

**EVALUATION OF EMAMECTIN BENZOATE 5 SG AGAINST
BOLLWORMS OF COTTON AND FRUIT BORERS OF OKRA
AND DETERMINATION OF INSECTICIDE RESISTANCE**

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COIMBATORE-641 003**

2013

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Thesis submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENTOMOLOGY
to the Tamil Nadu Agricultural University, Coimbatore-641 003.

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CERTIFICATE

This is to certify that the thesis entitled **“EVALUATION OF EMAMECTIN BENZOATE 5 SG AGAINST BOLLWORMS OF COTTON AND FRUIT BORERS OF OKRA AND DETERMINATION OF INSECTICIDE RESISTANCE”** submitted in partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENTOMOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a record of *bona fide* research work carried out by **Mr. P. KARTHIK**, under my supervision and guidance and that no part of this thesis has been submitted for the award of any 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.

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(P.KARTHIK)

Abstract

ABSTRACT

EVALUATION OF EMAMECTIN BENZOATE 5 SG AGAINST BOLLWORMS OF COTTON AND FRUIT BORERS OF OKRA AND DETERMINATION OF INSECTICIDE RESISTANCE

BY

P.KARTHIK

Degree : **DOCTOR OF PHILOSOPHY (AGRICULTURE)
IN AGRICULTURAL ENTOMOLOGY**

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Studies were conducted to evaluate emamectin benzoate 5 SG as foliar application for its bioefficacy against bollworms of cotton and fruit borers of okra, phytotoxicity, persistence, toxicity to natural enemies, physical and biological compatibility and residues and effect on resistance development and arthropod diversity in cotton.

Field experiments on cotton and okra revealed that emamectin benzoate 5 SG (EB) @ 11 and 8.5 g a.i. ha⁻¹ in cotton and okra respectively, was highly effective in checking the larval population of *Helicoverpa armigera* (Hubner) and *Earias vittella* Fabricius and were as effective as the higher test doses of 15 and 11 g a.i.ha⁻¹ in cotton and 8.5 and 11 g a.i.ha⁻¹okra, respectively. All emamectin benzoate treatments resulted in increased seed cotton and okra fruit yield under field conditions. The doses viz., emamectin benzoate @ 7, 9 and 11 g a.i. ha⁻¹ in cotton and emamectin benzoate @ 4.7, 6.7 and 8.5 g a.i.ha⁻¹ in okra were safer to predaceous spiders and coccinellids.

The foliar applications of emamectin benzoate at 11 (x), 22 (2x) and 44 (4x) g a.i. ha⁻¹ in cotton and 8.5, 17 and 34 in okra did not cause any phytotoxic effects like injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty. Emamectin benzoate at 11 and 8.5 g a.i. ha⁻¹ in cotton and okra was physically compatible with lambda cyhalothrin, buprofezin, carbendazim and mancozeb. When emamectin benzoate was sprayed as tank mix to cotton plants, in combination with lambda cyhalothrin, buprofezin, carbendazim and mancozeb, it did not exhibit any phytotoxic symptoms on cotton and was also effective in controlling bollworm, *H. armigera* and their damage to bolls as well as reducing fruit borers and their damage on okra plants.

The results of persistent toxicity tests with emamectin benzoate 5 SG (11 and 15 g a.i. ha⁻¹) recorded complete mortality of third instar larvae of *H. armigera* up to 5 and 7 days after treatment. Toxicity persisted for 17 days in emamectin benzoate @ 15 g a.i. ha⁻¹ in cotton, while it was 15 and 17 days for emamectin benzoate @ 8.5 and 11 g a.i. ha⁻¹ in okra.

Emamectin benzoate did not cause any adverse effects on the adult emergence and parasitization by *Trichogramma chilonis* Ishii. The highest dose of emamectin benzoate (15 g a.i. ha⁻¹) recorded 72.30 and 85.00 per cent parasitization and adult emergence, respectively. Emamectin benzoate at 15 g a.i. ha⁻¹ caused 36.33 per cent mortality to *Chelonus blackburni* Cameron at 6 hour after treatment. In all the emamectin benzoate treatments, hatchability of *Chrysoperla carnea* Stephens eggs ranged between 80.00 and 96.67 per cent, as compared to spinosad (76.67%). In the dry film method of *C. carnea*, emamectin benzoate @ 7 g a.i. ha⁻¹ recorded very high per cent pupation of 96.29 per cent and higher dose of emamectin benzoate (15 g a.i. ha⁻¹) recorded pupation of 82.35 per cent, respectively.

Emamectin benzoate tests doses were relatively safer to Indian bees, *Apis cerana indica* F, little bees, *Apis florea* F. and Italian bees, *Apis mellifera* Linn. than spinosad. There was no clear difference between mortality of three difference species of honey bee. The LC₅₀ value of emamectin benzoate to earthworm, *Eudrilus eugeniae* (Kinberg) was 17.22 ppm in soil and 16.47 ppm in cowdung at 2 day after treatment.

The harvest time residues of emamectin benzoate applied @ 11 and 22 g a.i. ha⁻¹ left residues at below detectable levels (BDL) in cotton lint, seed, oil and soil. The initial deposit of emamectin benzoate 5 SG @ 8.5 and 17.00 g a.i ha⁻¹ was 0.1521 and 0.2626 µg g⁻¹, respectively, which dissipated to below detectable level 5th day after spraying in okra. Since, the emamectin benzoate residues were found at below detectable levels on 5th day after application, five days could be suggested as waiting period for okra.

The susceptibility index to emamectin benzoate based on LD₅₀ and LD₉₅ was 2.37 and 3.03, respectively. Rate of resistance decline (R) when selection pressure was stopped at -0.0417. With regard to number of generations required for 10- fold decrease in LD₅₀, it was calculated as 27. Considering the F₉ *P. gossypiella* populations as the most susceptible, the tentative discriminating dose was fixed as 1.1µg⁻¹ for emamectin benzoate.

Assessing the level of insecticide resistance as one time survey in summer cotton revealed the per cent resistance of *H. armigera* in five districts ranged from 3.33 to 10.00. The highest resistance (10 per cent) was recorded in Coimbatore district. The survivability of fruit and shoot borer of okra varied from 6.66 to 15.00 per cent for emamectin benzoate. Erode population was found to be highly susceptible which was evident from 0.00 per cent survival during monitoring. The per cent survival of pink bollworm varied from 3.33 to 6.66 per cent for emamectin benzoate at 1.1µg larva⁻¹.

A total of 4232 individuals belonging to 51 families and 14 orders from both sprayed and unsprayed cotton field were recorded. Among the cotton fields, unsprayed cotton showed the maximum species richness, abundance and distribution at ordinal, familial, generic and species level followed by sprayed cotton field. In present study totally three families of orthoptera were collected from both sprayed and unsprayed cotton fields. More individuals were collected in the non-sprayed area than the sprayed area.

