statements reviewed on the length of life cycle of E. huegeli are well within range as demonstrated in this project.

3. Alternative Hosts.

Statements of Wright (1965) show that Hibiscus trionum occupies a similar position as an alternative host, in the Namoi region of New South Wales, to that which it occupies in southern Queensland. Melhania abyssinica (order Sterculiaceae) Anon. (1934), is the only record of a host outside the order Malvaceae. Pearson (1958), however, listed species in the orders Bombaceae, Sterculiaceae and Tiliaceae as hosts of Earias sp. in Africa. As the host range of Earias huegeli is not limited to the order Malvaceae, species of the orders Bombaceae and Tiliaceae may also serve as hosts.

4. Seasonal History.

A. Field Population Studies.

Observations by Richards (1964) agree with the conclusion drawn from the field studies, that

dry weather favours the breeding of rough bollworm, while Gurney (1924) supports the observation of the variable populations found during the season.

B. Seasonal History.

Passlow (1963) stated that, in southern Queensland, rough bollworm attacks cotton during the period from January until the end of the season. This period, which represents the fruiting season of the cotton on the Darling Downs is correct for this area, however, in the Lockyer Valley fruiting commences during December and attack normally commences at this time but larvae frequently attack plants before squaring commences.

The contention, made in this paper, that ratoon cotton helps to carry over populations is supported by Froggatt (1924), who also stated that prolongation of the life cycle, especially in the pupal stage, by lower temperatures, helps survival of the pest. No indication is given by the author of the area in Queensland to which he is referring.

5. Parasites.

The parasites collected during this study had not previously been recorded from E. huegeli, and, with the exception of Atherton (1932), no mention is made in literature of parasites attacking E. huegeli in Australia. It is unusual for a native insect to have so apparently low a rate of parasitism.

6. Control.

A. Laboratory Topical Testing.

No previous data of this nature were found in literature, so no comparison can be made. One point, however, must be mentioned with reference to parathion which was shown by Davis et al. (1963) to be of little value in control of E. huegeli. In this experiment, parathion was shown to be highly efficacious and this is confirmed by the results of the field work recorded in the following section. Carbaryl has been recommended by Wright (1965). Azinphos-ethyl was recommended by Wright (1965) and shown to be efficacious by Davis et al. (1963). Both of these chemicals were shown to have low LD_{50} values of 0.194 and 0.076 microgrammes per moth, respectively.

B. Cotton Schedule Spray Trial, 1965-66.

The greater production of squares on plants in control plots where boll production was inhibited by insect damage, agrees with the findings of Passlow and Trudgian (1960) working in central Queensland. The length of the growing season in the Lockyer Valley during 1965-66 precluded the maturation of these late squares.

It is difficult to compare the results of this spraying trial with previous work, as populations of the pest complex and growing

conditions vary. The demonstration of the value of parathion in the control of E. huegeli contrasts with the findings of Davis et al. (1963). The use of a mixture of 0.5 pounds active ingredient DDT per acre and 0.25 pounds active ingredient of endrin per acre, based on the trials of Davis et al. (1963), has been the recommendation of the Queensland Department of Primary Industries, for the control of the Heliothis spp.-rough bollworm complex in cotton. The results of this trial confirm these recommendations.

AN APPROACH TO THE CONTROL OF E. HUEGELI ROG.

Cotton is attacked by a complex of pests and it is difficult, if not impossible, to consider the control of E. huegeli as a separate problem divorced from the control of this complex. Thus, an understanding of the pest complex, as well as of the agronomic factors concerned with the growing of cotton, is required as a precursor to consideration of control of E. huegeli.

Heliothis armigera (Hubn.) and Heliothis punctigera Wall. may attack cotton at all times during its growth. The seriousness of the damage of these pests was rated previously as equal to that caused by E. huegeli, but in the 1966/67 and 1967/68 seasons, Heliothis species have been more important than the rough bollworm. The Heliothis spp. larvae are larger and more freely ranging than those of the rough bollworm and cause more damage per individual. Owing to the extremely wide host range of Heliothis spp. cotton crops may, at times, be subject to very heavy invasions of moths, these being the adults of larvae which fed on summer crops such as maize.

