PREDICTION OF DAMAGE AND YIELD LOSS CAUSED BY THE MAJOR BOLLWORMS IN COTTON BY SIMULATION MODEL

Thesis submitted in part fulfilment of the requirements for the Degree of **DOCTOR OF PHILOSOPHY** (Agriculture) in Agricultural Entomology to the Tamil Nadu Agricultural University, Coimbatore.

BY

V.V.SATHYASEELAN, M.Sc.(Ag.)
I.D.No. 99-803-005

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
CENTRE FOR PLANT PROTECTION STUDIES
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE – 641 003

2002

CERTIFICATE

This is to certify that the thesis entitled **"PREDICTION OF DAMAGE AND YIELD LOSS CAUSED BY THE MAJOR BOLLWORMS IN COTTON BY SIMULATION MODEL"** submitted in part fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRICULTURAL ENTOMOLOGY** to the Tamil Nadu Agricultural University, Coimbatore, is a record of bonafide research work carried out by **Mr.V.V.SATHYASEELAN** under my supervision and guidance and that no part of this thesis has been submitted for the award of other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place : Coimbatore
Date : 09.09.2002

(Dr.K.NATARAJAN)
Chairman

Approved by

Chairman **(Dr.K.NATARAJAN)**

Members **(Dr. N.DHANDAPANI)**

(Dr. AR.MUTHIAH)

(Dr. C.KAILASAM)

EXTERNAL EXAMINER

Date : 22.11.2002

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

I wish to express my heartfelt gratitude and indebtedness to **God**, the Divine power for his blessings, parental care and giving me the opportunity to complete this study successfully. It is my duty to keep my whole hearted thanks to my **Guru Yogiraj Vethathiri Maharishi** for his kind and Divine blessing to me for the successful completion.

I express my deep sense of gratitude to my beloved chairman **Dr.K.Natarajan**, Ph.D., Professor of Agricultural Entomology for his immaculate guidance, untiring advice and lofty inspiration during the period of my research.

I accolade with gratitude for the valuable suggestions, timely help and guidance given by **Dr.N.Dhandapani**, Professor, Department of Entomology, **Dr.AR.Muthiah**, Professor and Head, Department of Pulses as Members of Advisory Committee.

I personally and profoundly thank **Dr.C.Kailasam**, Professor of Mathematics and Advisory Committee Member, for his suggestions, keen association and guidance in preparation of mathematical modelling.

I am grateful to **Dr.S.Palaniswamy**, Professor and Head, Department of Agricultural Entomology for providing required facilities to take up the study.

I have the privilege of expressing my sincere thanks and grateful appreciation to **Dr.M.Muthuswami**, Assistant Professor and **Dr.N.Natarajan**, Associate Professor, Department of Agricultural Entomology for their care and creative guidance.

My special thanks are due to ***Dr.Sakthivelu****, Farm Manager,* ***Dr.M.Gopalan, Dr.K.Ramaraju, Dr.N.Chandramohan, Dr.A.Subramanian, Dr.S.Mohan, Dr.M.Bharathi, Dr.S.Kuttalam, Dr.G.Santharam, Dr.N.Sathiah, Dr.R.Krishnan*** *and* ***Dr.K.Thangaraj****, for their mammoth help during the investigation.*

I personally thank my Classmates, Junior and Senior friends who helped me in many ways.

As a personal note, I place my profound sense of gratitude and thanks to my father ***Thiru A.Varadharajan****, mother* ***Tmt.V.Bagyalakshmi****, brother* ***Mr.V.Baskaran*** *and* ***Mrs.B.Suganthi****, grand mother* ***Tmt.A.Papayammal****, sisters and relatives for their encouragement, moral support, overwhelming interest and patient endurance during the entire period of study.*

The help rendered by Mrs. ***K.Jayam*** *in the neat execution of printing work is thankfully acknowledged.*

V.V. Sathyaseelan

V.V.SATHYASEELAN

ABSTRACT

ABSTRACT

PREDICTION OF DAMAGE AND YIELD LOSS CAUSED BY THE MAJOR BOLLWORMS IN COTTON BY SIMULATION MODEL

BY

V. V. SATHYASEELAN

DEGREE : DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRICULTURAL ENTOMOLOGY

CHAIRMAN : Dr.K.NATARAJAN,
Professor,
Department of Agricultural Entomology,
Tamil Nadu Agricultural University,
Coimbatore-641 003.

2002

Investigations were carried out on the damage potential and resultant yield loss by varying larval densities of cotton bollworms *viz*., spotted bollworm, *Earias vittella* (Fabricius) and American bollworm, *Helicoverpa armigera* (Hubner) at different crop stages in cotton cultivar (cv) LRA 5166 under pot culture at Insectary, Department of Agricultural Entomology, and in field situation at Eastern Block, Tamil Nadu Agricultural University, Coimbatore during 2000-2002.

Studies on bollworm damage showed that the damage decreased with increase in crop stages. The shoot damage was more on plants infested at 50 DAS; the square damage was more at 60 DAS and the boll damage was more at 80 DAS for spotted bollworm. In the case of American bollworm, the square damage was more at 80 DAS and the boll damage was more at 100 DAS.

The bollworm damage increased with increasing larval intensities irrespective of crop stages. However, the damage increment though additive was not proportional to the increment in larval density. This trend was seen in all the crop stages and in all

experiments. Regarding the rate of damage, it was not influenced by the number of larvae per plant. It was higher for one larva per plant and there was no proportionate change with increasing larval densities and crop stages.

The yield loss was higher at 60 DAS for spotted bollworm and at 100 DAS for American bollworm when compared to other crop stages. There was no proportionate increase in yield loss with increasing larval densities. The crop yield was not affected by shoot damage because of rejuvenation.

More of bollworm infestation and increased yield loss were observed in the field experiment conducted during winter as compared to summer season experiment. The pot culture experiment which was conducted from August to December resembled like that of winter season trial.

The pot culture experiment indicated that the most susceptible stage of cotton crop for *E. vittella* attack was 60 DAS and for *H. armigera,* it was 100 DAS. At this stage a single *E. vittella* larva could cause 7.93 per cent square damage and 7.21 per cent boll damage with a yield loss of 11.27 per cent at 60 DAS. Whereas, *H. armigera* larva could cause 19.48 per cent boll damage with a yield loss of 13.64 per cent at 100 DAS.

Mathematical models were constructed under three different interactions *viz.*, damage vs larva, yield vs damage and yield vs larva. Prediction was done at various crop stages of cotton in all the experiments. Based on the present studies, one round of insecticidal spray at 50 DAS and the second round of insecticidal spray at 70 DAS will reduce the damage by spotted bollworm. If American bollworm incidence is noticed, three rounds of sprays at 60, 90 and 110 days may be advocated to contain the square and boll damage by American bollworm.

CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
1.	INTRODUCTION	1
2.	REVIEW OF LITERATURE	4
3.	MATERIALS AND METHODS	22
4.	EXPERIMENTAL RESULTS	43
5.	DISCUSSION	122
6.	SUMMARY	138
	REFERENCES	

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
1.	Head capsule width and duration of different instars of spotted bollworm, *Earias vittella* reared on bhendi fruits	27
2.	Head capsule width and duration of different instars of American bollworm, *Helicoverpa armigera* reared on semi-synthetic diet	27
3.	Yield loss at different larval population of spotted bollworm and crop periods in cotton – Pot culture experiment	44
4.	Yield loss at different larval population of spotted bollworm and crop periods in cotton – Field experiment (Summer-2001)	45
5.	Yield loss at different larval population of spotted bollworm and crop periods in cotton – Field experiment (Winter-2001)	47
6.	Yield loss at different larval population of American bollworm and crop periods in cotton - Pot culture experiment	48
7.	Yield loss at different larval population of American bollworm and crop periods in cotton – Field experiment (Summer-2001)	50
8.	Yield loss at different larval population of American bollworm and crop periods in cotton – Field experiment (Winter-2001)	51
9.	Estimated parameters for cotton square damage and spotted bollworm larvae at various stages of cotton crop	54
10.	Predicted square damage due to spotted bollworm at various stages of cotton crop	55
11.	Estimated parameters for cotton boll damage and spotted bollworm larvae at various stages of cotton crop	58
12.	Predicted boll damage due to spotted bollworm at various stages of cotton crop	59
13.	Estimated parameters for cotton square damage and American bollworm larvae at various stages of cotton crop	62
14.	Predicted square damage due to American bollworm at various stages of cotton crop	63
15.	Estimated parameters for cotton boll damage and American bollworm larvae at various stages of cotton crop	67
16.	Predicted boll damage due to American bollworm at various stages of cotton crop	68
17.	Predicted rate of square damage at different spotted bollworm intensity at various stages of cotton crop	69
18.	Predicted rate of boll damage at different spotted bollworm intensity at various stages of cotton crop	73

LIST OF TABLES (Contd.)

TABLE NO.	TITLE	PAGE NO.
19.	Predicted rate of square damage at different American bollworm intensity at various stages of cotton crop	74
20.	Predicted rate of boll damage at different American bollworm intensity at various stages of cotton crop	75
21.	Estimated crop model for yield and crop square damage (per cent) due to spotted bollworm in summer, winter and pot culture experiments at various crop stages	79
22.	Predicted crop yield at various levels of spotted bollworm damage (square) in various experiments	80
23.	Estimated crop model for yield and crop boll damage (per cent) due to spotted bollworm in summer, winter and pot culture experiments at various crop stages	81
24.	Predicted crop yield at various levels of spotted bollworm damage (boll) in various experiments	84
25.	Estimated crop model for yield and crop square damage (per cent) due to American bollworm in summer, winter and pot culture experiments at various crop stages	85
26.	Predicted crop yield at various levels of American bollworm damage (square) in various experiments	88
27.	Estimated crop model for yield and crop boll damage (per cent) due to American bollworm in summer, winter and pot culture experiments at various crop stages	91
28.	Predicted crop yield at various levels of American bollworm damage (boll) in various experiments	92
29.	Predicted rate of yield loss due to one per cent increase in spotted bollworm square damage (per cent) in various experiments	95
30.	Predicted rate of yield loss due to one per cent increase in spotted bollworm boll damage (per cent) in various experiments	97
31.	Predicted rate of yield loss due to one per cent increase in American bollworm square damage (per cent) in various experiments	100
32.	Predicted rate of yield loss due to one per cent increase in American bollworm boll damage (per cent) in various experiments	102
33.	Estimated parameters for yield and spotted bollworm larvae at different stages of cotton crop	103
34.	Predicted crop yield at various levels of spotted bollworm larvae in various experiments	105

LIST OF TABLES (Contd.)

TABLE NO.	TITLE	PAGE NO.
35.	Estimated parameters for yield and American bollworm larvae at different stages of cotton crop	106
36.	Predicted crop yield at various levels of American bollworm larvae in various experiments	110
37.	Rate of yield loss per spotted bollworm larvae at various stages of cotton crop	112
38.	Rate of yield loss per American bollworm larvae at various stages of cotton crop	113
39.	Effect of *Earias vittella* infestation on cotton fibre quality – Pot culture experiment	115
40.	Effect of *Earias vittella* infestation on cotton fibre quality – Field experiment (Summer – 2001)	116
41.	Effect of *Earias vittella* infestation on cotton fibre quality – Field experiment (Winter – 2001)	117
42.	Effect of *Helicoverpa armigera* infestation on cotton fibre quality – Pot culture experiment	119
43.	Effect of *Helicoverpa armigera* infestation on cotton fibre quality – Field experiment (Summer – 2001)	120
44.	Effect of *Helicoverpa armigera* infestation on cotton fibre quality – Field experiment (Winter – 2001)	121

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
1.	Predicted square damage (per cent) due to spotted bollworm	52
2.	Predicted boll damage (per cent) due to spotted bollworm	56
3.	Predicted square damage (per cent) due to American bollworm	60
4.	Predicted boll damage (per cent) due to American bollworm	64
5.	Predicted rate of square damage (per cent) due to spotted bollworm	66
6.	Predicted rate of boll damage (per cent) due to spotted bollworm	70
7.	Predicted rate of square damage (per cent) due to American bollworm	72
8.	Predicted rate of boll damage (per cent) due to American bollworm	76
9.	Predicted yield and square damage (per cent) due to spotted bollworm	78
10.	Predicted yield and boll damage (per cent) due to spotted bollworm	82
11.	Predicted yield and square damage (per cent) due to American bollworm	86
12.	Predicted yield and boll damage (per cent) due to American bollworm	89
13.	Predicted rate of yield loss and square damage (per cent) due to spotted bollworm	93
14.	Predicted rate of yield loss and boll damage (per cent) due to spotted bollworm	96
15.	Predicted rate of yield loss and square damage (per cent) due to American bollworm	98
16.	Predicted rate of yield loss and boll damage (per cent) due to American bollworm	101
17.	Predicted crop yield (per cent) and various levels of spotted bollworm	107
18.	Predicted crop yield (per cent) and various levels of American bollworm	109

LIST OF PLATES

Plate No.	Title	Page No.
1 a) b)	Mass culturing of *Helicoverpa armigera* Rearing of *Helicoverpa armigera* larvae in Semi- synthetic diet Adult emergence cage for *Helicoverpa armigera*	24
2 a) b)	Mass culturing of *Earias vittella* Rearing of *Earias vittella* larvae in Bhendi fruits Adult emergence cage for *E. vittella*	28
3 a) b)	Damage and yield loss assessment Pot culture experiment Field experiment (winter season)	30
4	Individual cotton plant covered with Mylar cage (Field experiment)	32
5 a) b)	Bollworm damage Shoot damage by *Earias vittella* Square damage at various boll development stages	33
6 a) b)	Square damage *Earias vittella* *Helicoverpa armigera*	34
7 a) b)	Boll damage *Earias vittella* *Helicoverpa armigera*	36
8 a) b)	Healthy and damaged bolls after burst Healthy and bollworm damage at various boll development periods	37

INTRODUCTION

1. INTRODUCTION

Cotton, *Gossypium* sp. known as the "King of the Fibres or White Gold" is an important cash crop grown under wide range of climatic conditions. Cotton is cultivated in 33 million hectares in 80 countries and the average annual production is 19 million tonnes. The share of cotton in world textile production is 45 per cent and production, processing and marketing sustain more than 250 million people. In India, cotton is cultivated in 9 million hectares in varied agro-climatic conditions across nine major states. It employs directly or indirectly more than 60 million people in production, processing and marketing. India has the largest area under cotton, but its production is just 15.8 million bales, much lower for the vast area. This is mainly because that 70 per cent area of cotton is coming under rainfed condition (Satish Kumar and Sudershan Rao, 2002).

The sequential development and introduction of new and high yielding varieties of cotton in the recent years have substantially contributed to the increased yield. Yet, this has often resulted in the frequent outbreak of pests and diseases. Besides favouring the large scale multiplication of the major pests, the introduction of these varieties has also created favourable condition for the minor pests to become major pests and cause serious damage in many crops (Pandi, 1997). Among the different pests which attack the cotton crop, the bollworm complex *viz*., the spotted bollworm (*Earias vittella* F.), the spiny bollworm (*E. insulana* Boisd.), the American bollworm (*Helicoverpa armigera* Hubner.) and the pink bollworm (*Pectinophora gossypiella* Saunders) are considered as serious pests inflicting heavy damage to the crop (Sachan and Yadava, 1991). Among them, *H. armigera* and *E. vittella* are important species causing serious problems in the cultivation of high yielding varieties of cotton in Tamil Nadu.

Bollworms are important because of their ability to feed on the economic parts like squares, flowers and bolls, thereby reducing the quality, yield and general vigour of the plant. Cotton is known for its vulnerability to many pests and diseases. Singh and Sidhu (1980) quantified the square damage at 14 to 33 per cent and Kaushik *et al.* (1969) estimated the yield loss at 41 to 56 per cent.

The annual loss caused by *H. armigera* were $ 300 million in India and $ 25 million in Australia (Reed and Pawar, 1982). In Tamil Nadu, the recent estimate of the crop loss caused by the pest was Rs.92.84 crores (Jayaraj, 1988). The damage by the pest ranged from 40 to 80 per cent in different states of India (Tewari and Krishnamoorthy, 1984; Lal and Lal, 1996).

In India, *Earias* sp. has been reported to cause 18.70 to 100 per cent damage (Singh and Sidhu, 1982), 27 to 48 per cent damage in Haryana (Anon, 1975), 11.1 to 59.2 per cent in Punjab (Dhawan *et al.*, 1990b) and 8.03 to 46.1 per cent in Tamil Nadu (Manisekaran *et al.*, 1991). Insecticides play a major role in the management of cotton pests. More than 50 per cent of the total pesticides consumed are used on cotton as against 17 per cent used on rice crop, though the cropped area under these crop are 5 per cent and 24 per cent respectively. In India, farmers even apply 36 to 40 rounds of pesticide to the cotton crop of a duration of 150 – 180 days in a single season (i.e.) one spray for every 5 days. Indiscriminate use of pesticide leads to the development of resistance, resurgence, environmental pollution and natural enemy mortality that warrants an integrated approach in the pest management system (Satish Kumar and Sudershan Rao, 2002).

The production of cotton does not commensurate with the area of cotton grown due to various constraints in IPM and IRM strategies followed. To overcome this problem, a long term remedy is necessary to forecast the incidence of pests well in advance. This can be achieved by using various mathematical computation and simulation models.

A timely forecasting is needed by the farmers for the various parameters like pest incidence, age factor, season, cultural practices and per cent yield loss. To predict the occurrence of insect pests, simulation studies are very much helpful to take up necessary precautionary measures to manage or overcome these problems. Further, it is a low or no cost technology.

Therefore, the present study was conducted to predict the bollworm damage and yield loss in the cotton cultivar (cv.) LRA 5166 at different larval population and crop period.

The following are the objectives included:

1. To work out the bollworm damage and corresponding yield loss at different larval population / intensity and boll development stages in pot culture experiment.
2. To estimate the boll damage and corresponding yield loss at different larval intensity / population and boll development stages in field experiment.
3. To form a crop simulation model to determine the boll damage at different larval population / density and in different boll development period in pot culture experiment.
4. To form a crop simulation model to determine the boll damage at different larval population / density and in different boll development period in field experiment.
5. To construct a mathematical model for the boll damage caused and the corresponding yield loss obtained due to different larval intensity / population at various boll development period.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The bollworm complex attacking cotton crop includes the spotted bollworm, *Earias vittella* (Fabricius), the spiny bollworm, *E. insulana* (Boisd), the American bollworm, *Helicoverpa armigera* (Hubner) and the pink bollworm *Pectinophora gossypiella* (Saunders). Hargreaves (1948) listed out 1,326 species of insects attacking cotton. Among them, 46 are identified as major pests spreading in 32 countries. Sundaramurthy (1988) considered *H. armigera* as the most serious pest in cotton growing area because of its voracious and polyphagous feeding habit. The work done on bollworm complex and models pertaining to the current studies both in India and abroad is reviewed hereunder.

2.1. Distribution and Taxonomy of Bollworm Complex

2.1.1. *Earias vittella*

The genus *Earias* (Lepidoptera : Noctuidae) is confined to the old world and Australasia. There are about 47 accepted species in the genus and others await description. Variation in the colouration of the moths of some of the species has led to considerable confusion in identification. *Earias insulana* has a wide range of occurrence covering most of Africa, Madagascar, Mauritius and the Canary Isles. It extends northwards in the Mediterranean islands and Southern Europe and eastwards through the Near and Middle East including Southern Arabia, India, China and Southeast Asia. *E. vittella* (Fabricius.), which was earlier recorded as *E. fabia* (Stoll) is widely distributed from Indus to Australasia. It is particularly important as a pest of cotton in several areas of India, China and Thailand. A report by Capizzi (1987) indicates that this species has been discovered in Sudan feeding on Okra. *Earias* spp. are important pests of cotton and *E. insulana is* closely associated with *Gossypium* and has a wide range of other members of the Malvales, adapted to existence in the arid regions of the old world. *E. biptaga* (Walker) and *E. vittella* resemble with each other in being common than *E. insulana* in the equatorial region but are barred off from each other by the arid area of Middle East and North Africa.

2.1.2. *Helicoverpa armigera*

The sub-family *Heliothinae* includes some of the most devastating pests of agricultural crops. Hardwick (1965), while studying the species belonging to the corn earworm complex described 11 species, two new sub species and created a new genus *Helicoverpa* which differs from *Heliothis* by its male and female genitalia and presence of specialised scales on the lower surface of the pro-femur of males. *Heliothis armigera* was placed in one of the five groups of the new genus *Helicoverpa* becoming *Helicoverpa armigera* (Hubner). This change has been accepted on taxonomic ground (Mathews, 1987; 1994).

Among the species of *Helicoverpa, H. armigera* is the predominant species in the Peninsular India and widely distributed throughout Africa, Middle East, Southern Europe, Central and South East Asia, New Zealand and many Eastern Pacific Islands (Fitt, 1989). For a long time there has been considerable controversy over the nomenclature of *H. armigera* and *H. zea* (Boddie). In 1965 Hardwick introduced the name *Helicoverpa* to distinguish it from corn earworm complex, *Heliothis* spp. A brief history on the nomenclature of *H. armigera* and *H. zea* was given by Poole (1989).

In recent years, it has assumed a key pest status and caused greater damage (Sachan and Yadava, 1991). It is a polyphagous, multivoltine pest attacking a variety of cultivated crops and wild plants. Among *Heliothinae, H. armigera* is widely distributed with 13,000 miles across the old world from the Western Pacific to Canary Islands (Mitter *et al.*, 1993) and Eastern and Northern Australia (Fitt, 1994).

2.2. Nature and Symptoms of Damage

2.2.1. *Earias vittella*

2.2.1.1. Shoot damage

Earias vittella is distinguished from other bollworms by its marked stem or shoot boring habit in the vegetative phase of crop growth prior to square formation. The larva bores into the tender terminal shoot feeding on the soft tissue. The shoot above the damaged part withers. The axillary buds developed are presenting a bushy appearance.

2.2.1.2. Square damage

The larva damages several squares and flowers by partially feeding on them. When the square is damaged, the bract (calyx) enclosing the flower bud gets "flared up". Several squares become 'flared up' and can be seen with slight punctures on the ovary. The damaged squares, flower buds and the young bolls drop down. The older attacked bolls remain attached to the plant which in turn lead to the development of pre-matured inferior, worthless fibre and the affected bolls open badly with hard locules (Anon, 1998).

2.2.2. *Helicoverpa armigera*

The damage by *H. armigera* is identified by the absence of ovaries, squares and young flower buds and by the presence of irregular holes without frass and excreta near the bore holes (Manisekaran *et al.*, 1991). The newly hatched larvae feed on the leaves, flower bud or flower which are eventually hollowed out. The growing larvae prefer buds and young bolls. In the severely attacked buds and bolls, an accumulation of faeces is noticed between the surface and the enclosing bract (King, 1994). Regupathy *et al.* (1998) reported that in the bolls showing regular, circular bore holes, the larvae were seen feeding on the boll by thrusting their heads inside with the presence of granular faecal pellets outside the bore holes.

2.3. Status of *Earias vittella* and *Helicoverpa armigera* as Major Pests of Cotton

The importance attached to *E. vittella* and *H. armigera* as pests of cotton varies considerably from place to place and in some cases it has been altered greatly with the course of time. They are usually regarded as little more than a nuisance in most of the rainfed cotton area of Africa. In the middle East and in several areas of the Indian sub continent, they are the important components of the pest complex on cotton (Reed, 1994).

Statistics of infestations had chiefly been given in terms of the percentage infestation in green bolls. In Egypt, there were occasional reports of 50 per cent or more boll damage during winter season and however, an average of 5 per cent damage appeared to be more typical (Pearson, 1958). *H. punctigera* (Wallengren) and *H. armigera* are serious pests of cash crops in Australia, particularly cotton, oilseeds, horticultural crops, and coarse grains (Wilson, 1982). Bughio *et al.* (1987) recorded 23 - 53 per cent boll damage by *Earias* sp. during three-year study in Pakistan.

2.3.1. Status of *Earias* sp. on Cotton in India

Earias spp. are the important pests in nearly all the principal cotton growing areas of the Indian sub continent. *E. insulana* is the most abundant species on cotton in Punjab, except during the rainy season in the less arid regions of the east and south east, where *E. vittella* may dominate. In Peninsular India, *E. vittella* is the predominant species causing 20 per cent loss of seed yield (Patel, 1949) and 57 - 80 per cent stained lint (Sidhu and Sandhu, 1977). The spotted bollworm, a sporadic pest of cotton, was quite serious and the damage was almost 100 per cent in 1977 when compared to the preceding two years (Singh and Sidhu, 1982). The seed cotton yield was reduced by 66.5 per cent in Punjab (Dhawan *et al.*, 1986).

2.3.2. *Helicoverpa armigera* as a major pest of cotton in India

Helicoverpa spp. are polyphagous insects infesting 60 cultivated plant species and 67 other plant species belonging to 39 natural orders in the plant kingdom (Sundaramurthy, 1988). Different factors have contributed towards the greater prevalence of the *Helicoverpa* in recent years (Fitt, 1989). The three species of bollworms are responsible for 50 per cent annual loss in the yield of seed cotton and among them, *H. armigera* is an important species assuming a key pest status and causing greater damage on cotton (Sachan and Yadava, 1991).

2.4. Damage and Yield Loss

2.4.1. Square damage

Spotted bollworm caused 34 to 51 per cent shedding of squares in South Gujarat and 27 to 48 per cent in Haryana. Maximum square shedding due to *Earias* spp. occurred from Mid August onwards (Anon, 1975).

Bhat and Jayaswal (1988) studied the factors involved in bollworm resistance in cotton (*G. hirsutum*) using isogenic lines. Smooth leaves resulted in the reduction of square damage (33.41%) and a combination of smooth and nectarless okra leaf types recorded 60.55 per cent reduction of square damage by *Earias* sp. and *H. armigera*.

Singh and Sidhu (1982) reported that the overall square shedding in different *hirsutum* varieties varied from 18.70 to 20.30 per cent. Square shedding due to *Earias vittella* was about 3.96 per cent of Faridkot, whereas it was a sporadic pest but it was serious during 1977. The square shedding in F 414 variety was recorded upto a maximum of 38 per cent during 1975 and 1976 and 43 to 100 per cent during 1977. In case of J 205 cotton variety square shedding varied from 0 to 51.2, 1.5 to 89.8 and 31.8 to 100 per cent during 1975, 1976 and 1977 respectively.

Studies carried out in Punjab during 1985-86 showed that there was increased square shedding from third week of August onwards and the highest (59.2%) was reached during the third week of September in the variety G 27. Similar trend was observed with varieties, LD 133 and LD 230. (Dhawan *et al.*, 1990b).

Manisekaran *et al.* (1991) reported that the incidence of *Earias* sp. was negatively correlated with the age of the crop in MCU 7 and MCU 9. The observations were recorded during different period of crop growth *viz.*, 80, 101 and 115 days and respective per cent square damage recorded were 20.12, 16.11 and 13.26 per cent for MCU 7 and 46.10, 36.25 and 8.03 per cent for MCU 9. The mean incidence of *Earias* sp. and *H. armigera* was more during winter (20.66% and 19.67%) than in summer (17.24% and 12.49%) respectively.

Gill and Simwat (1993) reported that the duration of square formation in LD 327 and LD 230 were 62.09 and 70.05 days respectively. The insecticidal sprays reduced the square formation phase as well as the number of squares/plant (58.82 days and 51.98) as compared to unsprayed conditions (73.61 days and 66.74). However, the square transformation into flowers and harvestable bolls were significantly higher (74.91 and 34.36%) under sprayed than unsprayed conditions (62.58 and 23.77%). Physiological factors were the major cause of shedding of squares followed by spotted bollworm and pink bollworm in both the varieties.

Simwat and Singh (1997) reported that the major portion of shedding of squares was due to physiological factors (22.1%) and it was significantly higher than that caused by spotted bollworm (3.8%), pink bollworm (0.7%) and American bollworm (0.45%).

Patel and Patel (2000) reported that *E. vittella* infestation on cotton shoots started from 6 weeks to 11 weeks and on buds from 8 weeks to 11 weeks. Highest pest population was found on cotton sown on 20th February, 5th and 20th March and lower population on 5th and 20th April, 5th May and June (Tomar *et al.*, 2000).

The desi cotton varieties were severely attacked by the bollworm and 65.7 per cent infestation on square was recorded in Madhya Pradesh (Kaushik *et al.*, 1969).

2.4.2. Boll damage

Singh *et al.* (1979; 1981) reported that the number of bolls per plant had a positive direct effect on yield while other traits contributed indirectly through boll weight and boll number.

The boll damage due to *H. armigera* ranged from 21.80 to 27.49 per cent in Orissa (Mishra and Mandal, 1995).

Gang *et al.* (1997) noted that terminal nipping in cotton helped to reduce bollworm infestation. Gupta *et al.* (1997) reported that the bollworm complex was responsible for the plant stress and fruit abscission which reduced the harvestable bolls upto 29 per cent resulting in reduction of seed cotton yield by 1328 kg/ha. Further a 2.2 times deterioration in quality of seed cotton and 1.6 times increase in bollworm incidence were noted.

H. armigera larval reduction was 38 per cent and boll damage was reduced by 51 per cent in IPM fields. The cost / benefit ratio was better for IPM farmers (1: 3.4) than the control farmers (1: 1.8) (Surulivelu *et al.*, 1998).

Among the bollworms, *H. armigera* was predominant and caused maximum damage on fruiting bodies (65.7%) and 3 larvae per plant were recorded during the middle of December. The average boll damage was less (5.5 to 6.6%) when compared to square damage (7.9% – 12.7%) (CICR, 1999-2000).

The boll damage was recorded in Gujarat at 12.28 to 30.52 per cent (Bharpoda *et al.*, 2000). Bollworm incidence in open bolls on boll basis ranged between 12.94 and 32.80 per cent and in green bolls it ranged between 12.00 and 31.23 per cent in South Haryana (Nath *et al.*, 2000).

2.4.3. Square and boll damage

Field tests were carried out in Punjab during 1985-86 by Dhawan *et al.* (1990a) to investigate the damage of different cotton varieties by bollworm *P. gossypiella.* It caused a loss of 3.3 – 7.7 per cent buds, 0 – 6 per cent flowers and 0.2 – 1.7 per cent bolls whereas *Earias* spp. caused a loss of 12.5 – 16.6 per cent, 0.9 – 2.5 per cent and 7.2 – 9.5 per cent for bud, flower and bolls respectively. The total boll shedding by bollworms was minimum in LD 326 (15.9%) and maximum in LD 323 variety (23.2%). They reported that the shedding of fruiting bodies due to bollworms may not contribute significantly towards reduction in yield of seed cotton.

Bughio *et al.* (1991) reported that the *E. vittella* caused more squares and boll abscission than *P. gossypiella,* whereas unknown physiological factors caused significantly higher abscission than bollworms.

The infestations of *E. vittella* were recorded as 42.6 per cent in growing shoots, 19.85 per cent in squares, and (26.25%) on green bolls of cotton in Gujarat (Anon., 1991-1992). *Earias* spp. attacked the cotton flowers, buds and early developing bolls to the tune of 75 per cent in Haryana (Khurana, 1992).

Young larvae were destructive; they did not consume the whole bolls and partially destroyed many flowers, squares and bolls. Such fruiting bodies were shed and this resulted in yield reduction (Du Toit, 1998).

2.4.4. Yield and yield loss

Agarwal and Katiyar (1979) noted that bollworms alone caused losses to the tune of $ 23.5 million every year. *H. armigera* alone caused a loss of approximately $ 98 million in cotton in one season in Andhra Pradesh.

The American bollworm, *H. armigera* was responsible for greater losses in seed cotton in South Africa (Annecke and Moran, 1982).

The damage by *H. armigera* and other pests was responsible for yield loss of upto 40 per cent in Tanzania (Nyambo, 1989). Sucking pests are active in the first eight weeks followed by bollworms in the next eight weeks (Hardcastle, 1989).

Narayanan (1991) reported 25 – 35 per cent loss in seed cotton yield due to bollworms. The yield loss due to *H. armigera* was from 30 to 45 per cent and sometimes even upto 60 per cent as reported by Thangaraj (1998; 2001).

Tariq *et al.* (1995) studied a positive correlation for seed cotton yield, with flowers per plant, boll setting, number of bolls per plant and boll weight. Valarmathi (1996) reported that number of bolls per plant, sympodia per plant, boll weight and lint index had significant positive correlation with seed cotton yield.

Pest attack was often increased by putting known number of eggs, larvae and adults on the crop. Fery *et al.* (1979) distributed *Helicoverpa* eggs uniformly as artificial infestation on tomato and the damage rate and the crop loss assessment were recorded. Lynch *et al.* (1980) distributed *Ostrinia* eggs uniformly as artificial infestation on maize and the extent of damage was studied.

Among the bollworm complex, *H. armigera* dominated in the trial area. *Earias* spp. was seen only in the early stage as shoot borers. *H. armigera* damage was maximum from mid September to December with three peaks during third week of September, second week of October and last week of November (Patil and Bheemanna, 1998).

Transgenic cotton cultivars, containing the INGARD® (Bt) gene, showed greater promise in tropical Australia. Although the gene does not provide total control of *H. armigera* and *H. punctigera* throughout the season, the use of trap and refuge crops as components of an IPM system assist in control (Strickland *et al.*, 1998).

Maximum square damage (25.87%) by bollworms and the green boll damage (26.98%) were observed in LRA 5166 cotton. The *H. armigera* larval population per 24 plants ranged from 0 to 13 and averaged 3.4. The square and boll damage ranged from 0 to 15.4 and 0 to 12.3 per cent and averaged 6.0 and 3.4 per cent respectively. There were three peak periods of square damage by bollworms *viz.*, early November (15%), early December (12–15%) and later half of January (11-15%) while only one peak for boll damage (11–12%) was observed during November (CICR, 1998-1999).

2.4.5. Economic threshold level

Helicoverpa damage to cotton in Australia may occur at any time from cotyledon development to boll maturity. In addition, the high cost of production and high potential returns make this crop very sensitive to economic loss. A threshold of four eggs or two small larvae/m^2 was indicated at that development stage, while the threshold was subsequently reduced to one larva/m^2. Protection was not normally required before square production commenced or after it ceased (Wilson, 1981).

Keerthisinghe (1982) correlated yield loss due to *H. armigera* with the number of damaged squares on the rainfed cotton in Sri Lanka and proposed an action threshold of

5 damaged flower buds (squares) per 30 plants of 7–10 weeks after sowing and then 6 damaged bolls per 30 plants of 11-18 weeks after sowing.

In South Africa, five bollworm larvae/24 plants was the current economic threshold level (Basson, 1987).

Butler *et al.* (1990) reported that the infested fruiting bodies (squares, buds, flowers and bolls) were counted for determining the economic threshold of bollworms as it was easier than the eggs and larval count. On reaching 4 per cent bollworm infestation two sprays were given to upland cotton and were found better as compared to eight sprays given to the crop on calendar basis.

Several workers have attempted to develop working IPM modules for cotton. The imposition of the IPM treatment was based on economic threshold level for different pests in the IPM fields (Sundaramurthy and Chitra, 1992).

Singh and Sandhu (1995) reported that alternate spraying with Fenvalerate (50 g a.i./ha) and Quinalphos (0.5 kg a.i./ha) controlled pests most efficiently. Applying insecticide when the pest population was at 5 per cent on freshly shed fruiting bodies was next effective followed by 2 larvae / plant and 10 per cent incidence on intact fruiting bodies.

Du Toit (1996) also reported that 5 larvae/ 24 plant was economic threshold level for *H. armigera* and 2 larvae/24 plants was the economic threshold level for *Earias* spp.

Simwat and Dhawan (1997) studied the economic threshold levels for controlling three bollworm complex with insecticides in LH 900, LH 134 and F 846 cotton varieties. The economic threshold levels *viz.*, 5 per cent bollworm incidence on intact floral forms (squares, flowers and bolls) on plants and 5, 10 and 15 per cent in the shed floral form were compared with standard spray schedule.

Egg-based economic threshold level for *H. armigera* was one egg/plant in India (Kairon, 1998). Six bollworms per 25 plants was the economic threshold level in Cameroon (Silvie *et al.*, 1998) and 3 larvae/10 plants was economic threshold level for bollworm complex in Cote d'Ivoire (Ochou *et al.*, 1998).

The economic threshold level of spotted bollworms on *G. arboreum* cotton variety, LD 327 was determined by Singh and Singh (1998). Six infestation levels *viz.*, 2, 3, 4, 5, 7 and 10 per cent in freshly shed fruiting bodies were compared against the recommended spray schedule. The 3 per cent incidence was determined as economic threshold level for bollworms and the higher cost / benefit ratio (1:4.16) was obtained.

Russel *et al.* (1998) worked out the economic threshold level for cotton bollworms during the different growth phases of cotton. The economic threshold level for *E. vittella* has been fixed as 5 damaged tips per 50 plants before squaring, 10 per cent square damage during the main squaring period and 10 per cent boll damage during green and open boll period. For *H. armigera* 5 per cent boll damage was fixed as the economic threshold level during green and open boll period. *H. armigera* caused a loss to the tune of $ 500 million in India during 1997-98. The desi cotton varieties were severely attacked by the bollworms and suffered 57.9 per cent reduction in seed cotton yield (Sharma, 1998).