In the order Hemiptera totally nine families were collected. The abundance of *Oxycarenus hyalinipennis* (Costa), *Dysdercus cingulatus* (Fabricius) and *Geocoris* sp. was higher in unsprayed field than in sprayed cotton field. The family Lygaeidae was more abundant in the sprayed area during the first month of sampling, and more numbers were recorded in the non-sprayed area than in sprayed area in the succeeding sampling periods.

The species richness indices based on Species number, Fishers Alpha index, Margalef's D index, Q Statistic, Brillouin diversity index and Shannon - Weiner index and different dominance indices viz., Simpson's index, McIntosh index and Berger Parker index, were higher in unsprayed cotton field. The maximum diversity of insects and spiders occurred in the month of July.

CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	5
III	MATERIALS AND METHODS	38
IV	EXPERIMENTAL RESULTS	84
V	DISCUSSION	184
VI	SUMMARY	237
	REFERENCES	

LIST OF TABLES

Table No.	Title	Page No.
1.	Bioefficacy of abamectin against crop pests	8
2.	Discriminating dose screen of various insecticides of <i>Plutella xylostella</i> (L.)	29
3.	Discriminating dose screen of various insecticides for <i>Spodoptera litura</i> Fabricius	29
4.	Pests recorded for their resistance to new molecules	30
5.	Effect of emamectin benzoate 5 SG on bollworms in cotton– (Location- Madampatti) I season	85
6.	Effect of emamectin benzoate 5 SG against bollworms damage on cotton – (Location- Madampatti) I season	87
7.	Effect of emamectin benzoate 5G against bollworms in cotton (Location- Narasimanayakkan palayam) II season	89
8.	Effect of emamectin benzoate 5 SG against bollworms damage in cotton – (Location- Narasimanayakkan palayam) II season	91
9.	Effect of emamectin benzoate 5 SG on spiders in cotton eco system (Location - Madampatti) I season	92
10.	Effect of emamectin benzoate 5 SG on coccinellids in cotton eco system (Location - Madampatti) I season	94
11.	Effect of emamectin benzoate 5 SG on spiders in cotton eco system (Location - Narasimanayakkan palayam) II season	95
12.	Effect of emamectin benzoate 5 SG on coccinellids in cotton eco system (Location - Narasimanayakkan palayam) II season	97
13.	Effect of emamectin benzoate 5 SG on yield of cotton (Location- Madhampatti) I season	98
14.	Effect of emamectin benzoate 5 SG on the yield of cotton (Location- Narasimanyakkan palayam) II season	100
15.	Effect of emamectin benzoate 5 SG on larval population of <i>Earias vittella</i> Fabricius in okra (Location- Madhampatti) I season	101
16.	Effect of emamectin benzoate 5 SG on larval population of <i>Helicoverpa armigera</i> Hubner in okra (Location - Madhampatti) I season	103

Table No.	Title	Page No.
17.	Effect of emamectin benzoate 5 SG against fruit borers damage in okra (Location - Madhampatti) I season	104
18.	Effect of emamectin benzoate 5 SG on larval population of <i>E.vittella</i> in okra (Location- Narasimanayakkan palayam) II season	106
19.	Effect of emamectin benzoate 5 SG on larval population of <i>Helicoverpa armigera</i> in okra (Location - Narasimanayakkan palayam) II season	108
20.	Effect of emamectin benzoate 5 SG against fruit borers damage in okra (Location - Narasimanayakkan palayam) II season	109
21.	Effect of emamectin benzoate 5 SG on spiders in okra eco system (Location - Madhampatti) I season	111
22.	Effect of emamectin benzoate 5 SG on coccinellids in okra eco system (Location- Madhampatti) I season	113
23.	Effect of emamectin benzoate 5 SG on spiders in okra eco system (Location - Narasimanayakkan palayam) II season	114
24.	Effect of emamectin benzoate 5 SG on coccinellids in okra eco system (Location - Narasimanayakkan palayam) II season	116
25.	Effect of emamectin benzoate 5 SG on the yield of okra (Location- Madhampatti) I season	117
26.	Effect of emamectin benzoate 5 SG on the yield of okra (Location- Narasimanyakkan palayam) II season	119
27.	Phytotoxic effect of emamectin benzoate 5 SG on cotton I and II season	120
28.	Phytotoxic effect of emamectin benzoate 5 SG on okra I and II season	120
29.	Physical compatibility of emamectin benzoate 5 SG with agrochemicals	121
30.	Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on cotton and okra (Laboratory and field experiment)	123
31.	Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on larval population of <i>H. armigera</i> in cotton (Location - TNAU)	124
32.	Biological compatibility of emamectin benzoate 5 SG with other agrochemicals against bollworms damage on cotton (Location- TNAU)	125

Table No.	Title	Page No.
33.	Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on larval population of <i>H. armigera</i> in okra (Location-TNAU)	127
34.	Biological compatibility of emamectin benzoate 5 SG on the damage caused by fruit borers in okra (Location- TNAU)	129
35.	Persistent toxicity of emamectin benzoate 5 SG to <i>H. armigera</i> in cotton	131
36.	Persistent toxicity of emamectin benzoate 5 SG to <i>E. vittella</i> in okra	132
37.	Effect of emamectin benzoate 5 SG on <i>Trichogramma chilonis</i> Ishii	133
38.	Effect of emamectin benzoate 5 SG against egg larval parasitoid, <i>Chelonus blackburnii</i> Cameron	135
39.	Effect of emamectin benzoate 5 SG against larval parasitoid, <i>Bracon hebator</i> Say	136
40.	Effect of emamectin benzoate 5 SG on the eggs of <i>Chrysoperla carnea</i> Stephens	138
41.	Effect of emamectin benzoate 5 SG on the grubs of <i>C. carnea</i>	139
42.	Effect of emamectin benzoate 5 SG on three species of honey bees	141
43.	Acute toxicity of emamectin benzoate 5 SG to earthworm, <i>Eudrilus eugeniae</i> (Kinberg) in soil	142
44.	Acute toxicity of emamectin benzoate 5 SG to earthworm, <i>E. eugeniae</i> in cow dung	142
45.	Recovery of emamectin benzoate	144
46.	Dissipation of emamectin benzoate 5 SG on okra fruit	145
47.	Correlation coefficient for emamectin benzoate 5 SG residues okra fruit by different methods of transformation of residue data	146
48.(a)	Dissipation pattern for emamectin benzoate 5 SG (x) on okra fruit with statistical parameters	147
48.(b)	Dissipation pattern for emamectin benzoate 5 SG (2x) on okra fruit with statistical parameters	148
49.	Harvest time residues of emamectin benzoate 5 SG in okra soil	149
50.	Harvest time residues of emamectin benzoate 5 SG in cotton	150
51.	Harvest time residues of emamectin benzoate 5 SG in cotton soil	150