Crocidosema plebiana Zell., the cotton tipworm, attacks the plants early in the season and most of the damage from this pest occurs before E. huegeli warrants control. Thus C. plebiana can seldom be considered as part of the complex associated

with the control of E. huegeli.

The cotton bugs occur in conjunction with E. huegeli in unsprayed fields but, while regular sprays for E. huegeli are being applied, bugs are a rarity in the cotton fields. The main species of bugs on cotton are:- the cotton stainer (Dysdercus sidae Montr.), the cotton harlequin bug (Tectocoris diophtalmus (Thunb.))and the cotton seed or coon bug (Oxycarenus arctatus (Walker) and O. luctuosus (Montr. and Sign.)).

The spider mites (Tetranychus ludeni Zacher and T. urticae (Koch)) are present during the season and, in nearly every season, warrant control. The mite problem is aggravated by the regular DDT-endrin sprays applied; however, T. urticae also occurs regularly in the Lockyer Valley on farms where regular DDT-parathion sprays are applied. This appears contrary to the statement by Brimblecombe (1953) that parathion will control tetranychid mites.

Cotton aphid (Apis gossypii Glov.) is a pest early in the cotton season and also later in the season when the problem is aggravated by the sprays applied for the control of other insects. Aphids, however, are seldom an economic problem in southern Queensland cotton.

Both thrips (Thrips tabaci Lind.) and cicadellids (mainly Austroasca terrareginae (Paoli))

are essentially pests of cotton during the early parts of the season. Passlow (personal communications 1968) has been unable to demonstrate any yield increase from control of T. tabaci Lind. during the seedling stage of the cotton plant, even when high populations of the pest were present on the plant. It is felt that, under southern Queensland conditions, cicadellids will be found to occupy a similar economic position.

Cutworms (Agrotis spp.), on occasions, appear as a pest during establishment, while the loopers (Anomis spp.) are present throughout the year, but the latter seldom are of economic importance as they are held in check by the spray schedule applied for the control of E. huegeli and Heliothis spp.

For discussion purposes, the pests of cotton may be conveniently divided into four groupings according to time during the season at which they occur and to the treatments required for their control.

The first grouping includes the pests which are important during the early part of the growing season, before the initiation of fruiting. These are the aphids, cicadellids, thrips, tipworm and cutworms. The Queensland Department of Primary Industries recommends BHC for the control of aphids, and DDT for cicadellids, thrips and cutworms. However, dieldrin has been shown to give a good control of

thrips (unpublished data, Queensland Department of Primary Industries). No recommendations are made for control of tipworm. Davis et al. (1963) showed none of these chemicals to be of use in the control of E. huegeli, and laboratory tests, recorded in this paper, confirm this. Thus, early season sprayings will have little or no effect on the populations of E. huegeli.

The second grouping is that of the pests which occur in the crop during the fruiting season, either despite the spray applications or owing to the favourable conditions created by the spraying, such as the elimination of the parasite predator complex. The most important pests in this group are the spider mites. Dicofol is the commonly used spray for mites but no information is available on the effects of this chemical on E. huegeli.

The third grouping is of the pests such as the cotton bugs and the loopers, which have the potential to attack cotton, but which are held in check by the routine spray applications for control of Heliothis spp. and rough bollworm.

The fourth grouping is that of the Heliothis spp. and rough bollworm which require controlling throughout the whole of the fruit producing season. DDT-endrin and DDT-parathion mixtures are used in commercial practice and give a satisfactory control

of the problem.

To sum up, routine sprays are applied for the control of E. huegeli and Heliothis species and these chemicals also give a control of cotton bugs and loopers while creating conditions favourable for outbreaks of spider mites. Sprays applied for the control of early season pests and mites appear to have little, if any, potential to affect populations of E. huegeli.

Cotton is a long season crop and, when grown on the Darling Downs, has to be produced under what is considered a near minimal season length. The warmer soil temperatures during spring in the Lockyer Valley allow faster growth during the seedling stage, than is possible with the lower soil temperatures on the Darling Downs. Comparisons of growth patterns in the Lockyer Valley and at Brookstead (Trudgian, personal communications 1968) have shown the period from planting to first squaring to be 49 days and 71 days respectively.

Table 21 shows some aspects of the fruit production pattern in the two areas (Trudgian, personal communications 1968).

Table 21.

Period in Days from Planting to Stages of Development of the Crop.

