WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 167

METEOROLOGICAL FACTORS AFFECTING THE EPIDEMIOLOGY OF THE COTTON LEAF WORM AND THE PINK BOLLWORM

by
M. H. Omar
CAgM rapporteur

WMO - No. 532

Secretariat of the World Meteorological Organization - Geneva - Switzerland

WMO

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It was created:

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— To promote the establishment and maintenance of systems for the rapid exchange of meteorological information;

— To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;

— To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;

— To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services;

— To encourage research and training in meteorology and, as appropriate, in related fields, and to assist in co-ordinating the international aspects of such research and training.

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NOTE

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CONTENTS

FOREWORD

The important role played by weather and climate in the epidemiology of many pests which cause serious damage to crops is widely recognized. The WMO Commission for Agricultural Meteorology (CAgM) has, over the years, been involved in the study of this subject and to date four WMO Technical Notes have been published dealing respectively, with the Climatic Aspects of the Possible Establishment of the Japanese Beetle in Europe (Technical Note No. 41), Meteorology and the Desert Locust (Technical Notes Nos. 54 and 69) and Meteorology and the Colorado Potato Beetle (Technical Note No. 137).

The fourth session of CAgM decided that, because of the considerable damage caused by two pests of cotton, the cotton leaf worm and the pink bollworm, and recognizing that the population, size and activities of these pests were highly weather-dependent, the meteorological aspects of their epidemiologies should be investigated. The Commission recommended, therefore, that an expert from Egypt should be appointed as a rapporteur on the subject. Subsequently, Dr. M. H. Omar was appointed rapporteur and was assigned the task of reviewing the existing state of knowledge in that field and of recommending measures for the improvement of meteorological assistance to efforts made to control these pests. Dr. Omar's report was reviewed by the president of CAgM who recommended that, because of its wide interest to agricultural meteorologists in many parts of the world, it should be published as a WMO Technical Note.

It is with pleasure that I take this opportunity of thanking Dr. Omar for the great effort he has made in collecting the information contained in this Technical Note. I feel confident that it will be studied with interest by agricultural meteorologists and agriculturalists alike.

Geneva,
June 1979

(D.A. Davies)
Secretary-General

SUMMARY

In many countries cotton is an important commercial crop, but two insects are widely distributed and inflict considerable loss and damage. This report deals with the meteorological factors affecting the epidemiology of these two pests, the cotton leaf worm, Spodoptera littoralis (Boisd) and the pink bollworm, Pectinophora gossypielia (Saund).

The cotton leaf worm is extremely polyphageous and is considered a major pest of maize, clover, vegetables and a variety of other crops, shrubs, fruit trees and ornamental plants, in addition to cotton. It is important in many African, Middle Eastern and Mediterranean countries. Chapters 2 and 3 of this Technical Note discuss effects of meteorological factors (temperature, humidity, soil moisture and wind) on various stages of the life cycle of the cotton leaf worm.

The pink bollworm is one of the most widespread of all cotton pests, occurring in almost every cotton-growing area of the world, including many countries of Africa, Asia, Australia, Europe, North America, South America, and the West Indies. Chapters 4 and 5 detail meteorological factors affecting the epidemiology of the pink bollworm and control measures applied during various stages in its life cycle.

The author presents some recommendations for improving the meteorological contributions towards understanding the epidemiology and facilitating control of both pests. He emphasizes the need for further research in field and laboratory.

RESUME

Dans de nombreux pays, le coton est une importante culture commerciale, mais deux insectes très répandus lui infligent d'énormes pertes et dégâts. Dans ce rapport, il est question des facteurs météorologiques qui influencent l'épidémiologie de ces deux ravageurs, à savoir le ver des feuilles du coton, Spodoptera littoralis (Boisd), et le ver rose des capsules du coton, Pectinophora gossypielia (Saund).

Le ver des feuilles du coton est extrêmement polyphage et on estime que c'est aussi un des grands ravageurs du maïs, du trèfle, des légumes et de diverses autres cultures, arbustes, arbres fruitiers et plantes ornementales. Il constitue un problème important dans de nombreux pays d'Afrique, du Moyen-Orient et du bassin de la Méditerranée. Dans les chapitres 2 et 3 de la présente Note technique, il est question des effets des facteurs météorologiques (température, humidité, humidité du sol et vent) à divers stades du cycle de vie du ver des feuilles du coton.

Le ver rose des capsules du coton est l'un des plus répandus de tous les ravageurs du coton puisqu'on le trouve dans pratiquement toutes les zones de culture cotonnière du monde, notamment dans de nombreux pays d'Afrique, d'Asie, d'Australie, d'Europe, d'Amérique du Nord, d'Amérique du Sud et aux Antilles. On trouvera dans les chapitres 4 et 5 des détails relatifs aux facteurs météorologiques qui influencent l'épidémiologie du ver rose des capsules du coton et aux mesures de lutte appliquées à divers stades de son cycle de vie.

L'auteur présente des recommandations pour améliorer la contribution de la météorologie à la compréhension de l'épidémiologie et faciliter la lutte contre ces deux ravageurs. Il souligne la nécessité de poursuivre les recherches, à la fois sur le terrain et en laboratoire.

РЕЗЮМЕ

Во многих странах хлопок является важной коммерческой сельскохозяйственной культурой, но широко распространены два вида насекомых, которые наносят этой культуре значительный ущерб. В этом докладе рассматриваются метеорологические факторы, оказывающие влияние на эпидемиологию этих двух вредителей: гусеницы хлопкового листа, **Spodoptera littoralis** (Бойс), и коробочного червя, **Pectinophora gossypielia** (Саунд).

Гусеница хлопкового листа является чрезвычайно полифагенной и рассматривается как серьезный вредитель не только хлопка, но и маиса, клевера, овощей и ряда других культур, кустарников, фруктовых деревьев и декоративных растений. Она представляет серьезную проблему во многих странах, расположенных в Африке, на Ближнем Востоке и в районе Средиземного моря. В главах 2 и 3 этой технической записки излагаются влияния метеорологических факторов (температура, влажность, влажность почвы и ветер) на различные стадии развития хлопкового листа.

Коробочный червь является одним из наиболее широко распространенных вредителей хлопка, встречающихся почти в каждом районе мира, в которых растет хлопок, включая многие страны в Африке, Азии, Австралии, Европе, Северной Америке, Южной Америке и Вест-Индии. В главах 4 и 5 подробно рассматриваются метеорологические факторы, оказывающие влияние на эпидемиологию коробочного червя, и меры по контролю, применяемые в течение различных стадий его жизненного цикла.

Автор дает некоторые рекомендации в отношении улучшения вклада метеорологии в понимание эпидемиологии и облегчение контроля за этими вредителями. Он подчеркивает необходимость проведения дальнейших полевых и лабораторных научных исследований.

RESUMEN

El algodón es un cultivo comercial importante en muchos países y dos insectos proliferan y causan considerables pérdidas y daños. Este informe trata de los factores meteorológicos que afectan a la epidemiología de estas dos plagas, que son el gusano de la hoja de algodón, Spodoptera littoralis (Boisd), y el gusano de la cápsula del algodón, Pectinophora gossypielia (Saund).

El gusano de la hoja del algodón es extremadamente polífago y se considera como una de las principales plagas del maíz, del trébol, de las verduras y de una variedad de otros cultivos, arbustos, árboles frutales y plantas ornamentales, además del algodón. Es muy importante en muchos países de Africa, de Oriente Medio y del Mediteráneo. Los Capítulos 2 y 3 de esta Nota Técnica tratan de los efectos que tienen los factores meteorológicos (la temperatura, la humedad, la humedad del suelo y el viento) en las diferentes fases del ciclo de vida del gusano de la hoja del algodón.

El gusano de la cápsula del algodón es una de las más extendidas plagas del algodón, y prolifera en casi todas las zonas del mundo donde se cultiva el algodón, incluidos numerosos países de Africa, Asia, Australia, Europa, América del Norte, América del Sur e Indias Occidentales. Los Capítulos 4 y 5 presentan detalladamente los factores meteorológicos que afectan a la epidemiología del gusano de la cápsula del algodón e indican las medidas que se toman para luchar contra el gusano en las diferentes fases de su ciclo de vida.

El autor hace algunas recomendaciones sobre las contribuciones de la meteorología a una mayor comprensión de la epidemiología y a la lucha contra estas dos plagas. Asimismo, recalca la necesidad de llevar a cabo la investigación sobre el terreno y en laboratorio.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance provided by individuals from many countries who contributed to this Technical Note by sending reprints, answering questionnaires and supplying data and information.

Special thanks go to Dr. R. Gonzalez, Italy, for his assistance in reviewing the manuscript.

CHAPTER 1

INTRODUCTION

The cotton leaf worm Spodoptera littoralis (Boisd) and the pink bollworm Pectinophora gossypiella (Saund) are two major pests of cotton. This report deals with the meteorological factors affecting the epidemiology of these two pests.

The cotton leaf worm is to be found in many African, Middle East and Mediterranean countries. It is extremely polyphagous and always apt to inflict excessive damage when it appears in masses during outbreak years. Apart from cotton, the insect is a major pest of maize, clover, certain vegetables and a variety of other crops, shrubs, fruit trees and ornamental plants. It is known to infest approximately 112 host plants belonging to 44 different plant families. Recent world-wide re-examination of the identity of this pest revealed that the same species were referred to as Prodenia litura (F.) in Africa and in the Middle East.

The pink bollworm is one of the most widespread of all cotton pests and is found in almost every cotton growing area of the world, i.e. in Africa, Asia, Australia, Europe, North America, South America and the West Indies. Cotton is its preferred host. Alternative hosts of world-wide distribution represent 7 families, 24 genera and 70 species. Okra is probably preferred next to cotton.

Biological processes of both pests are affected considerably by meteorological factors. Air temperature and humidity influence their development and fecundity. Some of these effects are similar, for example, the duration of the different stages of the life cycle decrease with increasing temperature. Adult longevity generally increases with increasing relative humidity.

An important difference between the life cycles of the two insects is that some cotton bollworm larvae have the ability to spend the period of diapause in a fully fed state. This insect inhabits a wide geographical range undoubtedly because of its ability to enter diapause at the onset of unfavourable environmental conditions. Chapman et al. (1960) demonstrated survival of the pink bollworm at temperatures below -17.8°C in the arid area around El Paso, U.S.A. On the other hand, Bishara (1934) found that the cotton leaf worm was confined to the tropical and subtropical zones where the mean air temperature does not fall below 10°C. Laboratory and field studies have indicated that diapause in the pink bollworm is controlled primarily by photoperiod, with temperature exerting a secondary effect. Hence photoperiod is an important factor in the geographical distribution of the pink bollworm.

Soil moisture and soil temperature are also important, because pupation, over-wintering of larvae and moth emergence occur generally below the soil surface. Infestation with pink bollworm moths can be spread by the wind as far as 400 km. Similar long-range movement of the cotton leaf worm has not yet been proved.

Meteorological factors play an important role in the control of both pests. Hosny and Iss-hak (1967) discovered a relationship between severity of the cotton leaf worm attack and the mean air temperature during a certain critical period. Results of this study are important because they help foresee potential outbreaks early enough to prepare for control.

Workers have observed that winter rainfall decreased survival of over-wintering pink bollworm larvae. Change of soil moisture has been used as a cultural practice for control of both pests but in different ways. In the United States of America, increase of soil moisture by irrigation during winter is an important way to control the pink bollworm since it decreases survival considerably. In Egypt, the harmful effect of low soil moisture on the cotton leaf worm is the basis of a cultural control method, i.e. it is prohibited to irrigate other hosts, for instance, berseem clover, after 10 May. Dry soil will allow fewer pupae to live and consequently will lead to decreased emergence of moths that infect cotton in June.

Early sowing of cotton is practised for control of both insects. For the cotton leaf worm, this allows plants to be sufficiently strong before infestation starts and for leaves to become unappetizing. For pink bollworms, early sowing allows bolls to form early in the season and thus avoid a severe damage as they mature before the pest builds up to maximum intensity. In both cases, the determination of the most suitable early planting date requires micrometeorological measurements in cotton fields and phenological observations of crop and pest.

This Technical Note includes two chapters for each insect. The first is on geographical distribution, life cycle, damage and control. The section on pink bollworm damage is of special interest as damage is affected by rainfall and humidity. The second chapter considers the effect of meteorological factors on biological processes. It includes sections on air temperature, relative humidity, soil moisture and wind. For the cotton leaf worm, there is an additional section on "light" which gives results of some light-trap studies. For the pink bollworm, there are additional sections on acqueous submersion, soil temperature and photoperiod. Additional sections on both pests include general discussion and conclusion, recommendations for control, and references.

C H A P T E R 2

COTTON LEAF WORM - GEOGRAPHICAL DISTRIBUTION, LIFE CYCLE AND CONTROL

2.1 Geographical distribution

According to the "Distribution Maps of Insect Pests", published by the Commonwealth Institute of Entomology, London, the cotton leaf worm is known in the following countries:

Europe: Crete, Cyprus, France, Greece, Italy, Majorca, Malta and Spain.