Bharpoda *et al.* (1999) reported that economic threshold level was about 1 or 2 *H. armigera* egg or larvae per plant. Spraying at 3 per cent damage also produced the lowest bud and boll damage (8.64 and 7.45%) and the highest yield of 2317 kg/ha as compared to 10897 kg/ha in the control. Spraying at 6 per cent damage had the highest cost benefit ratio (1: 4.26) followed by spraying at 3 per cent (1: 3.26).

2.5. Modelling

2.5.1. Bollworm modelling

The use of computer models in crop protection increases our management and forecast capacities as well as it allows to reduce their increasing pressure of agricultural activity on natural resources by the optimization of phytosanitary products use. Models have been developed in USA to aid in the management of *Helicoverpa* spp., HELSIM-2 for *H. zea* in North Carolina (Stinner *et al.*, 1974) and MOTHZV for both *H. zea* and *H. virescens* in Texas.

Butler (1976) developed a model to study the development rates and population dynamics of *H. armigera.*

Hartstack (1982) studied in detail about modelling and forecasting of *H. armigera* populations in USA. MOTHZV, a simple model on *Heliothis* population was later updated as MOTHZV-2 and MOTHZV-3 models during 1976 and 1978 respectively. MOTHZV-2 model predicted the timing of occurrence and size of future generation of *H. armigera* and simulations were initialised with input of data on either eggs or moth. MOTHZV-3 model was developed by including the larval stage of *Heliothis* that caused more damage to the cotton crop. A computerised pest management delivery system known as BUGNET was developed in Texas.

In Australia, SIRATAC, a computer based model for *H. armigera* and *H. punctigera* management was developed by Hearn *et al.* (1981).

DEMHELIC was developed by Hopper and Stark (1987) for *H. zea* and *H. virescens* management in cotton in Massachussets, USA.

Ilango and Uthamasamy (1989) evaluated three varieties of cotton in Tamil Nadu for their reaction to bollworms, *Earias vittella, E. insulana, P. gossypiella* and

H. armigera under different fertilizer levels and found that increased N levels led to increased infestation and more damage.

A population model HEAPS was developed by CSIRO in Australia against *H. armigera* and *H. punctigera* (Dillon and Fitt, 1990; Hamilton and Fitt, 1990).

Taware and Patil (1993) constructed a model, including the boll damage, boll weight and bolls/plant of 28 different cotton genotypes.

The adult movement and spatial dynamics of *Helicoverpa* populations were studied in Australia. In an effort to improve the *Helicoverpa* management in high value crops, such as cotton, a comprehensive population dynamics model *viz.*, HEAPS (*Helicoverpa armigera* and *Punctigera* simulation) was developed by Fitt *et al.* (1995).

In Andhra Pradesh, Pyrethroid resistance in the noctuid, *H. armigera* followed a seasonal cycle. Levels of resistance increased from August to March and then decreased in the dry period during April and July and the hypothesis was expressed in the form of a simple simulation model (Madden *et al.*, 1995).

Drapek *et al.* (1997) developed a spatial model to explain capture of *H. zea* males in pheromone trap as a Unix script file (Grass, V. 40) correlated with moth catches and damage predictions on sweet corn. Sutherst *et al.* (1997) started a National pest modelling facility in Australia. They included programs for forecasting *H. armigera* migrations, a Pest risk analysis expert system (PESKY), a climate risk assessment model (CLIMEX) and a population dynamics model.

The tomato fruit damage was increased with increasing larval densities irrespective of crop age. However, the increment though additive was not proportional to the increment in larval density. The yield loss was higher at 50 DAT when compared to

40 DAT which was lower in older crops (60, 70 and 80 DAT). There was no proportionate increase in yield loss with increasing larval densities (Balachandran, 2000).

Jian Zhou *et al.* (2000) constructed a model to simulate temporal and spatial dynamics of *H. armigera* on Bt cotton.

2.5.2. General pest modelling

Frisbie *et al.* (1989a, b) proposed a model which included the systems analysis and quantitative modelling that had been used to gain a better understanding of the biological and economic interactions in this system. The cotton model was used to understand the complexity of production and the relationship to the pest complex.

Gutierrez and Wilson (1989b) developed a model that could be used in the development of integrated pest management tactics wherein linkage of pest population models to the cotton model and field application were focussed. A population model for cotton growth and development and the effects of pests like *A. grandis* and plant density were correlated. The use of models on cotton growth and development as a basis for cotton IPM was suggested by Gutierrez and Curry (1989a). Gutierrez (1992) examined the development of crop pest models based on demographic theory and the simple rules of economic thresholds in case of cotton boll weevil, *Anthonomus grandis.* A simulation model using Time Varying Distributed Delays was created on the HERMES (Hierarchical Environment for Research Modelling of Ecological Systems) of the USDA/ARS. The specific host-parasitoid life system was used in the *Anthonomus grandis - Catolaccus grandis* system (Legaspi *et al.*, 1996).

Gage (1989) constructed a phenology model for the European corn borer, *Ostrinia nubilalis*.

Rosenthal *et al.* (1989) constructed a crop growth model, *SORKAM* to simulate the phenology and population dynamics of sorghum midge, *Contarinia sorghicola* (Coq). Raju *et al.* (1989) predicted the rice leaf folder damage and its relationship to total dry matter production.

Cox *et al.* (1991) have shown that significant improvements could be obtained by adjusting the threshold at specific time during the crop growth period. Abdul Kareem and Raju (1991) used the simulation model (LIQ crop growth model) for rice yellow stem borer in relation to growth and yield on ADT 39. A simulation model on the yield loss caused by *Ostrinia nubilalis* on maize was constructed taking into account the development, mortality and distribution of pest (Labatte and Got, 1991).

Murty and Singh (1991) developed a phenology model for the gypsy moth, *Lymantria dispar* L. based on laboratory studies.

A simulation model was developed by Singh *et al.* (1992) which included the current research on the mechanisms of drought tolerance in cotton.

Holt and Norton (1993) developed a simulation model to study the population dynamics and damage by providing a basis for pest management advice for Rice BPH, *Nilaparvata lugens* (Stal.). Buprofezin treatment of white backed planthopper, *Sogatella furcifera* (Horvath) at sublethal doses resulted in the survival of individuals with reproductive potentials. Logistic function serves as a mathematical model for predicting the second generation population building up in a buprofezin treated laboratory population.

Raju and Abdul Kareem (1994) predicted the relationship of rice yellow stem borer damage and yield of rice.

Monastyrskii and Suganyaev (1995) studied a model on rice leaf folder damage and its yield loss was assessed. Pinnschmidt *et al.* (1995) constructed a crop growth modelling to simulate the damage effects of single or multiple pests using the CERES, a rice crop growth model.

Morgan *et al.* (1996) developed a computerised pest forecasting system called PEST-MAN, for apple and pear pests.

Ramasubramanian (1996) constructed two mathematical models *viz.*, Mitcherlich's curve and Logistic curve for the prediction of yield loss caused by rice black bug, *Scotinophara coarctata* (Fabricius) on ADT 36 rice variety.

The reasonable economic thresholds under current cropping and monitoring systems were developed by Hua Di *et al.* (1997) and a new insecticidal spray technology was adopted against rice yellow stem borer.

Sadras and Wilson (1997) constructed a simulation model which analysed the effect of mite infestations at three stages during the crop cycle based on growth, dry matter partitioning and the yield of cotton. Pandi (1997), Pandi *et al.* (1998) constructed a simulation model to predict the damage and yield loss caused by rice leaf folders, *Cnaphalocrocis medinalis* Guenee and *Marasmia patnalis* Bradley in IR 50 rice variety. Two mathematical models were used *viz.*, Mitscherlich's model for prediction of damage and rate of damage and rectangular hyperbola model for prediction of yield and rate of yield loss.

Decoin (1999) proposed a simulation model of pest population dynamics for modelling, forecasting and control in relation to *Rhopalosiphum padi* (Fitch.) on cereals.

Sishui and Xiao XiJn (2000) constructed a model for rice leaf folder (*Cnaphalocrocis medinalis*) in China and that could be predicted with 72 per cent accuracy. Way *et al.* (2000) reported that the tactical models were proving increasingly valuable in forecasting and applied control measures.

The CIPRA (Centre informatique de Prevision de Ravageurs en Agriculture) is one of the first Canadian operational decision support systems in crop protection (Chokamani *et al.*, 2001).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigations were carried out with the aim of assessing the damage potential of the major bollworm pests of cotton *viz.*, American bollworm, *Helicoverpa armigera* and Spotted bollworm, *Earias vittella* and related yield loss associated with different larval populations at various growth stages of cotton.

The experiments were conducted both under pot culture and field conditions at Tamil Nadu Agricultural University, Coimbatore during 2000-2002.

3.1. Mass culturing of *Helicoverpa armigera*

The mass culturing of *Helicoverpa armigera* was done with a laboratory stock maintained under room temperature. The larvae were reared on a semi-synthetic diet in transparent plastic tray (30 x 15 cm) capped with plastic lids. Small holes were provided on the lid for aeration.

3.1.1. Semi-synthetic diet

The caterpillars were reared individually on a semi-synthetic diet developed by Shorey and Hale (1965) and Veera Reddy and Bhattacharya (1990) with certain modifications by Sathiah (2000) (Plate 1a). Commercial ABDEC vitamin aqueous solution was added (Patel *et al.*, 1968) in the place of usual vitamin stock as advocated by Berger (1963). Wesson's salt mixture (Wesson, 1932), consisting of

Sodium chloride	:	105 g
Potassium	:	120 g
Potassium dihydrogen phosphate	:	310 g
Calcium phosphate	:	144 g
Calcium carbonate	:	210 g
Anhydrous magnesium sulphate	:	90 g
Ferric phosphate	:	14.7 g
Manganese sulphate	:	0.20 g

Potassium aluminium sulphate	:	0.39 g
Sodium fluoride	:	0.59 g
and Potassium iodide	:	0.05 g

were mixed thoroughly and added to the diet in required proportion (Berger, 1963). Instead of kidney beans (Narayanan, 1979) chickpea flour was used in the present studies.

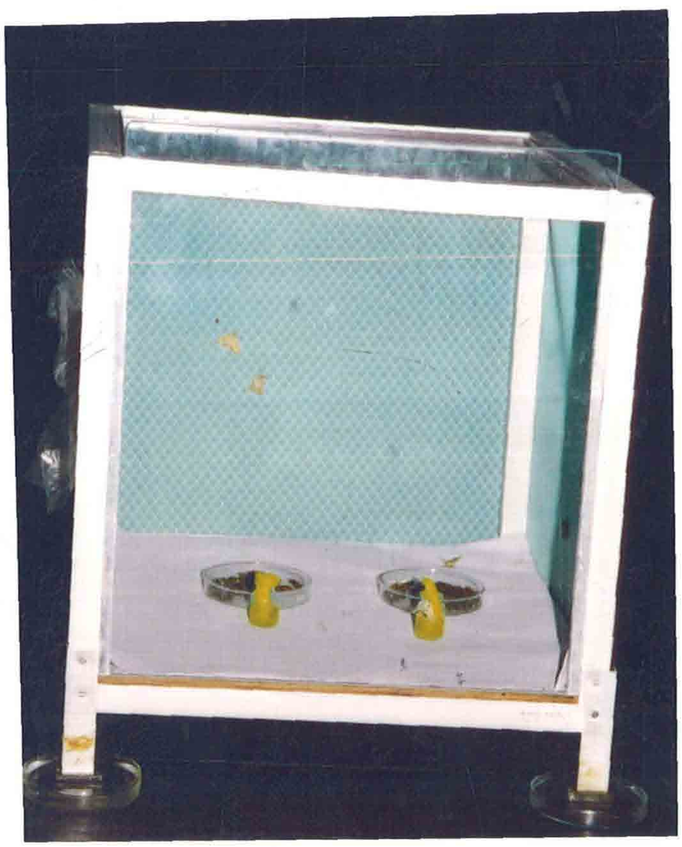
The following constituents were used to get 850 ml of the diet.

Water	:	720 ml
Yeast	:	30.0 g
Wesson's salt mixture	:	7.2 g
Methyl-Para hydroxy benzoate	:	2.0 g
Sorbic acid	:	1.0 g
Agar	:	12.8 g
Ascorbic acid	:	3.2 g
Choline chloride 10%	:	7.2 ml
ABDEC vitamin solution	:	2.0 ml
Streptomycin sulphate	:	0.04 g
Formaldehyde	:	1.0 ml
Chickpea flour	:	100 g

Chickpea flour was spread uniformly in an open pan. Boiling water (360 ml) was poured over it, mixed thoroughly and transferred to a blender. Yeast, Wesson's salt mixture, sorbic acid and methyl-parahydroxy benzoate were added while blending. Simultaneously agar was boiled in the remaining portion of water (360 ml), and then added to the above mixture. After thorough blending for 2-3 min the remaining fractions of the chemicals were added one after another. The hot liquid was dispensed into plastic trays (30 x 15 cm) and glass vials. After solidification, the trays and the vials were closed with cotton plugs and used during the next day.

Plate 1
Mass culturing of *Helicoverpa armigera*

a) Rearing of *Helicoverpa armigera* larvae in Semi-synthetic diet



b) Adult emergence cage for *Helicoverpa armigera*

3.1.2. Rearing Procedures

The method developed by Narayanan (1979) and Sathiah (2000) was followed for rearing *H. armigera.*

3.1.2.1. Adult Emergence Cage

The adult emergence cage of size (45 x 15 cm) was used (Plate 1b). The cage was provided with a glass slide door on one side and the remaining sides were covered with wire mesh. The pupae from the culture were cleaned and washed in running water. The adhering water particles were removed by gently rolling the pupae over a cotton wad. The pupae were then placed on potentials (10 media). Upon eclosion of moths, the adult's feed of 10% sugar solution enriched with ABDEC vitamin solution at 10.3 ml per 10 ml of sugar solution was provided in the cage.

The newly emerged adults were collected in specimen tubes (10 x 30 cm) sexed and allowed in plastic jars (15 x 10 cm) for mating and oviposition (Rabindra, 1973). Five pairs of male and female were introduced into each jar instead of 15 males and 5 females as introduced by Ramiah (1966). The top of the jar was covered with sterile muslin cloth which also served as an oviposition substrate. The containers were kept in dark to induce mating. The feed for adult was changed daily. The temperature and relative humidity were maintained at 22 ± 2°C and 70 – 75% respectively inside the culture room.

3.1.2.2. Egg collection

The clothes with egg deposit were collected daily in the morning from the third day onwards when the ovules start their egg laying. New cloth pieces were used daily to replace older ones. Clothes thus collected were kept in a plastic container (15 x 10 cm) placed inside a bigger plastic jar (30 x 25 cm) with a layer of water to maintain high humidity.

3.1.2.3. Egg sterilization

The eggs were observed under simple 10 x concave lens for the germ band formation. The eggs were surface sterilized with 10% formaldehyde for 10 min to prevent the incidence of polyhedrosis in culture. Formaldehyde was then decanted and the clothes were placed under running water for 30 min to ensure complete removal of formaldehyde. The egg clothes were allowed to dry in shade at room temperature and brought back to a sterile humidified chamber for hatching (Thompson and Steinhaus, 1950; Ignoffo, 1965).

3.1.2.4. Rearing of early instars of *H. armigera*

Freshly hatched larvae were released on Diet trays, where they were allowed to grow upto second instar. To fix the duration of larval instars, the head capsule measurement was used as the criterion. The head capsule measurement was taken for a set of ten larvae daily from the date of hatching to pupation using a stage and ocular micrometer and the mean width of head capsule was worked out and the growth ratio was determined for spotted bollworm (Table 1) and American bollworm (Table 2) as per Dyar (1890). The conformity of the head capsule measurements to Dyar's rule was worked out based on a 't' test. The required number of second instar larvae for the experiment were taken from the tray, the remaining larvae when reached the third instar were transferred individually to vials and maintained upto pupation for continuous culture.

3.2. Mass culturing of *Earias vittella*

An isogenic and healthy culture of spotted bollworm, *Earias vittella*, was maintained on natural and semi-synthetic diet at the insectary of the Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore and used for

Table 1. Head capsule width and duration of different instars of spotted bollworm, *Earias vittella* reared on bhendi fruits

Instar	Duration (days)	Head capsule width (mm.)		Growth Ratio
		Range	Mean ± SD	
I	1.56	0.25-0.46	0.35 ± 0.003	--
II	2.14	0.51-0.75	0.63 ± 0.011	1.8
III	3.18	0.79-0.96	0.87 ± 0.005	1.38
IV	3.06	1.01-1.22	1.12 ± 0.007	1.28
V	2.12	1.24-1.33	1.28 ± 0.012	1.14

Table 2. Head capsule width and duration of different instars of American bollworm, *Helicoverpa armigera* reared on semi-synthetic diet

Instar	Duration (days)	Head capsule width (mm.)		Growth Ratio
		Range	Mean ± SD	
I	2.12	0.53-0.85	0.73 ± 0.005	--
II	3.31	0.93-1.32	1.08 ± 0.003	1.48
III	4.48	1.35-1.80	1.38 ± 0.012	1.28
IV	4.15	1.84-1.98	1.91 ± 0.018	1.38
V	3.86	2.10-2.35	2.23 ± 0.007	1.17
VI	3.54	2.40-2.94	2.60 ± 0.108	1.16

Plate 2
Mass culturing of *Earias vittella*

a) Rearing of *E. vittella* larvae in Bhendi fruits

b) Adult emergence cage for *Earias vittella* various experiments during the course of this study. The culture was periodically replenished from field collected insects to avoid inbreeding depression.

The neonate larvae were transferred to the bhendi fruit, *Abelmoschus esculentus* which was cut into pieces and were kept inside a poly cheese cup (10 x 8 cm) (Plate 2a). The upperside of the cup was covered with muslin cloth to avoid the dispersal of the larvae. The entire set up was kept inside a cage to prevent parasitization or predation by natural enemies. The required number of second instar larvae were taken for the experiments from the rearing cups. The remaining larvae were transferred to the semi-synthetic diet (Gupta *et al.*, 1998) with certain modifications which is an enriched medium of bhendi seeds. The larvae were allowed to remain in these diets until the prepupal stage, then transferred to a plastic cup (10 x 5 cm) containing a tissue paper and cotton wad over which a bhendi fruit was kept for pupation. Rest of the mass culturing procedures of *E. vittella* is similar to that of the mass culturing of the American bollworm, *H. armigera*. This process facilitated an uninterrupted supply of test insects (Plate 2b).

3.3. Pot Culture Experiments

The pot culture experiment was conducted at the insectary of the Department of Agricultural Entomology, TNAU, Coimbatore under glasshouse condition (Plate 3a).

3.3.1. Pot culture experiment I

3.3.1.1. Raising of Test Plants

Cotton variety, LRA 5166 was selected as test plant. The level of damage caused at varying number of bollworms on the test variety was assessed under glasshouse condition. The mud pots (45 x 30 cm) was filled with the potting mixture (i.e.) Red earth, soil and farm yard manure and the treated cotton seeds were sown. The design used was

Plate 3
Damage and yield loss assessment

a) Pot culture experiment

b) Field experiment (Winter season)

Factorial completely Randomized design (FCRD), which was replicated four times. The other package of practices is followed as per the recommendation by TNAU.

3.3.1.2. Assessment of bollworm damage and yield loss

The level of damage caused by different larval density on cotton cv. LRA 5166 was assessed under glass house condition. The second instar larvae (*E. vittella*) were released on the cotton plants on 40, 50, 60, 70 and 80 DAS. The larval variants used were one to five larvae per plant, replicated four times with an untreated check (no larval release) and each plant was covered with mylar cage (Photomicron sheets). The damaged shoots, squares and bolls were recorded.

3.3.2. Pot culture experiment II

This pot culture experiment was also conducted simultaneously. The test insect, *H. armigera* was used with a slight change in the period of release *viz.*, 60, 80, 90, 100, 110 and 120 DAS. All other practices were similar to that of *E. vittella* experiment.

3.4.1. Field experiments I & II

3.4.1.1. Raising of test plants

The field experiments were conducted in March 2001 (Summer season) at the Eastern Block farm, TNAU, Coimbatore (Plate 3b). Cotton, LRA 5166 was selected as a test variety for this study. To confirm the pot culture experiment results the field experiments were conducted. The design used was Factorial randomized block design (FRBD), which was replicated four times. The level of damage caused at different bollworm larval populations on the test variety was assessed under field condition. The plot size was 8 m x 3 m. The treated seeds were sown with a spacing of 75 x 30 cm. Fertilizers were applied at 80:40:40 kg of NPK per hectare. The other package of practices were followed as per the recommendation by TNAU.

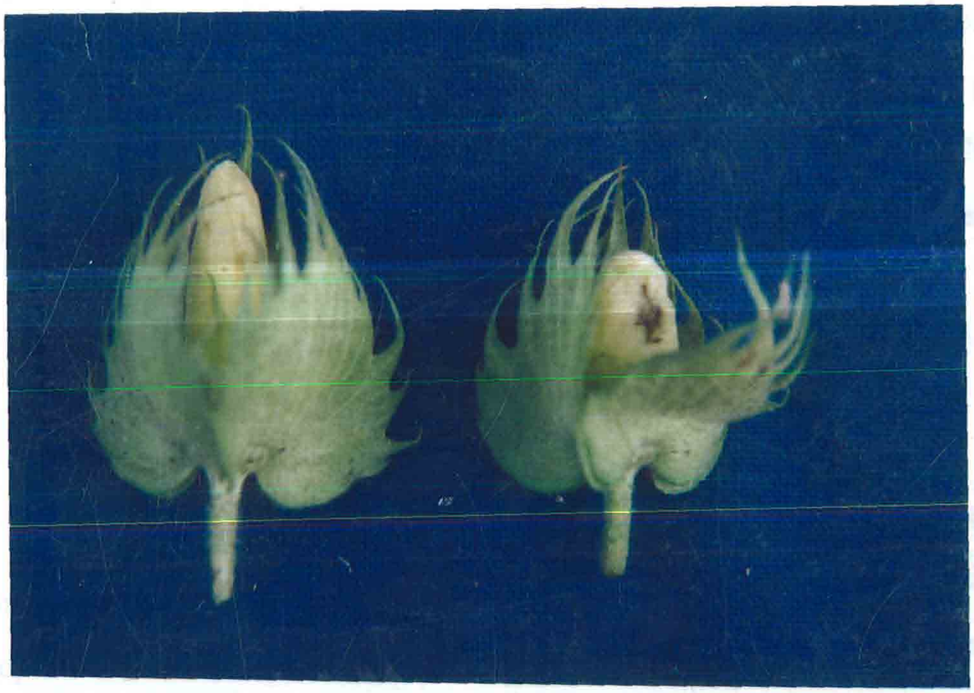
Plate 4
Individual cotton plant covered with Mylar cage (Field experiment)

Plate 5
Bollworm damage

a) Shoot damage by *Earias vittella*

b) Square damage at various boll development stages

Plate 6
Square damage



a) *Earias vittella*

b) *Helicoverpa armigera*

3.4.1.2. Assessment of bollworm damage and yield loss

The second instar larvae of *E. vittella* were released on the cotton plants at 40, 50, 60, 70 and 80 DAS. The larval variants used were one to five larvae per plant, which were replicated four times with an untreated check (no larval release). Two plants were selected randomly in each row and were individually covered with Mylar cage (Photomicron sheets) (Plate 4). The damaged shoot, squares and bolls were recorded (Plates 5, 6 & 7). The same procedure was followed in the second field experiment for *H. armigera* with slight modifications in the period of release *viz.*, 80, 90, 100, 110 and 120 DAS respectively.

The number of damaged, squares and bolls were recorded. The damaged bolls and healthy bolls per plant were recorded (Plate 8). The yield loss due to different larval population at different plant growth period (or) boll developing stages was assessed based on the uninfested control.

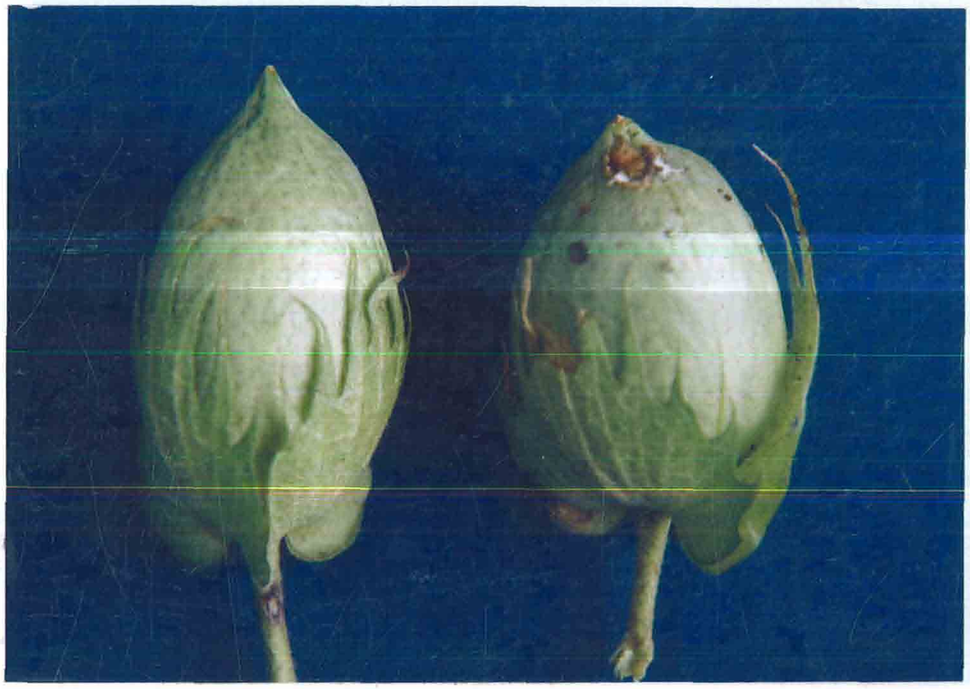
3.4.2. Field experiments III & IV

To confirm the results obtained in the field trial I and II, this study was conducted during September 2001 (winter season). The package of practices, spacing, test variety, days, number of larval release, damage and yield loss assessment were also similar to that of the previous field trial.

3.5. Quality parameters

The kapas samples from the selected plants of respective treatments were pooled. They were ginned and the lint obtained was sent to the Central Institute for Research on Cotton Technology (CIRCOT), Coimbatore for assessing the following fibre characters. The characters were estimated by High volume Instrument 900 classic installed at Department of Cotton, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore.

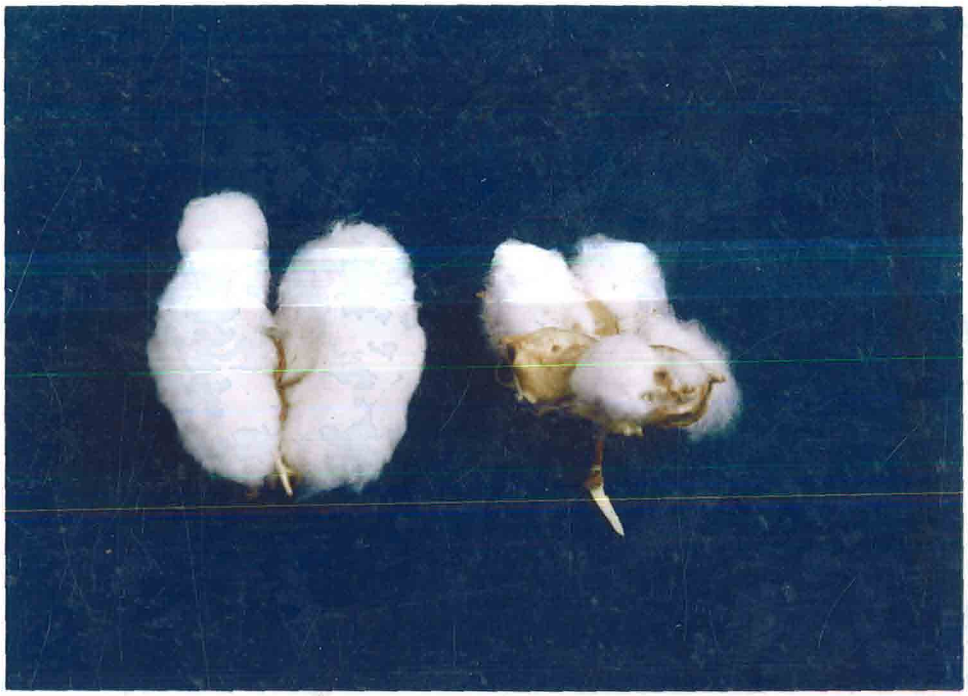
Plate 7
Boll damage



a) *Earias vittella*

b) *Helicoverpa armigera*

Plate 8



a) Healthy and damaged bolls after burst

b) Healthy and bollworm damage at various boll development periods

3.5.1. 2.5 per cent span length

The 2.5 per cent span length is the length of the fibre estimated by digital fibrograph. This is the fibre length representing majority of fibres and expressed in millimetre.

3.5.2. Uniformity ratio

This is the ratio between two span length *viz.*, 50 and 2.5 per cent span length and it is expressed as percentage. Uniformity ratio denotes the percentage of longer fibres.

$$\textbf{Uniformity ratio} = \frac{50\%\ \text{span length}}{2.5\%\ \text{span length}} \times 100$$

3.5.3. Fibre fineness

This is a relative measure of size, diameter and linear density of the fibres which denotes the fineness of the fibre. The instrument "Sheffield micronaire" was used to determine the fineness and expressed in microgram per inch.

3.5.4. Maturity co-efficient

This indicates the unitary expression of fibre maturity which is usually represented by the percentage of mature, half mature and immature fibres.

$$\textbf{Maturity co-efficient} = \frac{M + 0.6\,H + 0.4\,I}{100}$$

where

M, H and I are the percentage of mature, half mature and immature fibres.

3.5.5. Bundle strength

This denotes the fibre strength and also referred as tensile strength i.e., the maximum specific stress that is developed in a tensile test to rupture the fibres. The fibre strength was evaluated by using $^1/_8$ inch gauge length of the fibres. The instrument used for estimating the tensile strength is the stelometer and is expressed as tenacity in gram/tex.

3.6. Mathematical model

3.6.1. Prediction of yield loss using mathematical model

Simulation models for crop damage and the corresponding yield loss were constructed using the data collected as per sections 3.3.1.2. and 3.4.1. Attempts were made to fix a suitable mathematical model for assessing the damage, yield loss and rate of loss for unit increment in pest number/plant.

3.6.1.1. Prediction of bollworm damage function – Mitcherlich's model

To predict the bollworm damage at different stages of the crop by different larval population, various mathematical models *viz.*, Mitscherlich's model (Briggs, 1927; Balmukand, 1928 and Hexem *et al.*, 1976); Logistic model (Meek *et al.*, 1991), Hill model, Gombertz model, Richard model, Polynomical model, Cubic polynomial model and Gauss model (Ramachandra Prasad *et al.*, 1992) were tried to establish the functional forms. Based on the predicting ability of the model and correlation coefficient and goodness of fit, the Mitscherlich's model was found to be the best form between the per cent damage (shoot, square and boll) and the various levels of intensity of bollworm larvae.

The Mitscherlich's model is at the form

$$\mathbf{D_{(L,\,t)} = D_M\,[1\text{-}a\;e^{-b\,L(t)}]}$$

where

$D_{(L,t)}$ = Crop damage at various larval population and crop stages/period

$L(t)$ = Larval population at t^{th} period

D_M = Maximum crop damage at given larval population at various crop stages

a and b = Parameters to be estimated.

3.6.1.2. Prediction of rate of damage

The crop damage rate at different larval population under different crop stages were estimated using the function,

$$\mathbf{RD_{(L,t)} = D_M . abe^{-b\,L(t)}}$$

where RD = Rate of damage at various larval population and crop stages

(L,t) = Larval population at t^{th} crop periods

D_M = Maximum damage at given larval populations and crop periods

a and b = Parameters to be estimated

The non-linear form of Mitscherlich's model equation was estimated by the method of ordinary least squares (LS). The estimated model was tested for its validity using chi-squares goodness of fit and R^2 value.

3.6.2. Prediction of yield function – Rectangular hyperbola

To predict the yield obtained per plant after the infestation at various larval populations at different crop periods, rectangular hyperbola model was found to be the best based on the R^2 value and the prediction ability of the yield due to damage (Michaelis and Menten, 1913).

3.6.2.1. Prediction of yield

The model is of the form.

$$\mathbf{Y(L,t) = a + b\,D(L,t)^{-1}}$$

wherever, Y(L,t) = yield obtained after the infestation of various larval populations at different crop stages.

D(L,t) = crop damage at different larval population and crop stages.

a and b = Parameters to be estimated.

3.6.2.2. Prediction of rate of yield loss

The yield loss due to one per cent increase in damage from different base levels of damage was estimated using the formula.

$$\mathbf{RYL\ (L,t) = -b\ D(L,t)^{-2}}$$

where

RYL = Rate of yield loss at various larval population and crop stages

D(L,t) = Crop damage at various larval populations and crop stages

b = parameter to be estimated

The rectangular hyperbola model was estimated using the non-linear methods for ordinary least squares (OLS).

3.6.3. Prediction of yield at various level of larval population

3.6.3.1. Prediction of yield

To predict per cent yield obtained after infestation of various larval population at various crop periods, rectangular hyperbola model was found to be the best based on R^2 value and the prediction ability of the yield due to various larval intensity.

$$\mathbf{Y(L,t) = a + b\ L\ (D,t)^{-1}}$$

whereas

Y(L,t) = yield obtained after the infestations of various larval population at different crop stages

L(D,t) = Larval population and damage at various crop stages

a and b = parameters to be estimated

3.6.3.2. Prediction of rate of yield loss

The yield loss due to one per cent increase in larval population at various crop growth was estimated using the formula

$$\mathbf{RYL(D,t) = -\ b\ L(D,t)^{-2}}$$

whereas

RYL(D,t) = Rate of yield loss at various larval population and crop stages

L(D,t) = Larval intensity at various crop stages

a and b = Parameters to be estimated.

The rectangular hyperbola model was estimated using the non-linear methods for ordinary least squares (OLS).

3.7. Statistical Analysis

The data on per cent damage due to spotted bollworm and American bollworm at various crop periods during summer season and winter season were analysed as FRBD and for pot culture, FCRD was used. Percentage values were transformed into corresponding angles arcs in percentage. Analysis of variance was done and means were separated by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

EXPERIMENTAL RESULTS

4. EXPERIMENTAL RESULTS

Detailed investigations on the damage potential and yield loss caused by different larval population of bollworms *viz.*, the spotted bollworm, *Earias vittella* and the American bollworm, *Helicoverpa armigera* at different stages of the cotton variety, (cv.) LRA 5166 were carried out during 2000-2002 under pot culture and field experiments. The results of the studies are presented below.

4.1. Spotted bollworm

4.1.1. Shoot damage by spotted bollworm

The shoot damage by spotted bollworm was the highest at 40 days after sowing (DAS) followed by 50 DAS and the lowest was recorded at 60 DAS in all the experiments. The shoot damage of cotton was found increased with the increase in larval population in different stages studied. In the pot culture experiment, the shoot damage ranged from 70.41 to 99.50 per cent for one to five larvae per plant at 40 DAS, 40.67 to 76.53 per cent at 50 DAS and 5.21 to 31.05 per cent at 60 DAS (Table 3). In summer season, the shoot damage varied from 60.11 to 98.12 per cent at 40 DAS, 30.52 to 72.33 per cent at 50 DAS and 5.23 to 22.73 per cent at 60 DAS of cotton crop (Table 4) whereas during winter season, the shoot damage varied from 75.83 to 99.50 per cent at 40 DAS, 40.67 to 81.25 per cent at 50 DAS and 5.16 to 28.11 per cent at 60 DAS (Table 5).

4.1.2. Square damage by spotted bollworm

The square damage was also increased with increase in larval population in all crop stages. The highest square damage was noticed at 60 DAS followed by 50 DAS, 40 DAS and 70 DAS. The lowest square damage was recorded at 80 DAS in all the experiments.