Table No.	Title	Page No.
52.	Acute toxicity of emamectin benzoate to <i>Pectinophora gossypiella</i> (Saund.) by topical application	152
53.	Susceptibility index and rate of resistance decline of emamectin benzoate 5 SG against <i>P. gossypiella</i>	153
54.	Mean resistance of <i>H. armigera</i> against emamectin benzoate 5 SG in five districts of Tamil Nadu.	155
55.	Mean resistance of <i>E. vitella</i> against emamectin benzoate 5 SG in five districts of Tamil Nadu.	155
56.	Mean resistance of <i>P. gossypiella</i> against emamectin benzoate 5 SG in five districts of Tamil Nadu	155
57.	Diversity of arthropods in sprayed and unsprayed cotton field	156
58.	Arthropod diversity in cotton ecosystem – Alpha diversity (Species number)	171
59.	Arthropod diversity in cotton ecosystem – Alpha diversity (Fishers alpha)	173
60.	Arthropod diversity in cotton ecosystem – Alpha diversity (Margalef's D)	174
61.	Arthropod diversity in cotton ecosystem – Alpha diversity (Q Statistic)	175
62.	Arthropod diversity in cotton ecosystem – Alpha diversity (Brillouin diversity index)	176
63.	Arthropod diversity in cotton ecosystem – Alpha diversity (Shannon-Weiner index)	177
64.	Arthropod diversity in cotton ecosystem – Alpha diversity (Simpson's index)	179
65.	Arthropod diversity in cotton ecosystem – Alpha diversity (McIntosh index)	180
66.	Arthropod diversity in cotton ecosystem – Alpha diversity (Berger parker diversity index)	182
67.	Arthropod diversity in cotton ecosystem – Alpha diversity (Equitability J)	183

LIST OF FIGURES

Fig. No	Title	Page No.
1.	Structure of avermectins	6
2.	Structure of emamectin benzoate	39
3.	Standard chromatogram of emamectin benzoate	72
4.	Effect of emamectin benzoate 5 SG against bollworms damage in cotton - I season	185
5.	Effect of emamectin benzoate 5 SG against bollworms damage in cotton - II season	185
6.	Effect of emamectin benzoate 5 SG on spiders of cotton eco system - I season	189
7	Effect of emamectin benzoate 5 SG on spiders of cotton eco system - II season	189
8.	Effect of emamectin benzoate 5 SG on coccinellids of cotton eco system - I season	191
9.	Effect of emamectin benzoate 5 SG on coccinellids of cotton eco system - II season	191
10.	Effect of emamectin benzoate 5 SG on seed cotton yield	192
11.	Effect of emamectin benzoate 5 SG against fruit borers damage in okra - I season	195
12.	Effect of emamectin benzoate 5 SG on fruit borer damage in okra - II season	195
13.	Effect of emamectin benzoate 5 SG on spiders of okra eco system - I season	197
14.	Effect of emamectin benzoate 5 SG on coccinellids of okra eco system- I season	197
15.	Effect of emamectin benzoate 5 SG on spiders of okra eco system - II season	199

Fig. No	Title	Page No.
16.	Effect of emamectin benzoate 5 SG on coccinellids of okra eco system - II season	199
17.	Effect of emamectin benzoate 5 SG on okra fruit yield	200
18	Selective toxicity of emamectin benzoate 5 SG on <i>Trichogramma chilonis</i> Ishii	207
19.	Selective toxicity of emamectin benzoate 5 SG on <i>Chelonus blackburnii</i> Cameron	207
20.	Selective toxicity of emamectin benzoate 5 SG against egg larval parasitoid, <i>Bracon brevicornis</i> Say	210
21.	Selective toxicity of emamectin benzoate 5 SG on the eggs and adults of <i>Chrysoperla carnea</i> Stephens	210
22.	Selective toxicity of emamectin benzoate 5 SG on the grubs of <i>C. carnea</i>	212
23.	Selective toxicity of emamectin benzoate 5 SG on three species of honey bees	212
24.	Log concentration probit mortality curve for emamectin benzoate to <i>Eudrilus eugeniae</i> (Kinberg) at 2 DAT in soil	214
25.	Log concentration probit mortality curve for emamectin benzoate to <i>E. eugeniae</i> at 2 DAT in cow dung	214
26.	Dissipation of emamectin benzoate 5 SG on okra fruit	216
27.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₁ generation	218
28.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₂ generation	218
29.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₃ generation	218
30.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₄ generation	219
31.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₅ generation	219
32.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₆ generation	219
33.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₇ generation	220

Fig. No	Title	Page No.
34.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₈ generation	220
35.	Log concentration probit mortality line for <i>P.gossypiella</i> F ₉ generation	220
36.	Arthropod diversity based on species number in cotton ecosystem	227
37.	Arthropod diversity based on Fishers alpha index in cotton ecosystem	228
38.	Arthropod diversity based on Margalef's D index in cotton ecosystem	229
39.	Arthropod diversity based on Q statistic in cotton ecosystem	230
40.	Arthropod diversity based on Brillouin diversity index in cotton ecosystem	231
41.	Arthropod diversity based on Shannon- Weiner index in cotton ecosystem	232
42.	Arthropod diversity based on Simpson's index in cotton ecosystem	233
43.	Arthropod diversity based on McIntosh index in cotton ecosystem	234
44.	Arthropod diversity based on Berger Parker diversity in cotton ecosystem	235
45.	Arthropod diversity based on Equitability J in cotton ecosystem	236

LIST OF PLATES

Plate No	Title	Page No
1.	Bioefficacy of emamectin benzoate 5 SG against cotton bollworms - Field view	41
2.	Bioefficacy of emamectin benzoate 5 SG against okra fruit borers - Field view	41
3.	Biological compatibility of emamectin benzoate 5 SG with agrochemicals on cotton	46
4.	Biological compatibility of emamectin benzoate 5 SG with agrochemicals on okra	46
5.	Culturing of <i>Pectinophora gossypiella</i> Saund	50
6.	Culturing of <i>Helicoverpa armigera</i> Hubner	51
7.	Culturing of <i>Earias vittella</i> Fabricius	54
8.	Safety of emamectin benzoate 5 SG to <i>Trichogramma chilonis</i> Ishii	56
9.	Safety of emamectin benzoate 5 SG to <i>Chrysoperla carnea</i> Stephens	60
10.	Safety of emamectin benzoate 5 SG to honey bees	62
11.	Acute toxicity of emamectin benzoate 5 SG to earthworms	64
12.	Topical application on <i>E.vitella</i> and <i>P.gossypiella</i> larvae	66
13.	Sampling techniques	77
14a.	Arthropods observed in cotton ecosystem (Order : Araneae)	160
14b.	Arthropods observed in cotton ecosystem (Order : Araneae)	161
14c.	Arthropods observed in cotton ecosystem (Order : Araneae)	162
15.	Arthropods observed in cotton ecosystem (Order: Odonata, Dermaptera and Dictyoptera)	163
16.	Arthropods observed in cotton ecosystem (Order: Orthoptera and Hemiptera)	164
17.	Arthropods observed in cotton ecosystem (Order : Hemiptera)	165