Stage of Crop	Days		
	Lockyer	Brookstead	Diff.
Commencement of Squaring	49	71	22
Peak Squaring	77	107	30
Commencement of Boll Opening	124	152	28
Bolls Fully Open	156	207	51

Table 22.

Dates of Average First Frost at Queensland Agricultural College (Lawes) and at Dalby, and Number of Frost Free Days.

Location	Light Frost (36°F)	Heavy Frost (32°F)	Frost Free Days
Queensland Agricultural College, Lawes.	May 29 to June 6	June 19 to July 23	306
Dalby	May 3 to June 2	June 6 to June 28	246

The earliest period, when soil temperatures are satisfactory for germination and growth on the Darling Downs, is at the beginning of October. This gives 216 to 246 days in which to produce a crop before it is frosted. At Brookstead, 81 days are

required from commencement of squaring to commencement of boll opening, so in an average season, any fruit forms which are lost later than about 30 days after the peak of squaring, will not be replaced by the plant. To obtain a high yield from the crop, the plants must be protected from the depredations of E. huegeli and Heliothis spp. from the commencement of squaring to some period after the commencement of boll opening - a period of 81 days or more. The cotton plant has been shown to be able to replace lost fruit forms by the continued production of squares (Passlow and Trudgian, 1960). Under Darling Downs conditions, this is precluded except in the first half of the cotton season. It is also important to note, that cotton produced from fruit initiated in the latter part of the season has a lower fibre strength, as measured on the micronaire scale. This adds importance to the protection of fruit initiated during the early part of the season.

Studies on the biology of E. huegeli recorded in this paper, have shown that the insect is exposed and can therefore be brought in contact with insecticides only at certain stages during its life. The eggs and moths are completely exposed, while the larva is only exposed during the initial wandering period following hatching and when adverse conditions force a change of feeding site. It

again becomes exposed before pupation.

Therefore, spray applications should be aimed at these stages. No information is available on the ovicidal effects of insecticides applied to E. huegeli eggs but this is a criterion worthy of consideration in selection of insecticides. All field screenings of insecticides to date have been against the larval stage of E. huegeli. Davis et al. (1963) showed that endrin gave a satisfactory control of E. huegeli while parathion did not give a control. Larvae present in the field during these trials were in the fourth and fifth instars. Field experience has shown that both endrin and parathion will give a good control of E. huegeli. However, the degree of control is less, when larvae are allowed to reach third or later instars. This is logical, when it is realised that only the first instar larvae regularly move over treated surfaces, that the second instar larvae are occasionally partly exposed and that later instars are larger and normally fully protected.

Both endrin and parathion were shown in the topical testing to give excellent kills of E. huegeli moths, with very low dosages. This indicates that these chemicals may have a "knock down" effect on moths in the field. Being slow moving moths, especially during the daytime, they are sprayed

during the insecticide spraying of the cotton plants.

As was emphasised previously, larval numbers in the field are small and cause damage to the plant over a long period. No assessment has been made of what constitutes an economical damaging population and the recommendation for chemical control, must be to apply what could be termed a modified schedule spray. This schedule should be based on a 10 - 14 day regular spray programme, with sprays at more frequent intervals if the population in the field rises, or, if the larvae which are found in the field, are developing to the late instar stages.

Cultural control should, to an extent, alleviate the problem. Results of this work indicate that Hibiscus trionum is the major host of E. huegeli and provides an early season breeding place where no control can be exercised. It is therefore recommended that control of this weed on the farm and, as far as is possible, in surrounding areas, be made an important part of the cultural control programme. E. huegeli moths cannot emerge from buried pupae, and so to prevent this emergence, cotton should be slashed and the trash turned into the soil.

However, as E. huegeli is a native insect and has a range of available hosts as well as overwintering mechanisms, cultural control can only be expected, at the most, to minimise the problem.

Rough bollworm can be expected to be a continuing problem in cotton production, although in the period since the field studies were carried out, the insect has declined somewhat in importance as a pest of cotton. This may be due to a build-up of parasite numbers or to the initiation of some other population control factor.

The control of this pest in cotton will have to depend, in the foreseeable future, on the use of insecticides. Unless a more efficacious chemical becomes available, the only improvements which can be made on the currently accepted commercial control methods, are a more stringent application of the cultural control methods suggested in this paper, along with further investigations into the merits of the use of chemicals to kill the eggs and moths of the species.