Asia: Bahrain, Democratic Yemen, Dodecanese Islands, Iran, Iraq, Israel, Jordan, Lebanon, Saudi Arabia, Syria and Turkey.

Africa: Aldabra Islands, Algeria, Angola, Ascension Island, Burundi, Canary Islands, Central African Republic, Chad, Comoros, Egypt, Ethiopia, Gambia, Ghana, Guinea, Kenya, Libyan Arab Jamahiriya, Madagascar, Madeira, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Niger, Nigeria, Reunion, Rhodesia, Rodriguez Island, Rwanda, St. Helena, Sao Tomé and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Togo, Tunisia, Uganda, United Republic of Cameroon, United Republic of Tanzania, Upper Volta, Zaire and Zambia.

The pest is non-existent in many other countries of Europe, Asia, America and Australia.

In Egypt, it is the most important of all the cotton pests. Despite continuous control, it still causes considerable agricultural damage in addition to the time and expense devoted to control. Estimates place damage during outbreak years at about 20 to 40 million Egyptian pounds in addition to control expenses which vary from 4 to 14 million pounds.

In Kenya, for example, the pest is rarely known to attack economically-valuable plants, while in Tanzania, it is considered to be serious for tobacco and beans. It occasionally reaches the United Kingdom with consignments of flowers imported from the Mediterranean area or from the Canary Islands. Bishara (1934) studied its geographical distribution and concluded that the species was confined to the subtropical and tropical zones, where the mean temperature does not fall below 10°C.

2.2 Life cycle

The life cycle consists of (1) egg, (2) larva, (3) pupa and (4) adult.

2.2.1 Egg

Eggs are laid in masses on the under surface of leaves. The period from egg-laying till hatching varies according to the time of year, for example during summer, the egg stage in Egypt lasts about three days.

2.2.2 Larva

A fully grown larva is about five centimetres long and has six stars. The first three stars always remain on plants, while the other three spend the day almost motionless on the ground at the base of plants. Late in the afternoon they resume their activity and ascend the plants for feeding. The full larval period varies greatly according to the time of year, i.e. from two weeks in summer to over three months in winter. There is no true hibernation, but larvae feed and grow very slowly in cold weather.

2.2.3 Pupa

The last star larva constructs an earthen cell 3 to 5 cm below the soil surface. Length of the pupa is 14 to 18 mm; average width is 5 mm, and the general shape is conical. Duration of the pupal stage also varies depending on the season, for example, in Egypt the average for summer is eight days, and in winter about two months.

2.2.4 Adult

The adult is a moth with a body length of 14 to 18 mm and a wing spread of 28 to 38 mm. It is nocturnal in habit, hiding by day and actively flying for food, mating and oviposition during the night. Judging by their choice of certain fields for oviposition and their distances from the breeding grounds, the insects must be powerful fliers (Bishara, 1934). After emergence, copulation takes place within one or two days in summer and the females start egg-laying.

2.3 Frequency of life cycle

In Egypt the time taken by one generation was found to range from one month in summer to almost four months or more in winter. Under average conditions, seven generations are developed in one year - four chiefly on berseem and three on cotton. The three generations on cotton are many in number and conspicuous; they occur in summer between early June and mid-September. Autumn, winter and spring generations are few in number and inconspicuous.

2.4 Damage

At first, newly hatched larvae voraciously attack the surface tissues of leaves, but later they eat right through. While principally a leaf-feeding insect, the caterpillar also has the habit of boring into and feeding on twigs, stems and fruits of host plants.

2.5 Control measures

2.5.1 Cultural control

An effective method of control is to hand-pick egg masses and newly hatched larvae off the leaves and then burn them. Egg collection should continue for the longest possible period. Another effective method is to sow cotton early so that the plant will be sufficiently strong and the leaves unattractive to the pest before infestation starts. Other controls include weed destruction following the winter crop. In Egypt, it is prohibited to irrigate berseem after 10 May as fewer pupae emerge then from dry soils.

2.5.2 Chemical control

When the infestation is so serious that egg-mass collection alone is no longer effective, which occurs in Egypt about 20 to 30 June, chemical control of the larvae should be attempted. Insecticides recommended include cyolane, gusathion-tamaron, dursban, lannate, curacron, cytrolane and gardona. Hand-picking of egg-masses can continue until about mid-July when regular chemical control for bollworms normally begins.

Chemical control of the cotton leaf worm is usually effective, but larvae often acquire resistance when a particular chemical is used repeatedly over the years. Chemical control programmes differ from year to year depending on the level of pest resistance to the insecticides.

CHAPTER 3

EFFECTS OF METEOROLOGICAL FACTORS ON BIOLOGICAL PROCESSES OF THE COTTON LEAF WORM

3.1 Air temperature

Increasing temperatures tend to shorten life cycle stages of the cotton leaf worm. Extreme temperatures, high or low, are unfavourable to survival and insect reproduction. Impact of temperature varies with changes in other parameters, particularly with relative humidity.

3.1.1 Egg stage

3.1.1.1 Egg incubation period

Bishara (1934) found that the incubation period decreased with increasing temperature, and varied between three days for temperatures of 26°C and over, and 20 days for an average temperature of 13.5°C. Data are shown in Figure 1 where the points form a smooth curve. The reciprocal of this curve (Figure 2) is almost a straight line with zero displacement at about 11.5°C. This represents zero development, below which no growth is likely. Figure 2 shows also reciprocals (development per day) for larvae and pupae. Above 30°C, the straight line does not continue because high temperatures have deleterious effects on rate of development.

Nasr et al. (1974) also noted that the incubation period decreased as temperature increased.

3.1.1.2 Low temperature storage of eggs and its possible use as a quarantine measure

The market has increased for chrysanthemum cuttings produced in the Mediterranean area for north-western Europe. Some quarantine method to ensure that the pest is not spread through the trade is, therefore, highly desirable. Since the cuttings are often kept in cold storage for several days, the effect of low temperature on egg survival was investigated by Hussey and Gostick (1964). In some of their experiments, eggs kept in pill boxes were placed among chrysanthemum foliage in the standard storage packs and kept in commercial cold storage for periods of five to ten days. They found that no eggs hatched after ten days of storage with mean temperatures from -1.1°C to +1.7°C; however, some hatched after a shorter exposure period. They concluded that to subject plants, on which the pest may have oviposited, to temperatures of 1.7°C or less for a period of ten days would be a satisfactory quarantine method.

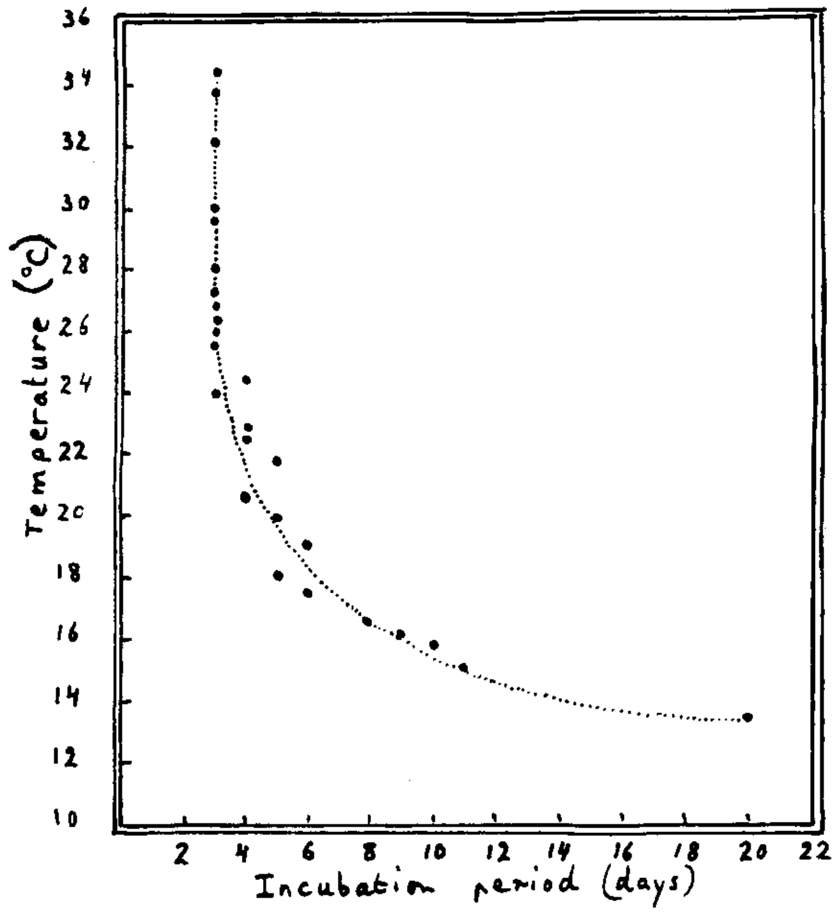
36
34
32
30
28
26
24
22
20
18
16
14
12
10
Temperature (°C)
2
4
6
8
10
12
14
16
18
20
22
Incubation period (days)

Figure 1

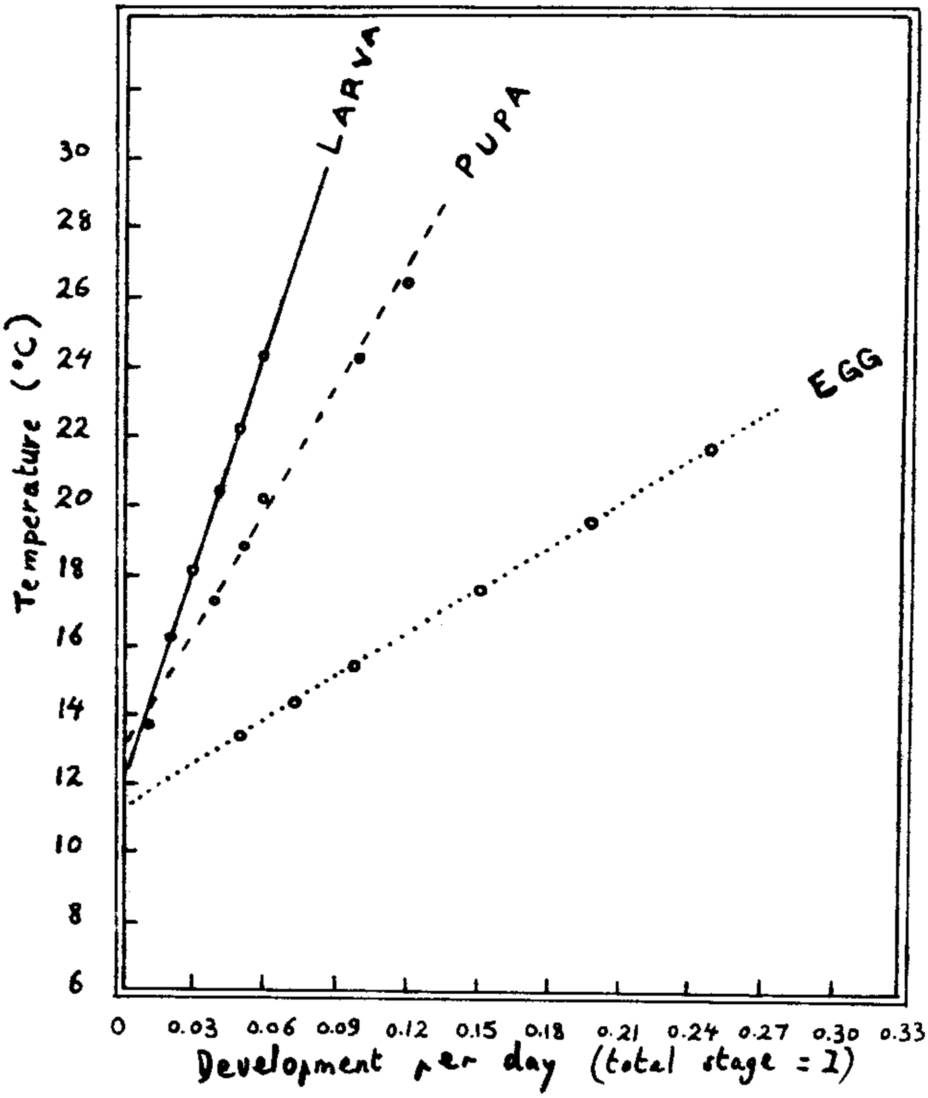

Figure 2

3.1.1.3 Predicting rate of infestation

Hosny and Iss-hak (1967) contributed towards predicting the approximate rate of insect infestation during the summer in Egypt. They noted that during outbreak years, the air temperature at screen level (average maximum and minimum, and daily average) as well as the average soil temperature at a depth of five centimetres, observed between 11 February and 10 April (the critical period), were about 2°C lower than corresponding values for ordinary years.