Plate No	Title	Page No
17a.	Arthropods observed in cotton ecosystem (Order : Hemiptera)	166
18.	Arthropods observed in cotton ecosystem (Order: Lepidoptera)	167
19.	Arthropods observed in cotton ecosystem (Order: Diptera and Neuroptera)	168
20.	Arthropods observed in cotton ecosystem (Order: Hymenoptera)	169
21.	Arthropods observed in cotton ecosystem (Order : Coleoptera)	170

Introduction

CHAPTER I

INTRODUCTION

Cotton (*Gossypium spp.*), is an important agricultural commodity, traded all over the world. In general, the conditions required for the cultivation of cotton are met within the seasonally dry tropics and subtropics in the Northern and Southern hemispheres. India has progressed substantially in improving both production and productivity of cotton over the last five years, transforming from a net importer of cotton, to becoming one of the largest exporters, shipping 5.5 million bales in 2010-11, second only to the USA. About 70 per cent of the global cotton production comes from four countries, which include China (27%), India (22%), USA (13%) and Pakistan (8%). Cotton cultivation is a very important part of the Indian agrarian landscape and provides sustainable livelihood to a sizeable population in India. It is cultivated in about 10.31 million hectares in the country, which accounts for 30 per cent of the global cotton area and contributes to 22 per cent of the global cotton production. It is estimated that more than 5.8 million farmers cultivate cotton in India and about 40-50 million people are employed directly or indirectly by the cotton industry. Cotton is cultivated in about 1.21 lakh hectares in Tamil Nadu (Anonymous, 2012).

The yield loss reported in cotton due to insect pests was 87 per cent (Taley *et al.*, 1988). Nearly 1,326 insects and mites all over the world (Hargreaves, 1948) and about 200 in India (Anonymous, 1991) have been documented of which 10 are economically important in Tamil Nadu (Venugopal, 1998). Bollworm complex consisting of three bollworms viz., American bollworm, *Helicoverpa armigera* (Hubner), spotted bollworms, *Earias spp.* and pink bollworms, *Pectinophora gossypiella* (Saund.) inflict heavy damage.

Bhendi or Ladies finger, which is also known as 'Okra', is one of the important vegetables in India. It is grown throughout the tropical and sub-tropical regions and also in the warmer parts of the temperate regions. The nutritional value of 100 g of edible okra is characterized by 1.9 g protein, 0.2 g fat, 6.4 g carbohydrate, 0.7 g minerals and 1.2 g fibre. Okra has a good potential as a foreign exchange crop and accounts for 60 per cent of the

export of fresh vegetables. It is cultivated in 452 ha area with the production of 4803 mt and productivity of 10 mt ha⁻¹ in India. The major okra producing states are Uttar Pradesh, Bihar, Orissa, West Bengal, Andhra Pradesh and Karnataka (Anonymous, 2012).

Besides various reasons for low productivity, heavy damage is inflicted by *Earias vittella* Fabricius, *Earias insulana* Fabricius and *H. armigera* which reduce vitality of the plant resulting in 54.04 per cent net yield loss (Sivakumar *et al.*, 2003).

Chemical insecticides are used as the frontline defence sources against these insect pests, in spite of their drawbacks, the cotton growers in India depend heavily on synthetic pesticides to combat pests and it has been estimated that cotton consumed about 54 per cent of the total insecticides used in the country (Anonymous, 1997). Indiscriminate use of organophosphates, carbamates and synthetic pyrethroids has created a number of problems such as pests developing resistance to insecticides (McCaffery *et al.*, 1989), pest resurgence (Hardin *et al.*, 1995) and bioconcentrations of pesticide residues in consumable produce at harvest (Rolando *et al.*, 1982). Among the harmful effects of insecticides, persistence of toxic pesticide residues in plants, soil and water are of great concern for consumer's health and safety to animals. It is estimated that more than 50 per cent of applied insecticides reach the soil and water bodies during application (Awasthi *et al.*, 2002).

The conservation of biological diversity seeks to maintain the life support system provided by nature in all its variety and the living resources are essential for ecologically sustainable development (Anonymous, 1992). Conservation of biodiversity, essential for maximizing the span of existence of the human species, meeting the needs of future generations and contributing to the stability and robustness of many economic and ecological systems (Tisdell, 1997). It could only take place when our knowledge of the organisms around us is enhanced (Hawksworth, 1991; Pearson and Carroll, 1998).

As chemical pesticides continue to be the mainstay of most of the pest control programmes. At the same time, to overcome the above problems, identification of new molecules are needed to combat the associated drawbacks. At present, the golden age of insecticide research has come with selective, neuro active and easily degradable compounds. These newer molecules always have a higher stability and superiority over

conventional pesticides to control the pest population in a classical manner at field level. In this array, newer groups with higher insecticidal property, selective action and lower mammalian toxicity fits well in the integrated pest management (IPM) concept. In IPM programmes, insecticides having selectivity, favouring non-target organisms like parasitoids and predators are highly preferred. Formulations that are safe to the applicant and more environment friendly are encouraged. One such new molecule, emamectin benzoate is a semi synthetic derivative of avermectin produced as fermentation metabolites of soil actinomycetes *Streptomyces avermitilis* Burg (Lasota and Dybas, 1991). This was discovered in 1984 and has both stomach and contact action being effective against lepidopteran pests.

Insects develop resistance in proportion to the intensity of selection pressure and the pests' genetic resources. In agricultural systems, selection pressure is often very intense because of the need or perceived need and lack of alternatives to insecticides for control and hence evaluation and introduction of newer formulations at low application rate to sustain the susceptibility is the need of the day for successful and timely management of insect and pests. The baseline data to monitor resistance is also crucial for preserving susceptibility. Insecticide susceptibility is recognized as a depletable natural resource that is extremely expensive once lost. There is also a need to assess the temporal effectiveness and environmental safety of these insecticides to the arthropod community associated with the canopy of these crops. Though avermectins are applied at a lower rate, even a small amount of insecticide residue is not acceptable.