Table 3. Yield loss at different larval population of spotted bollworm and crop periods in cotton –Pot culture experiment

Days	Larvae /plant	Shoot damage (%)*	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
40	1	70.41^{f}	0.00^{x}	0.00^{k}	55.01	0.00	100.0	0.00
	2	83.26^{d}	21.33^{r}	0.00^{k}	49.67	5.33	90.38	9.71
	3	90.61^{c}	36.81^{i}	0.00^{k}	45.80	9.22	83.32	16.75
	4	94.15^{b}	42.16^{f}	0.00^{k}	44.46	10.54	80.86	19.29
	5	99.50^{a}	51.62^{c}	0.00^{k}	42.09	12.91	76.50	23.50
	0	0.00^{p}	0.00	0.00^{k}	55.02	0.00	0.00	0.00
50	1	40.67^{j}	12.53^{l}	0.00^{k}	51.87	3.13	94.31	5.69
	2	48.15^{i}	23.51^{q}	0.00^{k}	49.12	5.88	89.31	10.69
	3	57.32^{h}	38.67^{h}	0.00^{k}	45.33	9.67	82.42	17.58
	4	65.19^{g}	44.23^{e}	0.00^{k}	43.94	11.06	79.89	20.11
	5	76.53^{e}	55.37^{b}	0.00^{k}	41.16	13.84	74.84	25.16
	0	0.00^{p}	0.00^{x}	0.00^{k}	55.02	0.00	0.00	0.00
60	1	5.21^{o}	17.43^{t}	0.00^{k}	50.64	4.36	92.07	7.93
	2	9.86^{n}	26.82^{o}	0.00^{k}	48.29	6.71	87.80	12.20
	3	17.22^{m}	40.25^{g}	0.00^{k}	44.94	10.06	81.71	18.29
	4	24.38^{l}	49.15^{d}	0.00^{k}	42.71	12.29	77.65	22.35
	5	31.05^{k}	60.43^{a}	0.00^{k}	41.41	13.59	75.29	24.71
	0	0.00^{p}	0.00^{x}	0.00^{k}	55.02	0.00	0.00	0.00
70	1	0.00^{p}	15.21^{u}	7.21^{i}	48.80	6.20	88.73	11.27
	2	0.00^{p}	19.11^{s}	12.10^{g}	46.19	8.81	83.98	16.02
	3	0.00^{p}	29.73^{m}	14.52^{f}	42.41	12.59	77.11	22.89
	4	0.00^{p}	31.57^{l}	17.75^{d}	40.01	14.99	72.75	27.25
	5	0.00^{p}	34.19^{j}	20.82^{a}	38.12	16.88	69.31	30.69
	0	0.00^{p}	0.00^{x}	0.00^{k}	55.02	0.00	0.00	0.00
80	1	0.00^{o}	6.14^{w}	4.53^{j}	53.49	1.51	97.25	2.75
	2	0.00^{o}	13.06^{v}	10.36^{h}	48.28	6.72	87.78	12.22
	3	0.00^{o}	24.05^{p}	15.33^{e}	42.86	12.14	77.93	22.07
	4	0.00^{o}	28.12^{n}	19.53^{c}	40.16	14.84	73.02	26.98
	5	0.00^{o}	33.41^{b}	20.51^{b}	38.42	16.58	69.85	30.15
	0	0.00^{o}	0.00^{x}	0.00^{k}	55.02	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05) level by DMRT.

Table 4. Yield loss at different larval population of spotted bollworm and crop periods in cotton – Field experiment (Summer - 2001)

Days	Larvae /plant	Shoot damage (%)*	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
40	1	60.11^{f}	10.42^{u}	0.00^{k}	55.41	2.61	95.50	4.50
	2	85.06^{d}	23.45^{p}	0.00^{k}	52.16	5.86	89.90	10.10
	3	92.41^{c}	43.17^{h}	0.00^{k}	47.23	10.79	81.40	18.60
	4	95.56^{b}	50.21^{f}	0.00^{k}	45.47	12.55	78.37	21.63
	5	98.12^{a}	56.95^{c}	0.00^{k}	43.53	14.49	75.03	24.97
	0	0.00^{p}	0.00^{w}	0.00^{k}	58.02	0.00	0.00	0.00
50	1	30.52^{j}	23.82^{p}	0.00^{k}	54.93	3.09	94.67	5.33
	2	38.21^{i}	25.45^{o}	0.00^{k}	51.56	6.46	88.87	11.13
	3	45.67^{h}	45.22^{gh}	0.00^{k}	46.71	11.31	80.51	19.49
	4	52.987^{g}	52.75^{e}	0.00^{k}	44.84	13.18	77.28	22.72
	5	72.33^{e}	60.21^{b}	0.00^{k}	42.97	15.05	74.06	25.94
	0	0.00^{p}	0.00^{w}	0.00^{k}	58.02	0.00	0.00	0.00
60	1	5.23^{o}	19.33^{r}	0.00^{k}	53.69	4.33	92.54	7.46
	2	9.16^{n}	29.78^{m}	0.00^{k}	50.57	7.45	87.16	12.84
	3	13.57^{m}	46.35^{g}	0.00^{k}	46.43	11.59	80.02	19.98
	4	17.45^{l}	54.23^{d}	0.00^{k}	44.52	13.50	76.73	23.27
	5	22.73^{k}	65.33^{a}	0.00^{k}	41.69	16.33	71.85	28.15
	0	0.00^{p}	0.00^{w}	0.00^{k}	58.02	0.00	0.00	0.00
70	1	0.00^{p}	18.46^{s}	8.16^{i}	49.63	8.39	85.54	14.46
	2	0.00^{p}	21.86^{q}	11.41^{g}	48.00	10.02	82.73	17.27
	3	0.00^{p}	33.51^{k}	14.83^{f}	43.71	14.31	75.34	24.66
	4	0.00^{p}	36.24^{j}	20.93^{c}	40.59	17.43	69.96	30.04
	5	0.00^{p}	42.51^{hi}	22.62^{b}	35.40	22.62	61.01	38.99
	0	0.00^{p}	0.00^{w}	0.00	58.02	0.00	0.00	0.00
80	1	0.00^{p}	9.93^{v}	5.32^{j}	53.41	4.61	92.05	7.95
	2	0.00^{p}	15.05^{t}	10.35^{h}	50.12	7.90	86.38	13.62
	3	0.00^{p}	27.16^{n}	15.26^{e}	45.13	12.89	77.78	22.22
	4	0.00^{p}	31.63^{l}	18.99^{d}	42.52	15.50	73.29	26.71
	5	0.00^{p}	40.36^{i}	23.41^{a}	38.57	19.45	66.48	33.52
	0	0.00^{p}	0.00^{w}	0.00^{k}	58.02	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05) level by DMRT.

The square damage at 60 DAS was ranging from 17.43 to 60.43 per cent for 1 to 5 larvae per plant in the pot culture experiment (Table 3). The square damage varied from 0.00 to 51.62 per cent at 40 DAS; 12.53 to 55.37 per cent at 50 DAS; 15.21 to 34.19 per cent at 70 DAS and 6.14 to 33.41 per cent at 80 DAS in pot culture experiment.

A similar trend was observed in summer (Table 4) and winter season (Table 5) trials. The square damage was more during winter season followed by summer season and pot culture experiment.

4.1.3. Boll damage by spotted bollworm

The boll damage due to spotted bollworm was found increased with increase in larval population irrespective of crop stages in all the experiments. The boll damage varied from 7.21 to 20.82 per cent at 70 DAS, and from 4.53 to 20.51 per cent at 80 DAS for one larva to five larvae per plant in pot culture experiment (Table 3).

The boll damage ranged from 8.16 to 22.62 per cent at 70 DAS and 5.32 to 23.41 per cent at 80 DAS in summer season (Table 4). In winter, the boll damage varied from 5.67 to 20.71 per cent at 70 DAS and 5.12 to 24.33 per cent at 80 DAS (Table 5).

4.1.4. The yield loss due to spotted bollworm

The yield loss due to spotted bollworm is presented in Tables 3, 4 and 5. Among the experiments, the yield loss was maximum during summer season followed by winter season and pot culture experiment. During summer, the yield loss ranged from 4.50 to 24.97 per cent at 40 DAS, 5.33 to 25.94 per cent at 50 DAS, 7.46 to 28.15 at 60 DAS, 14.46 to 38.99 at 70 DAS and 7.95 to 33.52 per cent at 80 DAS (Table 4).

A similar trend was noticed in winter and pot culture experiments.

Table 5. Yield loss at different larval population of spotted bollworm and crop periods in cotton – Field experiment (Winter - 2001)

Days	Larvae /plant	Shoot damage (%)*	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
40	1	75.83^{e}	12.98^{t}	0.00^{i}	56.76	3.25	94.58	5.42
	2	87.52^{c}	26.76^{o}	0.00^{i}	53.32	6.69	88.85	11.15
	3	95.67^{b}	42.15^{h}	0.00^{i}	49.47	10.54	82.44	17.56
	4	99.50^{a}	48.56^{g}	0.00^{i}	47.87	12.14	79.77	20.23
	5	99.50^{a}	55.06^{c}	0.00^{i}	46.24	13.77	77.05	22.95
	0	0.00^{o}	0.00^{u}	0.00^{i}	60.01	0.00	0.00	0.00
50	1	40.67^{i}	14.50^{s}	0.00^{i}	56.38	3.63	93.95	6.05
	2	48.12^{h}	28.72^{n}	0.00^{i}	52.83	7.18	88.04	11.96
	3	56.33^{g}	42.76^{h}	0.00^{i}	49.32	10.69	82.19	17.81
	4	60.42^{f}	49.33^{e}	0.00^{i}	47.68	12.33	79.45	20.55
	5	81.25^{d}	58.23^{b}	0.00^{i}	45.45	14.56	75.74	24.26
	0	0.00^{o}	0.00^{u}	0.00^{i}	60.01	0.00	0.00	0.00
60	1	5.16^{n}	21.82^{q}	0.00^{i}	54.55	5.46	90.90	9.10
	2	10.67^{m}	31.96^{m}	0.00^{i}	52.02	7.99	86.69	13.31
	3	15.33^{l}	48.78^{f}	0.00^{i}	47.81	12.20	79.67	20.33
	4	20.74^{k}	52.10^{d}	0.00^{i}	46.98	13.03	78.29	21.71
	5	28.11^{j}	69.75^{a}	0.00^{i}	40.87	19.14	68.11	31.89
	0	0.00^{o}	0.00^{u}	0.00^{i}	60.01	0.00	0.00	0.00
70	1	0.00^{o}	19.12^{r}	5.67^{h}	53.34	6.67	88.89	11.11
	2	0.00^{o}	25.34^{p}	12.67^{f}	49.45	10.56	82.40	17.60
	3	0.00^{o}	33.89^{l}	14.98^{e}	45.55	14.46	75.90	24.10
	4	0.00^{o}	35.25^{k}	18.56^{c}	43.77	16.24	72.94	27.06
	5	0.00^{o}	40.22^{i}	20.71^{b}	41.68	18.33	69.46	30.54
	0	0.00^{o}	0.00^{u}	0.00^{i}	60.01	0.00	0.00	0.00
80	1	0.00^{o}	12.43^{t}	5.12^{h}	54.86	5.15	91.42	8.58
	2	0.00^{o}	14.93^{s}	9.24^{g}	53.20	6.81	88.65	11.35
	3	0.00^{o}	29.07^{n}	14.92^{e}	47.09	12.92	78.47	21.53
	4	0.00^{o}	32.43^{lm}	16.68^{d}	45.30	14.71	75.49	24.51
	5	0.00^{o}	37.94^{f}	24.33^{a}	40.80	19.21	67.99	32.01
	0	0.00^{o}	0.00^{u}	0.00^{i}	60.01	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05) level by DMRT.

Table 6. Yield loss at different larval population of American bollworm and crop periods in cotton – Pot culture experiment

Days	Larvae /plant	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
60	1	20.72[j]	0.00[u]	51.92	5.18	90.93	9.07
	2	29.76[gh]	0.00[u]	49.66	7.44	86.97	13.03
	3	31.65[g]	0.00[u]	49.18	7.92	86.13	13.87
	4	38.19[e]	0.00[u]	47.55	9.55	83.27	16.73
	5	48.16[c]	0.00[u]	45.06	12.04	78.91	21.09
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00
80	1	26.52[h]	0.00[u]	50.47	6.63	88.39	11.61
	2	35.41[f]	0.00[u]	48.25	8.85	84.50	15.50
	3	44.83[d]	0.00[u]	45.89	11.21	80.37	19.63
	4	53.27[b]	5.41[t]	41.62	15.48	72.89	27.11
	5	58.63[a]	8.26[r]	39.14	17.96	68.55	31.45
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00
90	1	10.62[n]	12.37[p]	49.50	7.60	86.69	13.31
	2	12.98[m]	26.33[j]	43.32	13.78	75.87	24.13
	3	15.37[l]	30.76[i]	40.95	16.15	71.72	28.28
	4	18.53[k]	45.62[d]	34.22	22.88	59.93	40.07
	5	23.18[i]	50.74[b]	31.01	26.09	54.31	45.69
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00
100	1	0.00[r]	19.48[m]	49.31	7.79	86.36	13.64
	2	0.00[r]	29.12[ij]	45.45	11.65	79.60	20.40
	3	5.18[q]	38.10[g]	40.56	16.54	71.03	28.97
	4	7.26[p]	49.33[c]	35.55	21.55	62.26	37.74
	5	8.43[o]	61.91[a]	30.22	26.88	52.92	47.08
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00
110	1	0.00[r]	14.52[o]	51.29	5.81	89.82	10.18
	2	0.00[r]	21.56[l]	48.48	8.62	84.90	15.10
	3	0.00[r]	35.81[h]	42.78	14.32	74.92	25.08
	4	0.00[r]	41.53[f]	40.49	16.61	70.91	29.09
	5	0.00[r]	44.25[e]	39.40	17.70	69.00	31.00
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00
120	1	0.00[r]	6.58[s]	54.47	2.63	95.39	4.61
	2	0.00[r]	10.93[q]	52.73	4.37	92.35	7.65
	3	0.00[r]	16.94[n]	50.32	6.78	88.13	11.87
	4	0.00[r]	24.17[k]	47.43	9.67	83.06	16.94
	5	0.00[r]	31.45[i]	44.52	12.58	77.97	22.03
	0	0.00[r]	0.00[u]	57.10	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05) level by DMRT.

As regards the periods of crop growth, 70 DAS showed a maximum yield loss in summer trial (14.46% to 38.99%) for one larva to five larvae per plant followed by pot culture experiment (11.27% to 30.69%). The maximum yield loss was recorded at 80 DAS in case of winter season (8.58% to 32.01%) for one to five larvae per plant of cotton crop.

4.2. American bollworm

4.2.1. Square damage by American bollworm

A positive correlation was obtained between the square damage and different larval population per plant. Among the experiments the square damage was more during winter season followed by summer and lowest was recorded in pot culture experiment. The highest square damage was observed at 80 DAS followed by 60 DAS, 90 DAS and with the lowest damage at 100 DAS in all the experiments. It varied from 20.72 to 48.16 per cent at 60 DAS, 26.52 to 58.63 per cent at 80 DAS, 10.62 to 23.18 per cent at 90 DAS and 0.00 to 8.43 per cent at 100 DAS in pot culture experiment (Table 6). The highest damage was noticed at 80 DAS in summer season (30.41 to 60.15%) (Table 7) and in winter season (37.05 to 63.95%) (Table 8) for one to five larval population per plant.

4.2.2. Boll damage by American bollworm

The boll damage due to American bollworm was found increased with increased larval population. A positive correlation was observed between boll damage and different larval intensity in all the boll development stages. Among the experiments, the boll damage was more during winter season (Table 8) followed by summer season (Table 7) and lowest was recorded in pot culture experiment (Table 6). The highest boll damage was recorded at 100 DAS followed by 90 DAS, 110 DAS, 120 DAS and lowest damage was observed at 80 DAS in all the experiments. Highest boll damage varied from

Table 7. **Yield loss at different larval population of American bollworm and crop periods in cotton –Field experiment (Summer - 2001)**

Days	Larvae /plant	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
60	1	23.74^{k}	0.00^{u}	55.66	6.34	89.82	10.21
	2	33.86^{h}	0.00^{u}	53.49	8.51	86.38	13.75
	3	36.21^{g}	0.00^{u}	52.77	9.23	85.16	14.96
	4	44.15^{e}	0.00^{u}	50.96	11.04	82.23	17.83
	5	51.62^{c}	0.00^{u}	49.09	12.91	79.25	20.84
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00
80	1	30.41^{i}	0.00^{u}	54.40	7.62	87.77	12.31
	2	40.32^{f}	0.00^{u}	51.92	10.08	83.75	16.35
	3	48.07^{d}	0.00	49.98	12.02	80.65	19.42
	4	56.31^{b}	5.32^{t}	45.79	16.21	73.96	26.14
	5	60.15^{a}	10.25^{r}	42.86	19.14	69.13	30.93
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00
90	1	11.35^{o}	12.63^{q}	54.11	7.89	87.31	12.73
	2	14.56^{n}	28.46^{k}	46.98	15.02	75.81	24.21
	3	17.92^{m}	39.21^{g}	41.52	20.48	67.02	33.02
	4	20.43^{l}	49.17^{d}	37.22	24.78	60.01	40.01
	5	25.03^{j}	50.67^{c}	35.47	26.53	57.22	42.8
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00
100	1	0.00^{p}	20.33^{n}	53.87	8.13	86.91	13.13
	2	0.00^{p}	31.52^{j}	49.39	12.61	79.73	20.39
	3	0.00^{p}	45.10^{f}	43.96	18.04	70.91	29.14
	4	0.00^{p}	58.43^{b}	39.83	22.17	64.22	35.85
	5	0.00^{p}	63.10^{a}	34.66	27.34	55.91	44.13
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00
110	1	0.00^{p}	14.82^{p}	56.07	5.93	90.44	9.60
	2	0.00^{p}	23.51^{m}	52.65	9.44	84.82	15.28
	3	0.00^{p}	35.24^{h}	47.91	14.09	77.31	22.72
	4	0.00^{p}	45.93^{f}	43.63	18.37	70.44	29.64
	5	0.00^{p}	47.21^{e}	43.12	18.88	69.52	30.56
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00
120	1	0.00^{p}	6.41^{t}	59.44	2.56	95.91	4.12
	2	0.00^{p}	8.53^{s}	58.58	3.42	94.52	5.55
	3	0.00^{p}	17.05^{o}	55.18	6.82	89.02	11.05
	4	0.00^{p}	25.93^{l}	51.63	10.37	83.38	16.77
	5	0.00^{p}	33.86^{i}	48.46	13.54	78.26	21.89
	0	0.00^{p}	0.00^{u}	62.03	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05) level by DMRT.

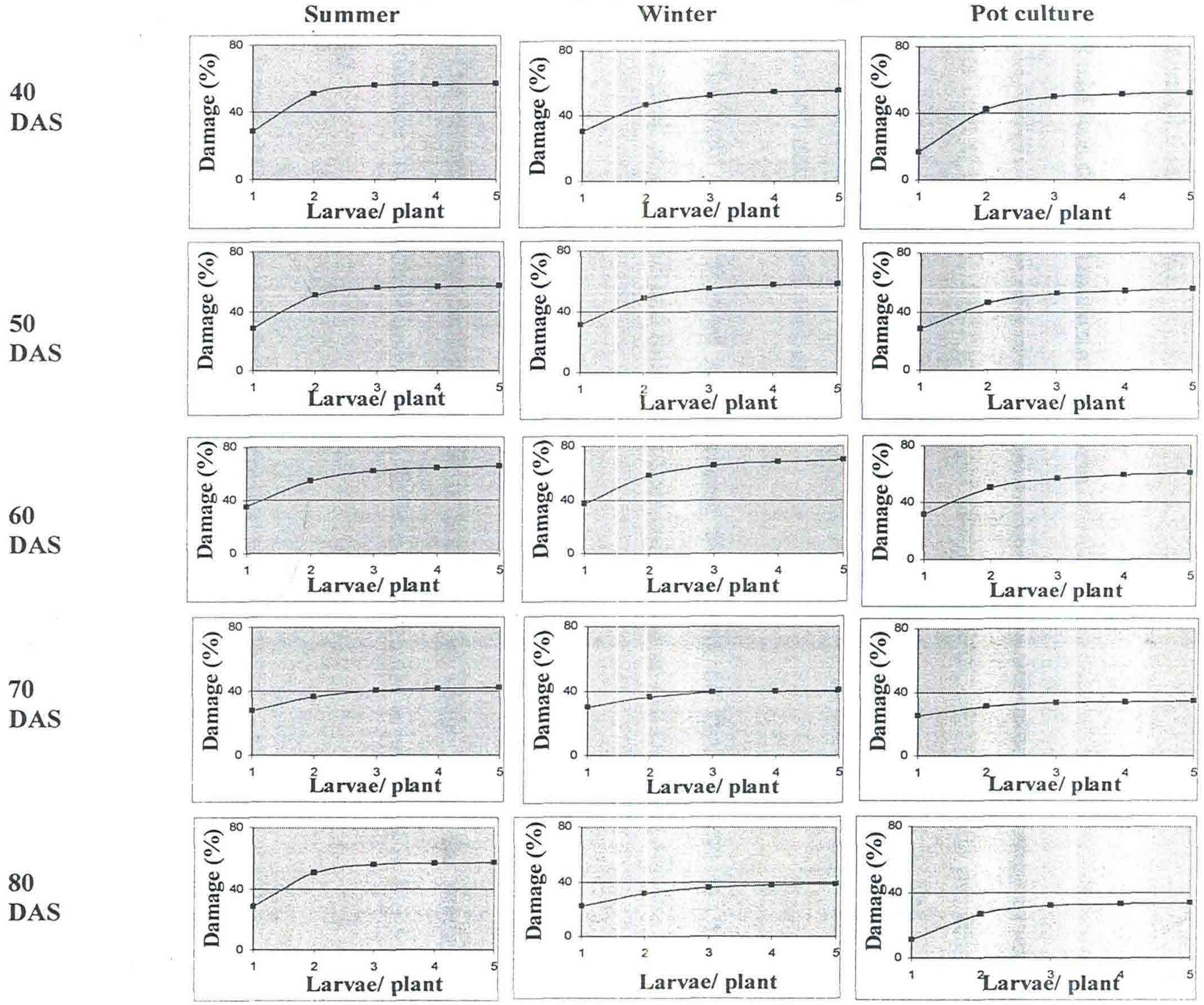
Table 8. Yield loss at different larval population of American bollworm and crop periods in cotton -Field experiment (Winter - 2001)

Days	Larvae /plant	Square damage (%)*	Boll damage (%)*	Yield obtained (g/p)	Yield loss (g/p)	Yield obtained (%)	Yield loss (%)
60	1	30.12^{j}	0.00^{r}	57.47	7.53	88.42	11.58
	2	40.86^{h}	0.00^{r}	54.78	10.22	84.28	15.72
	3	44.21^{g}	0.00^{r}	53.95	11.05	83.00	17.00
	4	51.33^{e}	0.00^{r}	52.17	12.83	80.26	19.74
	5	58.03^{c}	0.00^{r}	50.49	14.51	77.68	22.32
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00
80	1	37.05^{i}	0.00^{r}	55.74	9.26	85.75	14.25
	2	47.56^{f}	0.00^{r}	53.11	11.89	81.71	18.29
	3	54.92^{d}	0.00^{r}	51.27	13.73	78.88	21.12
	4	60.47^{b}	4.36^{s}	48.14	16.86	74.06	25.94
	5	63.95^{a}	12.03^{p}	44.20	20.80	68.00	32.00
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00
90	1	14.33^{n}	14.97^{o}	55.43	9.57	85.28	14.72
	2	19.23^{m}	23.03^{l}	51.03	13.97	78.51	21.49
	3	20.17^{l}	35.12^{h}	45.91	19.09	70.63	29.37
	4	22.82^{k}	44.33^{f}	41.56	23.44	63.94	36.06
	5	30.24^{j}	50.81^{c}	37.12	27.88	57.11	42.89
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00
100	1	0.00^{p}	23.06^{l}	55.78	9.22	85.82	14.18
	2	0.00^{p}	33.11^{i}	51.76	13.24	79.63	20.37
	3	0.00^{p}	46.07^{e}	46.57	18.43	71.65	28.35
	4	0.00^{p}	57.25^{b}	42.10	22.90	64.77	35.23
	5	10.67^{o}	68.12^{a}	35.08	29.92	53.97	46.03
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00
110	1	0.00^{p}	17.56^{n}	57.98	7.02	89.20	10.80
	2	0.00^{p}	25.33^{k}	54.87	10.13	84.42	15.58
	3	0.00^{p}	37.96^{g}	49.82	15.18	76.65	23.35
	4	0.00^{p}	45.81^{e}	46.68	18.32	71.82	28.18
	5	0.00^{p}	48.16^{d}	45.74	19.26	70.37	29.63
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00
120	1	0.00^{p}	5.41^{r}	62.84	2.16	96.68	3.32
	2	0.00^{p}	8.67^{q}	61.53	3.47	94.66	5.34
	3	0.00^{p}	20.15^{m}	56.34	8.66	86.68	13.32
	4	0.00^{p}	27.83^{j}	53.87	11.13	82.88	17.12
	5	0.00^{p}	35.27^{h}	50.89	14.11	78.29	21.71
	0	0.00^{p}	0.00^{r}	65.00	0.00	0.00	0.00

Means of four replications

*Means followed by the same letters are not significantly different at the (p=0.05)level by DMRT.

Fig.1. Predicted square damage (per cent) due to spotted bollworm



19.48 to 61.91 per cent at 100 DAS in pot culture experiment; from 20.33 to 63.10 per cent during summer and from 23.06 to 68.12 per cent during winter season for the different larval intensity. The lowest boll damage was observed at 80 DAS during summer (0.00 to 10.25%), during winter season (0.00 to 12.03%) and in pot culture experiment (0.00 to 8.26%).

4.2.3. Yield loss due to American bollworm

In winter, the yield loss ranged from 11.58 to 22.32 per cent at 60 DAS, 14.25 to 32.00 per cent at 80 DAS, 14.72 to 42.89 per cent at 90 DAS, 14.18 to 46.03 per cent at 100 DAS, 10.80 to 29.63 per cent at 110 DAS and 3.32 to 21.71 per cent at 120 DAS (Table 8). A similar trend was noticed in summer season trial and pot culture experiment at various boll development periods.

The yield curve showed an increasing trend from 60 DAS to 100 DAS and reached a peak at 100 DAS and followed a decreasing trend at 110 DAS and 120 DAS.

4.3. Predicted damage and different larval population at various crop stages

4.3.1. Predicted square damage due to spotted bollworm

The estimated crop damage model is presented in Table 9 and the predicted square damage due to spotted bollworm at different crop stages is presented in Fig.1 and Table 10.

It was observed that the damage increased with the increase in larval population at different crop periods. During summer, the damage, corresponding to the larval population increased from 28.30 per cent for one larva to 56.93 per cent for five larvae per plant at 40 DAS. The highest damage recorded was ranging from 34.89 to 65.30 per cent for one to five larvae per plant at 60 DAS (Table 10). A similar trend was noticed in 50 DAS (34.60% to 60.24%) and 70 DAS (27.84% to 42.58%) respectively.

Table 9. Estimated parameters for cotton square damage and spotted bollworm larvae at various stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
40 DAS	D_M	57.0000	55.5600	52.1200
	a	2.3185	1.2657	2.4636
	b	-1.5271	-1.0304	-1.2791
	r	0.8702	0.9274	0.9092
50 DAS	D_M	60.7100	58.7300	55.8700
	a	1.1795	1.2667	1.3315
	b	-1.0090	-1.0126	-0.9947
	r	0.9025	0.9015	0.8793
60DAS	D_M	65.8300	70.2500	60.9300
	a	1.303	1.2754	1.3097
	b	-1.0199	-0.9893	-1.9995
	r	0.8822	0.8399	0.8724
70 DAS	D_M	43.0100	40.7200	34.6900
	a	0.8612	0.622	0.6858
	b	-0.8927	-0.8689	-0.8933
	r	0.8992	0.9295	0.9605
80 DAS	D_M	40.8600	38.4400	33.9100
	a	1.2391	1.0818	2.1768
	b	-0.9278	-0.9267	-1.1724
	r	0.8782	0.9148	0.9373

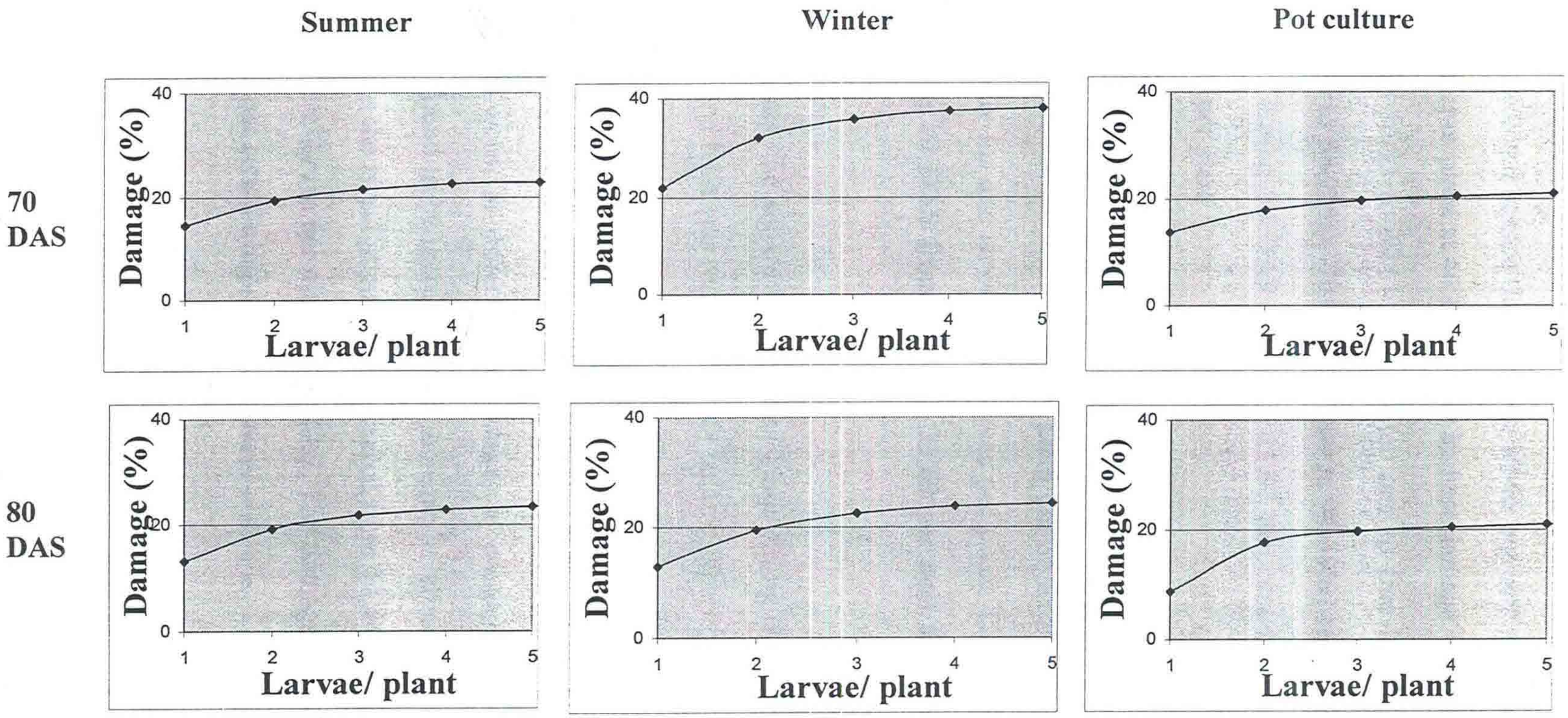
* DAS – Days after sowing

Table 10. Predicted square damage due to spotted bollworm at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage (%)		
		Summer	Winter	Pot culture
40 DAS	1	28.30	30.46	16.38
	2	50.76	46.60	42.17
	3	55.64	52.36	49.38
	4	56.70	54.41	51.34
	5	56.93	55.15	51.90
	0	--	--	--
50 DAS	1	34.60	31.70	28.35
	2	46.51	48.91	45.69
	3	57.23	55.16	52.10
	4	59.44	57.43	54.47
	5	60.24	58.25	55.35
	0	--	--	--
60 DAS	1	34.89	36.93	31.55
	2	54.69	57.86	50.11
	3	61.80	65.64	56.95
	4	64.37	68.53	59.46
	5	65.30	69.61	60.39
	0	--	--	--
70 DAS	1	27.84	30.09	24.95
	2	36.79	36.26	30.70
	3	40.46	38.85	33.05
	4	41.96	39.93	34.02
	5	42.58	40.39	34.41
	0	--	--	--
80 DAS	1	20.83	21.97	11.05
	2	32.94	31.92	26.83
	3	37.72	35.86	31.74
	4	39.62	37.41	33.23
	5	40.37	38.03	33.69
	0	--	--	--

* DAS – Days after sowing

Fig.2. Predicted boll damage (per cent) due to spotted bollworm



The lowest damage ranged from 20.83 for one larva to 40.37 for five larvae per plant at 80 DAS.

During winter, the predicted square damage was 30.46 per cent for one larva to 55.15 per cent for five larvae per plant at 40 DAS. The highest damage was recorded at 60 DAS which ranged from 36.93 to 69.61 per cent for one to five larvae per plant followed by 50 DAS (31.70 to 58.25%), 70 DAS (30.09 to 40.39%) respectively. The lowest damage was noticed during 80 DAS recording 21.97 per cent for one larva to 38.03 per cent for five larvae per plant.

A similar trend was observed in pot culture experiment. The highest damage was recorded on 60 DAS (31.55 to 60.39%) followed by 50 DAS (28.35 to 55.35%), 70 DAS (24.95 to 34.41%) respectively for one larva to five larvae per plant. The lowest square damage was observed during 80 DAS from 11.05 to 33.69 per cent for one and five larvae per plant.

Among the experiments, the square damage was more during the winter season followed by summer season and least was recorded in pot culture experiment.

4.3.2. Predicted boll damage due to spotted bollworm

The estimated crop damage model is presented in Table 11. The predicted boll damage due to spotted bollworm at different crop stages is presented in Fig.2 and Table 12. The damage was found to be increased with increase in larval population. The boll damage corresponding to the larval population increased from 14.44 per cent for one larva to 22.82 per cent for five larvae per plant at 70 DAS. The damage at 80 DAS was ranging from 13.25 to 23.51 per cent during summer season.

Table 11. Estimated parameters for cotton boll damage and spotted bollworm larvae at various stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
70 DAS	D_M	23.1200	21.3100	21.2200
	a	0.8757	0.6911	0.7846
	b	-0.8474	-0.7666	-0.8078
	r	0.9431	0.9596	0.9127
80 DAS	D_M	23.9100	24.8300	21.0100
	a	1.0168	1.0723	0.9649
	b	-0.8245	-0.7997	-0.8964
	r	0.9070	-0.8524	0.9794

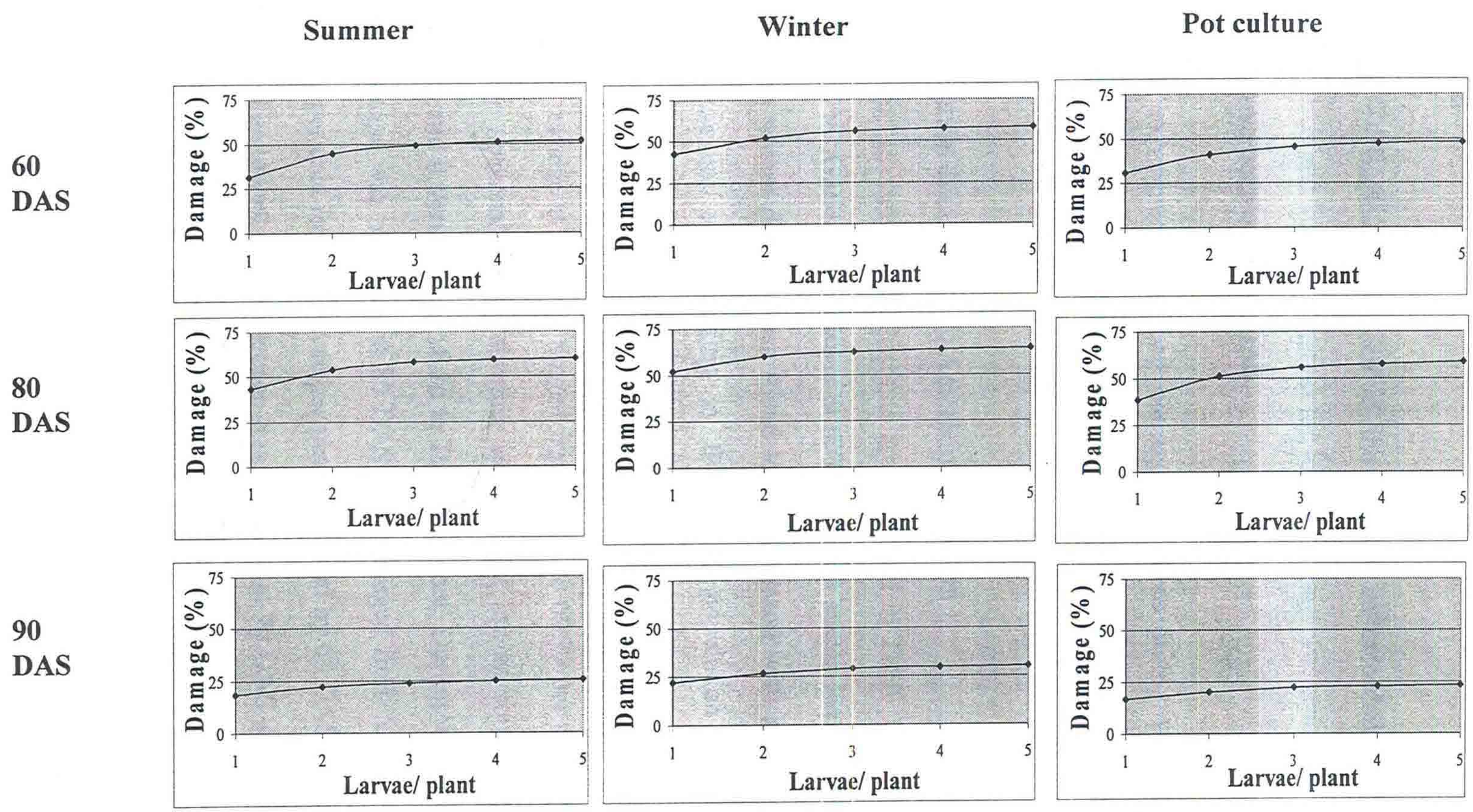
* DAS – Days after sowing

Table 12. Predicted boll damage due to spotted bollworm at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage (%)		
		Summer	Winter	Pot culture
70 DAS	1	14.44	14.46	13.79
	2	19.40	18.13	17.91
	3	21.52	19.83	19.74
	4	22.43	20.62	20.56
	5	22.82	20.99	20.92
	0	--	--	--
80 DAS	1	13.25	12.86	8.57
	2	19.23	19.45	17.63
	3	21.86	22.41	19.63
	4	23.00	23.74	20.44
	5	23.51	24.34	20.85
	0	--	--	--

* DAS – Days after sowing

Fig.3. Predicted square damage (per cent) due to American bollworm



The highest damage was recorded at 80 DAS from 12.86 to 24.34 per cent followed by 14.46 to 20.99 per cent for one larva to five larvae per plant at 70 DAS during winter season.