The correlation and regression coefficients between each of the four factors mentioned above, which were averaged during the critical period, and the annual counts of egg-masses for the Kalyoubia and Menoufia provinces of Egypt for seven years (1960 to 1966) indicated negative but highly significant effects. They demonstrated that the daily average temperature, daily minimum temperature and average soil temperature during the critical period were responsible, as a group, for about 90 per cent of the annual variation in egg-mass numbers. Annual egg-mass numbers could be estimated rather closely.

The relation between the provincial count of egg-masses during summer and those for all of Egypt proved to be positive and highly significant. This inferred, in a broad sense, that the level of infestation in Kalyoubia and Menoufia provinces corresponded to the general trend for the whole of Egypt.

It is clear that these results are important, as they help to foresee potential outbreaks early enough to prepare for insect control.

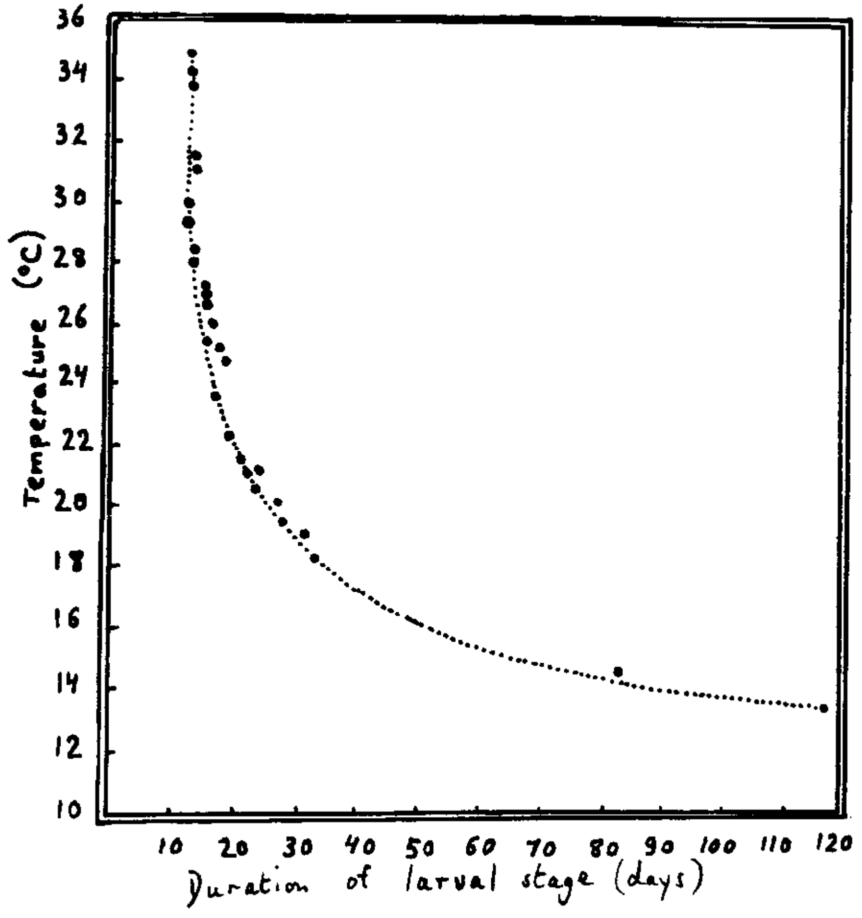

Figure 3

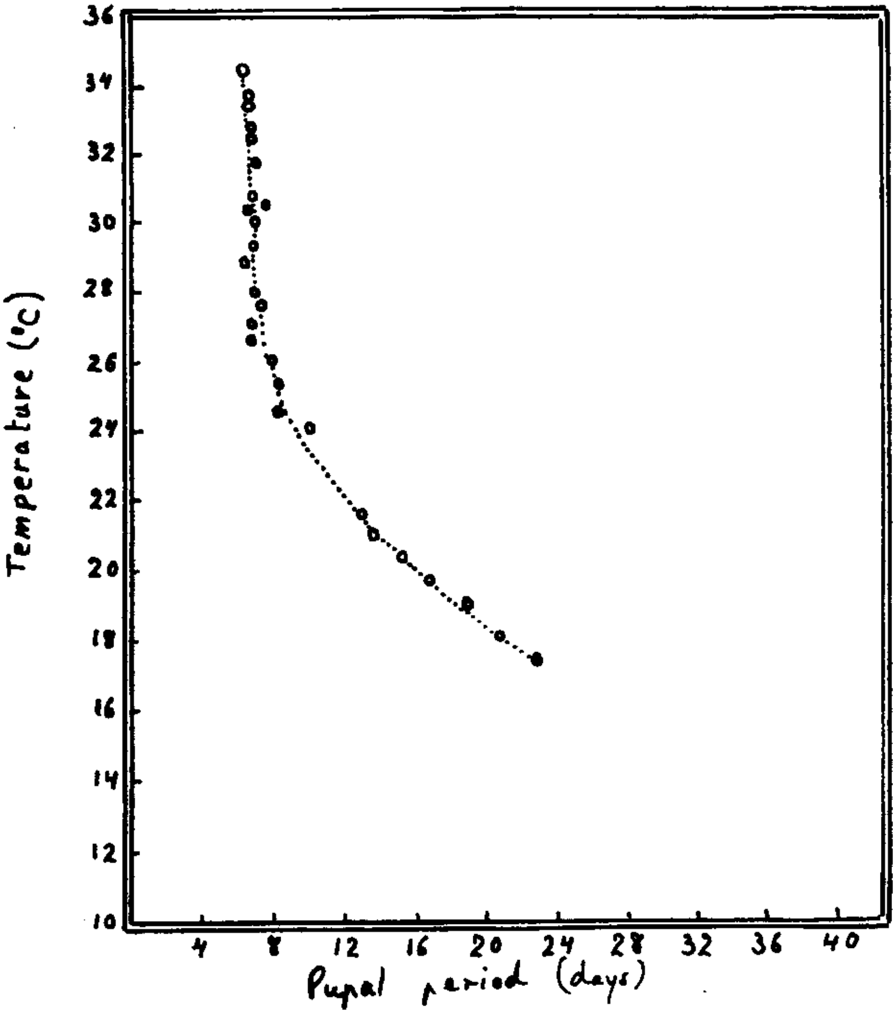

Figure 4

3.1.2 Larval stage

3.1.2.1 Duration

Bishara (1934) and Nasr et al. (1974) determined that the larval period decreased with increasing temperature. Data and their reciprocals are shown in Figures 2 and 3 respectively. Zero of development, below which probably no growth occurs, is about 12°C.

3.1.2.2 Adult fecundity

Rivnay and Meisner (1966) found that the proportion of barren females increased with increasing larval temperature, and the number of eggs laid decreased with increasing temperature.

3.1.3 Pupal stage

3.1.3.1 Pupal period and mortality

Bishara (1934), Rivnay and Meisner (1966), and Nasr et al. (1974) concluded that the pupal period decreased with increasing temperature. Data and their reciprocals are shown in Figures 2 and 4 respectively Zero of development would be about 13°C.

Jarczyk et al. (1957) also noted that the pupal period for females and males decreased with increasing temperature but, at the same temperature, the period was longer for males than for females.

Rivnay and Meisner (1966) observed that pupal mortality decreased with increasing temperature between 100 per cent at 10°C and 31.6 per cent at 20°C, then increased with increasing temperature to 60 per cent at 34°C.

3.1.3.2 Adult fecundity

The pre-oviposition period increased with increasing pupal temperature, according to Rivnay and Meisner (1966).

The percentage of females that laid non-viable eggs increased with increasing pupal temperature. Very low temperatures also appeared to be harmful; of two females that emerged from pupae kept at 16°C, one did not oviposit and the other laid only non-viable eggs. Increasing pupal temperature reduced egg-laying and the percentage of viable eggs.

3.1.3.3 Adult longevity

Rivnay and Meisner (1966) found that increasing pupal temperature shortened mean adult life.

3.1.4 Adult stage

3.1.4.1 Longevity

Nasr et al. (1974) generalized that adult longevity decreased with increasing temperature.

Longevity of adults was determined under natural conditions in different seasons at Giza, in Egypt, by Moussa et al.(1964). They noted that cool weather prolonged adult life and that longevity decreased from winter to autumn.

3.1.4.2 Egg production

Nasr et al. (1974) determined that egg production at specified relative humidities decreased with increasing temperatures between 30 and 35°C. Between 25 and 30°C, production decreased with increasing temperatures and 70 per cent relative humidity, but increased with increasing temperatures and 30 to 90 per cent relative humidity.

3.1.4.3 Stimulation of outbreaks in Egypt

Air and soil temperatures which are considerable below average during the critical period prevent emergence of adults and hold insects mainly as pupae. Mass emergence of moths would then be stimulated by the onset of warmer weather, normally during April. The sudden emergence of a large number of adults due to warm weather, particularly very early in the season, predisposes to mating and oviposition. In normal periods they would emerge gradually, or in smaller numbers and over a longer period, so that their chances of mating would be limited.

3.1.4.4 First appearance of the pest and stimulation of outbreaks in Israel

Rivnay (1970) studied the effect of temperature on the moth population in Israel. He indicated that moths were more numerous in sites where large fields of summer crops were under irrigation. Crops may be irrigated till late in the summer, therefore the peak in cotton leaf worm population will occur in autumn, about two months later than in Egypt. He concluded that the population was subjected to temperature fluctuations throughout the year and hence no distinct prediction could be made. However, it appeared that winter temperatures lower than the 15-year average retarded early appearance of the pest, and that cooler than average springs and summers favoured outbreaks.

3.1.5 High temperatures and mortality

3.1.5.1 Observations by Willcocks and Bahgat (1937)

According to Willcocks and Bahgat (1937), cotton growers in Egypt have long recognized that spells of very hot weather (maxima 37°C to over 40°C) kill enormous numbers of newly hatched cotton worms and prevent egg-masses from hatching.

3.1.5.2 Laboratory experiments

Bishara (1934) studied the effect of high temperatures on mortality in the egg, larval, and pupal stages.

3.1.5.2.1 Egg stage

Eggs incubating a whole day at 40°C hatch and produce pupae and eventually moths, while a two-day incubation kills the eggs. Complete mortality of eggs occurs after an incubation period of 17 hours at 42°C, 7 hours at 45°C, 50 minutes at 48°C and 15 minutes at 68 to 70°C.

3.1.5.2.2 Larval stage

Larvae, five to fourteen days old, exposed to 39.8°C, died after one to six days. Mortality occurred after 22 to 50 hours when larvae were exposed to 40°C, five to ten hours at 45°C, 40 to 70 minutes at 50°C, and two to five minutes at 67°C.

3.1.5.2.3 Pupal stage

Pupae heated for one day at 42.5°C were not killed, but when heated for two days they were all killed. At 48°C pupae died after an 80-minute exposure and at 57°C after ten minutes.

3.1.5.3 Experiments under plastic sheets in the field

Hosny et al. (1968) reported results of experiments under plastic made on sunny days in summer at Cairo. They found that exposure of egg-masses and larvae of different ages to 47°C and 100 per cent relative humidity for three hours under a 0.25 mm blue plastic caused the death of all egg-masses and larvae. Cotton plants were dried and wilted when air temperature went over 47°C. Eggs were dried and killed when exposed to 48°C and 100 per cent relative humidity for one hour. All larvae died when exposed for two hours to temperatures of 46, 47 and 48°C and 100 per cent relative humidity.

3.1.6 Observations by Bishara (1934) concerning the geographical distribution of the pest in Egypt

Bishara (1934) stated that the species was limited in its geographical distribution to zones of fairly warm, but not excessively hot, climate. In Egypt, the insect is very common in the northern provinces of the Delta, fairly common in the southern provinces, much less common in middle Egypt, and rare in upper Egypt.

3.1.7 Mortality of larvae exposed to insecticides

Temperature effect on insects exposed to insecticides has been the subject of numerous investigations over the last few years. This relationship has considerable value in pest control through practical application of insecticides.

Hassan and Hanna (1968), in Egypt, studied the effect of temperature on mortality of larvae exposed to toxaphene, carbaryl or trichlorphon. Larvae were treated with doses of these insecticides calculated to give 50 to 60 per cent mortality, and were then kept for 24 hours at 15, 28 and 37°C. This range of temperature is very close to natural environmental conditions which normally prevail during the cotton-growing season in Egypt. For each insecticide the mortality percentage increased with increasing temperature. The highest mortality percentage was that for carbaryl, followed by trichlorphon and toxaphene.

3.2 Relative humidity

The cotton leaf worm survives and multiplies most in relatively moist surroundings. Extremes in humidity, especially very dry conditions, discourage the insect's reproduction, growth and development.