With the above background, investigations were carried out on emamectin benzoate 5 SG a new formulation developed by Krishi Rasayan Export Limited, New Delhi with the following objectives.

- To assess the bioefficacy, phytotoxicity, safety and residues of emamectin benzoate 5 SG in cotton against bollworms complex.
- To assess the bioefficacy, phytotoxicity, safety and residues of emamectin benzoate 5 SG in okra against fruit borers complex.
- To study the compatibility of emamectin benzoate 5 SG with commonly used agrochemicals on cotton and okra.

- To determine baseline toxicity of emamectin benzoate to *P. gossypiella* and fixing discriminating dose.
- To monitor the insecticide resistance in American bollworm *H. armigera*, spotted bollworms *Earias spp* and pink bollworm *P.gossypiella* to emamectin benzoate.
- To assess the arthropod biodiversity in cotton ecosystem.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

The information available on bioefficacy of emamectin benzoate against bollworms of cotton and fruit borers of okra, its phytotoxic effects, persistence, compatibility with chemical pesticides and biocontrol agents, safety to natural enemies, residues, resistance and effect on biodiversity is reviewed hereunder.

2.1. Avermectins

2.1.1. Discovery

Avermectins belong to the family of 16-membered macrocyclic lactone compounds produced by the soil microorganism, *Streptomyces avermitilis* (Burg.) MA-4680 (NRRL 8165), which was isolated in culture at the Kitasato Institute from a soil sample taken from Kawana Ito City, Shizuoka Prefecture, Japan. The major component of the fermentation is avermectin B1, a mixture of B1a (80%) and B1b (20%) (Dybas and Green, 1984). Avermectins show a high biocidal activity against a wide spectrum of nematodes, insects and arachnids. The isolation, characterisation and structural elucidation of the avermectins have been described by Fisher and Mrozik (1984) and Burg and Stapley (1989). These macrolides were synthetically produced and altered to increase insecticidal activity and specificity (Wei *et al.*, 2005).

Chemical modifications on its original structure with the aim of increasing its insecticidal spectrum resulted in the discovery of emamectin benzoate, one of the many 4'-substituted analogues that shows an increased potency against lepidopteran larvae (Mrozik, 1994), with good photostability and translaminar movement, good field efficacy and lack of cross resistance with other commercially used pesticides (White *et al.*, 1997).

2.1.2. Structure and chemistry

The avermectins primarily consist of four major (A1a, A2a, B1a and B2a) components and four homologous minor (A1b, A2b, B1b and B2b) components. The “A” series has a methoxy group at the C₅ position of cyclohexane moiety, while the “B” series has a hydroxyl group. In the “2” series, the double bond is hydrated, having a hydroxyl group at C₂₃, while in “1” series a double bond exists between C₂₂ and C₂₃. The “A” series has a

secondary butyl group at C₂₅, while the “B” series has an isopropyl group. The disaccharide substituent at C₁₃ contains two identical α - L - oleandrose units. The “B” series has more biological activity than “A” series (Albers *et al.*, 1981). Abamectin is a mixture of B1a ($\geq 80\%$) and B1b ($\leq 20\%$), utilized for the control of agricultural and household arthropod pests.

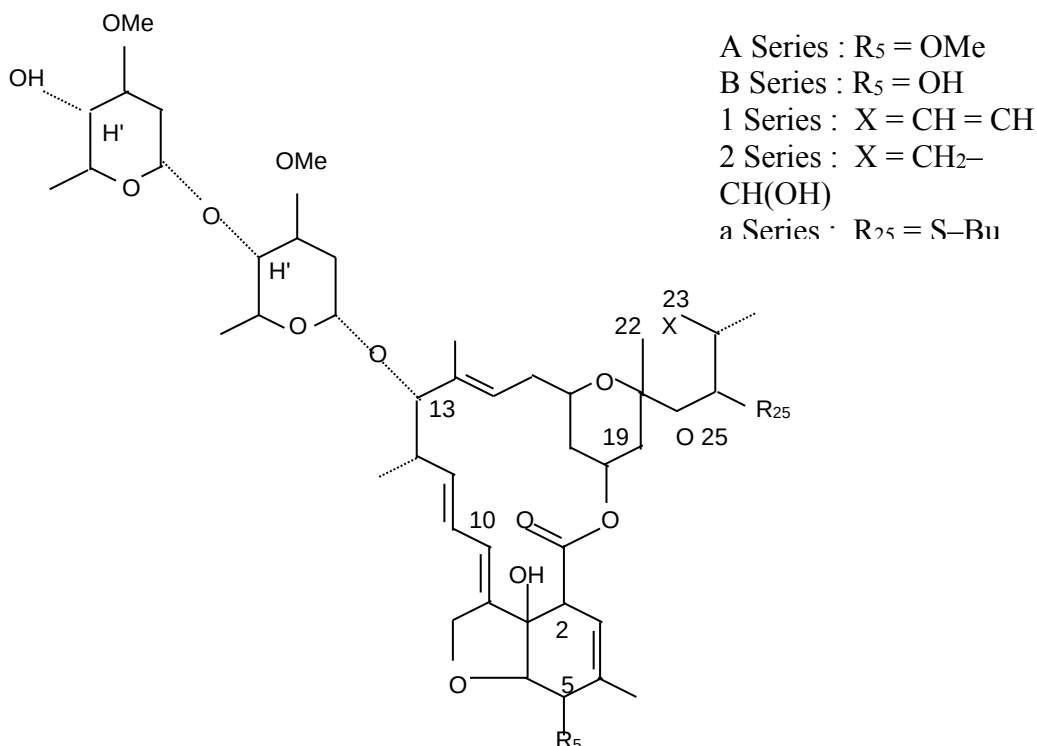


Fig 1. Structure of avermectins (Lasota and Dyas, 1991)

2.1.3. Mechanism of action

Wright (1985) and Turner and Schaeffer (1989) indicated that avermectins are likely to act on GABAergic (gamma - aminobutyric acid) neurons. Fritz *et al.* (1979) reported that avermectins increase the muscle permeability to chloride ions, thereby reducing excitatory potentials and input resistance and reduction in membrane permeability. It mimics the action of picrotoxin (chloride ion channel blocker) and bicuculline (GABA receptor antagonist).

Avermectins act as agonists on GABA and glutamate-gated chloride channels (Mellin *et al.*, 1983; Albrecht and Sherman, 1987). The chloride ion flux produced by the direct opening of channels in to neuronal cells results in loss of cell function and disruption of nerve impulses (White *et al.*, 1997). The avermectins exert their neurotoxic

effects by activating insect and nematode glutamate-gated chloride channels. In contrast with activation of these chloride channels by glutamate, which causes rapid activation and inactivation, avermectin-activated channels open slowly, but essentially irreversibly (Wolstenholme and Rogers, 2005).