There was no marked difference in the damage as recorded in pot culture experiments at 70 DAS and 80 DAS whereas the lowest damage was recorded as 8.57 per cent due to single larva per plant at 80 DAS.

Among the experiments, the boll damage was more during winter season as compared to summer and pot culture experiments. Among the days, 80 DAS recorded the maximum boll damage followed by 70 DAS.

4.3.3. Predicted square damage due to American bollworm

The estimated mathematical equations are presented in Table 13. The predicted square damage due to American bollworm at different crop stages is presented in Fig.3 and Table 14. The square damage was found to be increased with increase in larval population. The damage corresponding to the larval population increased from 31.38 per cent for one larva to 51.54 for five larvae per plant at 60 DAS.

The square damage at 80 DAS ranged from 43.14 to 60.29 per cent and this was the highest damage observed during summer season. The lowest square damage was noticed at 90 DAS and it varied from 18.26 to 25.16 per cent. During winter season, the highest square damage was observed at 80 DAS which ranged from 52.28 per cent for one larva to 64.17 per cent for five larvae per plant followed by 60 DAS recording 42.88 to 58.09 per cent. The lowest square damage was observed at 90 DAS which varied from 22.25 to 30.29 per cent in cotton. A similar trend was observed in pot culture experiment for all the crop stages.

Table 13. Estimated parameters for cotton square damage and American bollworm larvae at various stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
60 DAS	D_M	51.8200	58.5300	48.6600
	a	1.1540	0.6560	0.8579
	b	-1.0740	-0.8978	-0.8637
	r	0.8467	0.8863	0.8387
80 DAS	D_M	60.6500	64.4500	59.1300
	a	0.7652	0.4859	0.9236
	b	-0.9749	-0.9453	-0.9754
	r	0.9374	0.9485	0.9185
90 DAS	D_M	25.5300	30.7400	23.6800
	a	0.5994	0.5763	-0.6129
	b	-0.7456	-0.7356	-0.7257
	r	0.8798	0.8219	0.8636

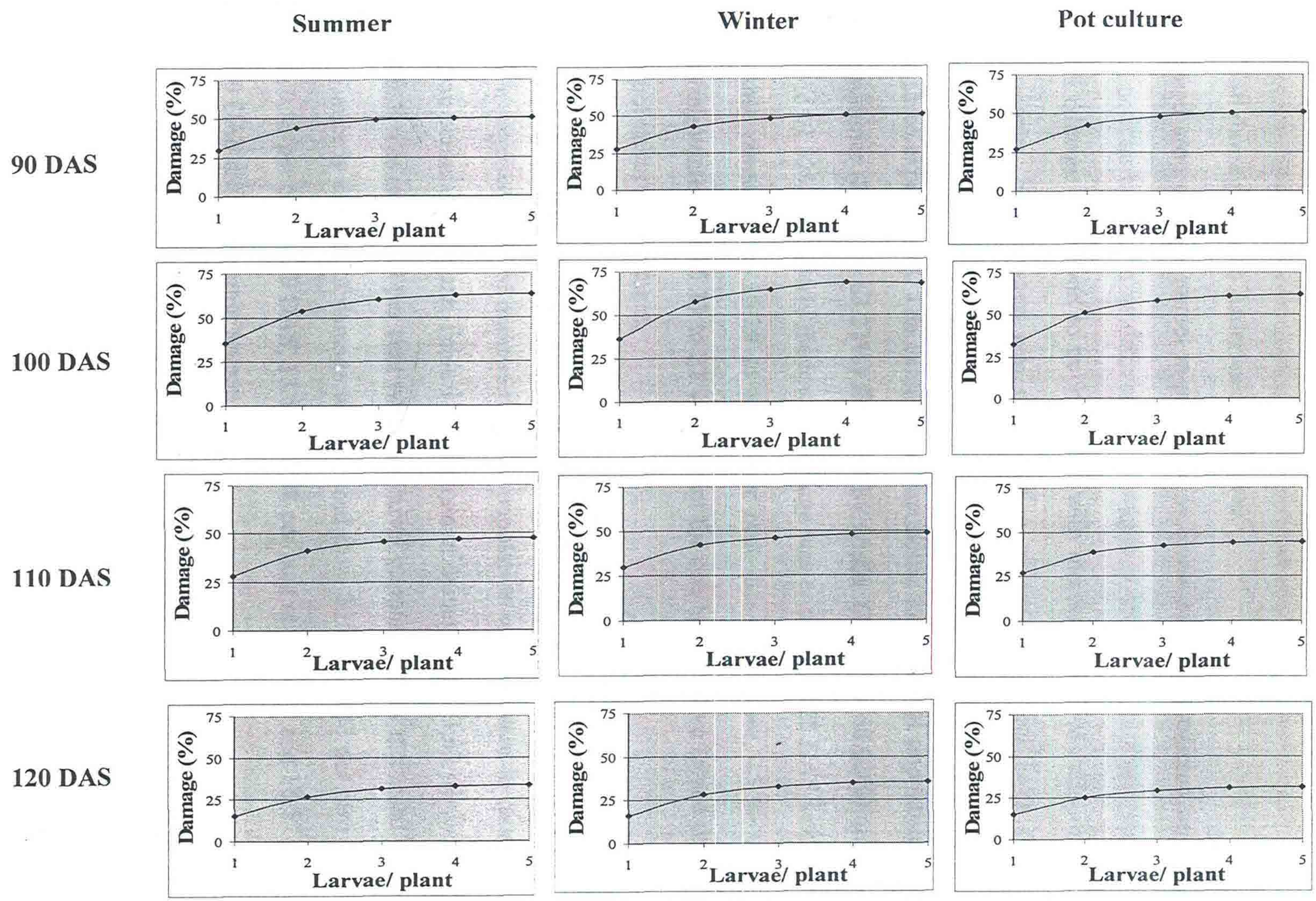
* DAS – Days after sowing

Table 14. Predicted square damage due to American bollworm at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage (%)		
		Summer	Winter	Pot culture
60 DAS	1	31.38	42.88	31.06
	2	44.84	52.15	41.23
	3	49.43	55.93	45.53
	4	51.00	57.47	47.34
	5	51.54	58.09	48.10
	0	--	--	--
80 DAS	1	43.14	52.28	38.53
	2	54.04	59.72	51.36
	3	58.15	62.61	56.20
	4	59.71	63.73	58.02
	5	60.29	64.17	58.71
	0	--	--	--
90 DAS	1	18.26	22.25	16.65
	2	22.08	26.67	20.28
	3	23.89	28.79	22.03
	4	24.75	29.80	22.89
	5	25.16	30.29	23.29
	0	--	--	--

* DAS – Days after sowing

Fig.4. Predicted boll damage (per cent) due to American bollworm



Among the experiments, square damage due to American bollworm was more during the winter season followed by summer season and pot culture experiments and between days 80 DAS was recorded the highest damage followed by 60 DAS and 90 DAS.

4.3.4. Predicted boll damage due to American bollworm

The estimated crop damage model is presented in Table 15. The predicted boll damage due to American bollworm at different crop stages is presented in Fig.4 and Table 16. The boll damage was found to be increased with increase in larval intensity. Among the experiments, boll damage was more during winter season followed by summer and pot culture experiments and between days 100 DAS recorded the highest damage in all the three experiments. The damage corresponding to the larval population increased during summer (35.54 to 63.21%) followed by winter (36.35 to 68.05%) and pot culture (32.43 to 61.82%). Similarly the lowest damage was noticed at 120 DAS in all the experiments that ranged from 15.29 to 33.37 per cent during summer, 15.96 to 35.31 per cent during winter and 15.33 to 31.46 per cent for one larva to five larvae per plant of cotton in pot culture experiment.

4.3.5. Predicted rate of square damage due to spotted bollworm

It showed a negative trend of damage to larval population with increase in larval population and crop periods (Fig.5 and Table 17). The rate of damage was 43.82 per cent for one larva while it was only 0.09 per cent when the larval population was increased to five at 40 DAS. Similarly the rate of damage was reduced from 26.34 to 0.46 per cent at 50 DAS, 31.54 to 0.53 per cent at 60 DAS, 13.54 to 0.38 per cent at 70 DAS and 18.57 to 0.45 per cent at 80 DAS during summer season.

A similar trend was noticed in case of winter and pot culture experiments, as the crop stages and larval intensity increase with decrease in the rate of damage. In other

Fig. 5. Predicted rate of square damage (per cent) due to spotted bollworm

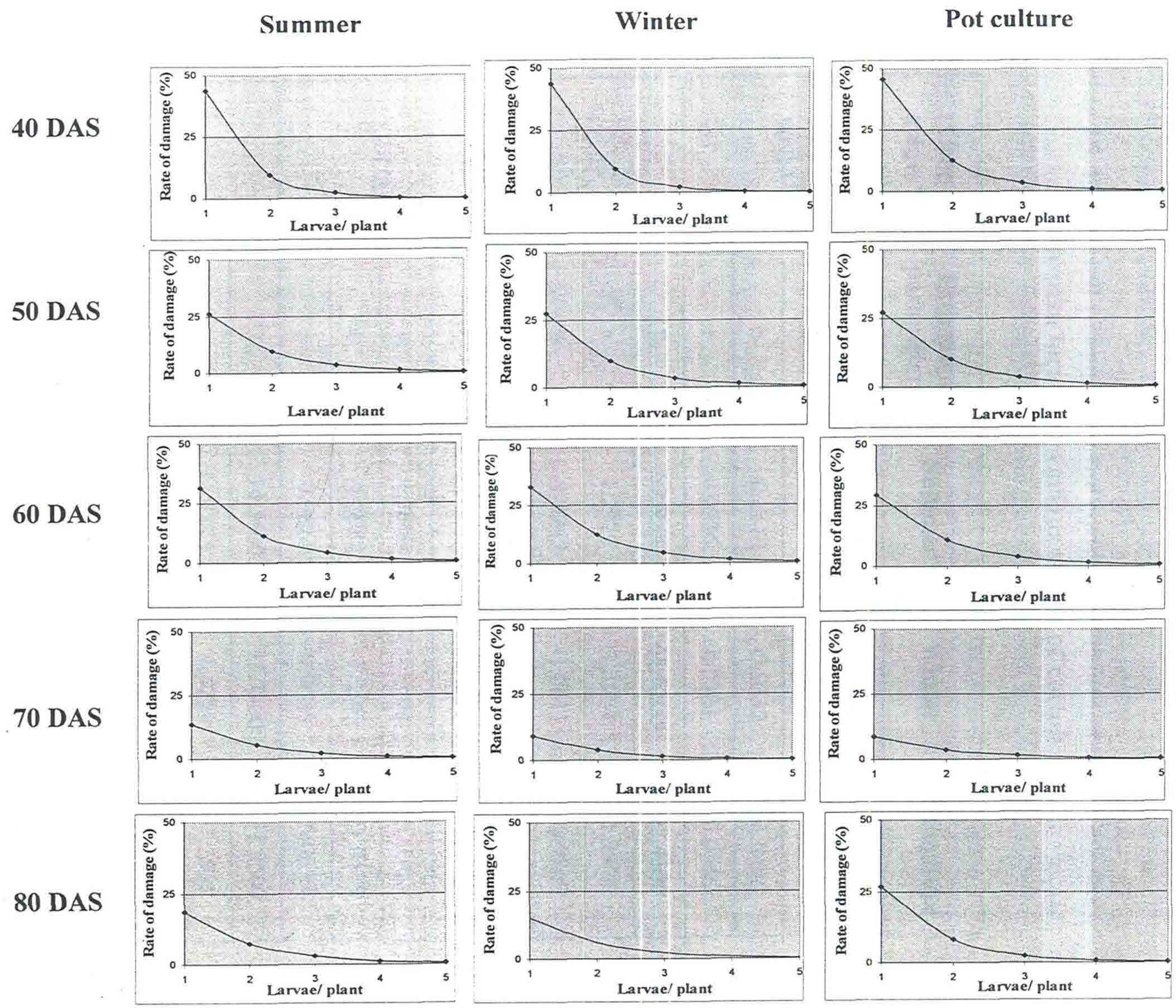


Table 15. Estimated parameters for cotton boll damage and American bollworm larvae at various stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
90 DAS	D_M	51.1700	51.3100	51.2400
	a	1.2519	1.2394	1.3078
	b	-0.1119	-0.9332	-1.0196
	r	0.9726	0.9101	0.9146
100 DAS	D_M	63.6000	68.5200	62.4100
	a	1.2920	1.3564	1.2849
	b	-1.0747	-1.0611	-0.9840
	r	0.9333	0.8701	0.8542
110DAS	D_M	47.7100	48.6600	44.750
	a	1.2468	1.0864	1.0963
	b	-1.0982	-1.0363	-1.0178
	r	0.9624	0.9626	0.9639
120 DAS	D_M	34.3600	35.7700	31.9500
	a	1.3875	1.4229	1.2593
	b	-0.9167	-0.944	-0.8847
	r	0.8670	0.8856	0.8697

* DAS – Days after sowing

Table 16. Predicted boll damage due to American bollworm at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage (%)		
		Summer	Winter	Pot culture
90 DAS	1	30.09	27.75	27.06
	2	44.23	42.58	42.51
	3	48.89	48.07	48.09
	4	50.42	50.11	50.10
	5	50.92	50.86	50.83
	0	--	--	--
100 DAS	1	35.54	36.35	32.43
	2	54.02	57.38	51.20
	3	60.33	64.66	58.22
	4	62.48	68.52	60.84
	5	63.21	68.05	61.82
	0	--	--	--
110 DAS	1	27.87	29.90	27.02
	2	41.09	42.00	38.34
	3	45.50	46.29	42.43
	4	46.97	47.82	43.91
	5	47.46	48.36	44.44
	0	--	--	--
120 DAS	1	15.29	15.96	15.33
	2	26.73	28.06	25.09
	3	31.31	32.77	29.11
	4	33.14	34.60	30.78
	5	33.37	35.31	31.46
	0	--	--	--

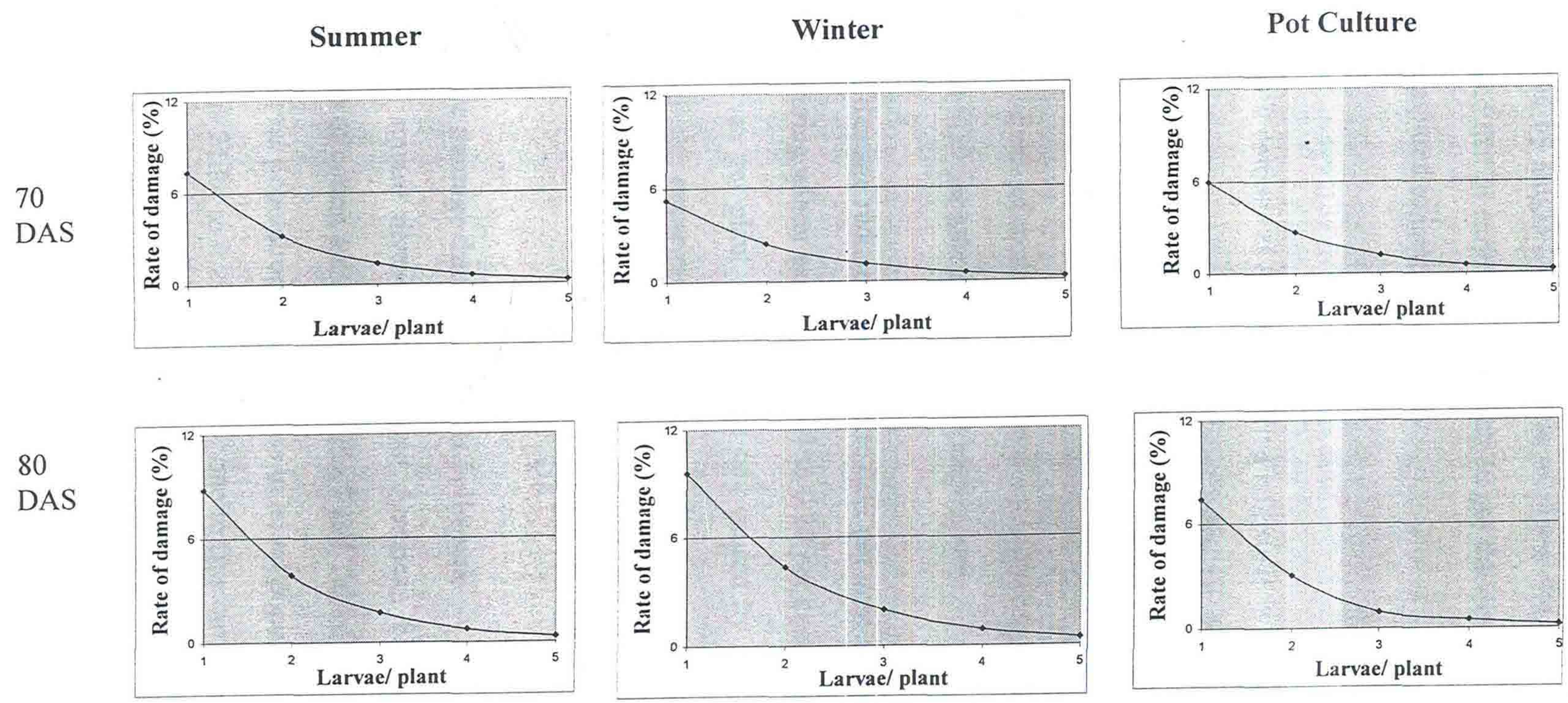
* DAS – Days after sowing

Table 17. Predicted rate of square damage at different spotted bollworm intensity at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage rate (%)		
		Summer	Winter	Pot culture
40 DAS	1	43.82	25.85	45.70
	2	9.51	9.22	12.71
	3	2.06	3.29	3.53
	4	0.44	1.17	0.98
	5	0.09	0.41	0.27
	0	--	--	--
50 DAS	1	26.34	27.36	27.36
	2	9.60	9.94	10.12
	3	3.50	3.61	3.74
	4	1.27	1.31	1.38
	5	0.46	0.47	0.51
	0	--	--	--
60 DAS	1	31.54	32.95	29.35
	2	11.37	12.24	10.80
	3	4.10	4.55	3.97
	4	1.47	1.69	1.46
	5	0.53	0.63	0.53
	0	--	--	--
70 DAS	1	13.54	9.23	8.69
	2	5.54	3.87	3.56
	3	2.27	1.62	1.45
	4	0.93	0.68	0.59
	5	0.38	0.28	0.24
	0	--	--	--
80 DAS	1	18.57	15.25	26.79
	2	7.34	6.03	8.29
	3	2.90	2.39	2.56
	4	1.14	0.94	0.79
	5	0.45	0.37	0.24
	0	--	--	--

* DAS – Days after sowing

Fig.6. Predicted rate of boll damage (per cent) due to spotted bollworm



words, the rate of damage is inversely proportional to the larval population and crop stages in cotton.

The damage rate caused by single larva is more in all these days and in all the experiments. The result revealed that in earlier days of crop stages the damage caused by a single larva is more when compared to later crop periods.

4.3.6. Predicted rate of boll damage due to spotted bollworm

The predicted rate of boll damage at different spotted bollworm larval intensity at 70 DAS and 80 DAS of cotton crop are presented in Fig.6 and Table 18. The damage rate declined with increase in larval population. The rate of damage was 7.35 per cent for one larva while it was only 0.24 per cent for five larvae per plant at 70 DAS during summer season. Similarly at 70 DAS, the rate of damage varied from 5.24 to 0.24 per cent during winter season and from 5.99 to 0.23 per cent in pot culture experiment.

On 80 DAS the rate of damage reduced from 8.78 to 0.32 per cent during summer season, 9.57 to 0.39 per cent during winter season and 7.41 to 0.20 per cent in pot culture experiment for one to five larvae per plant. The damage rate caused by single larva is more in all the days and in all the experiments. As the boll development started from 70 DAS, the damage rate was lower at 70 DAS and in later periods (80 DAS) the damage rate was found more.

4.3.7. Predicted rate of square damage due to American bollworm

The predicted rate of square damage at different American bollworm larval intensity at various crop stages of cotton are presented in Fig.7 and Table 19. It showed a negative trend of damage to larval population with increase in larval population and crop stages. The rate of damage was 21.94 to 0.29 per cent for one to five larvae per plant at 60 DAS during summer season. Similarly at 60 DAS the rate of damage was 14.04 to

Fig.7. Predicted rate of square damage (per cent) due to American bollworm

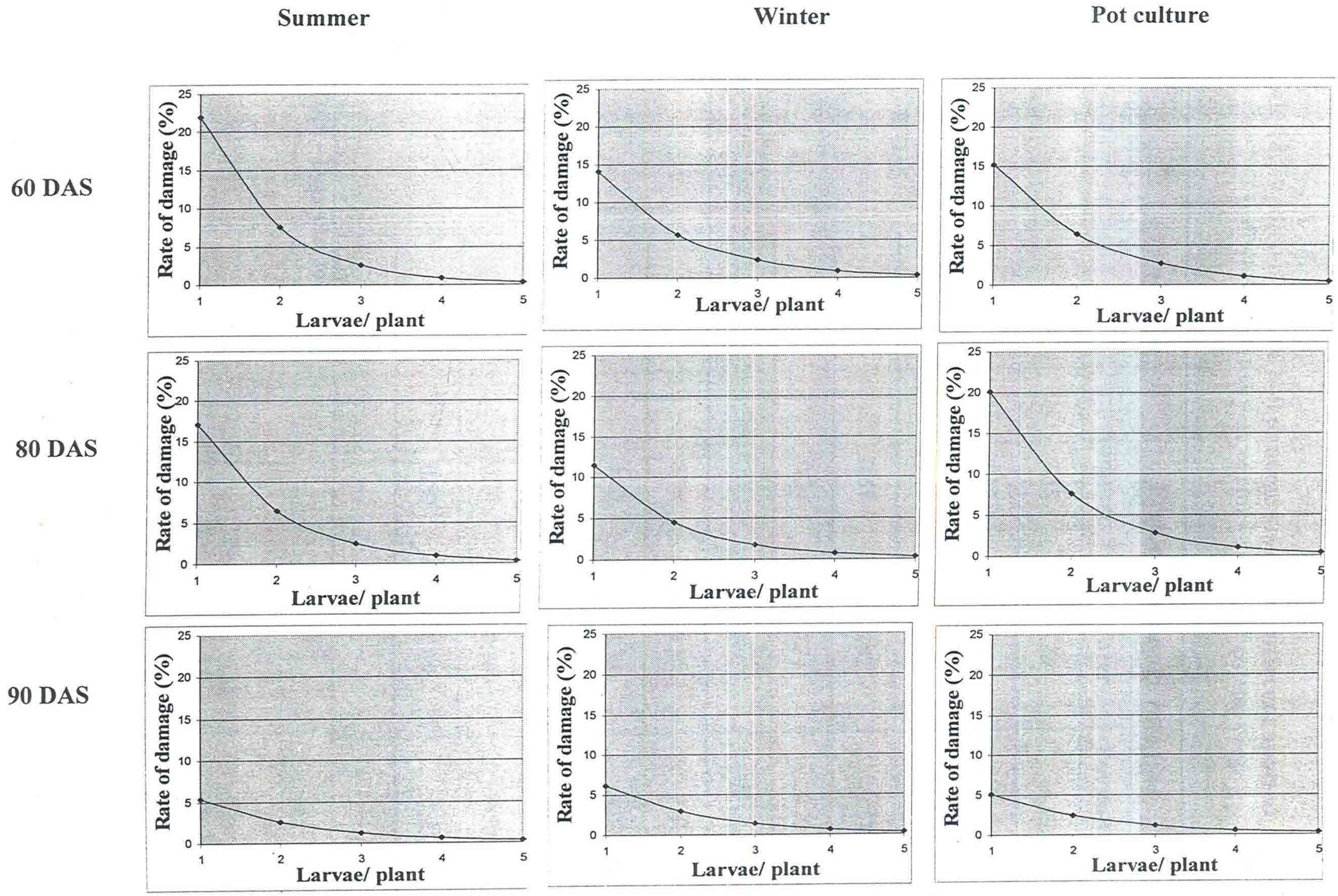


Table 18. Predicted rate of boll damage rate of at different spotted bollworm intensity at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage rate (%)		
		Summer	Winter	Pot culture
70 DAS	1	7.35	5.24	5.99
	2	3.15	2.43	2.67
	3	1.35	1.13	1.19
	4	0.57	0.52	0.53
	5	0.24	0.24	0.23
	0	--	--	--
80 DAS	1	8.78	9.57	7.41
	2	3.85	4.30	3.02
	3	1.68	1.93	0.89
	4	0.74	0.86	0.50
	5	0.32	0.39	0.20
	0	--	--	--

* DAS – Days after sowing

Table 19. Predicted rate of square damage at different American bollworm intensity at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage rate (%)		
		Summer	Winter	Pot culture
60 DAS	1	21.94	14.04	15.20
	2	7.49	5.72	6.40
	3	2.56	2.33	2.70
	4	0.87	0.95	1.13
	5	0.29	0.38	0.48
	0	--	--	--
80 DAS	1	17.06	11.50	20.08
	2	6.43	4.46	7.57
	3	2.42	1.76	2.85
	4	0.91	0.68	1.07
	5	0.34	0.26	0.40
	0	--	--	--
90 DAS	1	5.41	6.24	5.09
	2	2.56	2.99	2.46
	3	1.21	1.43	1.19
	4	0.57	0.68	0.57
	5	0.27	0.32	0.27
	0	--	--	--

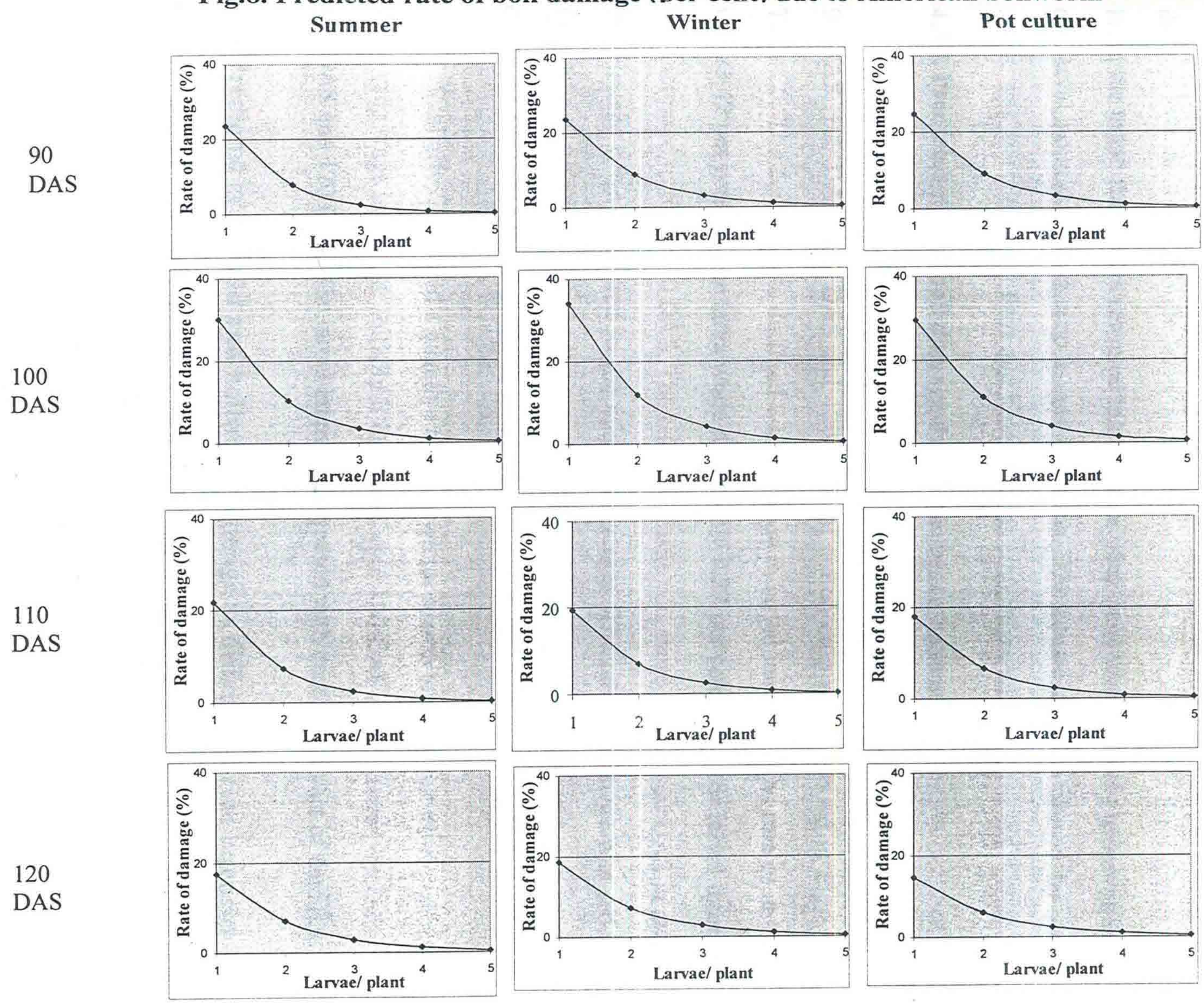
* DAS – Days after sowing

Table 20. Predicted rate of boll damage at different American bollworm intensity at various stages of cotton crop

Crop stages*	Larvae /plant	Predicted damage rate (%)		
		Summer	Winter	Pot culture
90 DAS	1	23.42	23.39	24.64
	2	7.70	8.66	8.89
	3	2.53	3.20	3.20
	4	0.83	1.18	1.15
	5	0.27	0.44	0.41
	0	--	--	--
100 DAS	1	30.14	34.12	29.49
	2	10.29	11.81	11.02
	3	3.51	4.08	4.12
	4	1.19	1.41	1.54
	5	0.40	0.48	0.57
	0	--	--	--
110 DAS	1	21.78	19.43	18.04
	2	7.26	6.89	6.52
	3	2.42	2.44	2.35
	4	0.80	0.86	0.85
	5	0.26	0.30	0.30
	0	--	--	--
120 DAS	1	17.47	18.69	14.69
	2	6.98	7.27	6.06
	3	2.79	2.82	2.50
	4	1.11	1.10	1.03
	5	0.44	0.42	0.42
	0	--	--	--

* DAS – Days after sowing

Fig.8. Predicted rate of boll damage (per cent) due to American bollworm



0.38 per cent during winter season and 15.20 to 0.48 per cent in pot culture experiment for one to five larvae per plant.

A similar trend was observed at 80 DAS and 90 DAS in all the experiments. The damage rate caused by single larva was more in all the days and in all the experiments. From the graph the results revealed that the rate of damage was inversely proportional to the larval population and crop stages in cotton. The square damage caused by single larvae was more in earlier days and it declined as crop stages advanced.

4.3.8. Predicted rate of boll damage due to American bollworm

The predicted rate of boll damage at different American bollworm intensity at 90 DAS, 100 DAS, 110 DAS and 120 DAS of cotton crop are presented in Fig.8 and Table 20. The damage rate declined with increase in larval intensity. The rate of damage was 23.42 per cent for one larva while it was only 0.27 per cent when the larval intensity was increased to five at 90 DAS. The rate of damage was more during 100 DAS in all the experiments when compared to the other crop stages. The rate of damage was reduced from 30.14 to 0.40 per cent at 100 DAS, 21.78 to 0.26 per cent at 110 DAS and 17.47 to 0.44 per cent at 120 DAS during summer season.

Similarly, it showed a negative trend in winter season and pot culture experiment, as the crop stage increased. Initially it increased upto 100 DAS and it started declining at 110 DAS and 120 DAS. The larval intensity increased with decrease in rate of damage.