3.2.1 Distribution of egg-masses in cotton fields

Moussa et al. (1964) studied the distribution of egg-masses in fields of annual cotton in Sakha, northern Egypt. In plots situated near the main irrigation canal, egg-masses reached maximum density in June and a second (lower) peak in

August. In plots about two kilometres away from the canal, egg-masses were laid only in June and peaked appreciably lower than plots near the canal. The researchers suggested that the difference might be due to the higher relative humidity observed near the canal.

3.2.2 Egg incubation period

Nasr et al. (1974) found that, in general, the egg incubation period decreased with increasing relative humidity.

3.2.3 Larval stage

Larval period

In contrast to egg incubation, Nasr et al. (1974) observed that the larval period increased with increasing relative humidity.

3.2.4 Pupal stage

3.2.4.1 Pupal period

Research by Nasr (1963a) indicated that the pupal period was shortest at 60 per cent relative humidity and longest at zero per cent and later, with co-workers (1974), he observed that the pupal period increased as relative humidity increased, in the range of 30 to 90 per cent relative humidity.

Rivnay and Meisner (1966) found that the pupal period was about two days longer at relative humidities above 80 per cent than at those below this level.

3.2.4.2 Development and mortality of pupae and rate of moth emergence

Bishara (1934) discovered that moth emergence occurred at all relative humidities ranging from 0 to 100 per cent, with the highest emergence at 100 per cent relative humidity. He observed that relative humidity greatly affected moth emergence with the highest rate at 90 and 100 per cent relative humidity and the lowest at 30 per cent.

Rivnay and Meisner (1966) found that pupal mortality was little affected by relative humidity although there was an increase at 32 per cent and a large decrease at 35 per cent.

3.2.4.3 Morphological state of emerged moths

Nasr (1963a) observed atrophied wings on many adults that developed at high or low humidities. Sixty per cent of relative humidity produced the highest percentage of normal adults.

3.2.4.4 Fecundity of adults

Rivnay and Meisner (1966) found that pupae kept at 76 per cent relative humidity produced the lowest percentage of barren females (including those laying only non-viable eggs); and the number became progressively higher at humidities above or below this.

Relative humidity during the pupal stage had no significant effect on the number of eggs laid by the resultant females except that more eggs were laid by females from pupae kept at 76 per cent relative humidity than by those kept at other degrees of humidity. Females from pupae kept at over 95 per cent relative humidity laid significantly fewer viable eggs.

3.2.4.5 Adult longevity

Rivnay and Meisner (1966) found no appreciable difference in longevity between males and females. Adults from pupae kept at 95 per cent relative humidity had the shortest life-span. Those with the longest mean life-span came from pupae kept at 76 per cent.

3.2.5 Adult stage

3.2.5.1 Fecundity

Nasr (1936b) determined that the percentage of females laying viable eggs was highest at 70 per cent relative humidity and lowest at 0 per cent. The number of eggs laid increased with increasing relative humidity. Nasr et al. (1974) verified this tendency.

3.2.5.2 Longevity

Nasr (1963b) and Nasr et al. (1974) observed that, in general, longevity of adults increased with increased relative humidity.

3.2.6 Observations by Bishara (1934) concerning the response of the insect to moisture

Bishara (1934) noted very marked insect response to moisture, for example, on the same farm at the same time, newly watered fields attracted more moths than unwatered (dry) fields. In upper Egypt, only those fields with excess water such as those near canals or special irrigation pumps were likely to be attacked.

Concerning distribution of the cotton leaf worm in Egypt, Bishara said that although the pest is mainly active in summer, regions of fairly high humidity and mild temperatures are much more favourable to it than dry hot regions.

3.3 Temperature and relative humidity

3.3.1 Behaviour of larvae and adults

From field and laboratory investigations of larvae and adults on cotton at Cairo, Hassan et al. (1960) concluded that comparatively cool and humid weather at night induced movement and feeding activity by larvae. Moths emerged at night.

Most of them rested during the day, but at night the increase of relative humidity and decrease of temperature induced flight activity. Feeding on nectar of flowers took place shortly before sunrise.

Most adults mate on the night of emergence, and about one half of the mated females lay their eggs on the same night. Oviposition occurs during a period of two hours before sunrise.

3.3.2 Infestation of berseem fields

Abul-Nasr and Naguib (1969) studied population density of larvae and pupae of the cotton leaf worm in berseem fields in Giza and Sakha in middle and northern Egypt, respectively. They found a definite relation between air temperature and humidity and the degree of infestation in berseem. For example, peak infestation in autumn occurred when the daily mean temperature was around 23°C and the daily mean relative humidity around 60 to 65 per cent.

3.3.3 Virulence and incubation period of polyhedrosis virus disease

In Egypt, a polyhedral virus disease attacks larvae of the cotton leaf worm and sometimes causes high mortality. Abul-Nasr (1956) studied the effect of temperature and relative humidity on the virulence and incubation period of the disease. High temperatures and high relative humidities increased virulence and shortened the incubation period of the pathogen.

3.4 Soil moisture

Nasr et al. (1960) studied in the laboratory the effects of soil moisture on pupation and moth emergence. Light clay soil containing 30, 20 and 10 per cent moisture content, and air-dried soil were used. They chose these moisture gradients because soil moisture in the field ranges from 10 to 30 per cent between successive irrigations.

3.4.1 Pupation

Soil with 20 per cent moisture content favoured pupation the most, while larvae pupated less frequently in dry soil and in soil with excessive moisture.

The depth at which fully grown larvae pupate depends on the soil moisture. In dry soil, larvae pupate near the soil surface at a depth of about one centimetre, while they tend to go slightly deeper in moist soil. Excessive moisture in the soil prolongs the pupal stage.

3.4.2 Moth emergence

Soils with 10 and 20 per cent moisture content have highest rates of moth emergence. Air-dried soil is least favourable to moth emergence. The results agree with Bishara's (1934) view that excessively dry clay soil mechanically hinders emergence.

3.5 Wind

Bishara (1934) found adults to be strong fliers, judging by their choice of fields for oviposition distances away from breeding grounds. Rivnay (1961) suggested that the insect was migrant, since the number of adults could increase abruptly and moths have been caught in places where they could not have developed locally due to lack of host plants. He stated that peak infestation years in Egypt (1915, 1930 and 1931) were also invasion years of the desert locust. Israel suffered locust invasions in 1954 and again in 1958 and 1960, when heavy infestation of the cotton leaf worm also occurred.

Rainey, in 1951, suggested downwind movement of the desert locust and later established this concept in 1963. Abrupt increase of cotton leaf worm adults may be explained, partly at least, by meteorological conditions, for example, air currents and below average air temperature during the critical period (Hosny and Iss-hak, 1967). Simultaneous infestation by desert locust and cotton leaf worm in the same years warrants critical study of meteorological data as well as of insect distribution, both locally and in surrounding countries. Study of cotton leaf worm migration is important for the prevention of outbreaks.

3.6 Light traps

Results of light-trap studies at Giza, in middle Egypt, by Hosny and Khattab (1960) and by Wafa and El-Borollossi (1962) did not reveal any conspicuous relation between fluctuations in catch and temperature, although most numbers increased with temperature in autumn and spring. Relative humidity had little effect. Catch decreased as night-time mean wind speed increased.

3.7 General discussion and conclusions

Observations by Bishara (paragraphs 3.1.6 and 3.2.6) concerning effects of air temperature and moisture on distribution of the pest in Egypt generally agree with laboratory studies.

Harmful effects of moisture on the cotton leaf worm are the basis of a cultural control programme in Egypt, i.e., prohibiting the irrigation of berseem after 10 May. The worm's feeding in May is limited to berseem since there is no other suitable food. Pupae of this generation produce moths that attack cotton in June. Naguib and Nasr (1962) found that the worm was more abundant in berseem fields irrigated after 10 May than in fields not irrigated. Similar methods may be useful in other countries where the cotton leaf worm is prolific.

The study of low temperature storage of eggs (Hussey and Gostick, 1964) is another example of how relationships determined between insects and meteorological factors can suggest control measures.

Hosny and Iss-hak (1967) discovered a relationship between severity of attack of the cotton leaf worm and mean air temperature during a certain critical period which could serve as a useful statistical approach for practical control. Similar methods may prove useful when forecasting the time of pest incidence. The work of Hosny and Iss-hak shows the importance of field studies. Such results could not be obtained through laboratory studies which are generally concerned with specific constant temperatures and humidities. Although no micrometeorological measurement was made in the insect environment, this would be useful in a study of the relationship between the insect and the micrometeorological factors directly affecting it.

One method of cultural control is to produce cotton early. In Egypt, yield increases the earlier cotton is sown (El-Qorashi, 1958). Determining suitable planting dates is partly a meteorological problem since yield depends on meteorological conditions during an entire season. A full study would require micrometeorological measurements and phenological observations of both crop and insect throughout the year.

3.8 Recommendations for control

(a) Improvement of meteorological assistance for pest-control measures will depend on more accurate and detailed information of the relationship between meteorological factors and insect life. Micrometeorological and statistical field studies could be usefully integrated with laboratory work;

(b) In order to facilitate better control, studies relating to pest outbreaks and meteorological factors, especially temperature, are recommended in countries concerned;

(c) Also recommended is the application of a quarantine method to those plants in the Mediterranean area which are subject to insect oviposition (such as chrysanthemum), by maintaining them at low temperatures (1.7°C or less) for ten days, thus preventing the insect from spreading into north-western Europe through the florist or nursery;

(d) It is recommended to profit by planting cotton early so as to escape adverse effects. Observation of micrometeorological elements, as well as phenological observations of both crop and insect are recommended for the determination of most suitable dates;

(e) Countries where the pest is prolific should consider control measures by creating unfavourable conditions through low soil moisture, i.e. prohibiting irrigation of berseem or other host plants after a certain date;

(f) Migration of the pest should be studied in relation to meteorological factors by applying methods similar to those for the desert locust. Thus simultaneous pest and synoptic meteorological data will be required from a number of neighbouring countries for a determined period of time. Attempts should be made to interpret changes in pest distribution in terms of changes in low-level wind speed and direction;

(g) The effect of temperature on larvae exposed to different insecticides should be studied in countries where the pest is prolific. Such studies would help selection of suitable insecticides for different regions with different temperature régimes.

CHAPTER 4

PINK BOLLWORM - GEOGRAPHICAL DISTRIBUTION, LIFE CYCLE AND CONTROL

4.1 Geographical distribution

According to the "Distribution Maps of Insect Pests" published by the Commonwealth Institute of Entomology, London, the pink bollworm is known in the following countries:

Europe : Cyprus, Greece, Israel, Italy, Sicily and Yugoslavia.

Asia : Burma, China, Democratic Kampuchea, Democratic Yemen, India, Indonesia, Iran, Japan, Jordan, Korea, Pakistan, Philippines, Sri Lanka, Thailand, Turkey and Viet Nam.

Africa : Algeria, Chad, Egypt, Ethiopia, Ivory Coast, Kenya, Libyan Arab Jamahiriya, Madagascar, Malawi, Morocco, Nigeria, Somalia, Sudan, Togo, Uganda, United Republic of Tanzania, and Zaire.

Australia and Pacific Islands : Australia, Fiji, Hawaii, New Britain, New Caledonia, New Guinea, New Hebrides, Society Islands and Somoa.

America, North : Mexico, United States of America (Arkansas, Arizona, New Mexico, Oklahoma and Texas) and the West Indies.

America, South : Argentina, Bolivia, Brazil, Colombia, Ecuador and Venezuela.

In Western Australia, pink bollworms caused considerable damage to cotton during the season of 1960/1961. Clean-culture, especially prompt destruction of plant material after harvest, is perhaps responsible for lower counts of the insect in recent years. Introduction, in 1965/1966, of ratoon cotton increased its propagation but it has not been a major pest since.

In Uganda, however, it is gradually becoming an important economic handicap. The worm is also one of the major yield-reducing insects of cotton in the western states of Nigeria.

The pink bollworm is also destructive in many states of India. In northern India, two distinct life cycles are found. One, during which caterpillars feed and pupate, is short; then moths emerge within 30 to 40 days. The other is long, with six to eight months of hibernation in larval stage, usually from

November/December to May/June, before pupation and moth emergence. Generally, from four to six generations develop between July and November. Although the pest is found in all cotton growing areas of Pakistan, it is more serious in Multan, Baha Bahawalpur and parts of Sind.

4.2 Life cycle

The pink bollworm undergoes four stages of development: egg, larva, pupa and adult. Much of the following information on its life cycle is from Noble (1969). In mid-summer, in areas where the cotton growing seasons are long, the life cycle may be completed in 25 to 30 days and there may be four to six generations a year.

4.2.1 Eggs

Incubation lasts four to five days in mid-summer. Eggs may be distributed over all parts of the cotton plant, but most are laid on the fruiting forms of cultivated varieties.