C O N C L U S I O N S

The experimental work conducted has yielded the following information:-

1. Two species of rough bollworm attack cotton in Queensland. Earias huegeli Rog. is present in most areas of the state, while Earias vitella (F.) is not present in southern or central inland Queensland cotton growing areas.

2. No larvae of E. huegeli emerged from eggs held at 13.0°C. or below. The minimum temperature allowing development of eggs was 16.2°C.

3. The shortest mean developmental period recorded for eggs was 60.0 hours at 37.5°C. and 83 per cent. relative humidity, while the longest mean developmental period recorded was 372.3 hours at 16.2°C. and 57 per cent. relative humidity.

4. Humidity differences produced large differences in the developmental periods of eggs only at 37.5°C., where the mean period increased from 70.5 hours at 49 per cent. relative humidity, to 120.0 hours at 0 per cent. relative humidity.

5. High egg mortalities occurred when eggs were subjected to extremes of humidities and temperatures, that is, at 0 per cent relative humidity combined with 16.2 and 37.5°C. and 100 per cent. relative humidity combined with 16.2, 23.5 and 37.5°C.

6. The larva passes through 5 instars and the head

capsule width ranges of each instar are given. The mean larval instar developmental periods are:- first, 3.5 days; second, 2.8 days, third, 3.1 days; fourth, 3.1 days; fifth, 4.6 days. This study was carried out under mean maximum and minimum temperatures of 24.7 and 22.6°C respectively. The mean larval life under these conditions was 17.1 days.

7. No pupation occurred with larvae held below 15.5°C. However, survival for up to 82 days is possible at 12.5°C. The shortest mean developmental period recorded for larvae is 12.2 days at 36.0°C., while the longest mean developmental period recorded was 53.3 days at 15.5°C.

8. Moths lay more eggs on younger and more hairy tissues, than on older tissues and initial attack by larvae is thus confined mainly to squares and young bolls.

9. Larvae of E. huegeli feed for the whole of the developmental period at one site and change feeding sites only if forced to do so by adverse conditions.

10. Most squares and young bolls attacked by larvae are shed while older bolls are retained.

11. The actual amount of tissues consumed by the larvae is small, compared with the resultant economic loss incurred owing to the subsequent distortion of the bolls and the entry of rotting organisms.

12. Larval pupation occurs principally in the soil and trash surrounding the plant, few pupae being found on the plant itself.

13. The longest mean pupal developmental period, recorded under controlled temperatures, was 48.3 days at 16.2°C., while the shortest mean developmental period was 7.6 days at 33.0°C. No moths emerged from pupae held at or below 13.0°C. The longest mean developmental period of pupae, held under laboratory conditions during autumn and winter, was 73.6 days.

14. Moths cannot emerge from pupae buried in the soil unless direct access to the surface is available.

15. Laying moths, fed on a sugar and water solution, survived for an average of 8.6 days and laid an average of 105.9 eggs per moth. The mean lengths of life of fed and unfed, non egg laying, virgin females were 40.2 and 14.1 days respectively.

16. Egg laying commences on the third day after the emergence of the moth and continues throughout the life of the moth. Most of the eggs are laid at night.

17. The mean length of life cycle from egg to egg was shown to vary from 139.0 days at 16.2°C. to 29.9 days at 36.0°C.

18. The principal alternative host of E. huegeli is Hibiscus trionum L. The insect was also recorded on Abutilon tubulosum Hook, Abutilon oxycarpum f.

acutatum F. v. M., Hibiscus heterophyllus Vent, Pavonia hastata Cav., Malvastrum spicatum Gray, Sida cordifolia L., and a Sida sp. Many of these species assist in the overwintering of the moth, while H. trionum is the principal summer host. The insect is not dependent upon cotton for its survival.

19. Hibiscus trionum, where present, plays an important part in the build-up and maintenance of populations in cotton fields.

20. The percentage of cotton fruit forms infested by E. huegeli is usually low, even when H. trionum is present and heavily infested. There is a clear preference by the insect for Hibiscus trionum as a breeding site.

21. Rainfall (possibly coupled with a dependent factor) and competition for food, are shown to be likely controlling factors of the populations of the insect in Hibiscus trionum.