4.4. Predicted crop yield and bollworm damage at different larval intensity in cotton crop

4.4.1. Predicted crop yield and square damage by spotted bollworm at various crop stages

The estimated mathematical model for damage and yield functions are presented in Table 21. The crop yield in terms of per cent rated against corresponding damage for various larval intensity and crop stages were predicted (Fig.9 and Table 22). The crop

Fig. 9. Predicted yield and square damage (per cent) due to spotted bollworm

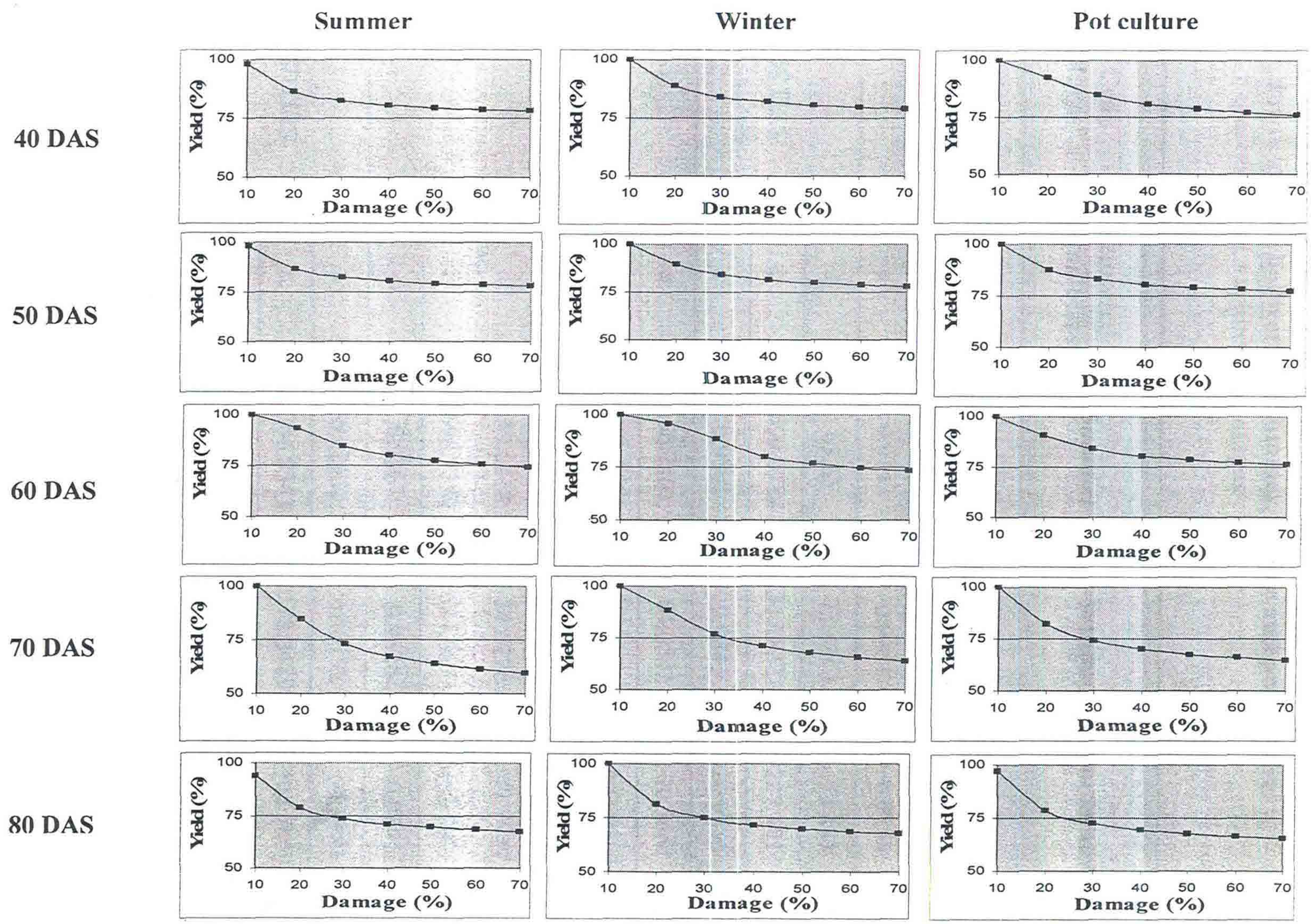


Table 21. Estimated crop model for yield and crop square damage (per cent) due to spotted bollworm in summer, winter and pot culture experiments at various crop stages

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
40 DAS	a	74.6759	74.9065	69.2181
	b	234.978	272.2445	461.2208
	r	0.9143	0.9351	0.9704
50 DAS	a	63.65	73.4363	73.483
	b	699.0784	317.8325	282.4915
	r	0.9801	0.9343	0.9253
60DAS	a	66.7401	64.0542	70.1661
	b	530.4483	635.8325	407.2303
	r	0.9587	0.9159	0.9649
70 DAS	a	49.6318	54.0226	57.7929
	b	698.9359	684.6673	483.9995
	r	0.9267	0.9826	0.9642
80 DAS	a	63.2132	62.3172	60.3983
	b	306.9343	378.3489	364.7659
	r	0.9486	0.954	0.9776

* DAS – Days after sowing

Table 22. Predicted crop yield at various levels of spotted bollworm damage (square) in various experiments

Crop stages*	Per cent damage levels	Predicted yield (%)		
		Summer	Winter	Pot culture
40 DAS	10	98.17	100.00	100.00
	20	86.42	88.51	92.27
	30	82.50	83.98	84.59
	40	80.55	81.71	80.74
	50	79.37	80.35	78.44
	60	78.59	79.44	76.90
	70	78.03	78.79	75.80
50 DAS	10	100.00	100.00	100.00
	20	98.60	89.28	87.60
	30	86.95	84.00	82.89
	40	81.12	81.36	80.54
	50	77.63	79.77	79.13
	60	75.30	78.72	78.19
	70	73.63	77.96	77.18
60 DAS	10	100.00	100.00	100.00
	20	93.26	95.84	90.52
	30	84.42	88.24	83.74
	40	80.00	79.95	80.34
	50	77.34	76.77	78.31
	60	75.58	74.65	76.95
	70	74.31	73.13	75.98
70 DAS	10	100.00	100.00	100.00
	20	84.57	88.25	81.99
	30	72.92	76.84	73.92
	40	67.10	71.13	69.89
	50	63.61	67.71	67.47
	60	61.28	65.43	65.85
	70	59.61	63.80	64.70
80 DAS	10	93.90	100.00	96.87
	20	78.55	81.234	78.63
	30	73.44	74.92	72.55
	40	70.88	71.77	69.51
	50	69.35	69.88	67.69
	60	68.32	68.62	66.47
	70	67.59	67.72	65.60

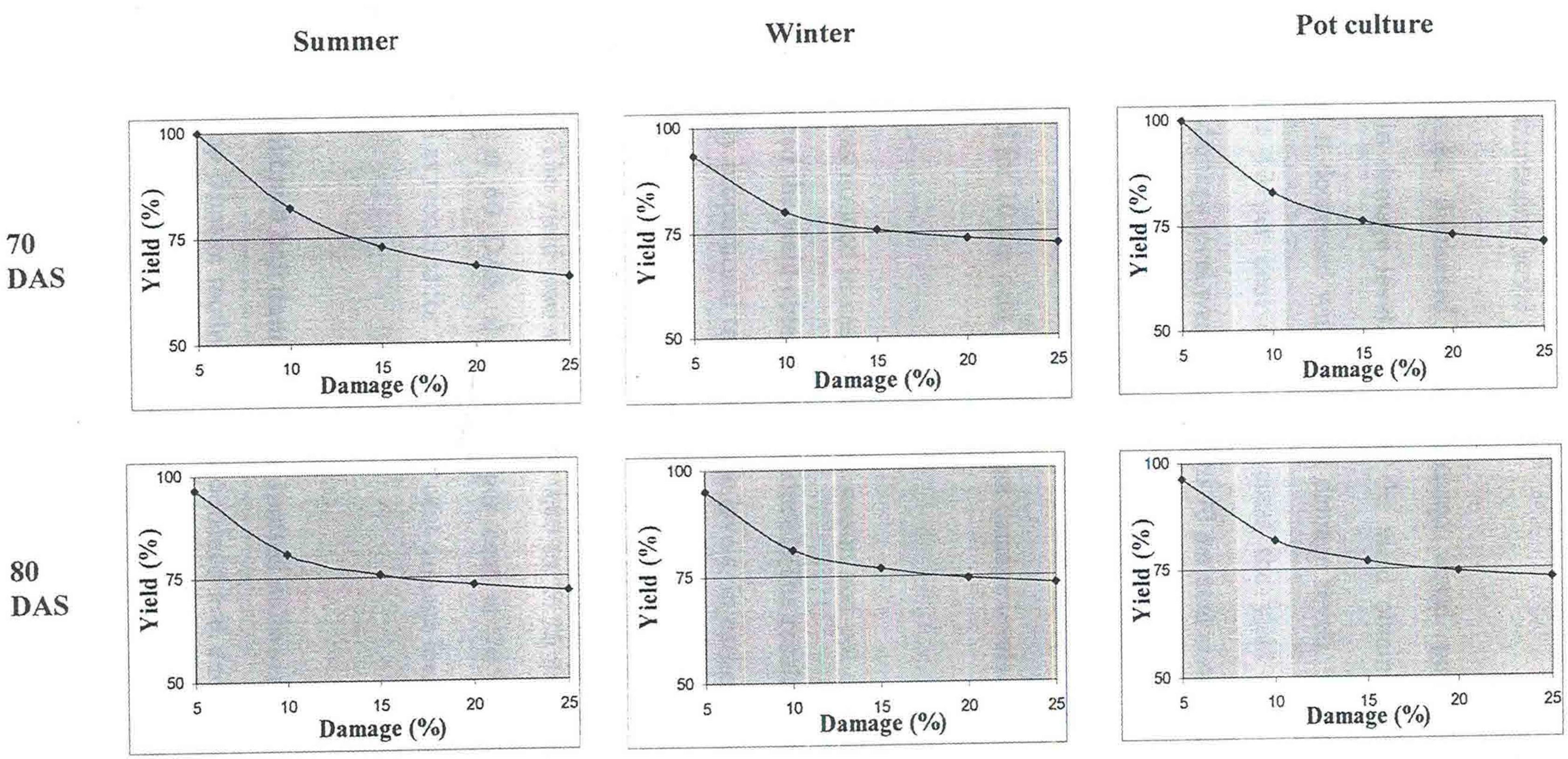
* DAS – Days after sowing

Table 23. Estimated crop model for yield and crop boll damage (per cent) due to spotted bollworm in summer, winter and pot culture experiments at various crop stages

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
70 DAS	a	54.2417	66.5569	62.1459
	b	279.6774	133.9068	205.6628
	r	0.9112	0.9063	0.9262
80 DAS	a	65.2959	67.2713	67.1711
	b	156.0068	139.2308	145.0344
	r	0.9013	0.8893	0.9275

* DAS – Days after sowing

Fig.10. Predicted yield and boll damage (per cent) due to spotted bollworm



was infested at the age of 40 DAS through 80 DAS at various larval population on plant basis. The damage was found to decrease with increasing crop stages. The damage however increased with increasing larval populations.

The yield obtained decreased with increased larval population and the corresponding increase in damage level. However, the yield obtained was higher for lower damage level and it decreased with increased damage levels. The yield obtained was 98.17 per cent for 10 per cent damage whereas the yield was decreased to 78.03 per cent when the damage level was increased to 70 per cent at 40 DAS.

Similarly, the yield obtained was varying from 100 to 73.63 per cent at 50 DAS, 100 to 74.31 per cent at 60 DAS, 100 to 59.61 per cent at 70 DAS and 93.90 to 67.59 per cent at 80 DAS for 10 per cent to 70 per cent damage levels as recorded during summer season.

A similar trend was noticed in case of winter season and pot culture experiment. As the crop stage advanced the yield obtained was reduced. The results revealed that the yield obtained is inversely proportional to the damage levels. In earlier days the damage level was increased with crop stages. As the damage level increased from 10 per cent to more, the yield loss was 1.82 per cent to 21.96 per cent for 70 per cent damage level as noticed during 40 DAS. The yield loss varied from 0.00 to 26.36 per cent at 50 DAS, 0.00 to 25.68 per cent at 60 DAS, 0 to 40.38 per cent at 70 DAS and 6.09 to 32.40 per cent at 80 DAS as recorded for 10 to 70 per cent damage levels in cotton during summer season.

4.4.2. Predicted crop yield and boll damage due to spotted bollworm

The estimated crop damage model for yield obtained and damage functions are presented in Table 23. The crop yield and boll damage were predicted (Fig.10; Table 24).

Table 24. Predicted crop yield at various levels of spotted bollworm damage (boll) in various experiments

Crop stages*	Per cent damage levels	Predicted yield (%)		
		Summer	Winter	Pot culture
70 DAS	5	100.00	93.33	100.00
	10	82.20	79.94	82.71
	15	72.88	75.48	75.85
	20	68.22	73.25	72.42
	25	65.42	71.91	70.37
80 DAS	5	96.49	95.11	96.17
	10	80.89	81.19	81.67
	15	75.69	76.55	76.84
	20	73.09	74.23	74.42
	25	71.53	72.84	72.97

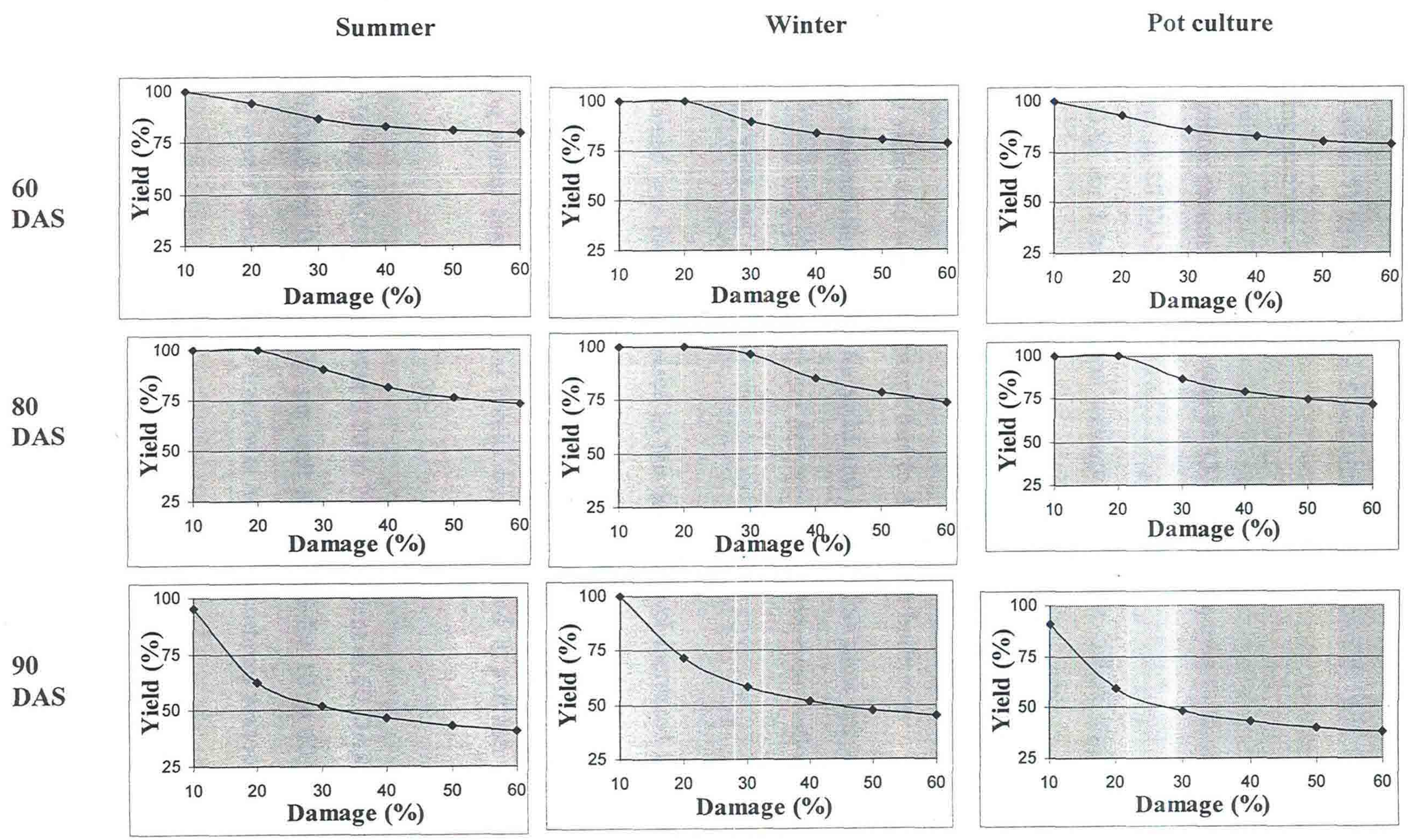
* DAS – Days after sowing

Table 25. Estimated crop model for yield and crop square damage (per cent) due to American bollworm in summer, winter and pot culture experiments at various crop stages

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
60 DAS	a	71.9628	67.5541	71.9112
	b	444.3597	648.4142	415.5245
	r	0.9616	0.9781	0.9596
80 DAS	a	55.4055	51.0541	56.4633
	b	1045.185	1352.954	905.7138
	r	0.9177	0.8986	0.9294
90DAS	a	30.1435	31.3173	26.937
	b	625.0351	801.1287	641.4166
	r	0.9948	0.9582	0.9904

* DAS – Days after sowing

Fig. 11. Predicted yield and square damage (per cent) due to American bollworm



It was observed that the damage level increased with the decrease in yield. The yield obtained was more at minimum damage level and less yield at maximum damage level. The yield obtained varied from 100.00 to 65.42 per cent at 70 DAS of cotton. The yield obtained was 96.49 to 71.53 per cent for 5 per cent to 25 per cent damage levels at 80 DAS of cotton during summer season.

Similarly for winter season, the yield was 93.33 to 71.91 per cent at 70 DAS and 95.11 to 72.84 per cent at 80 DAS and 100 to 70.37 per cent at 70 DAS and 96.17 to 72.97 per cent at 80 DAS for 5 to 25 per cent damage level in pot culture experiment. Among the days 70 DAS showed higher yield loss than 80 DAS for different damage levels in all the experiments.

4.4.3. Predicted crop yield and square damage due to American bollworm

The estimated mathematical model for yield and damage functions are presented in Table 25. The predicted crop yield and square damage due to American bollworm are presented in Fig.11 and Table 26.

The yield obtained was found decreased as the damage level increased in all the experiments. The yield obtained ranged from 100 to 78.36 per cent at 60 DAS, 100 to 73.60 per cent at 80 DAS and 100 to 44.66 per cent at 90 DAS for 10 to 60 per cent damage levels during winter season. Similar results were obtained in summer and pot culture experiments.

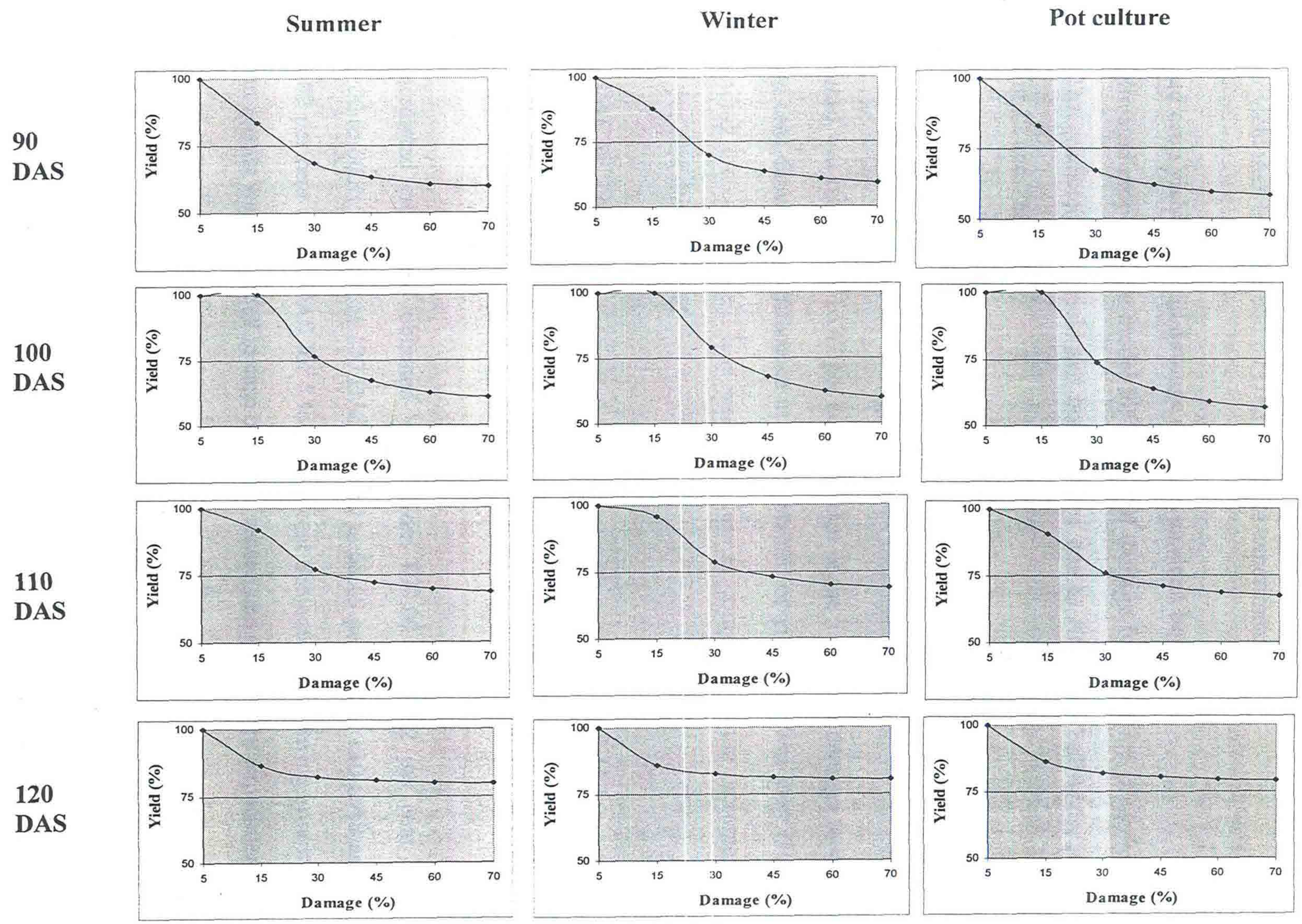
In other words, the yield reduction was 0.00 to 21.64 per cent at 60 DAS, 0.00 to 26.40 per cent at 80 DAS and 0.00 to 55.33 per cent at 90 DAS for 10 to 60 per cent damage levels during winter season. Similar trend was noticed in summer season and pot culture experiment.

Table 26. Predicted crop yield at various levels of American bollworm damage (square) in various experiments

Crop stages*	Per cent damage levels	Predicted yield (%)		
		Summer	Winter	Pot culture
60 DAS	10	100.00	100.00	100.00
	20	94.18	99.97	92.68
	30	86.77	89.16	85.76
	40	83.07	83.76	82.29
	50	80.84	80.52	80.22
	60	79.36	78.36	78.83
80 DAS	10	100.00	100.00	100.00
	20	100.00	100.00	100.00
	30	90.24	96.15	86.65
	40	81.53	84.87	79.10
	50	76.30	78.11	74.57
	60	72.82	73.60	71.55
90 DAS	10	95.3	100.00	91.07
	20	62.74	71.37	59.00
	30	51.87	58.02	48.31
	40	46.44	51.34	42.97
	50	43.18	47.33	39.76
	60	41.01	44.66	37.62

* DAS – Days after sowing

Fig.12. Predicted yield and boll damage (per cent) due to American bollworm



Among the experiments the predicted yield obtained was minimum in pot culture experiment followed by summer and winter season. As the crop stage advanced for the same level of damage the yield obtained was decreased. Among the days, 90 DAS recorded lower yield than 60 DAS and 80 DAS in all the experiments.

4.4.4. Predicted crop yield and boll damage due to American bollworm

The estimated crop damage model for yield and damage functions are presented in Table 27. The predicted crop yield and boll damage due to American bollworm are presented in Fig.12 and Table 28.

The damage and the corresponding yield loss were found more for increasing larval population. However, when the damage level was increased from 5 to 15 per cent the yield obtained was reduced to 16.47 per cent than that of the 5 per cent damage level. Beyond 30 per cent damage the difference in yield obtained or yield loss was very less. The corresponding increase in yield loss was much less as compared to the increment from 15 to 30 per cent damage level.

Thus, with 45, 60 and 70 per cent damage levels, the increase in yield loss was only one per cent as observed during summer. Similar results were recorded in other experiments also.

The predicted crop yield obtained varied from 100.00 to 59.52 per cent at 90 DAS, 100.00 to 60.81 per cent at 100 DAS, 100.00 to 68.69 per cent at 110 DAS and 100.00 to 79.82 per cent at 120 DAS for 5 to 70 per cent damage levels during summer season. Similar results were recorded in case of winter season and pot culture experiment. For validation of the efficiency of the model in prediction, the actual damage was also assessed and it was found that the variation between the predicted levels of damage and the observed values were not significantly different.

Table 27. Estimated crop model for yield and crop boll damage (per cent) due to American bollworm in summer, winter and pot culture experiments at various crop stages

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
90 DAS	a	52.981	51.4103	51.5578
	b	458.0283	543.9439	470.2102
	r	0.9288	0.9414	0.9051
100 DAS	a	48.9785	45.6869	43.6236
	b	828.428	999.8759	903.6435
	r	0.9312	0.9284	0.9424
110DAS	a	62.3372	61.4641	61.0433
	b	445.0902	514.8633	444.1971
	r	0.9541	0.9691	0.9673
120 DAS	a	78.0114	78.8948	77.5335
	b	127.1115	107.9845	131.0531
	r	0.9266	0.9247	0.9085

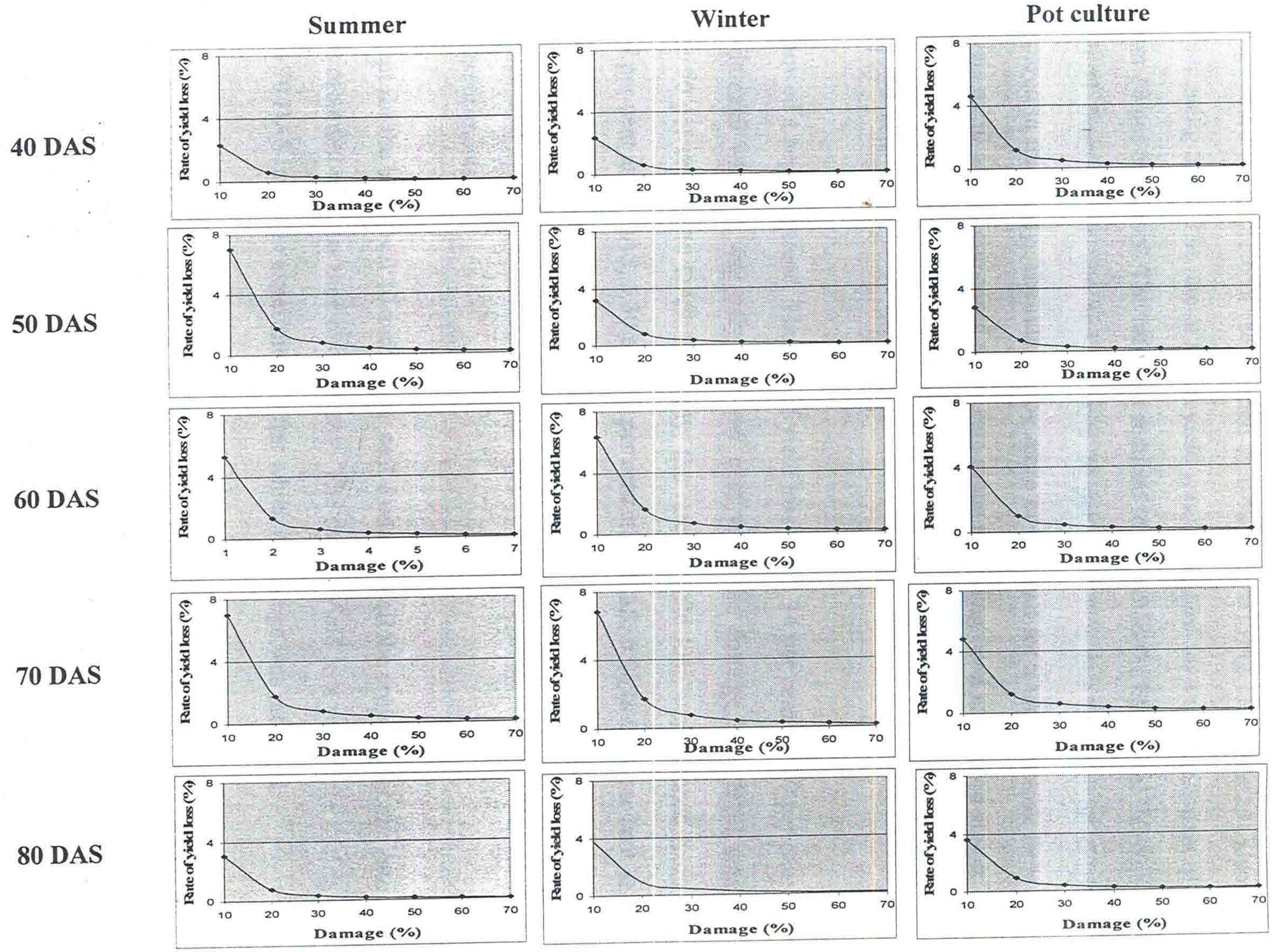
* DAS – Days after sowing

Table 28. Predicted crop yield at various levels of American bollworm damage (boll) in various experiments

Crop stages*	Per cent damage levels	Predicted yield (%)		
		Summer	Winter	Pot culture
90 DAS	5	100.00	100.00	100.00
	15	83.51	87.67	82.90
	30	68.24	69.54	67.23
	45	63.15	63.49	62.00
	60	60.61	60.47	59.39
	70	59.52	59.18	58.27
100 DAS	5	100.00	100.00	100.00
	15	100.00	100.00	100.00
	30	76.59	79.01	73.74
	45	67.38	67.90	63.70
	60	62.78	62.35	58.68
	70	60.81	59.97	56.53
110 DAS	5	100.00	100.00	100.00
	15	92.00	95.78	90.65
	30	77.17	78.62	75.84
	45	72.22	72.90	70.91
	60	69.75	70.04	68.44
	70	68.69	68.81	67.38
120 DAS	5	100.00	100.00	100.00
	15	86.48	86.09	86.27
	30	82.24	82.49	81.90
	45	80.83	81.29	80.44
	60	80.12	80.69	79.71
	70	79.82	80.43	79.40

* DAS – Days after sowing

Fig. 13. Predicted rate of yield loss and square damage (per cent) due to spotted bollworm



Predicted rate of yield loss due to unit increase in damage from base levels

4.4.5. Predicted rate of yield loss and square damage due to spotted bollworm

The predicted rate of yield loss for every unit increase in damage from the base levels damage of 10 to 70 per cent (segmented at 10% interval) (Fig.13; Table 29) also showed a decreasing trend. The rate of fall in yield was the highest for a unit increment of damage from 10 per cent level. The rate was reduced to ¼th when the base level damage increased to 11 from 10 per cent and 21 from 20 per cent. This was true for all crop stages compared in this study. The rate fell by more or less half for a unit increase from the base levels of 30 and 40 compared to the rate at the preceding level at all crop stages. For any unit increment from the base level damage of 50 and above the rate of loss suffered fell to $^{2}/_{3}$rd that of the preceding level.

It showed a negative trend. The rate of yield loss was 2.34 per cent for 10 per cent base level damage while it was only 0.04 per cent when the damage base level was increased to 70 per cent at 40 DAS. Similarly, the rate of yield loss was reduced from 6.99 to 0.14 per cent at 50 DAS, 5.30 to 0.10 per cent at 60 DAS, 6.98 to 0.14 per cent at 70 DAS and 3.06 to 0.06 per cent at 80 DAS for 10 to 70 per cent base level damage during summer season in cotton. A similar trend was noticed in case of winter season and pot culture experiments.

Except for the base level 10 and 20 per cent damage in all the crop stages, the rate of yield loss recorded was less than one per cent. The rate of yield loss was more during 60 DAS and 70 DAS in all the experiments, after which no change was recorded.

4.4.6. Predicted rate of yield loss and boll damage due to spotted bollworm

The rate of yield loss for every unit increase in damage was predicted (Fig.14; Table 30). Declining trend was noticed at 70 DAS and 80 DAS in all the experiments. The rate of yield loss was 2.80 per cent for 10 per cent base level damage and only

Table 29. Predicted rate of yield loss due to one per cent increase in spotted bollworm square damage (per cent) in various experiments

Crop stages*	Per cent damage levels	Rate of yield loss (%)		
		Summer	Winter	Pot culture
40 DAS	10	2.34	2.72	4.61
	20	0.58	0.68	1.15
	30	0.26	0.30	0.51
	40	0.16	0.17	0.28
	50	0.09	0.10	0.18
	60	0.06	0.07	0.12
	70	0.04	0.05	0.09
50 DAS	10	6.99	3.17	2.82
	20	1.74	0.79	0.70
	30	0.77	0.35	0.31
	40	0.43	0.19	0.17
	50	0.27	0.12	0.11
	60	0.19	0.03	0.07
	70	0.14	0.02	0.05
60 DAS	10	5.30	6.35	4.07
	20	1.32	1.58	1.01
	30	0.58	0.70	0.45
	40	0.33	0.39	0.25
	50	0.21	0.25	0.16
	60	0.14	0.17	0.11
	70	0.10	0.12	0.08
70 DAS	10	6.98	6.84	4.83
	20	1.74	1.71	1.20
	30	0.77	0.76	0.53
	40	0.43	0.42	0.30
	50	0.27	0.27	0.19
	60	0.19	0.19	0.13
	70	0.14	0.13	0.09
80 DAS	10	3.06	3.78	3.64
	20	0.76	0.94	0.91
	30	0.34	0.42	0.40
	40	0.19	0.23	0.22
	50	0.12	0.15	0.14
	60	0.08	0.10	0.10
	70	0.06	0.0772	0.07

* DAS – Days after sowing

Fig. 14. Predicted rate of yield loss and boll damage (per cent) due to spotted bollworm

Summer | Winter | Pot culture

70 DAS

80 DAS

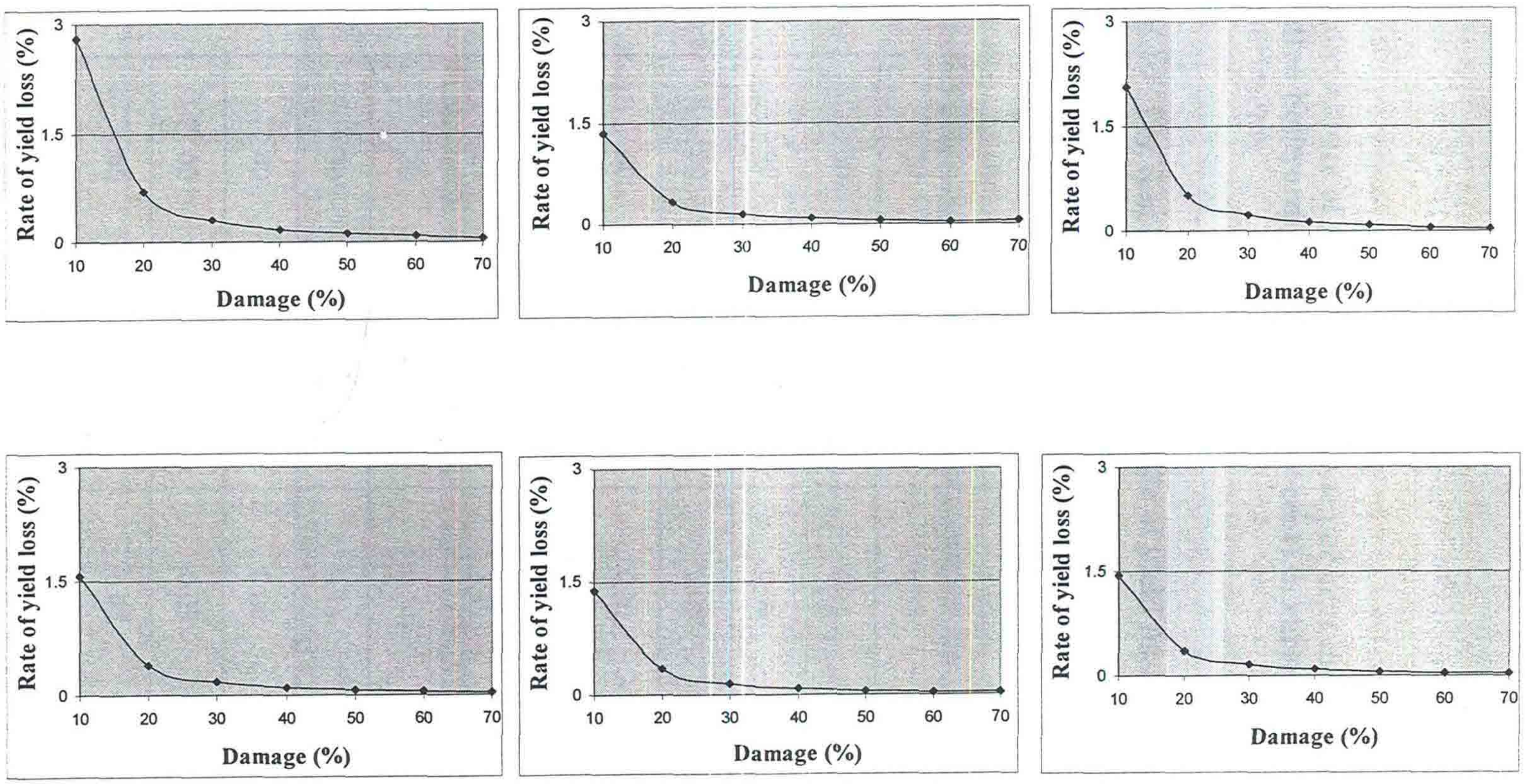
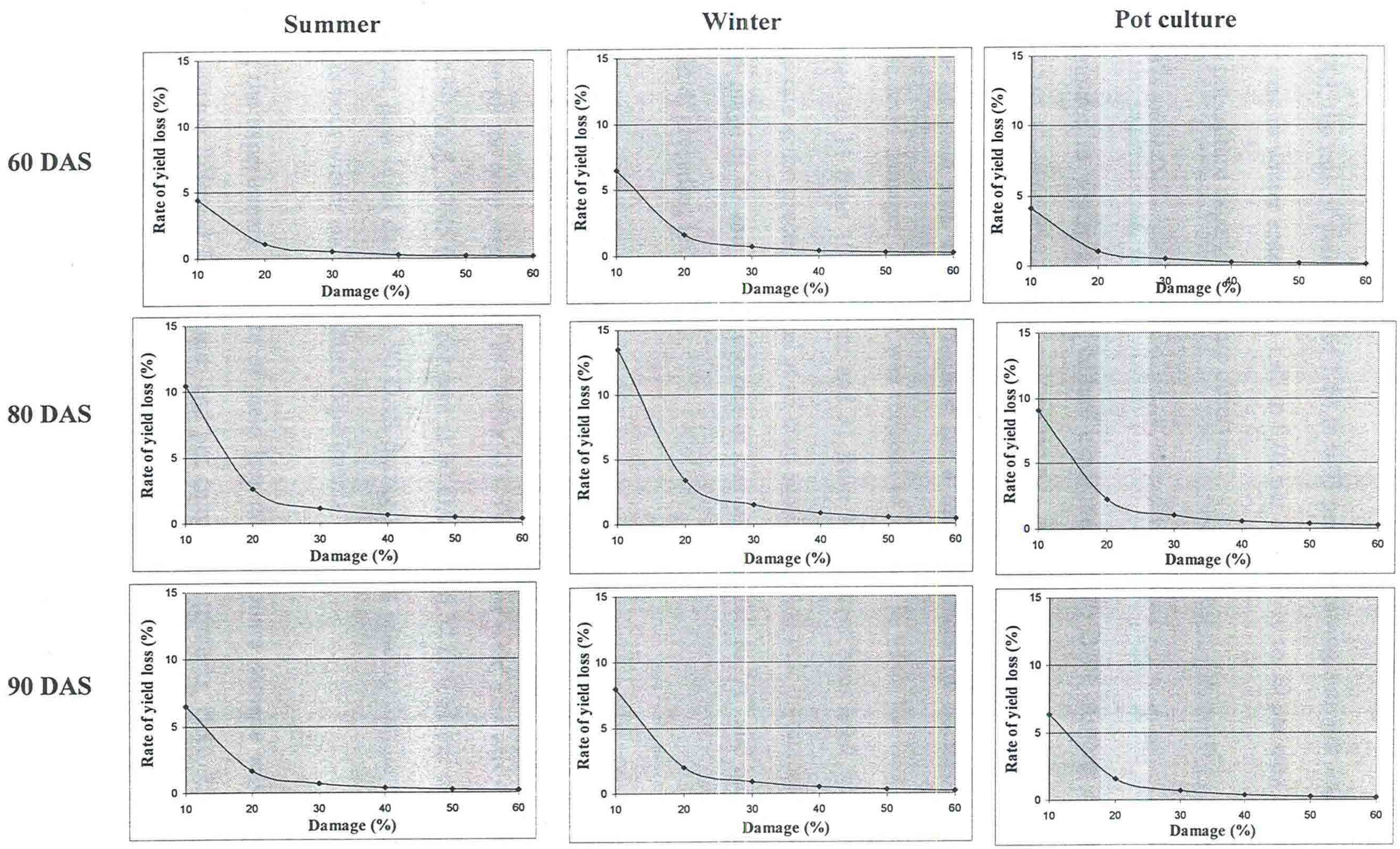


Table 30. Predicted rate of yield loss due to one per cent increase in spotted bollworm boll damage (per cent) in various experiments

Crop stages*	Per cent damage levels	Rate of yield loss (%)		
		Summer	Winter	Pot culture
70 DAS	10	2.79	1.33	2.05
	20	0.69	0.33	0.51
	30	0.31	0.14	0.22
	40	0.17	0.08	0.12
	50	0.11	0.05	0.08
	60	0.07	0.03	0.05
	70	0.05	0.05	0.04
80 DAS	10	1.56	1.39	1.45
	20	0.39	0.34	0.36
	30	0.17	0.15	0.15
	40	0.09	0.08	0.09
	50	0.06	0.05	0.05
	60	0.04	0.03	0.04
	70	0.03	0.03	0.02

* DAS – Days after sowing

Fig. 15. Predicted rate of yield loss and square damage (per cent) due to American bollworm



0.05 per cent was recorded for 70 per cent base level damage at 70 DAS. It varied from 1.33 to 0.05 per cent in winter season and 2.05 to 0.04 per cent in pot culture experiment.