4.2.2 Larva

The pink bollworm has four larval instars. The fourth instar has the deep pink appearance for which the insect is named. A cyclindrical, fully grown larva is about 2.5 mm in diameter and 11 to 13 mm long. Pink bollworm larvae usually infest bolls twenty days old or more. A larval entrance hole, which may be anywhere on the surface, is easily discernible with the naked eye. After feeding is completed, the non-diapause larva cuts a round exit hole in the carpel through which it crawls and then drops to the ground. Some diapause larvae exit in this manner to spin a cocoon for their winter stay.

4.2.3 Cocoon and pupa

The non-diapause larva spins an elongated, loose-fitting cocoon in which it pupates, while the diapause larva usually spins a closely woven, tight-fitting spherical cocoon which it abandons before pupating; it then may either spin a loose elongated one or pupate naked. Pupa are about 6 to 8 mm long by 2.5 mm at their widest part.

4.2.4 Adult

Adults have a wing-spread of 15 to 20 mm. Moths emerge early in the spring and summer from over-wintered larvae, and live from ten days to two weeks during mid-summer, and longer during cooler weather. Moths hide under objects on the soil, or in soil cracks during the day and become active for mating and egg-laying at night.

4.3 Diapause

One of the most interesting and important facets of the pink bollworm's life history is the ability of some larvae to spend the period of a diapause in a fully fed state. This period is termed "the resting stage" of the long cycle. The insect inhabits a wide geographical range undoubtedly because of this ability to enter diapause before onset of unfavourable environmental conditions. Moisture helps to break diapause and larvae have been found to live as long as two and a half years but, in the field, the insect has never been found to survive a second winter.

4.4 Means of spread

Because the diapause larva habitually remains in the seed where it developed, the insect is easily dispersed by man. It is transported in cotton seed, lint, mechanical cotton pickers, oil mill products and other items subject to contamination by infested seeds.

Moths collected on aircraft during flights, or in light traps, as well as those observed on isolated plantations demonstrate the insect's long-range movement.

4.5 Damage

Larval feeding in bolls lowers lint and seed quality and reduces yield (in weight). During heavy infestations, seed cotton loss is most felt; but reduction in quality may also be very important and usually happens when the infestation is too low to appreciably reduce yield.

A given degree of infestation causes more damage in an area with heavy rainfall and high humidity than in a dry area, since the result shows more boll rot. Rain helps organisms that cause rot to enter green bolls through larval exit holes, and moisture favours their development. As a result, many infested bolls do not open and the number of hard locks in those that do open is increased in wet areas.

4.6 Control measures

Most of the following information is from Noble (1969).

4.6.1 Chemical control

Satisfactory control has been achieved through contact with insecticides which kill the adult as well as the newly hatched larvae. DDT was the first highly effective insecticide. Others were effective but for one reason or another were not used. The pink bollworm has acquired a high resistance to DDT in some areas, for example the Terreon area of Mexico, and to a lesser degree in several localities in Texas. Field experiments near Torreon showed that DDT alone was no longer effective against the insect but that azinphosmethyl, carbaryl and other insecticides were excellent.

Good control can be obtained with insecticides applied when needed, as shown by infestation counts. Chemical treatment should begin in a field as soon as the spring count shows 350 or more larvae per acre inside the flowers. When less larvae are found, further inspection may be delayed until the first bolls are four weeks old. After that time, treatment should be started when two to fifteen per cent of the bolls are infested. Once treatment begins, scheduled applications should be continued.

Experiments at Brownsville, Texas, indicated that soil treatment with various chemicals effectively reduced the over-wintering pest population but was too expensive for practical use. Recent laboratory investigations in Arizona (Watson, 1968) gave encouraging results when the soil was thoroughly wetted following larval penetration and establishment.

4.6.2 Cultural control

Even with present-day insecticides, practical control of the pink bollworm is mainly dependent on cultural practices. These include production of an early crop in the shortest period possible; early harvest; prompt shredding and clean-up after harvest; early deep ploughing; and winter irrigation. The pest is especially vulnerable to this control régime since it spends the winter in crop residues in the field where it develops.

The main objective of cultural practices during the cotton-production season is to shorten the season to minimize pink bollworm damage and still permit satisfactory yield and profit. This objective involves selection of planting date and cultural practices designed to hasten crop maturity.

Many moths emerge from over-wintered larvae, early in the spring, and die before cotton squares become available for pink bollworm reproduction. This is known as suicidal emergence and it increases with the delay in planting. However, planting date experiments have indicated that delay in planting may increase the diapause larval population at harvest time. Bolls formed in the first part of the season escape severe damage as they mature before pest infestation builds up to its maximum intensity. Early cotton planting is, therefore, recommended. Agronomists report that cotton should not be planted until the daily minimum soil temperature at a 20-cm depth averages 15.6°C, or above, for the preceding ten days. Lower temperatures retard germination and seedling growth, increase incidence of seedling disease, and expose young plants to early-season insects for a longer period. Under conditions favourable for plant growth, upland cotton will mature sufficiently for chemical defoliation (which further hastens maturity) within 125 to 150 days of planting, so that it may be harvested within 160 days. Thus, there is sufficient time for maturing and harvesting before the pre-frost destruction of stalks, a recommended cultural practice. Pre-harvest chemical defoliants, in addition to hastening maturity, prevent plants from bearing fruit and make them unattractive to the moths to oviposit.

CHAPTER 5

EFFECTS OF METEOROLOGICAL FACTORS ON BIOLOGICAL PROCESSES OF THE PINK BOLLWORM

5.1 Air temperature

Optimum air temperature for the various stages of pink bollworm growth and development is about 25 to 28°C. Temperatures above or below tend to reduce survival. Higher temperatures shorten longevity and death is common at 40°C. Larvae can tolerate some near-freezing cold for short periods, if preconditioned by cool weather. Prolonged periods near freezing, or brief extreme cold snaps, induce high mortality which is intensified by increasing relative humidity.

5.1.1 Egg stage

5.1.1.1 Egg incubation period

El-Sayed and Abd El-Rahman (1960) noted that the average incubation period decreased with increasing temperature. Increase in the incubation period with drop of temperature was much more pronounced at lower than at high temperatures (see Figure 5). Plotting temperature against the hatching percentage (Figure 6), illustrates that the hatching percentage is rather high at temperatures ranging from 22 to 30°C in all relative humidities. The hatching percentage decreased steeply above or below this range. The most favourable temperature was 25°C, at which the greatest hatching and least mortality occurred.

5.1.1.2 Effect of high temperature on hatch

Guerra and Ouye (1968) found that exposure of eggs to temperatures of 46.1°C or above for 30 minutes reduced hatch to about 83 per cent of its value at 26.7°C. A temperature of 43.3°C did not influence the hatching-out of eggs exposed for four hours.

Fye and Surber (1971) observed that two exposures at 35°C with ten to twenty per cent relative humidity for 16 hours or more, and one or more exposures at 40°C for 16 hours or more, greatly reduced hatch.

5.1.2 Larval stage

5.1.2.1 Duration and mortality

El-Sayed and Abd El-Rahman (1960) reported that the four larval instar periods shorten with increasing temperature and increase with increasing instar order (see Figure 7).

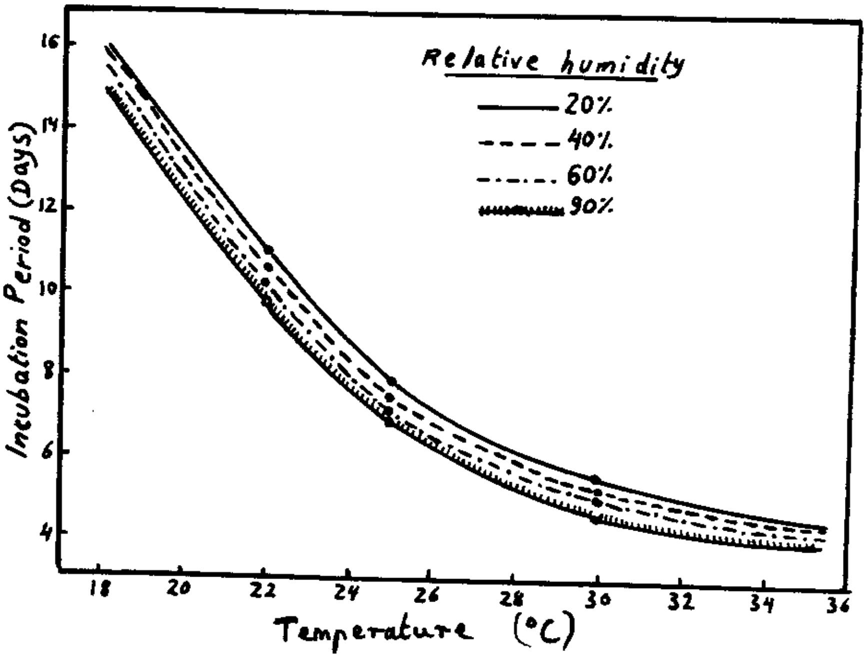

Figure 5

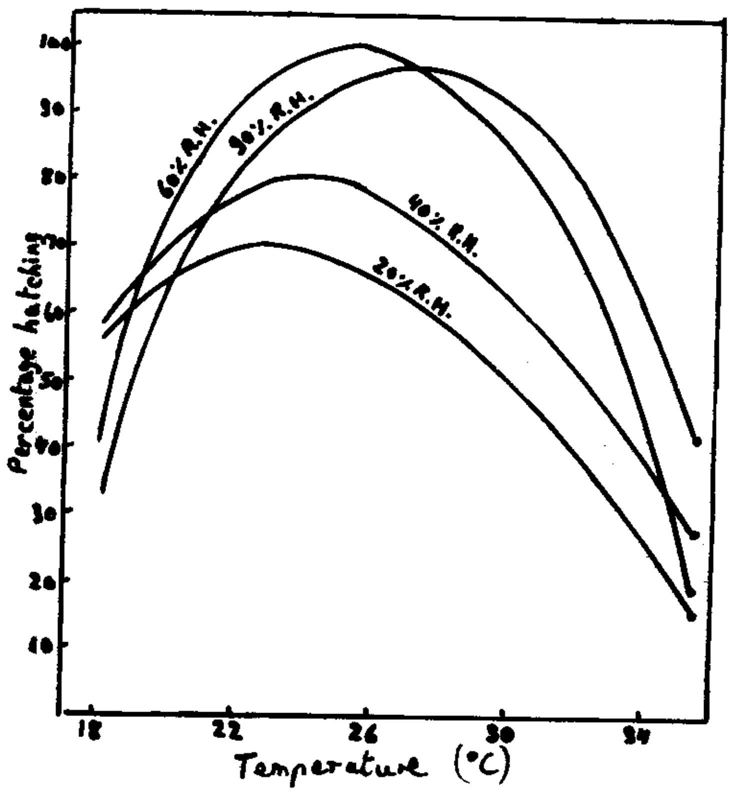

Figure 6

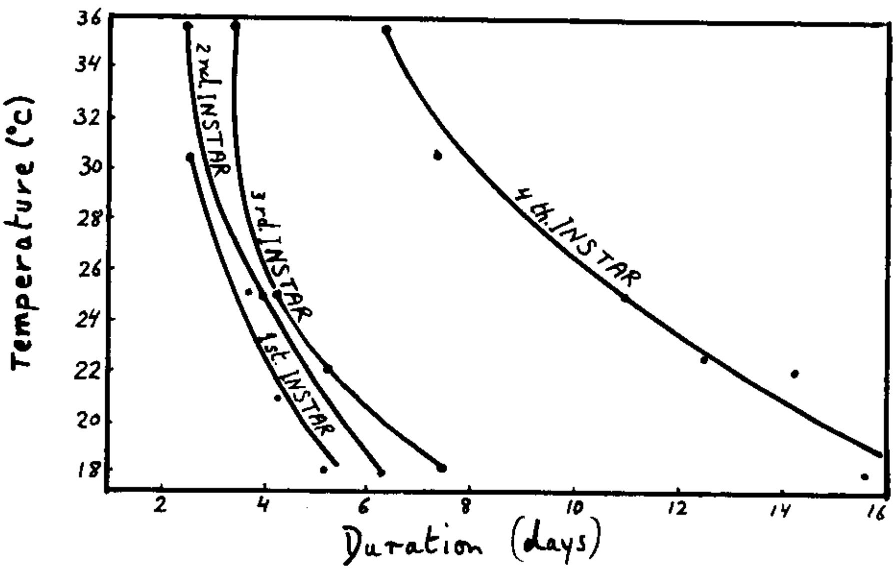

Figure 7

The mortality rate was lower with increased instar order. Average percentage of mortality for the four instars decreased with increase in temperature until 25°C, where it reached minimum value; then mortality increased with increasing temperature. At 40°C, mortality was complete in all larval instars.

5.1.2.2 Onset of diapause

El-Sayed and Rustom (1960a) concluded that the percentage of larvae entering diapause decreased appreciably with increase in temperature. At 13°C, little pupation took place. This temperature seemed to lie at or below the threshold of development of larvae.