Sami and Vaid (1988) proposed that the affinity of avermectins for retinol binding proteins would also have a possible mechanism of action of avermectins. Abamectin is ecologically a selective compound with short residual, low - contact activity rather than physiological selectivity. It is toxic to 84 species of insects (10 orders) most of which are of economic importance and also a promising and effective acaricide (Strong and Brown, 1987). Emamectin benzoate is a synthetic analogue of abamectin and the mode of action is similar to abamectin (a GABA and glutamate-gated chloride channel agonist) (Dunbar *et al.*, 1998).

2.2.2. Bioefficacy of emamectin benzoate on cotton and okra

Emamectin benzoate was toxic to the extent of 1720, 884 and 268 times to *Spodoptera eridania* (Cramer) and 3,300, 1,666 and 500 times to *H. virescens*, on parts per million (ppm) basis than the commercial standards methomyl, thiodicarb and fenvalerate, respectively (Dybas, 1989). Emamectin benzoate was very effective in reducing the tobacco budworm and cotton bollworm, (*Heliothis zea* Boddie) when sprayed at 8.5 to 17 g a.i.ha⁻¹ (Dunbar *et al.*, 1998). Ishaaya *et al.* (2002) reported that rows of cotton plants when sprayed until runoff with emamectin @ 25 g a.i ha⁻¹ resulted in a high potency on first instar *H. armigera* with over 90 per cent mortality, effective up to 28 days after application. Emamectin benzoate @ 8.0 and 9.5 g a.i. ha⁻¹ was effective in reducing the population of *H. armigera* (Monoosar *et al.*, 2001). These results indicate that emamectin has special efficiency against *Heliothis* spp.

The bollworm damage was the least in plots treated with emamectin benzoate @ 11 g a.i. ha⁻¹ (4.19%), which resulted in more number of good opened bolls along with the highest seed cotton yield (15.93 q ha⁻¹) (Udikeri *et al.*, 2004). Emamectin benzoate 1.9 EC @ 200 ml acre⁻¹ recorded the highest per cent mortality of *E. vittella* at 3 days after the treatment (Aslam *et al.*, 2004). Emamectin benzoate @ 8.50 and 11 g a.i. ha⁻¹ recorded lower fruit damage and boll damage against okra fruit borers and cotton bollworms, respectively (Bheemanna *et al.*, 2005).

2.2. Bioefficacy of avermectins against crop pests

2.2.1. Bioefficacy of abamectin

The reports on the effectiveness of avermectins against crop pests are tabulated in Table 1.

Table 1. Bioefficacy of abamectin against crop pests

S. No.	Crop	Pest	Formulations	Dose	Reference
1.	Cotton	Bollworm, <i>Helicoverpa armigera</i> (Hubner)	Abamectin 18 EC	28.3 g a.i. ha ⁻¹	Wright <i>et al.</i> (1985); Johnson (1985)
		Broad mite <i>Polyphagotarsonemus latus</i> Banks	Abamectin 18 EC	5-11.4 g a.i. ha ⁻¹	Donatoni <i>et al.</i> (1988)
		Tarsonemid, <i>P. latus</i>	Abamectin 18 EC	9 g a.i. ha ⁻¹	Bellettini <i>et al.</i> (1999)
		Whitefly, <i>Bemisia tabaci</i> (Gennadius)	Abamectin 18 EC	1 mg a.i. l ⁻¹	Horowitz and Ishaaya (2004)
		Two spotted spider mite <i>Tetranychus urticae</i> Koch	Abamectin 18 EC	7.2 g a.i. ha ⁻¹	Swart <i>et al.</i> (1990)
2.	Okra	Bollworm, <i>H. armigera</i>	Abamectin 18 EC	0.5 ml l ⁻¹	Nian <i>et al.</i> (1997)
		Boll worms	Abamectin 1.9 EC (Abasin®)	14.5 g a.i. ha ⁻¹	Sheeba Jasmine (2005)
		Bollworm complex	Abamectin 1.8% EC	22.5 g ai. ha ⁻¹	Ajanta <i>et al.</i> (2008)
		Fruit borers	Vertimec®	0.5 ml l ⁻¹	Ghosh <i>et al.</i> (1999)
		Diamond back moth, <i>Plutella xylostella</i> (L.)	Vertimec 1.8 EC	15 g a.i ha ⁻¹	Murugan and Ramachandarn (2004)
3.	Cabbage	Diamond back moth, <i>P. xylostella</i>	Abamectin 1.9 EC (Abasin®)	11 g a.i. ha ⁻¹	Sheeba Jasmine (2005)

S. No.	Crop	Pest	Formulations	Dose	Reference
4.	Tomato	Rust mite <i>Acalops lycopersici</i> Masse <i>H. armigera</i> Pin worm <i>Scrobipalpuloidea absoluta</i> (Meyrick) Serpentine leaf miner <i>Liriomyza trifolii</i> (Burgess)	Abamectin 1.8 EC Abamectin 1.8 EC Abamectin 1.8 EC Abamectin 1.8 EC (Vertimec®) Abamectin 1.8 EC	600 ml ha ⁻¹ 2.5 g a.i. ha ⁻¹ 1 ml l ⁻¹ 20 g a.i. ha ⁻¹ 5.0, 7.0 and 10.0 g a.i. ha ⁻¹	Haji <i>et al.</i> (1988) Xu <i>et al.</i> (2002) Branco <i>et al.</i> (1996) Logiswaran and Bhuvaneswari (2000) Walunj <i>et al.</i> (2002)
5.	Citrus	Rust mite, <i>Phyllocoptruta oleivora</i> Ashmead Citrus mite <i>Eutetranychus orientalis</i> (Gei.) Leaf miner <i>Liriomyza</i> sp. <i>Phyllocnistis citrella</i> (Stainton) <i>P. citrella</i>	Abamectin 1.8 EC Abamectin 1.15 EC Abamectin 18 EC Abamectin 18 EC Abamectin 18 EC	0.0125 kg a.i. ha ⁻¹ 30 ml plant ⁻¹ 50.75 and 100 ml l ⁻¹ 24.5 % 1.8 %	French and Villarreal (1990) Velosa <i>et al.</i> (1988) Lima <i>et al.</i> (1994) Hai and Neng (2000) Salas <i>et al.</i> (1997)
6.	Orange	<i>Tegolophus australis</i> Keifer	Abamectin 18 EC	0.0018, 0.0027 and 0.0045 g a.i. ha ⁻¹	Smith <i>et al.</i> (1998)
7.	Pear	Red spider mite <i>Panonychus ulmi</i> Koch	Abamectin 18 EC	13.5 - 27 g a.i. ha ⁻¹	Gillham <i>et al.</i> (1997)
8	Lettuce	Leaf miner <i>Liriomyza</i> sp.	Abamectin 1.8 EC	0.20 l ha ⁻¹	Rodrigo (1995)
9	-	Termite <i>Cornitermes cumulans</i> Kollar	Abamectin 1.8 EC	3.6 mg a.i. / mound ⁻¹	Valerio <i>et al.</i> (1998)
10	-	<i>H. armigera</i>	Novastar® 56 EC (abamectin + bifenthrin)	500 ml ac ⁻¹	Ahmed <i>et al.</i> (2003)
11	Rose	Two spotted spider mite	Abamectin 1.9 EC (Abasin®)	12 g a.i. ha ⁻¹	Sheeba Jasmine (2005)