At 80 DAS, the rate of yield loss of 1.56 to 0.03 per cent during summer season, 1.39 to 0.03 per cent in winter season and 1.45 to 0.02 per cent for 10 to 70 per cent base level damage in pot culture experiment were observed.

Among the experiments, summer season showed greater reduction in the rate of yield when compared to winter and pot culture experiment at 70 DAS. Among days, 70 DAS recorded higher rate of yield loss than 80 DAS in all the experiments.

The rate of yield loss was the highest for a unit increment of damage from 10 per cent base level damage. The rate was reduced to ¼th and ½ when the base level damage increased to 11 from 10 per cent and 31 from 30 per cent base level damage compared to the rate at the preceding level at all crop stages. For any unit increment from the base level damage of 40 and above, the rate of loss suffered fell to $^{2}/_{3}$rd and more or less equal as that of preceding level.

4.4.7. Predicted rate of yield loss and square damage due to American bollworm

The rate of yield loss and square damage due to American bollworm showed a negative trend in all the crop stages (Fig.15; Table 31). The rate of yield loss was 4.44 to 0.12 per cent at 60 DAS, 10.45 to 0.29 per cent at 80 DAS and 6.52 to 0.18 per cent for 10 to 60 per cent base level damage at 90 DAS during summer season. Similar results were recorded in both winter and pot culture experiments.

Among the experiments, the rate of yield loss due to square damage was more during winter season followed by summer and pot culture experiments. Between days 80 DAS showed higher rate of yield loss than 60 DAS and 90 DAS.

Table 31. Predicted rate of yield loss due to one per cent increase in American bollworm square damage (per cent) in various experiments

Crop stages*	Per cent damage levels	Rate of yield loss (%)		
		Summer	Winter	Pot culture
60 DAS	10	4.44	6.48	4.15
	20	1.11	1.62	1.03
	30	0.49	0.72	0.46
	40	0.27	0.40	0.25
	50	0.17	0.25	0.16
	60	0.12	0.18	0.11
80 DAS	10	10.45	13.52	9.05
	20	2.61	3.38	2.26
	30	1.16	1.50	1.00
	40	0.65	0.84	0.56
	50	0.41	0.54	0.36
	60	0.29	0.37	0.25
90 DAS	10	6.52	8.01	6.41
	20	1.63	2.00	1.60
	30	0.72	0.89	0.71
	40	0.40	0.50	0.40
	50	0.26	0.32	0.25
	60	0.18	0.22	0.17

* DAS – Days after sowing

Fig. 16. Predicted rate of yield loss and boll damage (per cent) due to American bollworm

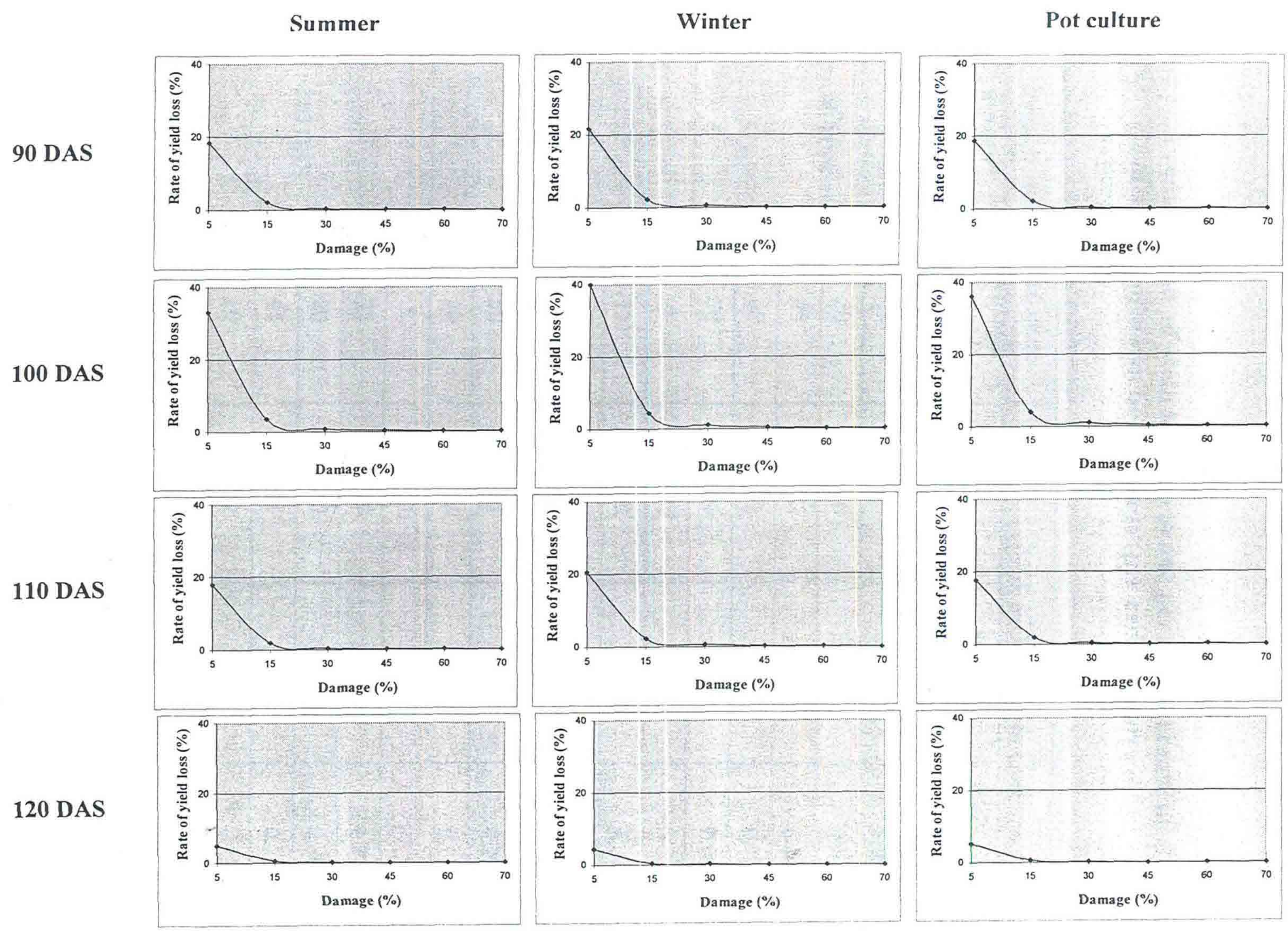


Table 32. Predicted rate of yield loss due to one per cent increase in American bollworm boll damage (per cent) in various experiments

Crop stages*	Per cent damage levels	Rate of yield loss (%)		
		Summer	Winter	Pot culture
90 DAS	5	18.32	21.75	18.80
	15	2.03	2.41	2.08
	30	0.50	0.60	0.52
	45	0.22	0.26	0.23
	60	0.12	0.15	0.13
	70	0.09	0.11	0.09
100 DAS	5	33.13	39.99	36.14
	15	3.68	4.44	4.01
	30	0.92	1.11	1.00
	45	0.40	0.49	0.44
	60	0.23	0.27	0.25
	70	0.16	0.20	0.18
110 DAS	5	17.80	20.59	17.76
	15	1.97	2.28	1.97
	30	0.49	0.57	0.49
	45	0.21	0.25	0.21
	60	0.12	0.14	0.12
	70	0.09	0.10	0.09
120 DAS	5	5.08	4.31	5.24
	15	0.56	0.47	0.58
	30	0.14	0.11	0.14
	45	0.06	0.05	0.06
	60	0.03	0.02	0.03
	70	0.02	0.02	0.02

* DAS – Days after sowing

Table 33. Estimated parameters for yield and spotted bollworm larvae at different stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
40 DAS	a	72.8748	74.9801	73.5516
	b	24.4494	20.9297	27.6534
	r	0.938	0.9539	0.9745
50 DAS	a	71.8168	74.2556	74.1424
	b	24.6595	21.0622	21.9231
	r	0.9403	0.9487	0.9226
60DAS	a	70.9306	70.2529	73.812
	b	23.4951	22.9469	19.9095
	r	0.9245	0.852	0.925
70 DAS	a	63.3584	67.4974	68.0529
	b	25.3087	22.8189	22.6052
	r	0.8292	0.9538	0.9201
80 DAS	a	66.2255	68.7044	65.9622
	b	28.4025	25.6197	33.293
	r	0.9041	0.8625	0.9589

* DAS – Days after sowing

The rate of yield loss was highest for a unit increment of damage from 10 per cent base level. The rate was reduced to ¼th when the base level damage increased to 11 from 10 per cent base level when compared to the rate at the preceding level at all the crop stages in all the experiments. Beyond 30 per cent the rate of loss suffered fell to half as that of the preceding level.

4.4.8. Predicted rate of yield loss and boll damage due to American bollworm

The rate of yield loss and boll damage due to American bollworm showed a declining trend in all the crop stages (Fig.16; Table 32). The rate of yield loss was 18.32 to 0.09 per cent at 90 DAS, 33.13 to 0.16 per cent at 100 DAS, 17.80 to 0.09 per cent at 110 DAS and 5.08 to 0.00 per cent for 5 to 70 per cent base level damage at 120 DAS as recorded during summer season. A similar trend was noticed in case of winter season and pot culture experiment.

Among the experiments, the rate of yield loss due to boll damage was more during winter season followed by summer and pot culture experiments. Between days, 100 DAS showed an increased rate of yield loss when compared to 90 DAS, 110 DAS and 120 DAS.

The rate of yield loss was highest for a unit increment of damage from 5 per cent base level. The rate was reduced to $^{1}/_{10}$th and half when the base level damage increased to 6 from 5 per cent and 16 from 15 per cent when compared to the rate at the preceding level at all the crop stages. The rate was reduced to ¼th and $^{2}/_{3}$rd in case of the increment as 46 from 45 and 61 from 60 per cent damage levels as that of the preceding one.

4.5. Predicted crop yield at different larval population of cotton bollworm

4.5.1. Predicted crop yield and various levels of spotted bollworm

The estimated mathematical equations for crop yield and spotted bollworm are presented in Table 33. The crop yield and different spotted bollworm intensity were

Table 34. Predicted crop yield and various levels of spotted bollworm larvae in various experiments

Crop stages*	Larvae/ plant	Predicted yield (%)		
		Summer	Winter	Pot culture
40 DAS	1	97.32	95.90	100.00
	2	85.09	85.44	87.37
	3	81.02	81.95	82.76
	4	78.98	80.21	80.46
	5	77.76	79.16	79.08
	0	--	--	--
50 DAS	1	96.47	95.31	96.06
	2	84.14	84.78	85.10
	3	80.03	81.27	81.45
	4	77.98	79.52	79.62
	5	76.74	78.46	78.52
	0	--	--	--
60 DAS	1	94.42	93.19	93.72
	2	82.67	81.72	83.76
	3	78.76	77.90	80.44
	4	76.80	75.98	78.78
	5	75.62	74.84	77.79
	0	--	--	--
70 DAS	1	88.66	90.31	90.65
	2	76.01	78.90	79.35
	3	71.79	75.10	75.58
	4	69.98	73.20	73.70
	5	68.42	72.06	72.57
	0	--	--	--
80 DAS	1	94.62	94.32	99.25
	2	80.42	81.51	82.60
	3	75.69	77.24	77.05
	4	73.32	75.10	74.28
	5	71.90	73.82	72.62
	0	--	--	--

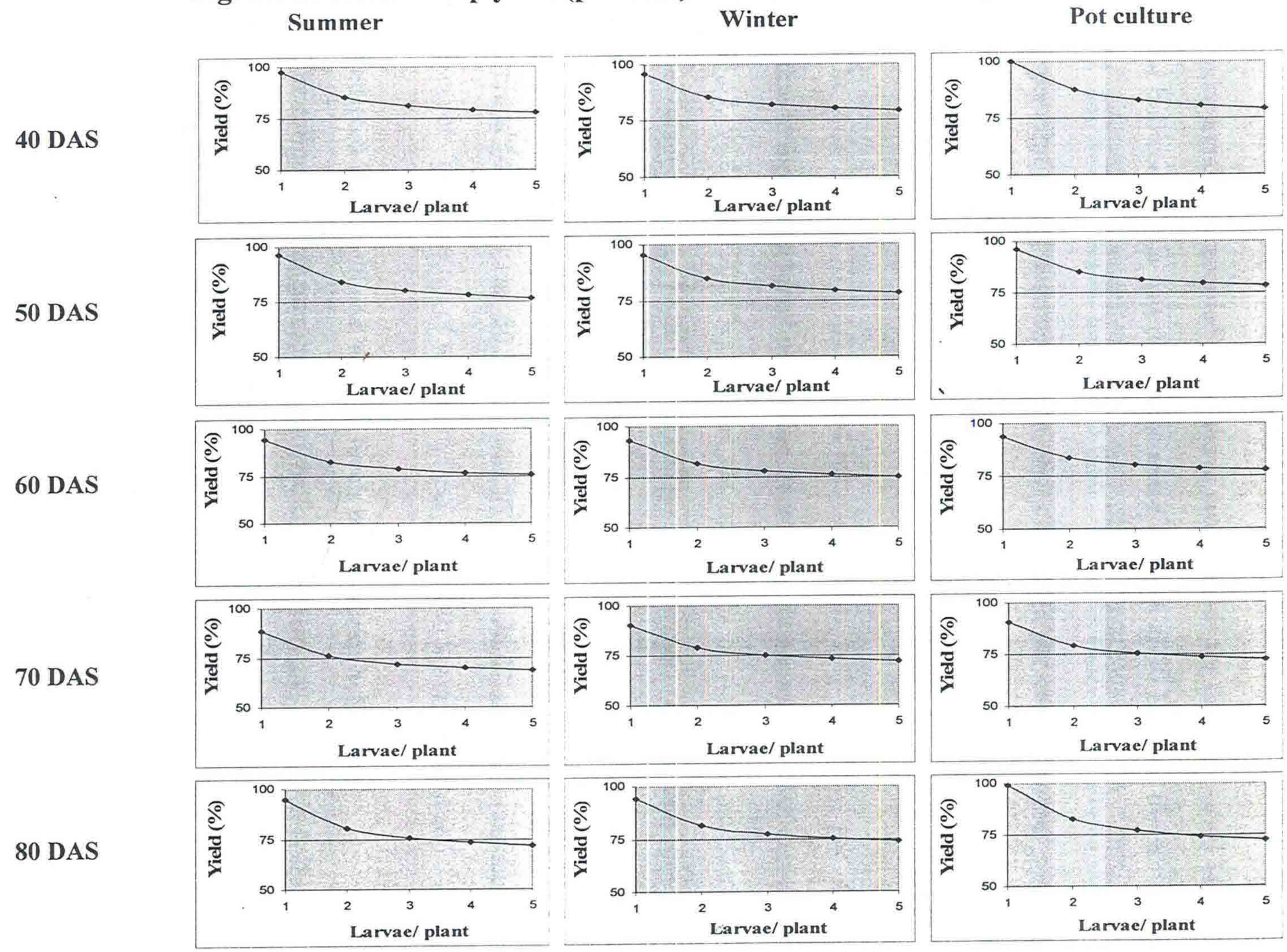
* DAS – Days after sowing

Table 35. Estimated parameters for yield and American bollworm larvae at different stages of cotton crop

Crop stages*	Estimated parameters	Summer	Winter	Pot culture
60 DAS	a	79.3995	77.3767	79.7208
	b	11.2128	11.7182	12.0901
	r	0.9018	0.9326	0.8763
80 DAS	a	69.9637	69.3862	69.049
	b	19.7875	18.1616	21.6593
	r	0.857	0.8557	0.8602
90DAS	a	52.7802	56.8218	53.1916
	b	36.5251	31.2529	36.1585
	r	0.9639	0.9039	0.911
100 DAS	a	55.9943	55.973	53.9838
	b	33.9979	33.2738	36.0223
	r	0.8994	0.8647	0.8761
110 DAS	a	66.6853	67.8963	66.1091
	b	25.8279	23.2023	25.8413
	r	0.9233	0.927	0.9256
120 DAS	a	79.568	78.379	78.9354
	b	18.8585	20.7131	18.4918
	r	0.8181	0.8642	0.8555

* DAS – Days after sowing

Fig. 17. Predicted crop yield (per cent) and various levels of spotted bollworm



predicted (Fig.17; Table 34). The yield obtained was decreased with increase in larval population. A single larva at 70 DAS caused more damage and the yield loss was also more (88.67%) during summer season, (90.32%) during winter season and (90.66%) in pot culture experiment, when it was compared to 40 DAS, 50 DAS and 60 DAS of cotton crop. Similar trend was recorded in the above crop periods for different larval intensities of spotted bollworm. This was due to increased damage at 70 DAS of the cotton crop. The yield obtained was higher at 80 DAS than 70 DAS in all the experiments *viz.*, 94.63 to 71.91 per cent during summer season, 94.32 to 73.83 per cent in winter season and 99.26 to 72.62 per cent in pot culture experiment for one to five larvae per plant of cotton crop.

The yield loss in 70 DAS showed increasing level with increasing percentage of damage due to increasing larval population. It suffered minimum loss with one larva per plant (88.67, 90.32 and 90.66%) and the maximum loss in yield was recorded in five larvae per plant (68.42, 72.06 and 72.57%) for summer, winter and pot culture experiment). This loss was roughly equal to the loss caused by two larvae per plant in 40 DAS (85.10, 85.45 and 87.38%). However, the corresponding loss suffered by younger crops (40 DAS and 50 DAS) was 97.32 and 96.47 per cent respectively for summer season. The quantum of loss in 40 DAS was much lower than that in 70 DAS.

4.5.2. Predicted crop yield and various levels of American bollworm

The estimated mathematical equations for crop yield and American bollworm are presented in Table 35. The crop yield and various American bollworm population were predicted (Fig.18; Table 36). As the larval population increased with corresponding decrease in yield obtained per plant or in other words the yield obtained was inversely proportional to increase in larval intensity per plant in all the experiments. A single larva caused more damage and the yield loss corresponding was also more in all the crop

Fig.18. Predicted crop yield (per cent) and various levels of American bollworm.

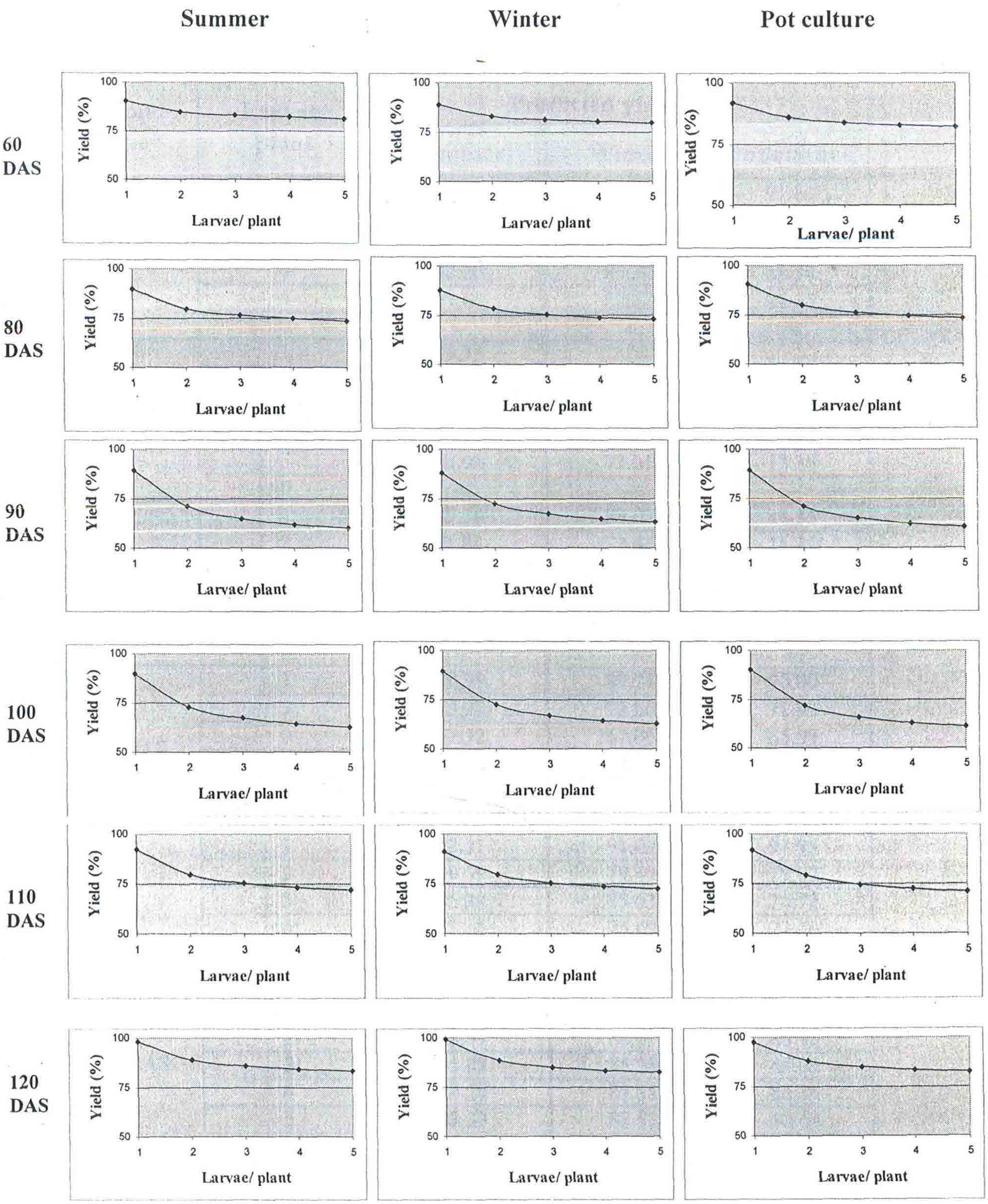


Table 36. Predicted crop yield and various levels of American bollworm larvae in various experiments

Crop stages*	Larvae/ plant	Predicted yield (%)		
		Summer	Winter	Pot culture
60 DAS	1	90.61	89.09	91.81
	2	85.00	83.23	85.76
	3	83.13	81.28	83.75
	4	82.20	80.30	82.74
	5	81.64	79.72	82.13
	0	--	--	--
80 DAS	1	89.75	87.547	90.70
	2	79.85	78.46	79.87
	3	76.55	75.44	76.26
	4	74.91	73.92	74.46
	5	73.92	73.01	73.38
	0	--	--	--
90 DAS	1	89.30	88.07	89.35
	2	71.04	72.44	71.27
	3	64.95	67.23	65.24
	4	61.91	64.63	62.23
	5	60.08	63.07	60.42
	0	--	--	--
100 DAS	1	89.99	89.24	90.00
	2	72.99	72.60	71.99
	3	67.32	67.06	65.99
	4	64.49	64.29	62.98
	5	62.79	62.62	61.18
	0	--	--	--
110 DAS	1	92.51	91.09	91.95
	2	79.59	79.49	79.02
	3	75.29	75.63	74.72
	4	73.14	73.69	72.56
	5	71.85	72.53	71.27
	0	--	--	--
120 DAS	1	98.42	99.09	97.42
	2	88.99	88.73	88.18
	3	85.85	85.28	85.09
	4	84.28	83.55	83.55
	5	83.33	82.52	82.63

* DAS – Days after sowing

stages and experiments. The predicted yield obtained was 90.61 to 81.64 per cent at 60 DAS, 89.75 to 73.92 per cent at 80 DAS, 89.31 to 60.08 per cent at 90 DAS, 89.99 to 62.79 per cent at 100 DAS, 92.51 to 71.85 per cent at 110 DAS and 98.42 to 83.33 per cent for one to five larvae per plant at 120 DAS as recorded during summer season. The lowest yield obtained per plant was observed at 90 DAS and 100 DAS followed by 110 DAS, 80 DAS, 60 DAS and 120 DAS respectively.

Among the experiments, the predicted crop yield was more or less equal in all the experiments and in different crop stages. The yield trend obtained was decreased from 60 DAS to 100 DAS and a raise in the curve was noticed at 110 DAS and 120 DAS. This was due to the damage caused was minimum during the later period of the crop stages. Therefore, the damage was more during the earlier period of the crop and less at later days. This was reflected in the yield obtained. The results revealed that the peak yield reduction was recorded during 90 DAS and 100 DAS.

4.5.3. Rate of yield loss per spotted bollworm in various stages of cotton crop

The predicted rate of yield loss for every unit increase in larval intensity from the base level as one to five larvae per plant (Table 37) showed a decreasing trend.

The rate of yield loss was more at one larva per plant and it was decreased as the larval intensity increased as observed in all the crop stages and experiments. The rate of yield loss was 24.45 per cent to 0.98 per cent at 40 DAS, 24.66 to 0.99 per cent at 50 DAS, 23.50 to 0.94 per cent at 60 DAS, 25.31 to 1.01 per cent at 70 DAS and 28.40 to 1.14 per cent at 80 DAS for one larva to five larvae per plant during summer season. A similar trend was noticed in case of winter season and pot culture experiment.

Among the experiments, the rate of yield loss was more during winter season than in pot culture and summer season of cotton crop. Between days, 50 DAS and 60 DAS

Table 37. Rate of yield loss per spotted bollworm larvae at various stages of cotton crop

Crop stages*	Larvae /plant	Rate of yield loss (%)		
		Summer	Winter	Pot culture
40 DAS	1	24.45	20.93	27.65
	2	6.11	5.23	6.91
	3	2.72	2.33	3.07
	4	1.53	1.31	1.73
	5	0.98	0.84	1.11
	0	0.00	0.00	0.00
50 DAS	1	24.66	21.06	21.92
	2	6.16	5.27	5.48
	3	2.74	2.34	2.44
	4	1.54	1.32	1.37
	5	0.99	0.84	0.88
	0	0.00	0.00	0.00
60 DAS	1	23.50	22.95	19.91
	2	5.87	5.74	4.98
	3	2.61	2.55	2.21
	4	1.47	1.43	1.24
	5	0.94	0.92	0.80
	0	0.00	0.00	0.00
70 DAS	1	25.31	22.82	22.61
	2	6.33	5.70	5.65
	3	2.81	2.54	2.51
	4	1.58	1.43	1.41
	5	1.01	0.91	0.90
	0	0.00	0.00	0.00
80 DAS	1	28.40	25.62	33.29
	2	7.10	6.40	8.32
	3	3.16	2.85	3.70
	4	1.78	1.60	2.08
	5	1.14	1.02	1.33
	0	0.00	0.00	0.00

* DAS – Days after sowing

Table 38. **Rate of yield loss per American bollworm larvae at various stages of cotton crop**

Crop stages*	Larvae /plant	Rate of yield loss (%)		
		Summer	Winter	Pot culture
60 DAS	1	11.21	11.72	12.09
	2	2.80	2.93	3.02
	3	1.25	1.30	1.34
	4	0.70	0.73	0.76
	5	0.45	0.47	0.48
	0	0.00	0.00	0.00
80 DAS	1	19.79	18.16	21.66
	2	4.95	4.54	5.41
	3	2.20	2.02	2.41
	4	1.24	1.14	1.35
	5	0.79	0.73	0.87
	0	0.00	0.00	0.00
90 DAS	1	36.53	31.25	36.16
	2	9.13	7.81	9.04
	3	4.06	3.47	4.02
	4	2.28	1.95	2.26
	5	1.46	1.25	1.45
	0	0.00	0.00	0.00
100 DAS	1	34.00	33.27	36.02
	2	8.50	8.32	9.01
	3	3.78	3.70	4.00
	4	2.12	2.08	2.25
	5	1.36	1.33	1.44
	0	0.00	0.00	0.00
110 DAS	1	25.83	23.20	25.84
	2	6.46	5.80	6.46
	3	2.87	2.58	2.87
	4	1.61	1.45	1.62
	5	1.03	0.93	1.03
	0	0.00	0.00	0.00
120 DAS	1	18.86	20.71	18.49
	2	4.71	5.18	4.62
	3	2.10	2.30	2.05
	4	1.18	1.29	1.16
	5	0.75	0.83	0.74
	0	0.00	0.00	0.00

* DAS – Days after sowing

showed a lower rate of yield loss when compared to 70 DAS, 80 DAS and 40 DAS in various experiments.

The rate of fall in yield loss was highest for a unit increment in larval population from one larva per plant (24.45%). The rate was reduced to ¼th when the larva increased to two from one per plant. This was true for all the stages compared in this study for one larva (24.45, 20.93 and 27.65%) and for two larvae (6.11, 5.23 and 6.91%) per plant at various experiments.

The rate fell by more or less half of a unit increase from the base level of 3 larvae per plant compared to the rate at the preceding level at all crop stages. For any unit increment from 4 larvae and above the rate of yield loss was decreased to $^{2}/_{3}{}^{rd}$ as that of the preceding level.

4.5.4. Predicted rate of yield loss per American bollworm in various stages of cotton crop

The predicted rate of yield loss for every unit increase in larval population from one to five larvae per plant (Table 38) showed a decreasing trend. The rate of yield loss was more at one larva per plant and it was decreased with increase in larval intensity. The rate of yield loss was 11.21 to 0.45 per cent at 60 DAS, 19.79 to 0.79 per cent at 80 DAS, 36.53 to 1.46 per cent at 90 DAS, 34.00 to 1.36 per cent at 100 DAS, 25.83 to 1.03 per cent at 110 DAS and 18.86 to 0.75 per cent for one larva to five larvae per plant at 120 DAS during summer season and also similar trend was observed in other experiments.

A single larva at 90 DAS and 100 DAS caused more damage and yield loss (36.53% and 34.00%) during summer season. At this stage, the rate of loss was roughly equal to the loss caused by two larvae per plant at 80 DAS and 120 DAS and was equal

Table 39. Effect of *Earias vittella* infestation on cotton fibre quality - Pot culture experiment

Crop stages *	Larvae released	2.5 % Span length (mm)	Uniformity Ratio (%)	Fiber fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
40 DAS	1	24.53	41.20	3.51	0.68	17.12
	2	24.59	41.17	3.53	0.67	17.23
	3	24.56	41.22	3.51	0.69	17.15
	4	24.51	41.15	3.54	0.70	17.18
	5	24.55	41.23	3.50	0.73	17.11
	0	24.61	41.23	3.54	0.70	17.25
50 DAS	1	24.59	41.16	3.53	0.69	17.22
	2	24.53	41.19	3.51	0.65	17.10
	3	24.58	41.22	3.50	0.67	17.21
	4	24.55	41.20	3.49	0.64	17.24
	5	24.59	41.18	3.52	0.59	17.18
	0	24.61	41.23	3.54	0.70	17.25
60 DAS	1	24.57	41.21	3.54	0.67	17.21
	2	24.55	41.19	3.52	0.65	17.11
	3	24.61	41.23	3.49	0.62	17.16
	4	24.58	41.20	3.51	0.66	17.20
	5	24.60	41.22	3.48	0.70	17.25
	0	24.61	41.23	3.54	0.70	17.25
70 DAS	1	24.55	41.23	3.50	0.61	17.24
	2	24.51	41.21	3.53	0.63	17.14
	3	24.48	41.20	3.51	0.67	17.16
	4	24.43	41.18	3.50	0.69	17.10
	5	24.39	41.12	3.51	0.65	17.23
	0	24.61	41.23	3.54	0.70	17.25
80 DAS	1	24.54	41.20	3.49	0.69	17.20
	2	24.47	41.12	3.51	0.68	17.16
	3	24.40	41.15	3.48	0.70	17.24
	4	24.39	41.12	3.49	0.66	17.19
	5	24.35	41.09	3.48	0.62	17.21
	0	24.61	41.23	3.54	0.70	17.25

* DAS – Days after sowing

Table 40. Effect of *Earias vittella* infestation on cotton fibre quality - Field experiment (summer – 2001)

Crop stages*	Larvae released	2.5 % Span length (mm)	Uniformity Ratio (%)	Fiber fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
40 DAS	1	25.30	42.20	3.64	0.72	19.20
	2	25.32	42.21	3.60	0.71	19.31
	3	25.35	42.23	3.62	0.72	19.24
	4	25.30	42.20	3.66	0.69	19.29
	5	25.29	42.19	3.60	0.70	19.16
	0	25.35	42.28	3.64	0.72	19.33
50 DAS	1	25.36	42.22	3.63	0.72	19.31
	2	25.33	42.20	3.64	0.69	19.33
	3	25.30	42.18	3.62	0.71	19.29
	4	25.29	42.19	3.60	0.70	19.31
	5	25.28	42.23	3.59	0.68	19.29
	0	25.35	42.28	3.64	0.72	19.33
60 DAS	1	25.33	42.26	3.60	0.70	19.28
	2	25.30	42.23	3.62	0.71	19.26
	3	25.28	42.21	3.63	0.69	19.30
	4	25.10	42.19	3.60	0.71	19.25
	5	25.16	42.17	3.58	0.72	19.26
	0	25.35	42.28	3.64	0.72	19.33
70 DAS	1	25.21	42.21	3.60	0.70	19.33
	2	25.19	42.28	3.64	0.69	19.29
	3	25.10	42.19	3.62	0.68	19.26
	4	25.05	42.17	3.60	0.70	19.23
	5	24.97	41.98	3.59	0.72	19.20
	0	25.35	42.28	3.64	0.72	19.33
80 DAS	1	25.20	42.25	3.60	0.71	19.31
	2	25.14	42.20	3.61	0.70	19.24
	3	25.08	42.18	3.59	0.69	19.27
	4	25.02	42.17	3.58	0.71	19.25
	5	24.90	41.95	3.56	7.40	19.20
	0	25.35	42.28	3.64	0.72	19.33

* DAS – Days after sowing

Table 41. Effect of *Earias vittella* infestation on cotton fiber quality - Field experiment (winter- 2001)

Crop stages*	Larvae released	2.5 % Span length (mm)	Uniformity Ratio (%)	Fiber fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
40 DAS	1	26.10	42.25	3.62	0.73	20.12
	2	26.17	42.31	3.70	0.74	20.07
	3	25.99	42.33	3.72	0.72	20.14
	4	26.02	42.10	3.65	0.73	20.03
	5	26.21	42.27	3.59	0.74	20.17
	0	26.15	42.35	3.71	0.73	20.18
50 DAS	1	26.12	42.30	3.61	0.75	20.18
	2	26.09	42.33	3.64	0.74	20.14
	3	26.16	42.39	3.69	0.71	20.16
	4	26.07	42.28	3.66	0.70	20.12
	5	26.00	42.29	3.60	0.72	20.17
	0	26.15	42.35	3.71	0.73	20.18
60 DAS	1	26.15	42.31	3.70	0.70	20.14
	2	26.08	42.34	3.67	7.40	20.16
	3	26.11	42.35	3.65	7.30	20.15
	4	26.10	42.27	3.68	0.72	20.11
	5	25.97	42.21	3.71	0.70	20.06
	0	26.15	42.35	3.71	0.73	20.18
70 DAS	1	26.10	42.30	3.68	0.71	20.15
	2	25.96	42.32	3.65	0.72	20.07
	3	25.92	42.34	3.61	0.70	20.09
	4	25.87	42.21	3.70	0.69	20.12
	5	25.78	42.16	3.66	0.67	20.03
	0	26.15	42.35	3.71	0.73	20.18
80 DAS	1	26.09	42.32	3.70	0.70	20.10
	2	25.97	42.29	3.64	0.72	20.12
	3	25.94	42.20	3.67	0.71	20.14
	4	25.82	42.18	3.62	0.69	20.07
	5	25.70	41.95	3.60	0.68	20.05
	0	26.15	42.35	3.71	0.73	20.18

* DAS – Days after sowing

to three larvae per plant at 60 DAS. The quantum of loss in rest of the crop stages was much lower than that of 90 DAS and 100 DAS of cotton crop.