In early research on the insect, the rapid increase in proportion of larvae entering diapause as the season advanced, in late summer and fall, was attributed to seasonal change in temperature. Laboratory and field studies by Lukefahr et al. (1964) indicated that diapause was controlled primarily by photoperiod, with temperature and bollworm diet exerting secondary effects. They found that cool weather may induce diapause under a photoperiod otherwise conducive to pupation.

5.1.2.3 Fluctuating temperature and diapause induction

Menaker and Gross (1965) found a higher incidence of diapause in larvae reared in continuous darkness on 24-hour temperature cycles with diurnal variation, than in those reared in continuous darkness at a constant temperature equal to the daily mean.

5.1.2.4 Termination of diapause

Metwally and Hosny (1972) observed that, of three constant temperatures studied, 26°C was the most favourable to induce pupation.

From constant temperature studies, Watson et al. (1973) learned that 13.9°C was below the threshold of insect development under both wet (contact moisture) and dry (about 50 per cent relative humidity) conditions and that 15.6°C was favourable only under wet conditions. The higher temperatures are more favourable to pupation and adult emergence than the lower temperatures.

5.1.2.5 Average duration of the diapause larvae

El-Sayed and Rustom (1960b) noted that, generally speaking, the average duration of diapause decreased with increasing temperature at an age in that stage. At the same time the average duration of diapause in older larvae was much lower than that of younger larvae. Temperature proved to be more influential than fat content in terminating the resting stage.

5.1.2.6 Low temperature in autumn and winter and survival of over-wintering larvae

Laboratory studies by Noble (1969) and an experiment he conducted in a bioclimatic cabinet indicated that survival was not only affected by the extreme minima but greatly reduced by long periods in which the maxima are about 4.4°C. Diapause larvae stored for experimental use may be held for a long period under dry conditions at about 12.8°C. A high mortality would occur within a month at a refrigerator temperature of approximately 3.3°C.

5.1.2.7 Results of field work

Chapman et al. (1960) determined that in autumn a sudden drop in temperature sufficient to freeze succulent bolls results in almost a 100 per cent death of larvae in green bolls, whereas death is negligible if light frosts persist for several days before sub-freezing temperatures.

Survival of the insect under winter temperatures with a minimum below -17.8°C was demonstrated near arid El-Paso, U.S.A. The wide fluctuation in winter survival during eight years of experiments there was attributed to low temperatures.

5.1.2.8 Mortality of larvae injected with Bacillus thuringiensis Berliner

Laboratory, field cage and small plot tests showed that this pathogen was effective in reducing over-wintering and summer populations of the pest, but only at application rates too high for practical use as a control measure.

Ignoffo (1962) found that 40.1°C was the optimum temperature for killing larva injected with the pathogen. Optimum germination and generation temperatures for the pathogen were 51.2°C and 31.1°C respectively.

5.1.3 Pupal stage

5.1.3.1 Duration and mortality

El-Sayed and Abd El-Rahman (1960) observed that the pupal period decreased with increasing temperature. The rate was much more pronounced at lower temperatures than at higher ones. Mortality was lower compared to other stages; it decreased gradually to zero when temperatures increased from 18 to 25°C and then increased as temperature increased to 35.5°C.

5.1.3.2 Cooling effects on moth emergence, longevity and fecundity

Hussein et al. (1962) concluded that exposure of pupae to 9°C under 78 per cent relative humidity for 12, 24 and 30 days gradually decreased the percentage of emerging moths and gradually decreased moth longevity.

Richmond et al. (1972) found that exposure of pupae five to seven days old to 10°C inhibited adult emergence during the exposure period, and it affected the adults adversely when it lasted for longer than one day. When pupae were exposed to 15.6°C for more than one day, appreciable emergence occurred during the exposure period but fecundity was reduced when exposure lasted seven days.

5.1.4 Adult stage

5.1.4.1 Emergence from over-wintering larvae

Brazzel and Martin (1959) found from hibernation experiments using field cages in central Texas, that mean temperatures below 21.1°C immediately reduced the number of emerging moths. Figure 8 shows this and also the effect of rainfall on adult emergence.

Fife (1961) studied factors influencing adult emergence from over-wintering larvae in open cotton bolls in central Texas. He noted that major peaks of emergence occurred usually 16 to 25 days after 2.4 cm or more of rain had fallen on one or more days. The number of days between heavy rainfall and high peaks of emergence decreased as the temperature increased.

5.1.4.2 Longevity

Fenton and Owen (1953), El-Sayed and Abd El-Rahman (1960), Hussein et al. (1962) and Graham et al. (1967) found that longevity decreased with increasing temperature. Hussein et al. determined that females lived a little longer than males. However, Graham et al. discovered little difference in longevity of the sexes. Their range of longevity for females was appreciably longer than that of Hussein et al. Moths were reared on natural host material in the study of Hussein et al., while they were reared from larvae on artificial medium in the study of Graham et al. This could explain different results.

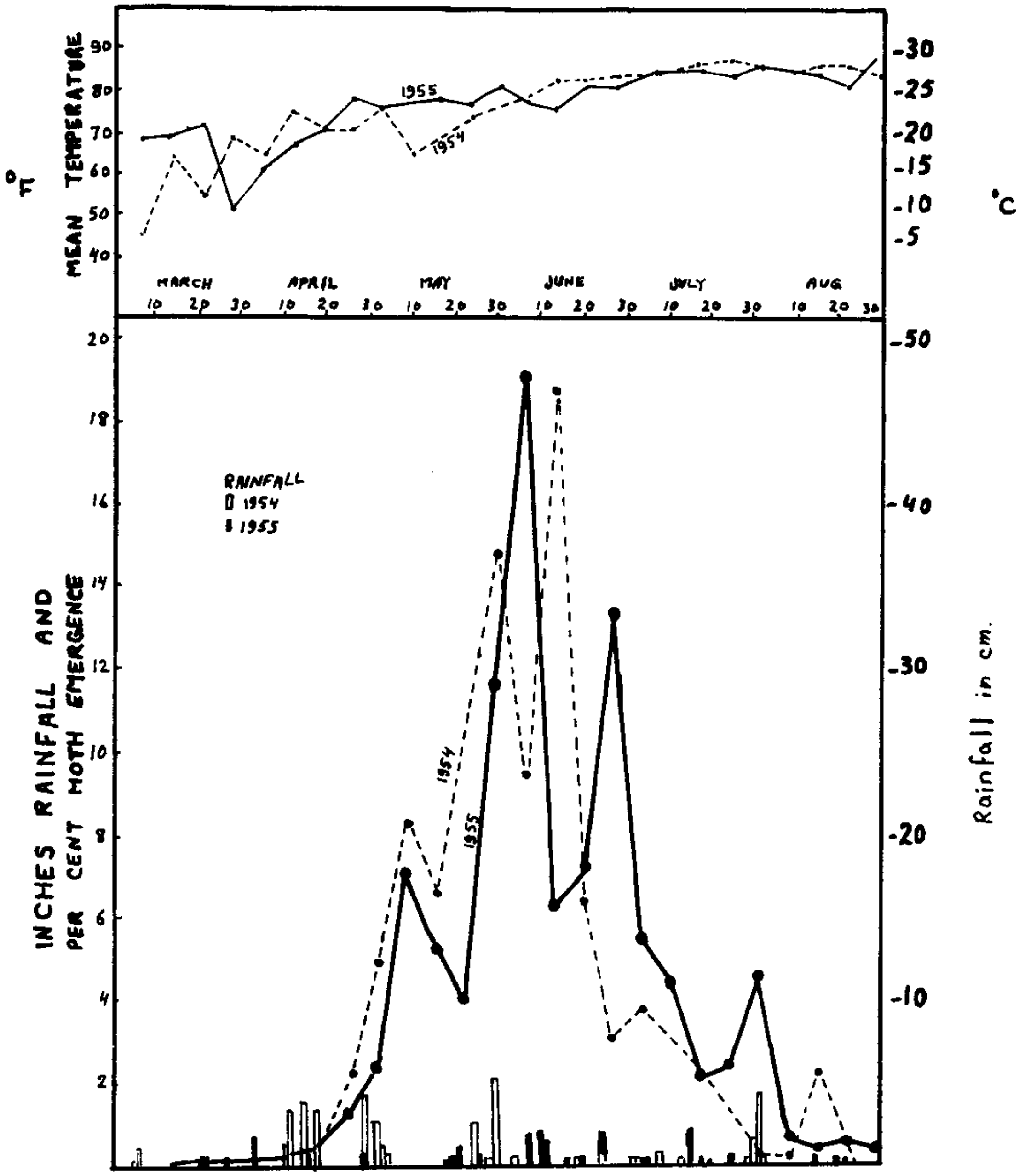

Figure 8

Richmond et al. (1972) observed that, when adults were kept at 15.6°C for one, three or six days, the life span for both males and females increased as the exposure time increased. When adults were kept at 10°C, the life span of females showed the same trend but that of males generally decreased as exposure time increased.

5.1.4.3 Fecundity

El-Sayed and Abd El-Rahman (1960) determined that 35.5°C was unfavourable for oviposition, and females seemed to be sterile at this temperature. Best oviposition resulted in the range of 22 to 30.5°C and the most favourable temperature was 25°C. Oviposition was very much reduced at 18°C. Hussein et al. (1962) demonstrated that fecundity increased between 18 to 22°C.

Graham et al. (1967) discovered that few eggs were produced and the percentage of non-reproductive females was high at temperatures above 32.4°C and below 18.3°C.

Noble (1969), summarizing results of research in the United States, stated that egg deposition was sharply reduced below 21.1°C and that it practically ceased at 15.6°C. Noble's report, as well as the work of El-Sayed and Abd El-Rahman (1960), lends support to a field study by Chu (1959) who found that the optimum temperature for egg-laying was from 22 to 30°C with none occurring below 20°C or above 31°C.

5.1.4.4 Effect of storage at 10°C on mating, fecundity and fertility

Richmond et al. (1972) found that when adults were exposed to 10°C for six days, mating, fecundity and fertility were affected adversely.

5.1.5 Effect of daily exposure to high temperatures on development, fecundity and fertility of larvae, pupae and adults

Fye and Poole (1971) noted that daily exposures of larvae, pupae and adults for two, four and eight hours at 35°C decreased the development period as the exposure increased, but fecundity and fertility were not affected. However, exposure at 35°C for 16 hours did reduce both fecundity and fertility.

Daily exposure of larvae, pupae and adults for two, four and eight hours at 35°C decreased the development period. Exposure for eight hours increased the development period and reduced fecundity and fertility. When larvae and pupae were exposed to 40°C for 16 hours, development was poor and fecundity and fertility were drastically reduced. Adults exposed to 40°C for 16 hours had reduced fecundity and fertility.

5.1.6 Duration of life cycle

El-Sayed and Abd El-Rahman (1960) reported that duration of the life cycle (from egg to emergence of adult) decreased with increasing temperature. Of the temperatures used, the most favourable appeared to be 25°C, at which the maximum number of eggs were laid and the immature stages had the least mortality. Figure 9 shows the effect of temperature on duration of different life-cycle stages. Figure 10 shows the effect of temperature on mortality during early stages.