22. It is demonstrated that the larval, pupal and moth stages are present in the field during winter and that development occurs.

23. Eight parasites were recorded from larvae and pupae. The percentage of larvae parasitised was very low.

24. The LD_{50} levels of twenty chemicals were determined and are listed.

25. The relative values of DDT-endrin and DDT-

parathion mixtures in the control of the pest complex of cotton, showed that both mixtures give a satisfactory control when applied on a weekly schedule. The highest yield was gained from cotton sprayed weekly with a DDT-endrin mixture and the most economical return for expenditure on insecticide was also obtained with this treatment.

26. The short growing season for cotton plants makes the protection of fruit, produced during the early part of the cotton season, essential.

27. Under field conditions, it is impossible to consider the control of one insect and thus, the reaction of all insect species in the complex to chemicals applied, should be considered.

28. The cultural control measures of destruction of Hibiscus trionum, and burying of pupae together with trash, are necessary to reduce the levels of rough bollworm populations in the fields. In dealing with a native insect that has a range of hosts, such measures can be expected, at the most, only to minimise the problems.

29. Insecticide sprays should be applied so as to contact larvae during the periods at which the latter are exposed.

30. Future control measures against rough bollworm should continue to depend upon chemicals applied on a "modified schedule", the intervals between

sprayings being varied in the range from a week to a fortnight, depending upon the insect populations observed in the field. Cultural control efforts should be coupled with this programme.

31. Future research into insecticidal control of E. huegeli should include investigations into the efficacy of chemicals in the control of eggs and moths in the field.

Acknowledgements

The assistance of the following officers of the Queensland Department of Primary Industries is gratefully acknowledged.

Dr. A.R. Brimblecombe (Deputy Government Entomologist) and Mr. T. Passlow (Senior Entomologist) who have assisted with advice and constructive criticism. Mr. S. Everist (Government Botanist) for identification of alternative host species. The late Mr. P. McGovern for statistical analysis. Mr. W.M. Manley (Illustrator) for preparation of line drawings. Mrs. M. Roubicek and Mr. L. Rigby for assistance with collection of data.

The valuable assistance of my supervisor Dr. G. Hooper is also gratefully acknowledged.

Declaration

I certify that all work recorded in this paper was carried out by me, with the exception of the assistance acknowledged above. The junior authorship of my then senior officer, Mr. T. Passlow, (Turner and Passlow, 1965), was an acknowledgement of his advice and constructive criticism during this project.

BIBLIOGRAPHY

References cited in text

ANON. 1906. Rep. Dep. Agric. Stk Qd, 1905-6.

ANON. 1907. Rep. Dep. Agric. Stk Qd, 1906-7.

ANON. 1918. Rep. Dep. Agric. Stk Qd, 1917-18.

ANON. 1934. Biloela Research Station Report. Reports received from Research Stations, Empire Cotton Growing Corporation, 1934.

ANON. 1942. Rep. Dep. Agric. Stk Qd, 1941-42.

ANON. 1963. The Report of the Conference of Commonwealth and State Entomologists. Canberra, 1963.

ATHERTON, D.O. 1932. Pests of Cotton in the Callide Valley. Qd Agric. J. 38 (6): 488-92.

BALLARD, E. 1925. Third Entomological Progress Report (Aust.). Emp. Cott. Grow. Rev. 2 (3): 237-40.

BALLARD, E. 1926. Sixth Entomological Progress Report (Aust.). Emp. Cott. Grow. Rev. 3 (4): 365-73.

BRIMBLECOMBE, A.R. 1953. Red Spider Mites and their Control. Qd Agric. J. 76: 63-68.

COTES, E.C. and SWINHOE, C. 1887. A Catalogue of the Moths of India. Calcutta Govt. Printer, India. 812 pp.

DAVIS, J.J., KIRKPATRICK, T., and PASSLOW, T. 1963. Cotton Pests Control Trials in Northern and South Western Queensland. Qd J. agric. Sci. 20 (2): 129-36.

FROGGATT, J.L. 1924. Entomological Notes. Qd agric. J. 21 (2): 120-23.

FROGGATT, W.W. 1922. Agric. Gaz. N.S.W. 33: 863-66.