4.6. Effect of bollworm infestation on cotton fibre quality

The quality parameters *viz.*, 2.5 per cent span length, uniformity ratio, fibre fineness (micronaire value), maturity co-efficient and bundle strength were assessed for quality (Tables 39 to 44). All the parameters in the infested kapas were below the standard values. The reduction in the 2.5 per cent span length ranged from 25.02 to 25.35 per cent in summer 2001. A similar trend was noticed in all the experiments. The reduction in the fibre qualities was observed in all the experiments, but the reduction in the quality of the infested cotton fibre was not significantly high when compared to the healthy fibre. The quality of fibre decreased as the number of larval population increased. Among the experiments, the quality of fibre was reduced more in pot culture, followed by summer and winter season. The highest reduction in quality was noticed during 70 DAS and 80 DAS in case of spotted bollworm in all the experiments. For American bollworm, the quality was affected more at 100 DAS when compared to other periods in all the experiments.

Table 42. Effect of *Helicoverpa armigera* infestation on cotton fibre quality – Pot culture experiment

Crop stages*	Larvae released	2.5 % Span length (mm)	Uniformity Ratio (%)	Fibre fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
60 DAS	1	25.40	40.32	3.50	0.71	18.60
	2	25.36	40.35	3.49	0.70	18.59
	3	25.38	40.34	3.52	0.70	18.64
	4	25.42	40.36	3.48	0.72	18.63
	5	25.40	40.30	3.49	0.71	18.50
	0	25.42	40.36	3.52	0.71	18.64
80 DAS	1	25.36	40.35	3.51	0.71	18.61
	2	25.39	40.31	3.50	0.70	18.55
	3	25.34	40.36	3.53	0.69	18.60
	4	25.35	40.27	3.49	0.69	18.59
	5	25.30	40.78	3.46	0.70	18.57
	0	25.42	40.36	3.52	0.71	18.64
90 DAS	1	25.41	40.26	3.50	0.71	18.60
	2	25.42	40.30	3.49	0.72	18.59
	3	25.40	40.29	3.51	0.71	18.62
	4	24.89	40.31	3.47	0.68	18.58
	5	25.36	40.33	3.55	0.67	18.60
	0	25.42	40.36	3.52	0.71	18.64
100 DAS	1	25.43	40.30	3.50	0.69	18.61
	2	25.40	40.21	3.51	0.69	18.64
	3	25.38	40.19	3.49	0.70	18.60
	4	25.35	39.96	3.48	0.67	18.59
	5	24.82	40.08	3.45	0.65	18.58
	0	25.42	40.36	3.52	0.71	18.64
110 DAS	1	25.41	40.32	3.52	0.70	18.63
	2	25.39	40.24	3.50	0.72	18.60
	3	25.37	40.29	3.42	0.71	18.59
	4	24.86	39.87	3.35	0.69	18.48
	5	24.93	39.96	3.33	0.68	18.55
	0	25.42	40.36	3.52	0.71	18.64
120 DAS	1	25.40	40.27	3.49	0.70	18.59
	2	25.41	40.28	3.47	0.71	18.57
	3	25.37	40.30	3.38	0.74	18.56
	4	24.85	39.93	3.39	0.67	18.60
	5	24.92	39.89	3.38	0.66	18.59
	0	25.42	40.36	3.52	0.71	18.64

* DAS – Days after sowing

Table 43. Effect of *Helicoverpa armigera* infestation on cotton fibre quality - Field experiment (Summer-2001)

Crop stages*	Larvae /plant	2.5 % Span length (mm)	Uniformity Ratio (%)	Fibre fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
60 DAS	1	26.50	41.30	3.60	0.76	19.00
	2	26.55	41.26	3.55	0.71	19.42
	3	26.45	41.35	3.68	0.74	19.11
	4	26.30	41.18	3.57	0.72	19.26
	5	26.35	41.22	3.42	0.70	19.07
	0	26.50	41.52	3.65	0.71	19.00
80 DAS	1	26.40	41.25	3.68	0.76	19.40
	2	26.45	41.39	3.61	0.74	19.33
	3	26.45	41.17	3.55	0.71	19.25
	4	26.30	41.45	3.53	0.70	19.21
	5	26.12	42.09	3.41	0.69	19.10
	0	26.50	41.52	3.65	0.71	19.00
90 DAS	1	26.21	41.45	3.52	0.77	19.32
	2	26.30	40.89	3.64	0.72	19.17
	3	26.25	41.16	3.41	0.76	19.16
	4	25.16	41.37	3.55	0.71	19.37
	5	25.07	41.22	3.46	0.70	19.22
	0	26.50	41.52	3.65	0.71	19.00
100 DAS	1	26.16	41.15	3.63	0.76	19.05
	2	26.05	41.21	3.58	0.74	19.16
	3	25.87	41.33	3.60	0.75	19.30
	4	24.92	40.74	3.47	0.71	18.98
	5	24.61	41.18	3.65	0.75	19.21
	0	26.50	41.52	3.65	0.71	19.00
110 DAS	1	26.27	41.26	3.51	0.78	19.26
	2	26.10	41.15	3.58	0.73	18.75
	3	25.88	41.09	3.63	0.75	19.08
	4	25.29	41.23	3.67	0.72	18.79
	5	24.96	40.64	3.49	0.79	19.33
	0	26.50	41.52	3.65	0.71	19.00
120 DAS	1	26.36	41.32	3.55	0.76	19.26
	2	26.21	41.18	3.64	0.74	18.88
	3	26.30	41.23	3.42	0.79	19.20
	4	26.12	41.29	3.58	0.71	19.14
	5	25.90	41.12	3.60	0.75	19.35
	0	26.50	41.52	3.65	0.71	19.00

* DAS – Days after sowing

Table 44. Effect of *Helicoverpa armigera* infestation on cotton fibre quality - Field experiment (winter - 2001)

Crop stages*	Larvae /plant	2.5 % Span length (mm)	Uniformity Ratio (%)	Fibre fineness (micronaire)	Maturity co-efficient (%)	Bundle strength (g/tex)
60 DAS	1	27.21	42.15	3.70	0.71	204.00
	2	27.12	42.18	3.73	0.72	20.41
	3	27.16	42.23	3.69	0.70	20.39
	4	27.30	42.30	3.72	0.69	20.43
	5	27.25	42.21	3.70	0.73	20.45
	0	27.25	42.36	3.73	0.72	20.43
80 DAS	1	27.25	42.19	3.62	0.67	20.42
	2	27.20	42.25	3.73	0.70	20.45
	3	27.16	42.35	3.59	0.68	20.40
	4	27.14	42.08	3.68	0.74	20.39
	5	27.09	41.35	3.70	0.71	20.38
	0	27.25	42.36	3.73	0.72	20.43
90 DAS	1	27.12	42.30	3.62	0.73	20.35
	2	27.19	41.98	3.71	0.74	20.38
	3	27.25	42.16	3.69	0.69	20.35
	4	26.94	42.24	3.73	0.67	19.30
	5	26.89	42.08	3.67	0.64	20.31
	0	27.25	42.36	3.73	0.72	20.43
100 DAS	1	27.16	42.26	3.65	0.73	20.40
	2	27.10	42.20	3.68	0.72	19.88
	3	27.08	42.15	3.57	0.69	20.41
	4	26.91	41.89	3.70	0.68	19.93
	5	26.83	42.06	3.68	0.71	19.95
	0	27.25	42.36	3.73	0.72	20.43
110 DAS	1	27.20	42.31	3.69	0.69	20.42
	2	27.31	42.18	3.63	0.70	20.40
	3	27.25	42.22	3.73	0.68	19.87
	4	27.06	42.15	3.65	0.70	19.98
	5	27.30	42.29	3.69	0.65	19.83
	0	27.25	42.36	3.73	0.72	20.43
120 DAS	1	27.12	42.33	3.76	0.71	20.37
	2	27.18	42.36	3.80	0.68	19.83
	3	26.93	42.19	3.66	0.70	19.96
	4	27.05	42.21	3.70	0.70	19.89
	5	26.74	42.28	3.68	0.67	19.81
	0	27.25	42.36	3.73	0.72	20.43

* DAS – Days after sowing

DISCUSSION

5. DISCUSSION

Studies were carried out to investigate the damage potential and the resultant yield loss due to differential larval populations of spotted bollworm, *Earias vittella* and American bollworm, *Helicoverpa armigera* at different crop growth stages in cotton (cv.) LRA 5166 under pot culture and field situations during summer (2001) and winter season (2001). The results obtained are discussed hereunder.

5.1. Shoot damage by spotted bollworm

The results of the shoot damage under varying larval population and crop stages showed that the damage was decreased as the crop advanced in age. Shoot damage was inversely proportional to the crop stages of cotton crop. Among the days, shoot damage due to spotted bollworm was uniformly high at 40 days after sowing (DAS) followed by 50 DAS and minimum was recorded at 60 DAS in all the experiments. Among the experiments, shoot damage was more during winter season followed by pot culture experiment and lowest damage was recorded at 60 DAS during summer season.

In winter season, shoot damage ranged from 75.83 to 99.50 per cent at 40 DAS and 40.67 to 81.25 per cent at 50 DAS. In pot culture experiment, the shoot damage was ranging from 70.41 to 99.50 per cent for one to five larvae per plant at 40 DAS. In summer season, the shoot damage was ranging from 60.11 to 98.12 per cent at 40 DAS followed by 50 DAS recording 30.52 to 72.33 per cent. The shoot damage is high during winter which may be due to the factor that favourable climate exists in winter leading to increased pest build up and shoot infestation by spotted bollworm.

Walker (1991) reported that the shoot damage was easily compensated by the plants during early crop growth. The damage caused can easily be repaired (or) replenished by the plant, whereas in late stage attack, full compensation could not occur and caused more yield loss. These observations are in conformity with present findings.

Thus, there was not much yield reduction due to shoot damage caused by the spotted bollworm. Similar results were observed by Singh and Sidhu (1982), Natarajan (1990) and and Patel and Patel (2000). Side shoots or laterals from the main stem after shoot damage will help the plant to produce more squares and gives a normal yield as that of other plant. This is a physiological adaptation to get rid of insect damage or infestation during adverse period.

Natarajan and Sundaramurthy (1990) opined that cotton plant can recover from early season damage with little or no yield loss as the plant compensates by producing side shoots and more new squares.

5.2. Predicted damage at different larval intensity in cotton

5.2.1. Predicted square damage due to spotted bollworm

The predicted square damage was recorded and it increased with the increase in larval population. A positive correlation was obtained between the square damage and larval population per plant. This holds good for various crop stages of cotton in all the three experiments.

Bhat and Jayaswal (1988) reported that bollworm caused square damage to the tune of 33.4 to 60.58 per cent and the young larvae consumed the bolls partially and destroyed many flowers, squares and bolls. Such fruiting bodies were shed and this resulted in yield reduction.

Among the experiments, the predicted square damage was more during winter season followed by summer season and the least was recorded in pot culture experiment. Between days, the highest damage was noticed at 60 DAS followed by 50 DAS for one to five larvae per plant. The lowest damage was recorded at 80 DAS. Similarly Manisekaran *et al.* (1991) reported that the incidence of *Earias* sp. was negatively correlated with the age of the crop in MCU 7 and MCU 9 The mean incidence of *Earias* sp. was more during winter than in summer (Chakravarthy, 1982). This is in agreement with present findings.

Singh and Sidhu (1982) reported that the square shedding in F 414 variety was recorded upto a maximum of 38 per cent during 1975 and 1976 and 43 to 100 per cent during 1977 and in J 205, 38 to 100 per cent square shedding was recorded. Similar results were recorded in the present studies.

5.2.2. Predicted boll damage due to spotted bollworm

A positive correlation was found between boll damage and the larval population. Among the experiments, boll damage was more during winter season followed by summer and pot culture. Between days, highest damage was recorded during 80 DAS followed by 70 DAS.

The yield reduction was mainly due to the damage caused on fruiting bodies *viz.*, the bolls as observed by Singh *et al.* (1979, 1981), Gang *et al.* (1997) and Nath *et al.* (2000).

Walker (1991) reported that the plants are capable of repairing the damage caused by the insects to certain extent; and they can compensate the damage by some physiological means and gives a normal yield as that of the healthy plant. But this compensation cannot occur when the infestation is late, on reproductive and yielding parts such as fruit or cotton bolls.

5.2.3. Predicted square damage due to American bollworm

The square damage by American bollworm was found increased with increase in larval density as was seen in spotted bollworm. Among the experiments, square damage was more during winter season followed by summer and lowest damage was recorded in pot culture experiment. Manisekaran *et al.* (1991) obtained similar results as that of present finding (i.e.) the mean incidence of *Helicoverpa armigera* was more during winter (19.67%) than in summer (12.49%). Kaushik *et al.* (1969) reported that desi cotton varieties are severely affected by American bollworm and 65.7 per cent square damage was recorded during winter in Madhya Pradesh. Similar square damage *viz.*, 64.17 per cent was obtained in present studies during winter season at 80 DAS. The square damage started increasing initially and reached a peak at 80 DAS and fall in trend was noticed at 90 DAS. Patil and Bheemanna (1998) reported that *H. armigera* was maximum from mid September to December with three peaks during September, October and November. Similar studies were conducted by Keerthisinghe (1982), Bharpoda *et al.* (1999) and Balachandran (2000) and CICR (1999-2000).

5.2.4. Predicted boll damage due to American bollworm

The highest boll damage was recorded by 100 DAS in all the three experiments followed by 90 DAS, 110 DAS and lowest boll damage was observed at 120 DAS.

Similar studies conducted by different authors also confirmed that the boll damage was increased with increase in larval population. The bollworm infestation in open bolls on boll basis in different genotypes of cotton ranged from 12.94 to 32.80 per cent as recorded by Nath *et al.* (2000). Balachandran (2000) reported that the tomato fruit damage by tomato fruit borer, *Helicoverpa armigera* increased with increase in larval population.

Pearson (1958) reported that young larvae rarely attacked bolls while the older larvae preferred squares and bolls. Present finding is in consonance with observation made by Mabbett *et al.* (1979). Reese *et al.* (1981) observed the feeding site of young larvae on cotton grown in New Mexico and more than half of all the 4 to 8 day old larvae were found in squares. Ramalho *et al.* (1984) found that first and second instar larvae were noticed on upper third of the plant and third to sixth instar larvae moved throughout the plant thereby damaging both squares and bolls of cotton.

The model constructed in the present investigations has been predicted in lines with BUGNET with the potential of a computer based system involved in forecasting insect pest population and crop yield. The goal of BUGNET is to aid farmers in making decisions concerning insect control and crop management (Hartstack *et al.*, 1976; 1977 and Hartstack, 1982).

Models are conceptual or mathematical or at least computer-based devices which aim to describe or simulate natural processes. They can be used to predict the outcome of hypothetical eventualities and as management tools, to predict or establish the optimal tactics required to achieve a particular result, within the constraints of the model (King, 1994).

Predicted rate of damage at different larval population

5.2.5. Predicted rate of square damage due to spotted bollworm.

When only one larva was present per plant and the damage implicit due to addition of one more larva to the existing population indicated that the increment due to the addition of larva had not caused the same quantum of damage. In other words, the damage caused by more than one larva was not simply a mathematical multiplication of damage caused by a single larva. It showed a negative trend of damage with increase in larval population and crop periods.

Similar results were obtained in rice leaf folder damage as studied by Pandi (1997). Advancement in crop age contributed for reduced damage rate. The physiological status of the plant might vary with advancement in age of the crop. Therefore, aged crops might not be preferred for active feeding. Focus has to be given more to make clarify this in elaborate manner. The rate of square damage clearly reveals that the rate is in a decreasing trend as the number of larvae per plant increases in all the crop stages and in all the experiments.

5.2.6. Predicted rate of boll damage due to spotted bollworm

The results obtained from the experiments showed that the rate of damage is inversely proportional to the larval population and crop stages in cotton. A negative correlation was noticed between the boll damage and larval population in all the experiments.

Among the experiments, the rate of damage was more during summer followed by winter season and lowest was noticed in case of pot culture experiment. Between days, the rate of damage was more at 80 DAS followed by 70 DAS of cotton crop. The damage rate caused by single larva is more in all the days in all the experiments. As the boll development starts only by 70 DAS, the damage rate was lower at 70 DAS. The damage rate was more in later period *viz.*, 80 DAS and a steep decline was recorded later on.

Normally when the larval population is increased, the food availability is narrowed down. The sharing of food source among the competing larvae might restrict the feeding and consequently reduce the rate of damage. The present results obtained are in agreement with Gill and Simwat (1993) and Simwat and Singh (1997). There could also be another possible reason. Though the quantum consumed was comparatively less in older fruiting bodies (bolls) in comparison with younger parts, probably even the less quantity of food consumed in boll stage has the same energy equivalents of the quantity of food consumed in square stages. Hence, the square damage recorded was more when compared to the boll damage.

5.2.7. Predicted rate of square damage due to American bollworm

The data obtained from the present investigation revealed that the rate of damage decreased with increase in larval population. The increment due to the addition of larva had not caused the same quantum of damage. Hence a negative trend was noticed in case of the rate of square damage and larval population of cotton.

Advancement in crop stage beyond 80 DAS contributed for reduced damage rate. This result obtained is in agreement with the results by Gill and Simwat (1993) and Simwat and Singh (1997). The average duration of square formation phase varied from 43 to 45 days in different cotton cultivars, but got reduced in case of late sown crop. The square damage was more possible during early days of the crop stages. A maximum rate was recorded during 60 DAS for summer and winter season whereas in pot culture maximum was recorded at 80 DAS and lowest rate was observed at 90 DAS in all the experiments.

A regression model was worked out by the scientist at CICR between the larval population (X) and fruiting body damage in percentage (Y).. The larval variants used were similar to the present research with one larva to five larvae per plant. The predicted damage is coinciding with the observed damage value. Hence, the study was conducted between 77 – 78 DAS and 88 – 90 DAS of cotton crop and a complete picture of the damage and the larval incidence was not obtained (CICR, 1999-2000). It was further indicated that the larval incidence and damage at the peak period of infestation can be taken to observe the damage and larval incidence clearly.

5.2.8. Predicted rate of boll damage due to American bollworm

The results revealed that the rate of damage is inversely proportional to the larval population in all the experiments. As regards the crop stages are concerned, the peak damage rate was recorded at 100 DAS and it started declining from 110 DAS to

120 DAS. Hence, control measures should be taken at 100 DAS which will effectively reduce the damage. Management measures adopted in later part of crop stages like 110 DAS and 120 DAS would have less effect when compared to 100 DAS.

The rate of damage due to two larvae per plant was less than one larva per plant, but larval increment beyond three had no marked increase in the rate of damage and the trend showed a static or straight line. Hence control measures at higher larval intensity will not give that much effective reduction in damage as compared to lower larval intensity.

The rate of damage for every unit increment in larval population independent of crop stages was predicted. The fall in rate was steepest, when the larval population was increased from one and the rate gradually declined thereupon. A single larval increment from zero level accounted for 23.42 per cent damage in 90 DAS and 17.47 per cent in 120 DAS during summer and similar trend was observed in winter and pot culture experiments.

5.3. Predicted crop yield and damage at different larval intensity in cotton crop

5.3.1. Predicted crop yield and square damage due to spotted bollworm at various crop stages

The data were obtained from the crop infested at the age of 40 DAS through 80 DAS at various larval population on plant basis. The square damage was found to decrease with increasing crop stages and however, the damage however increased with increasing larval population. The yield was found reduced with increased larval population and the corresponding increase in damage level.

In the present study, the results are in agreement with that of Natarajan and Sundaramurthy (1990) who reported that the cotton bollworms, *H. armigera* and

E. vittella feeding on the reproductive parts of all stages from pinhead stage of bolls, caused damage and shedding of squares and bolls. However, cotton plant could recover from early season fruit damage with little or no loss of yield as the plant compensated by producing new squares. These results are also in line with Reed (1985) who worked on cotton bollworms, and IPM practices.

5.3.2. Predicted crop yield and boll damage by spotted bollworm at various crop stages

There is a negative correlation between damage level and yield obtained. The yield obtained was more at minimum damage level and less yield at maximum damage level.

Among the experiments, the yield obtained was less during winter at 70 DAS and 80 DAS when compared to summer and pot culture experiment. In other words, the yield loss was more during winter season. In winter crop, the yield loss was 6.66 to 28.09 per cent for 5 to 25 per cent damage level at 70 DAS, while 4.83 to 27.16 per cent was recorded at 80 DAS.

Sellammal Murugesan and Chelliah (1986) observed that the damage caused at boll stage and fruiting bodies accounted for greater yield loss. They have also reported a negative relationship between yield and damage. It was reported that the fruiting bodies are the main source of seed cotton and damage to this fruiting bodies might result in greater yield loss. The present results obtained are in consonance with the research findings of Nyambo (1989).

5.3.3. Predicted crop yield and square damage due to American bollworm at various crop stages

The yield obtained was found to be decreased as the damage level increased in all the experiments. A negative association was noticed between the crop yield and square damage by American bollworm.

Among the experiments, predicted crop yield obtained was minimum in pot culture experiment followed by summer and winter season. As the crop stages advanced for the same level of damage the yield obtained was decreased. Among the days, 90 DAS recorded lower yield than 60 DAS and 80 DAS in all the experiments. The results obtained from the present study are in conformity with Manisekaran *et al.* (1991) in case of MCU 7 and MCU 9 cotton varieties.

A computerized decision making model – SIRATAC was explained by Wilson (1982) for *H. armigera*, in which the damage potential, yield loss and population dynamics were included. The model predicted that the yield reduction was 0.00 to 21.64 per cent at 60 DAS. Similar trend was noticed in the present pot culture, summer and winter season experiments.

5.3.4. Predicted crop yield and boll damage due to American bollworm

The damage and the corresponding yield loss for varying larval population showed increasing levels of yield loss or lower yield with increasing larval population. However, the yield reduction at lower damage level was more but beyond 30 per cent damage the difference between yield obtained and yield loss was very less. Between days, the damage was more at 90 DAS, 100 DAS, 110 DAS and lowest damage was recorded at 120 DAS.

The results obtained in this study are in agreement with Balachandran (2000) who constructed a mathematical model between the fruit damage and various levels of *H. armigera* larvae in tomato.

Dhawan *et al.* (1990a) reported that the damage on fruiting body might not contribute significantly towards reduction in the yield of seed cotton.

It is advisable for the farmers to take up control measures only during the early damage levels and in turn it will increase the yield obtained per plant. Management practices carried out during the higher damage levels may not have effect on the yield improvement. It would be a waste of cost.

For validation of the efficiency of the model in prediction, the actual damage was also assessed and it was found that the variation between the predicted levels of damage and the observed values were not significantly different.

Predicted rate of yield loss due to unit increase in damage from base level

5.3.5. Predicted rate of yield loss and square damage due to spotted bollworm

The rate of loss in yield defines the quantum of loss suffered for unit increase in damage from the base level. The rate of yield loss was higher for a unit increment of damage from 10 to 11 per cent than for higher damage levels such as 20 to 21, 30 to 31 per cent and so on. The rate of yield loss was more in 70 DAS than in 60 DAS, 50 DAS and the lowest was recorded at 40 DAS.

In the present study, it was found that the rate of yield loss was drastically reduced when the base levels of damage were increased. These findings are in conformity with Bughio *et al.* (1991) and Du Toit (1998).

5.3.6. Predicted rate of yield loss and boll damage due to spotted bollworm

Among the experiments, summer season showed greater reduction in the rate of yield when compared to winter season and pot culture experiment. Between days, 70 DAS recorded higher rate of yield loss than 80 DAS in all experiments.

The yield loss was high for a unit increment damage from 10 per cent base level. The loss was further reduced to ¼th and ½ when the base level damage increased to 11 from 10 per cent and 31 from 30 per cent. For any unit increment from the base level damage 40 per cent and above, the rate of loss suffered fell to $^{2}/_{3}$rd and more or less equal as that of the preceding level.

It is advisable for the farmers to take up necessary control measures only upto 20 per cent damage level beyond which it was not economically viable for the efficient farming system.

The present investigation is in conformity with Gupta *et al.* (1997), Khurana (1992) and Du Toit (1998). Raju and Abdul Kareem (1994) predicted the relationship between rice yellow stem borer damage and yield of rice.

5.3.7. Predicted rate of yield loss and square damage due to American bollworm

It showed a negative trend in all the experiments. Among the experiments, the rate of yield loss due to square damage was more during winter season followed by summer and pot culture. Between days, 80 DAS showed higher rate of yield loss than 60 DAS and 90 DAS.

The rate of yield loss was the highest for a unit increment of damage from 10 per cent base level. Beyond 30 per cent, the rate of loss suffered fell to half as that of the preceding level.

In the present study, it was found that the rate of yield loss was drastically reduced when the base levels of damage increased. Similar results were obtained in rice leaf folder by Sellammal Murugesan and Chelliah (1986). The rate of yield loss suffered in this study was also minimum against an increase in damage after 30 per cent.

The relationship between the damage and yield follows the asymptotic curve. Under this relationship, the damage and yield have negative relationship upto certain level beyond which the curve tends to flatten up. The highest point where the curve tends to become plateau, which means, even with almost total damage (the highest point at which the direct relationship ceases) the plant will be able to put forth the same yield. Similar results were obtained by Pandi (1997), Pandi *et al.* (1998), Ramasubramanian (1996) and Balachandran (2000).

The model thus constructed would predict the damage and yield loss relationship with more than 75 per cent accuracy. Similarly, Sishui and Xiao XiJn (2000) constructed a model for rice leaf folder in China and that could be predicted with 72 per cent accuracy. Some more models were also in line with our findings *viz.*, MOTHZV-2, MOTHZV-3 and BUGNET in USA (Hartstack, 1982), SIRATAC in Australia (Hearn *et al.*, 1981), DEMHELIC for *Heliothis* spp. in Massachussets (Hopper and Stark, 1987) and COTTAM in South America (Jackson *et al.*, 1988).

5.3.8. Predicted rate of yield loss and boll damage due to American bollworm

The yield loss due to boll damage by American bollworm was more during winter season followed by summer and pot culture experiment. An increased rate of yield loss was recorded at 100 DAS. The forecasting can be easily done by this type of prediction. The farmers may be informed to take up necessary control measures before or at 100 DAS which will help them to harvest a good yield. Or in other words, control measures are given before the damage reached 15 per cent level, beyond which the control measures taken against American bollworm may not give good result.

The present investigation was further supported by Balachandran (2000) who studied the damage and yield loss in tomato by fruit borer, *H. armigera*. The damage was increased with increased larval population and a negative correlation was obtained between the yield and damage. He predicted that 50 DAT is the most vulnerable crop stage for fruit borer attack.

5.4. Predicted crop yield at different larval population of cotton bollworm

5.4.1. Predicted crop yield and various levels of spotted bollworm

The data obtained on yield at various levels of larva at varying crop stages signified the following. The yield obtained was decreased with increase in larval population. Single larva at 70 DAS caused more damage and yield loss was also more. In other words, the yield loss in 70 DAS showed increasing level with increasing per cent of damage due to increasing larval population. It suffered a minimum loss for one larva per plant and the maximum loss in yield was recorded in five larvae per plant. However, the corresponding loss suffered by youngest crops was more during summer season. The quantum of loss in 40 DAS was much lower than in 70 DAS. Similar finding was reported by Sellammal Murugesan and Chelliah (1986) and Walker (1991).

5.4.2. Predicted crop yield and various level of American bollworm

As the larval population is increased, there is corresponding decrease in yield obtained per plant. In other words, the yield obtained is inversely proportional to larval intensity in all the experiments. Single larva causes more damage when compared to more number of larvae/plant.

The results revealed that peak yield reduction was recorded during 90 DAS and 100 DAS. Therefore, the farmers may be informed to take up necessary control measures against the American bollworm during the peak periods of attack.

5.4.3. Rate of yield loss per spotted bollworm

The rate of yield loss was more at one larva per plant and it was decreased as the larval intensity increased. Among the experiments, the rate of yield loss was more during winter than in pot culture and summer season. Between days, 50 DAS and 60 DAS showed a lower rate of yield loss when compared to 70 DAS, 80 DAS and 40 DAS in various experiments. The rate of fall in yield loss was highest for a unit increment in larval population from one larva per plant. Similar results were obtained from Ramasubramanian (1996) and Balachandran (2000).

5.4.4. Predicted rate of yield loss per American bollworm

Among the experiments, there was no marked difference in rate of yield loss. Between days, 90 DAS and 100 DAS showed an increase in rate of yield loss. This was because it was the peak or critical boll developmental period in cotton. The damage caused at this period by the larval population directly affects the cotton yield. The rate of yield loss was more at one larva per plant and it decreased with increased larval intensity.

5.5. Effect of bollworm infestation on fibre quality

Seed cotton from the healthy and damaged were ginned and analysed for fibre qualities. Though there was no significant difference noticed between damaged and infested fibres, the data indicated that the 2.5 per cent span length, fibre fineness (micronaire value), maturity coefficient and bundle strength were inferior to that of fibres from uninfested bolls. Not much information is available in quantitative terms on damage to fibre quality, though it is generally held that cotton bolls attacked by insects will be having weak fibre and less mature (Sundaram and Munshi Singh, 1988). Nadkarny (1951) observed that the bolls attacked by spotted or pink bollworm open three to four days earlier than healthy ones. Early opening had adverse effect on seed and lint weight and ginning percentage of sound bolls. He also reported that although there were significant differences in fibre properties of lint from infested bolls and uninfested bolls of American Pima cotton, these differences were very minor. Reduction in quality has been attributed by them to subsequent boll rot infection following bollworm infestation. Feeding of larvae on the contents of green bolls and the immature seeds also affects the yarn strength and staple length (Lukefahr and Martin, 1963; Tsao and Lowry, 1963;

Tripathi *et al.*, 1963; Dhawan *et al.*, 1986; Sivasubramanian, 1991; Gupta *et al.*, 1997 and Thangaraj, 2001).

Dhawan *et al.* (1986) compared the quality of fibres from healthy and bollworm infested bolls and reported that the boll weight and fibre quality parameters were affected to some extent in *G. hirsutum* and *G. arboreum*.

As concluding remarks, simulation models are required for forecasting and decision making in IPM programmes. Any control measures taken should coincide with the peak days of boll development so as to enhance the yield. The present findings indicated that the spotted bollworm causes more damage on square and boll at 60 DAS and 80 DAS and the American bollworm causes more damage on square and boll at 80 DAS and 100 DAS respectively. If plant protection measures are adopted at right period *viz.*, one round of insecticidal spray at 50 DAS and the second round of insecticide spray at 70 DAS will take care of the spotted bollworm. If American bollworm incidence is noticed, three rounds of sprays at 60, 90 and 110 DAS may be advocated to contain the square and boll damage by American bollworm.

Predicting the timing of events when an insect pest is likely to cause more yield loss is important for IPM. It is suggested that the use of an economic threshold based on the ratio of the rate of boll production to boll damage could greatly reduce the number of insecticide applications (Gutierrez *et al.*, 1991).

Crop loss modelling has a strong need for much more effort in crop growth research. Without elegant crop growth and yield models, yield loss modelling and crop loss modelling will be severely limited in their applications (Pace and Mackenzie, 1991; Zadoks, 1991).

SUMMARY

6. SUMMARY

Detailed investigations were carried out to predict the damage and the corresponding yield loss due to various larval populations of cotton bollworms *viz.*, spotted bollworm, *Earias vittella* (Fabricius) and American bollworm, *Helicoverpa armigera* (Hubner) at different crop stages in cotton cultivar (cv) LRA 5166 under pot culture and field conditions. The pot culture study was conducted at Insectary, Department of Agricultural Entomology, and the field study was conducted at Eastern block, Tamil Nadu Agricultural University, Coimbatore during 2000-2002 and the results are summarised below.

1. Among the experiments, the predicted damage was more during winter season followed by summer and pot culture experiments. Between days, the highest predicted square and boll damage was at 60 days after sowing (DAS) and 80 DAS for spotted bollworm and 80 DAS and 100 DAS for American bollworm in all experiments.

2. In the pot culture experiment, the highest predicted square damage varied from 31.55 to 60.39 per cent (60 DAS) and the boll damage ranged from 3.57 to 20.85 per cent (80 DAS) for one to five larvae of spotted bollworm. Under field conditions, the highest predicted square and boll damage were ranging from 34.89 to 65.30 per cent (60 DAS) and 13.25 to 23.51 per cent (80 DAS) respectively during summer season. During winter, the predicted square and boll damage varied from 36.93 to 69.61 per cent and 12.86 to 24.34 per cent respectively. Further the square damage was decreased with increase in crop stages. More of shoot damage by spotted bollworm was recorded at 50 DAS. However, the crop yield was not affected by shoot damage because of rejuvenation of the plant.

3. Under pot culture experiment, the highest predicted square and boll damage by American bollworm varied from 38.53 to 58.71 per cent (80 DAS) and 32.43 to 61.82 per cent (100 DAS) respectively for one to five larvae per plant. In field experiments, the predicted damage ranged from 43.14 to 60.29 per cent and 35.54 to 63.21 per cent during summer and 52.28 to 64.17 per cent and 36.35 to 68.05 per cent during winter for one larva to five larvae per plant respectively.

4. The rate of square damage and boll damage due to spotted bollworm varied from 29.35 to 0.53 per cent (60 DAS) and 7.41 to 0.20 per cent in pot culture, whereas in the field experiments, it varied from 31.54 to 0.53 per cent and 8.78 to 0.32 per cent during summer season and 32.95 to 0.63 per cent and 9.57 to 0.39 per cent during winter season for one to five larvae per plant.

5. Pot culture experiment revealed that the rate of damage due to American bollworm varied from 20.08 to 0.40 per cent (80 DAS) and 29.49 to 0.57 per cent (100 DAS). In the field experiments, the damage rate ranged from 17.06 to 0.34 per cent and 30.14 to 0.40 per cent in summer season, while it varied from 11.50 to 0.26 per cent and 24.12 to 0.48 per cent for one to five larvae per plant during winter season. The rate of damage decreased with increase in crop stages and larval population.

6. The damage was found to increase with increasing larval population. The yield obtained decreased with increase in larval population in all the experiments.

7. For spotted bollworm, the highest predicted crop yield at 10 per cent damage level was recorded in all the crop stages except 80 DAS and lowest yield was recorded at 80 DAS in pot culture experiment. Similar results were obtained in summer and winter field experiments. There was no marked difference between the days in the

experiments. The highest yields recorded for 25 per cent damage level were 65.42, 71.91 and 70.37 per cent during summer, winter and pot culture experiments respectively.

8. For American bollworm, the yield obtained was reduced as the damage level increased in all the experiments. The yield reduction was 0.00 to 26.40 per cent at 80 DAS in winter season. The predicted crop yield obtained varied from 100.00 to 59.52 per cent at 90 DAS.

9. The predicted rate of yield loss for every unit increase in damage from the base levels damage of 10 to 70 per cent showed a decreasing trend for spotted bollworm. The rate of fall in yield was the highest for a unit increment of damage from 10 per cent level. The rate fell by more or less half for a unit increase from the base levels of 30 and 40. The rate of loss suffered fell to $^{2}/_{3}{}^{rd}$ of the preceding level for a unit increment from the base level damage of 50 and above.

10. The rate of yield loss due to square damage by American bollworm showed a negative trend in all the crop stages. The rate of yield loss was more during winter followed by summer and pot culture experiments. The rate of yield loss was 4.44 to 0.12 per cent at 60 DAS for 10 to 60 per cent base level damage during summer and similar results were recorded in winter and pot culture experiments.

11. The yield obtained was decreased with increase in larval population of spotted bollworm. A single larva at 70 DAS caused more damage and the yield loss was also more during winter (90.32%), in pot culture (90.66%) and in summer season (88.67%). The quantum of loss in 40 DAS was much lower than that in 70 DAS.

12. The larval population of American bollworm increased with corresponding decrease in yield obtained per plant. A single larva caused more damage and the corresponding

yield loss was also more in all the crop stages and experiments. The predicted yield obtained was 90.61 to 81.64 per cent at 60 DAS and 98.42 to 83.33 per cent for one to five larvae per plant at 120 DAS during summer season. Similar results were obtained during winter and pot culture experiments.