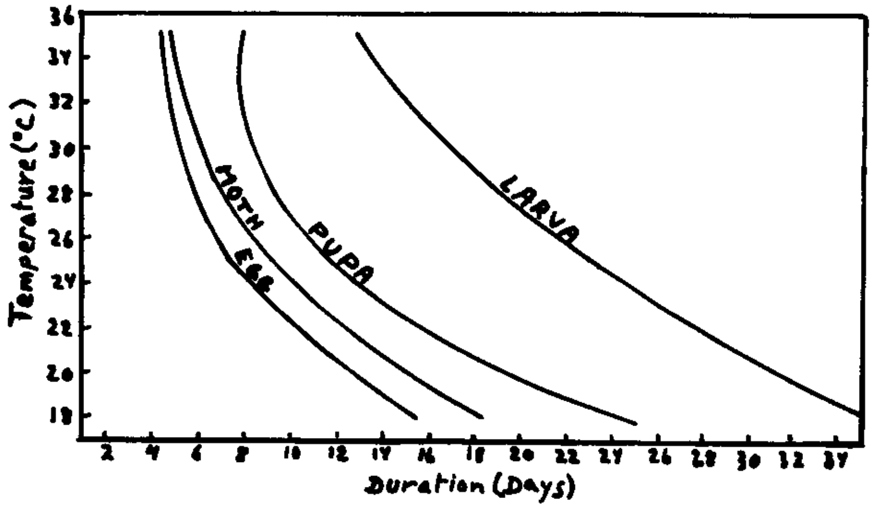

Figure 9

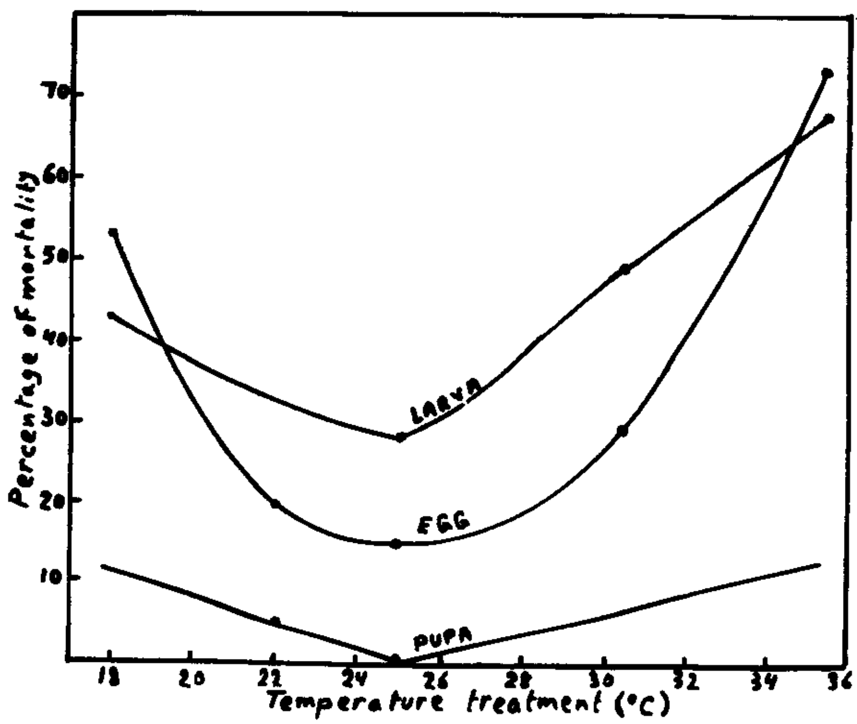

Figure 10

5.1.7 Population growth

Philipp and Watson (1971) studied in the laboratory the influence of various temperatures on population, using temperatures typical of the growing season in the Salt River Valley, Arizona, U.S.A. They selected three constant temperatures to correspond with average temperatures; and three truncated temperatures averaging the same as the constant temperatures in approximate field conditions. The authors concluded that the intrinsic rate of increase and the net reproduction rate were greatest and the mean generation time shortest at a constant temperature of 28.3°C. A constant 32.2°C régime was the most detrimental to population increase. Results from the lowest constant temperature (23.9°C) were intermediate.

5.2 Relative humidity

High relative humidity favours egg hatch and, depending on photoperiod, induces rapid termination of diapause and pupation. Longevity increases with increasing relative humidity.

5.2.1 Egg stage

Hatching

Adkisson (1959) learned that the percentage of hatched eggs was larger at high relative humidities than at low ones. El-Sayed and Abd El-Rahman (1960) also observed that hatching increased with increasing relative humidities (see Figure 6) while the incubation period decreased slightly (see Figure 5).

5.2.2 Larval stage

5.2.2.1 Onset, duration and termination of diapause

El-Sayed and Rustom (1960a) found that relative humidity had negligible effects on the onset of diapause; and again (1960b), they confirmed that effects were negligible on duration and termination of diapause.

On the other hand, Wellso and Adkisson (1964) observed that, under two photoperiod régimes (14 or 16 hours and 8 or 12 hours) at 20°C and 27°C respectively, larvae matured in 100 per cent relative humidity, terminated diapause and pupated more rapidly than larvae kept in 65 per cent relative humidity.

5.2.2.2 Mortality of the larvae injected with Bacillus thuringiensis Berliner

Ignoffo (1962) found that relative humidity had little effect on the mortality of injected larvae.

5.2.3 Pupal stage

Pupal period

El-Sayed and Abd El-Rahman (1960) noted that, in general, the pupal period was slightly longer in lower relative humidities than in higher ones.

5.2.4 Adult stage

5.2.4.1 Adult fecundity

Lukefahr and Griffin (1957) determined that relative humidity had a negligible effect on the rate of oviposition. Hussein et al. (1962) reported that average fecundity of long-cycle moths decreased with increasing relative humidity.

5.2.4.2 Adult longevity

Fenton and Owen (1953), El-Sayed and Abd El-Rahman (1960), and Hussein et al. (1962) concluded that adult longevity increased with increasing relative humidity. In the last work, the average longevity was generally higher for males than for females. Longevity of short-cycle moths was longer than that of long-cycle ones.

5.3 Air temperature and relative humidity

Moth emergence and oviposition (in India)

Work in India has shown that average day temperatures of 23.9 to 26.7°C with 60 to 80 per cent humidity during emergence of long-cycle moths encouraged rapid multiplication. Hot, dry weather during July to October increased sterility in males and delayed emergence of long-cycle moths, reducing the number of broods to one.

Oviposition was highest when pupae were exposed to a maximum temperature of 32.2°C and minimum temperature of 22.2°C with 70 per cent mean relative humidity.

5.4 Effects of aqueous submersion

5.4.1 Larvae and pupae

Ohlendorf (1926) reported that insect populations were reduced in flooded cotton fields. Laboratory investigations by Clark and Richmond (1962) on larvae and pupae showed that death occurred more rapidly with increasing water temperature and that it influenced diapause larvae more than non-diapause larvae.

5.4.2 Hot-water treatment of infested cotton seed

Clark (1957) found that the hot-water treatment sometimes used to hasten germination of American/Egyptian cotton was effective in killing larvae in infested seeds.

5.5 Soil temperature

5.5.1 Laboratory studies

5.5.1.1 Diapause and non-diapause larvae buried in the soil

Richmond and Clark (1965) studied the effects of soil temperature, soil moisture and soil type on larvae buried in the soil. Conditions studied were combinations of three soil temperatures (8.5, 29.0 and 28.0°C); three moisture levels (dry, one-half field capacity and field capacity) and three soil types.

Active and diapause larvae had, in general, the same reactions except diapause larvae reacted more slowly. Greatest larval movement occurred in dry soils at 29.0°C. The most favourable combination for larval survival was 29.0°C, and soil moisture at one-half field capacity. Consistently high temperature was detrimental, particularly above 38.0°C. Temperature and high soil moisture were inter-related and the mortality rate increased with corresponding increases of these two factors (see Figure 11). Temperature and median lethal time were inversely inter-dependent; the lower the temperature, the longer the time required to cause any adverse effects.

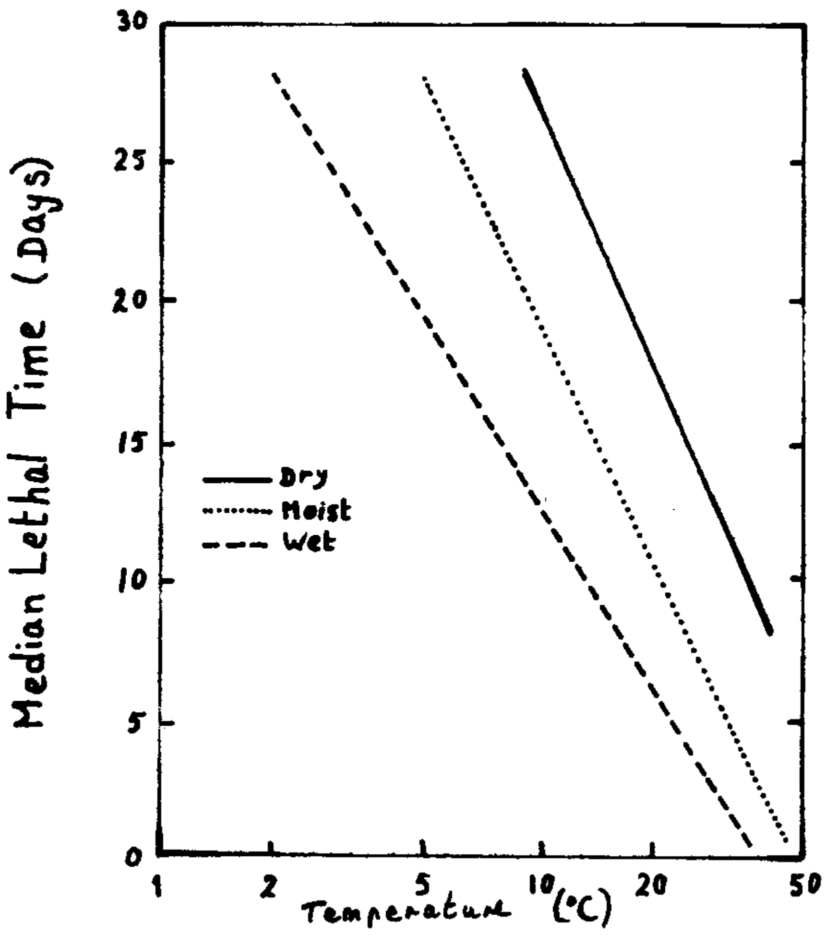

Figure 11

5.5.1.2 High soil temperatures and mortality of mature larvae

Larvae are unprotected while they leave cotton bolls and enter the soil to pupate. Fye (1971) observed that dry soils and high soil temperatures caused considerable death. Mortality increased with increase of soil temperature and length of exposure. Mortality in wet soil was not so rapid as in dry soil. Discontinuous exposure generally caused higher mortality than continuous exposure for the same length of time.

5.5.1.3 Survival of diapause larvae in buried bolls

Fife and Graham (1966), from climatic cabinet studies, found that in moderate soil temperatures representing areas of generally high winter survival, the death rate was higher in moderate soil moisture than in low soil moisture. In low soil temperatures, representing areas of generally low winter survival, low survival occurred at both levels of soil moisture and with no significant difference. The authors concluded that, in the northern areas of pest propagation, the influence of low soil temperature on survival was so great that the effect of high moisture could be insignificant.

5.5.2 Field studies

5.5.2.1 High temperatures and mortality of diapause larva

Chapman et al. (1960) noted that, in Texas, when soil surface temperatures ranged from 50.6 to 68.3°C in autumn there was high mortality of diapause larvae in bolls remaining on the soil surface after pre-frost shredding of stalks.

5.5.2.2 Seasonal activity of buried diapause larvae

Fife and Graham (1965) studied seasonal activity of diapause larvae buried in field cages under different soil moisture conditions in central Texas. Activity was based on the number of larvae burrowing to the soil surface, which increased appreciably in the spring with warm soil temperatures associated with high soil moisture.

5.5.2.3 Diurnal fluctuations and mortality of non-diapause larvae that drop to the soil

Richmond and Clark (1965) considered that repeated diurnal fluctuations of soil temperature had a detrimental effect on larvae. In a single five-day experiment in an outdoor insectary with sandy soil at field capacity, the soil surface temperature varied from 13 to 31°C and mortality was 97.5 per cent.

5.6 Soil moisture

5.6.1 Introduction

Soil moisture was recognized many years ago as a factor for control of the pink bollworm. Williams and Bishara (1925) found that mortality in Egypt increased with increased soil moisture and that no moths emerged in excessively irrigated fields to infest the following year's crop. Nangpal (1937) observed that larvae in buried bolls disappeared at the end of the monsoon season in India, about mid-October, and low survival was probably due to excessive moisture coupled with high post-monsoon temperatures.

5.6.2 Laboratory studies

5.6.2.1 Buried larvae and pupae

Richmond and Clark (1965) learned that high soil moisture, in conjunction with high temperature was very detrimental to larvae and pupae. Larval activity was least, and mortality the most, in high soil moisture. High soil moisture deterred cocoon spinning and greatly reduced the period of time the cocoon protected the larvae.

Both non-diapause and diapause larvae buried in wet soil attempted to seek drier and more suitable environments for pupation and spinning cocoons. The percentage of larvae reaching the surface was low in soils held at field capacity.

Of all the combinations of conditions used, the one most favourable to the larvae was 29°C with soil moisture at one-half field capacity. With this set of conditions, larvae made no attempt to get above the soil surface and little attempt to reach it. In general, more pupation occurred in moist soils.

5.6.2.2 Effect of simulated heavy rainstorms on pupae in the soil

Greenhouse tests by Fye (1973) in Arizona demonstrated that simulated heavy rainstorms killed many pupae in the soil as long as the simulated plant canopy (cut rubber sheeting) did not greatly impede rapidly falling raindrops. Fye believed that mortality caused by the combination of heavy rainfall and high soil temperatures led to the low pest population on Arizona cotton in early summer.

5.6.3 Field studies

5.6.3.1 Winter irrigation and survival of over-wintering larvae

Chapman et al. (1960) conducted field cage experiments on clay soils in arid Texas to study the effect of winter irrigation on survival of buried larvae. Winter burial of infested bolls followed by winter irrigation greatly decreased pest survival and two irrigations were more effective than one. The earlier bolls were buried and irrigated in winter, the lower the rate of survival. Survival also decreased as depth of burial increased. It is therefore apparent that early, deep ploughing coupled with high soil moisture is a major method of pink bollworm control.

5.6.3.2 Spring and summer irrigation and survival of over-wintering larvae

Chapman et al. (1960) reported that spring and summer irrigations favoured pupation. In one experiment spring irrigation doubled the amount of survival.