Emamectin benzoate at 11 g a.i.ha⁻¹ recorded higher yield of 2474.7 kg ha⁻¹ cotton due to lower incidence of bollworms (Gupta *et al.*, 2005). Razaq *et al.* (2005) reported highest larval mortality in plots treated with emamectin benzoate (73.5%) and indoxacarb (71.2%) after five days of application. Application of emamectin benzoate @ 9.5 g a.i. ha⁻¹ recorded the lowest locule and boll damage and it was on par with 11 g a.i. ha⁻¹ which ultimately increased the yield of cotton (Duraimurugan *et al.*, 2007). Srinivasan *et al.* (2007) reported that emamectin benzoate 1.9 EC @ 20 g a.i ha⁻¹ effectively reduced the damage due to bollworm complex in cotton and increased the kapas yield.

Sontakke *et al.* (2007a) observed that emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ was effective in controlling the shoot and fruit borer in okra and also found that emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ and spinosad 45 SC @ 75 g a.i ha⁻¹ were equally effective against bollworm, *H. armigera* in cotton (Sontakke *et al.*, 2007b). Aiswariya (2010) reported that emamectin benzoate 5 WSG (EB) at 9, 11, 13 and 15 g a.i. ha⁻¹ recorded more than 90 per cent mean reduction of bollworms compare to untreated check after two sprays in the first field experiment.

Emamectin benzoate 5 SG @ 11g a.i ha⁻¹ was effective in reducing the incidence of bollworm complex and increased the cotton yield (Raghuraman *et al.*, 2008). Kumar *et al.* (2008) observed emamectin benzoate and spinosad to be quite effective against *Earias vittella* (Fabricius) in cotton. Emamectin benzoate is similar to abamectin, a GABA and glutamate gated chloride channel agonist and is 1500 times more toxic than abamectin and 77 times more toxic than spinosad against *Spodoptera litura* (Fabricius) under laboratory conditions (Suby *et al.*, 2008). Kuttalam *et al.* (2008) observed that emamectin benzoate 5 EC @ 13 and 15g a.i ha⁻¹ was effective in suppressing the larval population of *E. vittella* in okra. Achaleke *et al.* (2009) reported that emamectin benzoate @ 12 g a.i ha⁻¹ is effective in suppressing boll damage and larval population of *H. armigera* in cotton. Govindan (2009) revealed that emamectin benzoate 5 SG (EB) at 15 g a.i. ha⁻¹ recorded 93.96 and 92.60 per cent reduction of bollworms in the first and second field experiments, respectively. The lowest larval population was recorded in plots sprayed with emamectin benzoate 5 SG at 11 and 15 g a.i. ha⁻¹ having 1.45 and 1.25 larvae plant⁻¹ respectively, at 5 day after treatment (DAT) in cotton.

All the larval stages of cotton leaf worm *Alabama argillacea* Hub. died 12 h after eating the leaves treated with emamectin benzoate at 9.6 g a.i ha⁻¹ under laboratory condition (Scarpellini, 2001).

Brevault *et al.* (2009) reported that emamectin benzoate 5 EC @10 g a.i ha⁻¹ had recorded 85.40 per cent mortality against fifth instar larvae of *H. armigera* in cotton. Emamectin benzoate 5 SG @ 11g a.i ha⁻¹ recorded the lowest infestation of bollworms on square basis (9.2-10.1%), green boll basis (7.4-8.2%), open boll basis (4.5-4.6 %) and had the highest seed cotton yield (1565 and 1645 kg ha⁻¹) during the two seasons (Prakash and Tomar, 2009). Vichiter and Chander (2009) observed that plots treated with emamectin benzoate 5 SG @ 9.8 g a.i ha⁻¹ reduced the bollworm damage and increased the seed cotton yield. Foliar application of emamectin benzoate 5 SG @ 6.75 g a.i ha⁻¹ was effective in controlling the bollworms and reducing shed material, locule infestation and bad kapas (Gaikwad *et al.*, 2009; Deore *et al.*, 2009). Parmar and Broad (2009) reported that indoxacarb 14.5 SC (0.0075%), emamectin benzoate 5 WG (0.001%) and diafenthiuron 75 WP (0.05%) performed better against *H. armigera* on okra, with a fruit yield of 119.91, 116.71 and 108.63 q ha⁻¹, respectively. Wankhede and Kale (2010) reported that emamectin benzoate at 10 g a.i ha⁻¹ proved to be the most effective against fruit borer and this treatment produced the highest fruit yield.

Emamectin benzoate 5 SG at 15 g a.i ha⁻¹ reduced larval population of *H. armigera* up to 85.84 and 93.19 per cent in the end of first and second season field trials in okra, respectively, followed by emamectin benzoate at 13 g a.i. ha⁻¹ which recorded 72.02 and 76.91 per cent reduction of *H. armigera* larval population on 5 DAT after first and second spray (Govindan *et al.*, 2012 a). Aiswariya (2010) reported that emamectin benzoate in comparison with the standard insecticide Proclaim® 5 WSG at 9 g a.i. ha⁻¹ against cotton bollworms revealed that Proclaim® was on par with emamectin benzoate 5 WSG at 7g a.i. ha⁻¹ recording 85.28 and 85.99 per cent reduction of *H. armigera* larval population in the two field experiments.

Aulakh *et al.* (2012) reported that all the emamectin benzoate treatments reduced the larval population of fruit borer significantly after first, second and third spray.

The per cent fruit damage by the fruit borer after three rounds of spray was significantly lower in plots treated with emamectin benzoate @ 150, 170 and 200 g ha⁻¹ with borer infestation of 4.0, 3.7 and 3.2 per cent, respectively.