13. For spotted bollworm, the rate of yield loss was more at one larva per plant and it was decreased as the larval intensity increased. The rate of yield loss was 24.45 to 0.98 per cent at 40 DAS and 28.40 to 1.14 per cent at 80 DAS for one to five larvae per plant during summer season. The rate of yield loss was more during winter season followed by pot culture and summer season. Among days, 50 DAS and 60 DAS showed lower rate of yield loss than rest of the crop periods.
14. A single larva at 90 DAS and 100 DAS caused more damage and yield loss (36.53% and 34.00%) during summer season. The rate of loss was more at one larva and it was decreased with increase in American bollworm larval intensity. The quantum of loss in rest of the crop stages was much lower than that of 90 DAS and 100 DAS of cotton crop.
15. The quality parameters in the infested kapas were below the standard values. The reduction in the 2.5 per cent span length ranged from 25.02 to 25.33 per cent in summer. A similar trend was noticed in all the experiments. The reduction in the quality of the infested cotton fibre was not significantly high when compared to the healthy fibre.
16. Mathematical models were constructed under three different interactions *viz*., damage vs larva, yield vs damage and yield vs larva. Prediction was done at various crop stages of cotton in all the experiments. Based on the present studies, one round of insecticidal spray at 50 DAS and the second round of insecticidal spray at 70 DAS will reduce the damage by spotted bollworm. If American bollworm incidence is noticed, three rounds of sprays at 60, 90 and 110 days may be advocated to contain the square and boll damage by American bollworm.

REFERENCES

REFERENCES

Abdul Kareem, A. and N.Raju. 1991. A simulation model for rice yellow stemborer in relation to growth and yield on ADT 39. International Workshop on Impact of Pests and Diseases on Rice, 1991, IRRI.

*Agarwal, R.A. and K.N.Katiyar. 1979. An estimate of losses of seed kapas and seed due to bollworms on cotton in India. *Indian J. Ent.,* **41**(2): 143-148.

Annecke, D.P. and V.C.Moran. 1982. *Insects and mites of cultivated plants in South Africa*. Butterworths, Durban. pp.55.

Anonymous, 1975. All India Co-ordinated Cotton Improvement Project. *Prog. Rep.* (Entomology Part). Haryana agric. univ., Hisar. 1974-75.

Anonymous, 1991-1992. *Annual Research Report*. Main Cotton Research Station, Gujarat Agric. Univ., Surat, pp.15-16.

Anonymous, 1998. Cotton production manual. EID Parry (India) Ltd., Seed division, Dare House, 234, N.S.C. Bose Road, Chennai-600 001. 68 p.

Balachandran, J. 2000. Damage and yield loss caused by *Helicoverpa armigera* (Hubner) in Tomato. M.Sc.(Ag.) Thesis, Tamil Nadu Agric. Univ., Coimbatore. 99 p.

*Balmukand, B.H. 1928. Studies in crop variation: The relation between yield and soil nutrients. *J. Agr. Sci.,* **18**: 602-627.

Basson, N.J.C. 1987. An integrated control programme for cotton pests in South Africa. Farming in South Africa Leaflet Series: *Cotton* G1.1.6/1987. Department of Agriculture and Water Supply. Pretoria, South Africa.

*Berger, R.S. 1963. Laboratory techniques for rearing *Heliothis* species on artificial medium. *U.S. Dept. Agri., A.R.S.*, pp.33-84.

Bharpoda, T.M., H.P.Patel, J.J.Patel, U.Patel and G.P.Patel. 1999. Evaluation of Economic Threshold Levels for *Helicoverpa armigera* on 'H6' cotton (*Gossypium hirsutum*) in Central Gujarat Region. *Indian J. Agric. Sci.*, **69**(4): 304-305.

Bharpoda, T.M., H.P.Patel, P.Patel, G.P.Patel, J.J.Patel and J.R.Patel. 2000. Integrated Pest Management (IPM) in cotton H-6 cultivated in Middle Gujarat. *Indian J. Ent.*, **62**(4): 327-331.

Bhat, M.G. and A.P.Jayaswal. 1988. A study on factors of bollworm resistance in cotton (*Gossypium hirsutum* L.) using isogenic lines. *Journal of the Indian Society for Cotton Improvement,* **13**(2): 149-153.

*Briggs, G.E. 1927. Plant yield and the intensity of external factors. Mitscherlich's Wirkungsgesetz'. *Ann. Bot.,* **39**: 475-502.

Bughio, A.R., T.Hussain and Z.A.Qureshi. 1991. Role of pink bollworms in the abscission of squares and bolls in cotton. In: *Proc. Pakistan Congress of Zoology*. Atomic Energy Agricultural Research Centre, Tandojam, Pakistan. 7: 90-104.

Bughio, A.R., Z.A.Qureshi and T.Hussain. 1987. Influence of boll age, size and moisture content on pink and spotted bollworms infestation in cotton. In: *Proc. Pakistan Congress of Zoology*, 8-11, January 1986, University of Karachi, Zoological Society of Pakistan, Karachi. pp.127-131.

Butler, G.D. 1976. Bollworm development in relation to temperature and larval food. *Environ Entomol.*, **5**: 520-522.

Butler, N.S., J.S.Kular and H.S.Sukhija. 1990. Determination of economic threshold level vis-à-vis fixed spray schedule for the control of bollworms on upland cotton. *J. Insect Sci.*, **3**(1): 67-71.

*Capizzi, A. 1987. *Earias vittella* (F.) (Lepidoptera : Noctuidae), dannosa al cotone, Presente anche in Africa. *Orientale Bolletino di Zoologia Agraria e di Bachicoltura*, **19**: 199-203.

*Chakravarthy, A.K. 1982. Bollworms infestation in relation to the phenology of arboreum cotton. Unpubl. Ph.D. Thesis, Punjab Agric. Univ., Ludhiana, 106 p.

Chokmani, K.A., A.Viau and G.Bourgeois. 2001. Outputs uncertainity analysis of four crop protection models relative to agrometeorological inputs measurement errors. *Agronomie*, **21**(2): 147-167.

CICR., 1998-1999. *Annual Report*, Central Institute for Cotton Research, Nagpur. pp. 45-60.

CICR. 1999-2000. *Annual Report*. Central Institute for Cotton Research, Nagpur, pp.56-58.

Cox, P.G., S.G.Marsden, K.D.Brook, H.Talpaz and A.B.Hearn. 1991. Economic optimisation of *Heliothis* thresholds on cotton using a pest management model. *Agricultural Systems*, **35**: 157-171.

Decoin, M. 1999. Awareness of the dynamics of pest populations, modelling and forecasting for more rational protection in large scale farming. *Phytoma*, **522**: 27-32.

Dhawan, A.K., G.S.Simwat and A.S.Sidhu. 1990a. Shedding of fruiting bodies by bollworms in Asiatic cotton. *J. Res. Punjab agric. Univ.*, **27**(3): 441-443.

Dhawan, A.K., G.S.Simwat and A.S.Sidhu. 1990b. Square-shedding due to bollworms in different varieties of *Gossypium arboreum*. *J. Res. Punjab agric. Univ.*, **27**(4): 605-610.

Dhawan, A.K., G.S.Simwat, A.S.Sidhu and U.K.Madam. 1986. Pink bollworm damage in cotton at different levels of loculi infestation. *Indian J. agric. Sci.*, **56**(10): 738-742.

Dillon, M.L. and G.P.Fitt. 1990. HEAPS: A regional model of *Heliothis* population dynamics. In: *Proc. of V Australian Cotton Conference*, 8-9August. Broad beach, Queensland, Australian Cotton Growers Research Association, Brisbane, pp.337-344.

Drapek, R.J., G.Fisher and B.A.Croft. 1997. Spatial modelling of the influence of corn planting and wind blocking features on catch of *Helicoverpa zea* (Boddie) in pheromone traps and subsequent pest damage. *Agricultural Systems*, **54**(3): 381-397.

Du Toit, C.L.N. 1996. Threshold values and control of insect pests species of cotton. *ARC-TCRI, Project Report*, TK205/13.

Du Toit, C.L.N. 1998. Integrated Pest Management on cotton in South Africa. In: *Proc. World Cotton Research Conference*. 6-12 September, Athens, Greece. pp.814-817.

*Dyar, H.G. 1890. The number of moults of Lepidopterous larvae. *Psyche.*, **5**: 420-422.

*Fery, R.L., F.P.Cuthbert, Jr. and W.D.Perkins. 1979. Artificial infestation of the tomato with eggs of the tomato fruit worm. *J. Econ. Ent.*, **72**: 392-394.

Fitt, G.P. 1989. The ecology of *Heliothis* species in relation to agro ecosystems. *Annu. Rev. Entomol.*, **34**: 17-52.

Fitt, G.P. 1994. Cotton pest management: Part 3. An Australian perspective. *Annu. Rev. Entomol.*, **39**: 543-562.

Fitt, G.P., M.L.Dillon and J.G.Hamilton. 1995. Spatial dynamics of *Helicoverpa* populations in Australia: Simulation modelling and empirical studies of adult movement. *Computers and Electronics in Agriculture*, **13**(2): 177-192.

Frisbie, R.E., J.L.Crawford, C.M.Bonner and F.G.Zalom. 1989a. Implementing IPM in cotton. In: *IPM systems and cotton production,* Frisbie, R.E., K.M.EL-Zik and L.T.Wilson (eds.). Wiley, New York. 437 p.

Frisbie, R.E., K.M.EL-Zik and L.T.Wilson. 1989b. The future of cotton. In: *IPM systems and cotton production*. Frisbie, R.E., K.M.EL-Zik and L.T.Wilson (eds.). Wiley, New York, 437 p.

Gage, S.H. 1989. Predicting pest occurrence and impact in a dynamic environment. In: *Climate and Agriculture Systems Approaches to Decision-making.* W.Albert (ed.) Charlston Publishers, South Carolina. pp.110-145.

Gang, W., L.Z.Yong, L.B.Yung, W.Bin and S.C.Ling. 1997. The reduction of bollworm incidence by cultural control. *China Cottons*, **24**(1): 31.

Gill, B.S. and G.S.Simwat. 1993. Studies on square formation and bollworm incidence in *Gossypium arboreum* cotton. *J. Insect Sci.*, **6**(1): 82-84.

Gomez, K.A. and A.A.Gomez. 1984. Statistical procedures for agricultural research. A Wiley-Interscience Publication, John Wiley and Sons, New York, 680 p.

Gupta, G.P., E.D.Sharma, G.S.Dhaliwal, R.Arora and A.K.Dhawan. 1997. Management of bollworms for sustainable agroecosystem in cotton. In: *Proc. Ecological Agriculture: Towards Sustainable Development*, 15-17 November, 1997, Chandigarh, India, pp.267-273.

Gupta, G.P., G.K.Mahapatro and A.Chandra. 1998. Partial larval rearing of *Earias vittella* (Fabricius) on artificial diet. *Insect. Sci. Applic.*, **18**(4): 371-375.

Gutierrez, A.P. 1992. The ecological basis for crop protection: Theory and Practice. In: *Proc. Brighton Crop Protection Conference Pests and Diseases*. 23-26 November 1992, Brighton. U.K. pp. 955-964.

Gutierrez, A.P. and G.L.Curry. 1989a. Conceptual framework for studying crop-pest systems. In: *IPM Systems and Cotton Production,* Frisbie, R.E., K.M.EL-Zik and L.T.Wilson (eds.). Wiley, New york. pp.37-64.

Gutierrez, A.P. and L.T.Wilson. 1989b. Development and use of pest models. In: *IPM Systems and Cotton Production.* Frisbie, R.E., K.M.El-Zik and L.T.Wilson (eds.). Wiley, New York, pp.64-83.

Gutierrez, A.P., J.W.Santos, M.A.P.dos, M.Ellis and I.Tutida. 1991. Modelling the interaction of cotton and the cotton boll weevil (*Anthonomus grandis*) in Brazil. *J. Applied Ecology,* **28**(2): 398-418.

Hamilton, J.G. and G.P.Fitt. 1990. HEAPS: *Heliothis armigera* and *punctigera* simulation. In: *Proc. of V Australian Cotton Conference*, 8-9 August. Broad beach, Queensland. Australian Cotton Growers Association, Brisbane. pp.139-145.

Hardcastle, M.J. 1989. A strategy for economic pest control in cotton. In: Green, M.B. and D.J.B.Lyon (eds.). *Pest Management in Cotton*. Eillis Horwood Ltd., Chiockester, England, UK, pp.219-236.

*Hardwick, D.F. 1965. The corn ear worm complex. *Man. Entomol. Soc. Can.*, **40**: 247.

*Hargreaves, H. 1948. Recorded cotton insect pests of the world. Commonwealth. Instt. of Entomol., London UK.

Hartstack, A.W. 1982. Modelling and Forecasting *Heliothis* Populations in USA. In: *Proc. International Workshop on Heliothis Management*, 15-20 November, 1981. ICRISAT Centre, Patancheru, A.P., India. pp.51-60.

*Hartstack, A.W., J.A.Witz, J.P.Mollingo and J.D.Lopez. 1976. MOTHZV-2: A computer simulation of *Heliothis zea* and *Heliothis virescens* population dynamics, US. Department of Agriculture User's Manual ARS-S-127, Washington DC, USA 55 p.

*Hartstack, A.W., J.K.Henson, J.A.Witz and R.E.Frisbie. 1977. The Texas programme for forecasting *Heliothis* spp. infestations on cotton. In: *Proc. Beltwide Cotton Producers Research Conference*, Memphis, Tennessee, pp.151-154.

Hearn, A.B., P.M.Ives, P.M.Room, N.J.Thompson and L.T.Wilson. 1981. Computer based cotton pests management in Australia. *Field Crop Research*, **4**: 321-332.

*Hexem, R.W., V.A.Sposito and E.A.Heady. 1976. Application of two variable Mitscherlich function analysis of yield, water and fertilizer relationship for corn. *Water Resource Research*, **12**: 6-10.

Holt, J. and G.A.Norton. 1993. Simulation models. In: *Tools in pest management*. Norton, G.A. and J.D.Mumford (eds.). IRRI, Manila. pp.119-146.

Hopper, K.R. and S.B.Stark. 1987. A simulation model for making decisions about *Heliothis* control. In: *Proc. Beltwide Cotton Producers Research Conference*, Memphis, Tennessee. pp.286-291.

Hua Di, W., Z.Z.Sheng, C.J.An, W.X.Geng and T.J.Yi. 1997. Study on control strategy and prediction of yellow stem borer. *Scientia Agricultura Sinica*, **30**(3): 14-20.

*Ignoffo, C.M. 1965. The nuclear polyhedrosis virus of *Heliothis zea* (Boddie) and *Heliothis virescens* (Fabricius). Its biology and propagation of diet reared *Heliothis*. *J. Invertebr. Pathol.*, **7**: 217-226.

Ilango, K. and S.Uthamasamy. 1989. Influence of spacings and fertilizer levels on the incidence of bollworms and boll rot complex in three varieties of cotton (*Gossypium hirsutum*). *Applied Agricultural Research*, **4**(3):173-178.

Jackson, B.S., G.F.Arkin and A.B.Hearn. 1988. The cotton simulation model. COTTAM: fruiting model calibration and testing. *Trans. Amer. Soc. Agric. Egr.*, **31**: 846-854.

Jayaraj, S. 1988. The problem of *Heliothis* and its integrated management. In: *Proc. of Heliothis management*. February 1988. Tamil Nadu Agric. Univ., Coimbatore. pp.4-6.

Jian Z hou, Z., R.C.Hui, L.M.Guang, X.Lin, R.L.Jun and M.X.Qing. 2000. Monitoring and Management of *Helicoverpa armigera* resistance to transgenic Bt cotton in Northern China. *Resistant Pest Management*, **11**(1): 28-31.

Kairon, M.S. 1998. Recent advances in cotton production for efficient Insect Pest Management. In: *Proc. World Cotton Research Conference*. 6-12 September, Athens, Greece. pp.823-828.

Kaushik, U.K., V.S.Rathore and N.K.Sood. 1969. Incidence of bollworms and losses caused to cotton in Madhya Pradesh. *Indian J. Ent.*, **31**(10): 175-177.

Keerthisinghe, C.I. 1982. Economic threshold for cotton pest management in Sri Lanka. *Bull. Ent. Res.*, **72**: 239-246.

Khurana, A.D. 1992. Effectiveness of different spray schedules against bollworms on *arboreum* cotton. *J. Insect Sci.*, **5**(1): 54-56.

King, A.B.S. 1994. Heliothis / Helicoverpa (Lepidoptera : Noctuidae). In: *Insect Pests of Cotton*. Mathews, G.A. and J.P.Tunstall (eds.). CAB International, Wallingford, Oxon U.K. pp.39-106.

Labatte, J.M. and B.Got. 1991. Modelling damage on maize by the European corn borer, *Ostrinia nubilalis*. *Annals of Applied Biology*, **119**(3): 401-413.

Lal, S.T. and B.T.Lal. 1996. Economic injury level and sequential sampling plant for *Heliothis armigera* (Hubner) infesting tomato. *Giornale Italiano Di Entomologia*, **8**(17): 429-443.

Legaspi, B.C.Jr., R.I.Carruthers and J.A.M.Ramos. 1996. Functional response as a component of dynamic simulation models in biological control : the catolaccus-boll weevil system. *Ecological Modelling*, **89**(1/3): 43-57.

*Lukefahr, M.F. and D.F.Martin. 1963. Evaluation of damage to lint and seed cotton caused by pink bollworm. *J. Econ. Entomol.*, **56**(5): 710.

Lynch, R.E., J.F.Robinson and E.C.Berry. 1980. European corn borer: yield losses and damage resulting from simulated natural infestation. *J. Econ. Entomol.*, **73**: 141-144.

*Mabbett, T.H., P.Darcept, N.Nachapong and S.Wangboopang. 1979. Studies into the feeding distribution and movement of the American bollworm, *Heliothis armigera* (Hubner). *Thailand J. Agric. Sci.*, **12**: 115-122.

Madden, A.D., J.Holt and N.J.Armes. 1995. The role of uncultivated hosts in the spread of pyrethroid resistance in *Helicoverpa armigera* populations in Andhra Pradesh, India: A simulation approach. *Ecological Modelling*, **82**(1): 61-74.

Manisekaran, S., T.Kumaraswami and N.Natarajaratnam. 1991. Control of bollworms (*Earias* spp., *Heliothis armigera* Hub. and *Pectinophora gossypiella* Saunders) on cotton. *Indian J. Ent.*, **53**(3): 412-422.

Mathews, G.A. 1994. The effect of insects attack on the yield of cotton. In: *Insect pests of cotton*. Mathews, G.A. and J.P.Tunstall (eds.). CAB International, Wallingford, Oxon U.K. pp.427-431.

Mathews, M. 1987. The classification of the *Heliothinae* (Noctuidae). Ph.D. Thesis. British Museum and Kings College. London. 253 p.

Meek, D.W., R.B.Hutmacher, B.E.Mackey and K.R.Davis. 1991. Hetroscadasticity in whole plant growth curves developed from non-replicated data. *Agron. J.,* **93**: 417-424.

*Michaelis, L. and M.L.Menten. 1913. Die kinetik den Invertinwirkung. *Biochem. Z.,* **49**: 333-369

Mishra, B.K. and S.M.A.Mandal. 1995. Integrated management of cotton pests with emphasis on bollworms. *Indian J. Plant Prot.*, **23**: 135-138.

Mitter, C., R.W.Poole and M.Mathews. 1993. Biosystematics of the *Heliothinae* (Lepidoptera: Noctuidae). *Annu. Rev. Entomol.*, **38**: 207-225.

Monastyrskii, A.L. and E.S.Suganyaev. 1995. Ecological basis of integrated rice Lepidopteran pest management in North Vietnam 1. Damage modelling of the rice tortricid *Cnaphalocrocis medinalis* Guen. (Lepidoptera: Pyralidae). *Entomologicheskoe obozremie*, **74**(1): 19-37.

Morgan, D., M.G.Solomon, R.Habib and P.Blaise. 1996. PEST-MAN: a forecasting system for orchard pests. *Acta Horticulturae*, **416**: 273-277.

Murthy, N.S. and R.D.Singh. 1991. Report on Spatial Dynamics of Insect Pests. Training Report. Entomology Spatial Analysis Laboratory, Department of Entomology, Michigan State University (Unpublished).

Nadkarny, N.T. 1951. A note on the diapause in pink bollworm of cotton. *Indian Cott. Gr. Rev.,* **5**(1): 49.

Narayanan, K. 1979. Studies on the nuclear polyhedrosis virus of the gram pod borer, *Heliothis armigera* (Hubner) (Noctuidae: Lepidoptera). Ph.D. Thesis, Tamil Nadu Agric. Univ., Coimbatore. 184 p.

Narayanan, S.S. 1991. Resistance to Heliothis and other serious insect pests in *Gossypium* spp. In: *Symposium on Genetic Research and Education: Current Trends and the next fifty years*, 12-15 February, 1991, New Delhi.

Natarajan, K. 1990. Investigation on the ovipositional preference of *Heliothis armigera* (Hub.) as affected by certain genotypes. In: *Heliothis Management of National Workshop*. S.Uthamasamy, M.Gopalan and R.J.Rabindra (eds.). Centre for Plant Protection Studies, Tamil Nadu Agric. Univ., Coimbatore.

Natarajan, K. and V.T.Sundaramurthy. 1990. Action threshold level for bollworms infestation on MCU 5 VT cotton. In: *Proc. of Heliothis Management*. Jayaraj, S., S.Uthamasamy, M.Gopalan and R.J.Rabindra (eds.). Tamil Nadu Agric. Univ., Coimbatore, pp.92-95.

Nath, P., O.P.Chaudhary, P.D.Sharma and H.D.Kaushik. 2000. Studies on incidence of important insect-pests of cotton with special reference to *Gossypium arboreum* (desi) cotton. *Indian J. Ent.*, **62**(4): 391-395.

Nyambo, B.T. 1989. The use of scouting in the control of *Heliothis armigera* in the western cotton growing area of Tanzania. *Crop Protection*, **8**: 310-317.

Ochou, O.G., T.Martin and N.F.Hala. 1998. Cotton insect pest problems and management strategies in Cote d' Ivoire, WestAfrica. In: *Proc. World Cotton Research Conference*. 6-12 September, Athens, Greece. pp. 833-837.

Pace, M.E. and D.R.Mackenzie. 1991. Modelling of crop growth and yield for loss assessment. In: *Crop Loss Assessment and Pest Management*. P.S.Teng (ed.). APS Press, Minnesota. USA. pp.30-36.

Pandi, V. 1997. Prediction of damage and yield loss caused by rice leaf folder in IR 50 by simulation model. M.Sc.(Ag.) Thesis, Tamil Nadu Agric. Univ., Coimbatore. 110 p.

Pandi, V., P.C.Sundara Babu and C.Kailasam. 1998. Predicting rice leaffolder damage and yield loss in IR 50 rice by mathematical modelling. *Madras Agric. J.,* **85** (7-9): 429-432.

Patel, J.R. and N.C.Patel. 2000. Behaviour of *Earias vittella* in relation to weather factors on cotton H 6. *Indian J. Ent.,* **62**(4): 363-366.

Patel, R.C., J.K.Patel, P.B.Palel and R.Singh. 1968. Mass breeding of *Heliothis armigera* (Hubner). *Indian J. Entomol.,* **30**: 272-280.

Patel, R.M. 1949. Control of cotton spotted bollworm (*Earias fabia*) in Baroda. *Indian Cotton Growing Review,* **2**: 135-144.

Patil, B.V. and M.Bheemanna. 1998. Integrated Pest Management Strategy for Irrigated Cotton. In: *Proc. World Cotton Research Conference.* 6-12 September, 1998. Athens. Greece. pp.801-805.

Pearson, E.O. 1958. *The insect pests of cotton in Tropical Africa.* Empire Cotton Growing Corporation and Commonwealth Institute of Entomology, London. pp.74-95.

Pinnschmidt, H.O., W.D.Batchelor and P.S.Teng. 1995. Simulation of multiple species pest damage in rice using CERES – rice. *Agricultural Systems,* **48**(2): 193-222.

Poole, R. 1989. A general synopsis of the systematics of *Heliothis* and *Helicoverpa.* In: *Proc. Biological Control of Heliothis: Increasing the Effectiveness of Natural Enemies.* King, E.G. and Jackson, R.D. (eds.). 11-15 November 1985. New Delhi, India. FERRO/USDA. New Delhi, India. pp.161-171.

Rabindra, R.J. 1973. Studies on polyhedrosis of three species of Lepidoptera. M.Sc.(Agri.) thesis, Tamil Nadu Agri. Univ., Coimbatore, pp.91.

Raju, N. and A.Abdul Kareem. 1994. Modelling yellow stemborer damage in relation to growth and yield of rice. Simulation and Systems Analysis for Rice Production (SARP) Workshop, 18 April – 6 May, 1994, IRRI.

Raju, N., S.Palaniswamy, T.M.Thiagarajan, M.N.Budhar and S.Chelliah. 1989. Simulation of leaf folder damage and its relationship to growth and yield of rice. *Crop Protection,* **11**: 419-426.

Ramachandra Prasad, T.V., K.Krishnamurthy and C.Kailasam. 1992. Functional crop and cob growth models of maize (*Zea mays* L.) cultivars. *J. Agron. Crop Sci.,* **168**: 208-212.

Ramalho, F.S., J.C.McCarty and J.N.Jenkins. 1984. Distribution of tobacco budworm (Lepidoptera: Noctuidae) larvae within cotton plants. *J. Econ. Entomol.,* 77(3): 591-594.

Ramana Rao, B.U. and M.Srinivasa Rao. 1996. Weather Effects on Insect Pests. In: *Climate Variability and Agriculture*. Abrol. Y.P., S.Gadgil and G.B.Pant (eds.). Narosa Publishing House, New Delhi, India. pp.281-294.

Ramasubramanian, G.V. 1996. Bioecology and management of rice black bug, *Scotinophora coarctata* (Fabricius). M.Sc.(Agri.) thesis, Tamil Nadu Agri. Univ., Coimbatore.171 p.

*Ramiah, E. 1966. Reproductive behaviour of *Heliothis armigera* in laboratory condition. M.Sc.(Ag.) Thesis, Sardar Patel Univ. Vallabh Vidhyanagar.44 p.

Reed, W. 1985. Principles and concepts of insect pest management. In: *Microbial control and Pest Management*. S.Jayaraj (ed.). Tamil Nadu Agric. Univ., Coimbatore. 276 p.

Reed, W. 1994. *Earias* spp. (Lepidoptera: Noctuidae). In: *Insect pests of cotton.* Mathews, G.A. and J.P.Tunstall (eds.). CAB. International, Wallingford, Oxon, U.K. pp.151-176.

Reed, W. and C.S.Pawar. 1982. *Heliothis*: A global problem. In: Reed, W. and V.Kumble (eds.). *Proc. International Workshop on Heliothis management,* 15-20 Nov. 1981, ICRISAT Center, Patancheru, A.P., India. pp.529-535.

Reese, J.C., B.C.Chan, N.R.Malim and A.C.Jr. Waise. 1981. Feeding sites of bollworm larvae on cotton. *Environ. Entomol.*, **10**(1): 81-84.

Regupathy, A., S.Palaniswamy, N.Chandramohan and K.Gunathilagaraj. 1998. A guide on crop pests. Ms.Sooriya Desktop Publishers, Coimbatore, India. pp.38-39.

Rosenthal, W.D., R.L.Vanderlip, G.F.Arkin and B.S.Jackson. 1989. Sorkam: a grain sorghum crop growth model. Texas Agric. Exptl. Station, Rep. No. MP-1699.

Russell, D.A., J.Singh, D.R.Jadhav, T.Surulivelu, A.Regupathy and K.R.Kranthi. 1998. Management of Insecticide Resistant *Helicoverpa armigera* (Lepidoptera: Noctuidae) in cotton in India. In: *Proc. World Cotton Research Conference.* 6-12 September, Athens, Greece. pp.679-688.

Sachan, J.N. and C.P.Yadava. 1991. *Heliothis* ecology in relation to different agro ecosystem. Paper presented during ICAR / IOPERM / USDA. Joint Project development group meeting on managing insecticide resistance with focus on *Heliothis* resistance management in India, 16-17 Oct. 1991, DRR, Rajendra Nagar, Hyderabad, A.P., India.

Sadras, V.O. and L.J.Wilson. 1997. Growth analysis of cotton crops infested with spider mites: Partitioning of dry matter. *Crop Science*, **37**(2): 492-497.

Sathiah, N. 2000. Studies on improving production and formulation of the Nuclear polyhedrosis virus of cotton bollworm *Helicoverpa armigera* (Hubner.). Ph.D. Thesis, Tamil Nadu Agric. Univ., Coimbatore. 220 p.

Satish Kumar, G.D. and B.V.Sudershan Rao. 2002. Factors for the suicide of cotton farmers. *Crop Res.*, **23**(1): 129-132.

Sellammal Murugesan and S.Chelliah. 1986. Yield loss and economic injury by rice leaffolder. *Indian J. Agric. Sci.*, **56**: 394-395.

Sharma, P.D. 1998. Extent of damage by different insect-pests in cotton. *Annual Report Cotton Entomology.* 1997-1998. AICCIP. pp.63-64.

Shorey, H.H. and R.L.Hale. 1965. Mass rearing of the larvae of nine noctuid species on a simple artificial medium. *J. Econ. Entomol.*, **58**: 522-524.

Sidhu, A.S. and S.S.Sandhu. 1977. Damage due to the spotted bollworm (*Earias vittella* Fab.) in relation to age of the bolls of *hirsutum* variety J-34. *J. Res. Punjab Agric. Univ.*, **14**: 184-187.

Silvie, P., J.P.Deguine, S.Nibouche, B.Michel and M.Vaissayre. 1998. Procedures, advantages and constraints of staggered targeted control programmes on cotton in West Africa. In: *Proc. World Cotton Research Conference*. 6-12 September, Athens, Greece. pp.829-832.

Simwat, G.S. and A.K.Dhawan. 1997. Field evaluation of different Economic Threshold Levels for chemical control of pink bollworm (*Pectinophora gossypiella*), spotted bollworm (*Earias vittella, E. insulana*) and cotton bollworm (*Helicoverpa armigera*) on cotton (*Gossypium* spp). *Indian J. Agric. Sci.*, **67**(6): 259-261.

Simwat, G.S. and J.H.Singh. 1997. Square formation phase and bollworms incidence in *hirsutum* cotton hybrids PCHH 31 and LHH 121 in Punjab. *Insect. Sci.*, **10**(1): 38-41.

Singh, B.N., H.G.Singh and V.P.Singh. 1979. Path analysis of yield and fibre components in upland cotton. *Indian J. Agric. Sci.*, **14**: 136-140.

Singh, D.P., S.Seth and A.P.Tyagi. 1981. Genetics of heterosis in upland cotton. *Indian J. Agric. Sci.*, **53**(9): 782-785.

Singh, J. and A.S.Sidhu. 1980. Studies on *Heliothis armigera* (Hubner) as a pest of *hirsutum* cotton in the Punjab. *Entomon.*, **5**: 185-189.

Singh, J. and A.S.Sidhu. 1982. Bollworms and square-shedding in *hirsutum* cotton in the Punjab. *Indian J. Ent.*, **44**(4): 318-328.

Singh, J. and B.S.Sandhu. 1995. Economic Threshold for chemical control of spotted bollworms (*Earias vittella* and *E. insulana*) and pink bollworm (*Pectinophora gossypiella*) on tree cotton (*Gossypium arboreum*). *Indian J. Agric. Sci.*, **65**(8): 613-616.

Singh, J. and K.Singh. 1998. Economic Threshold for spotted bollworms, *Earias* spp. in cotton, *Gossypium arboreum* L. *J. Insect Sci.*, **11**(1): 60-61.

Singh, S.B., R.G.Dani and Devendra Singh. 1992. Improving drought resistance in cotton: a review. *Cotton-et-Fibres-Tropicales,* **47**(4): 289-300.

Sishui, W. and Z.X.Xijn. 2000. Factor integration in Modelling of insect pest forecasting. *J. Nanjing Agric. Univ.*, **23**(2): 35-38.

Sivasubramanian, P. 1991. Ecology, host-plant interactions and management of pink bollworm, *Pectinophora gossypiella* (Saunders) on cotton. Ph.D. Thesis, Tamil Nadu Agric. Univ., 226 p.

Stinner, R.A., R.L.Rabb and J.R.Bradley. 1974. Population dynamics of *Heliothis zea* (Boddie) and *H. virescens* (F.) in North Carolina: a simulation model. *Environ. Entomol.,* **3**: 163-168.

Strickland, G.R., S.J.Yeates, G.P.Fitt, G.A.Constable and S.J.Addision. 1998. Prospects for a sustainable cotton industry in Tropical Australia using novel crop and pest management. In: *Proc. World Cotton Research Conference*. 6-12 September, Athens, Greece. pp.850-857.

Sundaram, V. and Munshi Singh. 1988. Effect of application of insecticides for control of bollworms on cotton fibre quality. In: Group discussion on bollworm resistance in cotton. Central Institute for Cotton Research, Nagpur, pp.197-207.

Sundaramurthy, V.T. 1988. A review of distribution, ecology, behaviour and management of *Heliothis armigera.* In: *Proc. Group Discussion on Bollworm Resistance in Cotton,* Central Institute for Cotton Research, Nagpur, India. pp.61-76.

Sundaramurthy, V.T. and K.Chitra. 1992. Integrated Pest Management in Cotton. *Indian J. Plant Protec.,* **20**: 1-17.

Surulivelu, T., K.Venugopal, R.Kannan and V.Pandi. 1998. A system approach to sustainable Insect Pest Management in Cotton. In: *Proc.World Cotton Research Conference*. 6-12 September. Athens, Greece. pp.806-808.

Sutherst, B,M.Zalucki, G.Maywald and N.White. 1997. National pest modelling facility. *Agricultural Systems and Information Technology,* 7(1): 43-46.

Tariq, M., M.A.Khan and G.Idris. 1995. Inheritance of boll weight, boll number and yield of seed cotton in upland cotton (*G. hirsutum* L.). *Sarhad J. Agric.,* **11**(5): 599-605.

Taware, S.P. and V.P.Patil. 1993. Analysis of variability under bollworm infested conditions in cotton. *Biovigyanam,* **19**(2): 1-6.

Tewari, K.N. and V.K.Krishnamoorthy. 1984. Feasibility of using *Trichogramma* spp. against *Heliothis armigera* (Hubner) on cotton. *Indian J. Plant Prot.,* **12**(2): 237-239.

Thangaraj, K. 1998. Genetical and Bio-chemical studies on intra-racial hybrid derivatives of *Gossypium hirsutum* L. with special reference to bollworm resistance. M.Sc.(Ag.) Thesis, Tamil Nadu Agric. Univ., Coimbatore. 135 p.

Thangaraj, K. 2001. Genetic studies on metrical traits and bollworm (*Helicoverpa armigera* Hubner.) resistance in interspecific and interracial derivatives of cotton (*Gossypium* spp.). Unpub. Ph.D. Thesis, Tamil Nadu Agric. Univ., Coimbatore. 178 p.

*Thompson, G. and E.A.Steinhaus. 1950. Further tests using a polyhedrosis virus to control the alfalfa caterpillar. *Hilgardia,* **19**: 411-441.

Tomar, S.K., A.Tomar, B.P.Dhyani and J.M.Singh. 2000. Incidence of bollworms in relation to variety and time of sowing in cotton (*Gossypium* species). *Indian J. Agric. Sci.,* **70**(9): 633-634.

*Tripathi, R.L., V.M.Sahni and R.N.Katiyar. 1963. Pest problem of American cotton in Vidarbha. *Indian Cott. Gr. Rev.,* **17**(5): 314-315.

Tsao, C.H. and W.L.Lowry. 1963. Control of the pink bollworm and a method for estimating losses in cotton yield. *J. Econ. Entomol.*, **56**(2): 156-160.

Valarmathi, M. 1996. Genetic studies on yield, yield components and fibre characters in intraspecific and interspecific hybrids of cotton. M.Sc.(Ag.) Thesis, Tamil Nadu Agric. Univ., Coimbatore. 106 p.

Veera Reddy, C. and A.K.Bhattacharya. 1990. Development of semi-synthetic diets for the rearing of *Heliothis armigera* (Hubner.). *J. Insect. Sci.,* **3**(1): 23-33.

Walker, P.T. 1991. Quantifying the relationship between insect populations, damage, yield and Economic Thresholds. In: *Crop loss Assessment and pest management.* P.S.Teng (ed.) APS Press, Minnesota, USA. pp.114-125.

Way, M.J., H.F.Emden and F.Van. 2000. Integrated pest management in practice – pathways towards successful application. *Crop Protection,* **19**(2): 81-103.

*Wesson, G.L. 1932. A modification of the Osborne-Mendel salt mixture containing only inorganic constituents. *Science,* **75**: 339-340.

Wilson, A.G.L. 1981. *Heliothis* damage to cotton and concomitant action levels in the Namoi valley, New South Wales. *Prot. Ecol.,* **3**: 311-325.

Wilson, A.G.L. 1982. Past and future Heliothis management in Australia. In: *Proc. International workshop on Heliothis management,* 15-20 Nov. 1981, ICRISAT Centre, Patancheru, A.P., India. pp.324-354.

Zadoks, J.C. 1991. The concepts of Thresholds: Warning, Action and Damage thresholds. In: *Crop Loss Assessment and Pest Management.* P.S.Teng (ed.) APS. Press. Minnesota. USA. pp.168-175.

* Originals not seen.