5.6.3.3 Rainfall and survival of over-wintering larvae

Chapman et al. (1960) observed that effects of rainfall were evident in yearly fluctuations of larvae survival at several localities in Texas. Wet winters decreased survival, while wet springs favoured pupation.

Fife and Graham (1966) studied effects of natural and simulated rainfall patterns on larvae winter survival in field cages at Waco, Texas. They found that survival in buried bolls decreased when soil moisture increased during December/January or February/March. High levels of moisture during April/May had little or no influence on survival, suggesting that reasonable moisture is essential for normal pupation and emergence. Moths emerging from extremely dry soil are often decrepit and malformed. Fife and Graham also reported that, in central Texas, the majority of the over-wintering larvae leave buried bolls and burrow to the soil surface during April and May as soil temperatures rise and soil moisture increases.

5.6.3.4 Rainfall and adult emergence from over-wintering larvae

Brazzel and Martin (1959) showed, by using screen cages, that rainfall in central Texas had a delayed but very pronounced effect on moth emergence, for example an increase in emergence occurred within ten to fourteen days after 1.2 cm or more of precipitation. But emergence always began to drop after a period of two to three weeks without rainfall.

Fife (1961) studied over a six-year period the time and rate of adult emergence from over-wintering larvae in open cotton bolls in two central Texas environments. Two major peaks of emergence occurred in most years, usually 16 to 25 days after 2.4 cm or more of rain had fallen on one or more days. Smaller peaks occurred within the same interval after about 1.2 cm of rain. The greater the rainfall, the higher and longer were the peaks. Increasing temperatures reduced the number of days between heavy rainfall and peaks of emergence. In general, dry conditions in April and June prolonged the diapause period and increased mortality.

5.6.3.5 Rainfall and egg-laying

Chu (1959) studied the effect of weather factors on egg-laying in China. He found rainfall to be the most important factor affecting the number of eggs laid, followed by relative humidity and temperature. Deep conditions favoured oviposition, though too much rain was detrimental.

5.7 Photoperiod

5.7.1 Diapause induction

Data from different regions of the world indicate that larvae enter diapause at more or less the same time at similar latitudes. This suggests insect sensitivity to photoperiod or day length. Bull and Adkisson (1960), Adkisson et al. (1963), Adkisson (1963) and Lukefahr et al. (1964) used bioclimatic cabinets to study the effect of photoperiod on inducing diapause.

Bull and Adkisson (1960) found that a high incidence of diapause occurred when larvae reared on cotton-seed-meal diets were exposed to either short or abnormally long days, but no diapause occurred with a fourteen-hour day exposure. Larvae reared on a wheat-germ medium showed no response, so there is probably a relationship between photoperiod and diet in inducing diapause. Adkisson et al. (1963) also noted that 13-hour day lengths, or less, induced diapause but those of 13.25 hours or more, did not. Diet and temperature may have effects as well. Adkisson (1963) observed that diapause may be prevented if the insect is exposed to short periods of light during the night. To be effective, these must occur at an appropriate time; for instance, periods of one hour, fourteen to sixteen hours after dawn or ten hours after dusk, are most effective.

Lukefahr et al. (1964) studied photoperiod effect on diapause under controlled conditions of light, temperature and humidity. Laboratory and field studies indicated that photoperiod controlled diapause the most, with boll age (or diet) and temperature exerting secondary effects. Photoperiods progressively increasing from 12 to 16 hours, and a constant photoperiod of 14 hours favoured development of non-diapause larvae, whereas decreasing photoperiods and constant ones above or below 14 hours induced larvae to enter diapause. Results listed in the order of ascending proportions can be ranked by constant photoperiods as: 14, 16, 12 and 10 hours. Diapause was induced when the parents emerged in a photoperiod longer than that in which the F_1 progeny developed.

Lukefahr et al. concluded that the diapause habits of the insect, as affected mainly by photoperiod, largely determine its distribution and seasonal abundance. Diapause is generally rare in the equatorial region between 10^{o}N and 10^{o}S, since day length is almost constant throughout the year. Including light before sunrise and after sunset, the photoperiod at the Equator is about 13 hours which corresponds closely to the 14-hour constant photoperiods which produced very few diapause larvae in the laboratory. In areas removed from the Equator, diapause may be initiated or averted by changes in day length. From summer solstice to autumnal equinox, decreasing photoperiod increases diapause. After autumnal equinox, with photoperiods less than 12 hours, nearly all larvae should be in diapause despite temperatures favourable to pupation. This conclusion agrees with results of field studies in other areas by Fife (1956) and Storey (1923).

In latitudes higher than 32^{o}N, the growing season is relatively short and fewer generations develop there than in areas near the Equator. Under such conditions, cotton bolls are not ready for infestation until after 1 July. Due to larval response to photoperiods above 14 hours, to decreasing photoperiods and to cool late-season temperatures of the area, a high percentage of larvae enter diapause before frost.

5.7.2 Reversibility of diapause induction

Bell and Adkisson (1964) studied photoperiodic reversibility of diapause induction and discovered that 8- or 10-hour nights may reverse induction caused by 12-hour dark phases. A 10-hour night was much more effective than an 8-hour night.

5.7.3 Termination of diapause

Wellso and Adkisson (1964) found that laboratory-reared diapause larvae exposed to daily photoperiods of 14 or 16 hours terminated diapause more rapidly than larvae kept 8 or 12 hours at 20°C.

Watson et al. (1973) discovered that a slightly higher pupation occurred in 14-hour days than in 10-hour days. This was more evident under constant-temperature conditions than under fluctuating conditions.

5.8 Wind

Fenton and Owen (1953) noted that moths travel both with and against light air currents near the surface. Light-trap data showed that the greatest number of moths flew into a light-prevailing wind with a speed of 5 km/hr or less (Glick and Hollingsworth, 1956). Wind tunnel experiments by the same workers indicated that moths could not regulate their flight when air speed was above this value. Since most prevailing winds are greater, the moths must be carried by the wind to be dispersed.

Researchers have simulated in the laboratory some of the meteorological conditions which moths would experience during their dispersal, to determine the moth's ability to survive and reproduce after being carried by the wind for long distances. Packchanian and Pinkerton (1955) subjected several insects to barometric pressures corresponding to those at altitudes of 3 000 and 9 000 m; they discovered that low temperature rather than reduced pressure was responsible for detrimental effects. Glick (1967) concluded that if any moths were carried to altitudes as high as 3 000 m they would probably survive, unless exposed to harsh weather conditions, such as rain, hailstorms or severe turbulence. If gravid moths can reach the earth again without meeting unfavourable conditions, they should be able to establish new populations in the new areas.

Glick (1967) reported that, over the United States and Mexico, infestations were conveyed long distances by wind; and in 1947, infestations had spread northward over several counties of Texas and Western Oklahoma, 270 to 400 km away from the infested Texas counties. Ability of the pest to be carried by wind to heights of 900 m over considerable distances makes control very difficult.

5.9 General discussion and conclusions

Temperature is an important factor in pink bollworm epidemiology and control. In areas of China where the minimum temperatures can fall to -20°C, hibernating larvae are killed by the cold and additional control is unnecessary (Fu et al. 1958). Rainfall is also important. It may be useful to study what control measures are needed in association with low winter temperatures and different amounts of rainfall. Results may give some idea of the irrigation needs in arid areas for decreasing survival of over-wintering larvae.

Chapman et al. (1960) reported results of widely separated experiments on winter survival in Texas and Oklahoma. They used field cages and simulated four winter cultural practices under natural rainfall conditions. Climate ranged from subtropical and humid to cold and arid, and cold and wet. Results showed that cultural practices affected survival which varied in different localities largely because of climate. Further studies on interrelationship of cultural practices and different climates would enhance development of control measures.

While Chapman et al. (1960) found that spring irrigation increased pest survival; Fife and Graham (1966) found that high levels of moisture during April and May had little or no influence. Rice (personal communication) has noted that although soil moisture tends to help the insect break diapause and pupate, it also cools the ground and may actually delay moth emergence. Temperature and soil moisture relationships may be useful for forecasting moth emergence, and even for effecting control.

According to Rice, certain experimental methods seem to affect moth emergence. Cages, for example, affect wind movement and moths seem to stay near the surface and consequently are not trapped. The type of emergence cage may also alter soil temperatures compared to uncaged ground, perhaps delaying moth emergence.

Meteorological and pest data may be useful for predicting the time and severity of outbreaks, even after emergence, and therefore enhance preparation for control. However, little work has been done on this problem. A statistical approach may relate outbreaks to meteorological factors. A more fundamental approach would be to study environmental and phenological relationships of both crop and pest, using intimate observations and measurements. The situation justifies both approaches.

Production of an early crop, with early harvest, is very important in reducing over-wintering pink bollworms. Selection of the most suitable planting data is partly agrometeorological and requires study of prevailing micrometeorological elements along with phenological observations of crop and pest.

Harvest may be advanced by using chemical defoliants. Effective chemical defoliation is done before the seasonal progression of diapause, for which photoperiod is the primary control factor. For example, in Figure 12, Rice (personal communication) shows the seasonal progression of larval diapause which occurs in the Imperial Valley of southern California. The critical photoperiod usually occurs about mid-September, as illustrated by the steep rise in the curve. For practical application of this relationship, growers in southern California should chemically defoliate cotton prior to 15 September. Rice indicated that, in 1969, defoliation on 11 September resulted in approximately 85 per cent fewer moths than defoliation on 19 October.

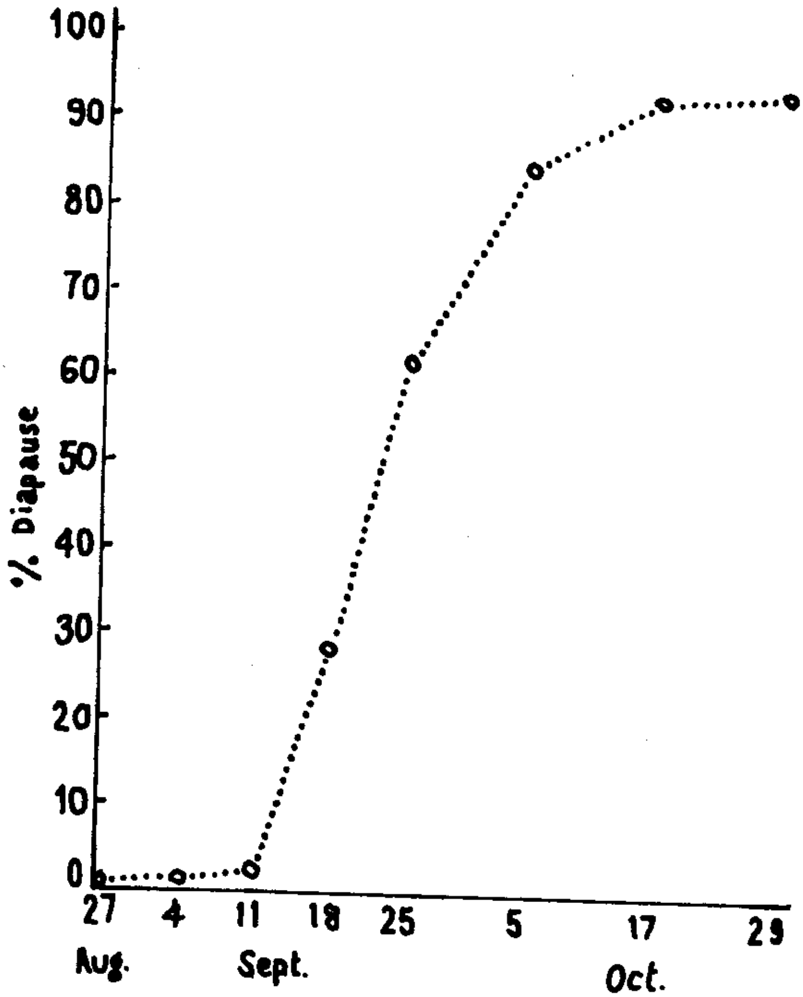

Figure 12

5.10 Suggested studies

Studies have demonstrated the importance of agrometeorological factors in the epidemiology and control of the pink bollworm. There is need for additional study on the following topics:

(a) Effect of air temperature and humidity during larval and pupal stages on adult longevity and fecundity;

(b) Control measures required in different localities in relation to low winter air temperature and winter rainfall;

(c) Cultural practices and their effectiveness on pest control in different climates;

(d) Effect of temperature and rainfall on survival of over-wintering larvae and on moth emergence in order to forecast moth emergence and population;

(e) Modelling, to predict the time and severity of pink bollworm outbreaks on the basis of meteorological crop and pest data. Both statisticol and agrometeorological studies may give useful results;

(f) Indication of preferable plonting, harvesting and plough-up dates in order to reduce pest damage;

(g) Effects of temperature on mortality of larvae exposed to different insecticides, and selection of insecticides best suited for regions with appreciably different temperature régimes.

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