GURNEY, W.B. 1924. Insect Pests of Cotton in N.S.W. Agric. Gaz. N.S.W. 34 (12): 887-93.

HAMPSON, G.F. 1894. Fauna of British India including Ceylon and Burma. Vol. 2. London. Taylor and Francis. 609 pp.

HAMPSON, G.F. 1912. Catalogue of Lepidoptera (Phalaenae) in the British Museum. Vol. 11. London. 689 pp.

HARGREAVES, H. 1948. List of Recorded Cotton Insects of the World. Commonwealth Institute of Entomology, London. 50 pp.

HILL, G.F. 1915. Insect Pests of Plants. Northern Territory of Australia. Dept. External Affairs, Melbourne. Bull. Nth. Terr. Aust. No. 13. August, 1915.

HILL, G.F. 1924. Insects Affecting Cotton in Australia. Proc. pan-Pacif. Sci. Congr. August, 1923: 406-8.

JENKIN, C.F.H. 1945. Entomological Problems of the Ord River Irrigation Area. J. Dep. Agric. West. Aust. 22 (2): 131-45.

KIRBY. 1892. Catalogue of Lepidoptera (Heterocera) Vol. 1. Gurney and Jackson, London. 951 pp.

KHAN, H. 1944. Studies on Earias Species (the spotted bollworms) in the Punjab. Indian J. Ent. 6 (1): 15-27.

LEA, A.M. 1928. The Cotton Bollworm in South Australia. J. Dep. Agric. S. Aust. 31 (6): 608-15.

NEWMAN, L.J. 1924. Report of the Economic Entomologist. Rep. Dep. Agric. West. Aust. 1923-24.

PASSLOW, T. 1958. Control of Insects in Cotton in Central Queensland. Qd agric. J. 84: 557-60.

PASSLOW, T. 1961. Insect Pest Control and Yield Patterns in Central Queensland Cotton Crops. Qd J. agric. Sci. 18 (3): 269-86.

PASSLOW, T. 1963. Cotton Pests in Queensland. Qd Dep. Agric. Stk., Brisbane. 12 pp.

PASSLOW, T. and TRUDGIAN, K. 1960. Effects of Fruit Form Removals on Cotton Yields in Central Queensland. Qd J. agric. Sc. 17 (4): 311-20.

PEARSON, E.O. 1958. Insect Pests of Cotton in Tropical Africa. Empire Cotton Growing Corporation and Commonwealth Institute of Entomology. 355 pp.

RIBLEC, J. 1934. Un pentatome parasite de la chenille épineuse du cotonnier. C.r. hebd. Séanc. Acad. Sci., Paris. 193 (4): 247-50.

RICHARDS, K.T. 1964, Insect Pests of Cotton in the Ord River Area. J. Dep. Agric. West. Aust. 5 (2): 79-86.

ROGENHOFER, A. 1870. Über die Synonymie und die fruhen Stande von Earias insulana B. (siliquana H. Sch.) and Beschreibung einer neuen Art. Verh. zool.-bot. Ges. Wien, Band XX: 872.

SNODGRASS, R.E. 1935. Principles of Insect Morphology. McGraw-Hill, London and New York. 667 pp.

TRYON, H. 1923. Cotton Pests - Entomologist's Report. Qd agric. J. 19 (2): 156-7.

TSAI, P.H. 1935. Epidemiological experiments with the paddy borer. I. The influence of temperature and relative humidity on oviposition and hatching. Agricultura sin. 1 (9): 273-317.

TURNER, J.W. and PASSLOW, T. 1965. Controlling Rough Bollworm in Southern Queensland Cotton. Qd agric. J. 91 (7): 436-8.

TUXEN, S.L. (ed.) 1956. Taxonomist's Glossary of Genitalia in Insects. Ejnar Munksagaards, Copenhagen.

VEITCH, R. 1938. Cotton Growing in Queensland. Part 2 Cotton Pests. Bull. Dep. Agric. Qd No.15.

WELLS, W.G. 1930. Report of the Biloela Research Station 1929-30.

WRIGHT, W.E. 1965. Insect Pests of Cotton in N.S.W. Agric. Gaz. N.S.W. 76 (9): 535-42.

WRIGHT, W.E. and NIKITIN, M.I. 1964. A survey of Cotton Pests in New South Wales. Aust. J. Sci. 27 (6): 178-9.