2.2.3. Bioefficacy of emamectin benzoate on other crop pests

Emamectin benzoate @ 8.4 g a.i. ha⁻¹ was effective against *H. zea* on tomato (Jansson *et al.* 1997a), *Spodoptera exigua* (Hubner) and *H. zea* (Jansson *et al.* 1996; Dunbar *et al.* 1998) as well as *Trichoplusia ni* (H.) (Jansson *et al.*, 1997b). Duff *et al.* (2002) reported that emamectin benzoate @ 15 g a.i ha⁻¹ recorded the lowest number of *H. armigera* on lettuce. Laboratory Studies indicated that emamectin was a powerful toxicant against *Spodoptera littoralis* (Boisduval), *H.armigera* and the western flower thrips *Frankliniella occidentalis* (Pergande) (Ishaaya *et al.*, 2002).

Helicoverpa armigera was checked effectively in the field by emamectin benzoate @ 10 g a.i. ha⁻¹ on okra and chillies (Shobanadevi, 2003). Foliar spray of emamectin benzoate @ 8.75 g a.i. ha⁻¹ resulted in 81.3 per cent reduction in larval population of *P. xylostella* and was effective up to 14 days after treatment (Suganyakanna, 2003). Emamectin benzoate 5 SG @ 7.5 g a.i. ha⁻¹ was also effective against brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guenee) (Stanley *et al.*, 2007). Suganyakanna *et al.* (2005) reported that emamectin benzoate 5 SC @ 10 g a.i.ha⁻¹ and 8.75 g a.i.ha⁻¹ was effective in reducing the larval population of tomato fruit borer, *H. armigera* and fruit damage, recording the highest yield.

Murugaraj *et al.*, (2006) reported that emamectin benzoate @ 11 g a.i ha⁻¹ recorded the minimum fruit damage (2.47%) and the maximum of 91.46 per cent reduction over control in tomato. Meena *et al.* (2006) found that plots treated with emamectin benzoate 5 WSG @ 11 g a.i ha⁻¹ recorded the lowest pod borer damage (9.12%) and higher grain yield (810 kg ha⁻¹) in pigeon pea. Emamectin benzoate 5 SG @ 11 g a.i ha⁻¹ reduced the pod damage (5.13%) and increased the yield (2264 kg ha⁻¹) in chick pea (Raghvani and Poshia, 2006).

Prasad kumar and Devappa (2006a and b) reported that Proclaim® 5 SG at 200 g ha⁻¹ was effective against cabbage diamond back moth and brinjal shoot and fruit borer. Emamectin benzoate 5 SG @ 220 g ha⁻¹ (Balikai and Patil, 2007) and 11g a.i. ha⁻¹ (Kulkarni and Adsule, 2007) was found to be effective against grape vine thrips.

Emamectin benzoate 5 SG at 0.2 g l⁻¹ reduced the pod borer damage (11.75%) and seed damage (20.61%) which resulted in higher seed yield (11.88q ha⁻¹) in dolichous bean (Rekha and Mallapur, 2007). Proclaim® 5 SG at 220g a.i ha⁻¹ was highly effective in reducing flea beetle population in grapes (Balikai and Patil, 2007). Emamectin benzoate @ 0.5 g l⁻¹ was effective in causing larval mortality of rice leaf folder (91.66%) (Nalini *et al.*, 2008). Emamectin benzoate was also effective against *P. xylostella* (Kang and Dhaliwal, 2008). KhalidAhmed and Prasad (2009) reported that emamectin benzoate @ 10 and 7.5 g a.i. ha⁻¹ was found to be effective against chilli fruit borer, whereas higher dose of 10 g a.i. ha⁻¹ is promising against chilli thrips.

2.3. Phytotoxicity

2.3.1. Phytotoxicity of emamectin benzoate

No phytotoxic symptoms were noticed when emamectin formulation was sprayed at 5.0, 10.0 and 20.0 g a.i.ha⁻¹ on okra and chillies (Shobanadevi, 2003). Emamectin 5 SG at 22 g a.i. ha⁻¹ had no phytotoxic symptoms on tomato plants (Suganyakanna *et al.*, 2005). Prasad Kumar and Devappa (2006b) reported no phototoxic symptoms on brinjal when sprayed with Proclaim® 5 SG at 100, 200, 300 and 400 g a.i ha⁻¹.

Balikai and Patil (2007) reported that emamectin benzoate 5 SG did not cause any phytotoxic effects on grapes. Emamectin benzoate @ 8.5 g a.i. ha⁻¹ produced no phytotoxic effects on okra plants (Sontakke *et al.*, 2007a). Sontakke *et al.* (2007b) reported that emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ exhibited no phytotoxic effects on cotton plants. Emamectin benzoate 5 EC @ 11 and 22 g a.i ha⁻¹ was found to cause no phytotoxic effects on cotton plants (Raghuraman *et al.*, 2008). Studies conducted by Govindan (2009) revealed that emamectin benzoate 5 SG did not cause any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty on cotton and okra.

Aiswariya (2010) observed that emamectin benzoate 5 WSG did not cause any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty on cotton and okra.

2.4. Compatibility

Incompatibility in the mixture of insecticides, fungicides and fertilizers might be the result of chemical reaction between the individual components or their formulating agents. Physical properties are also likely to change, which could affect the efficiency of application and uniform distribution and adherence on plants. Indiscriminate use, without proper understanding of such compatibility, may reduce the efficacy of the combinations in controlling the pests and diseases. The information on the compatibility of insecticides, fungicides and fertilizers, as tank mix, is therefore highly essential in view of ease and economy involved in their use.

2.4.1. Compatibility with insecticides and fungicide

Suganthi (2003) reported that imidacloprid (17.8% SL) at 25 g a.i. ha⁻¹ was highly compatible with azoxystrobin (1 ml l⁻¹), wettable sulphur (2 g l⁻¹), carbendazim 50 WP (1 g l⁻¹), spiromesifen 240 SC (0.3 ml l⁻¹), dicofol 18.5 EC (2 ml l⁻¹), neem oil (5 ml l⁻¹), neem seed kernel extract (50 ml l⁻¹) and emamectin benzoate (0.3 g l⁻¹). It did not cause any phytotoxic symptoms on the potted plants of cotton, chilli and okra.

Sheeba Jasmine *et al.* (2007) reported that abamectin was physically and biologically compatible with dimethoate, methyl-o-demeton, cypermethrin, carbendazim and mancozeb no phytotoxicity was observed in cabbage and cotton.

Aiswariya (2010) revealed that all emamectin benzoate combination treatments were compatible with imidacloprid, mancozeb and endosulfan and no phytotoxicity was observed in cotton and okra.

Emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ was highly compatible with carbendazim, endosulfan and urea was highly compatible and did not exhibit any phytotoxic symptoms on cotton and okra plants in the laboratory and field conditions (Govindan *et al.*, 2012c). Aiswariya (2010) reported that emamectin benzoate 5 WSG was found to be compatible with agrochemicals like imidacloprid, mancozeb and endosulfan and when sprayed did not cause any phytotoxic symptoms on cotton and okra plants in both laboratory and field conditions.

2.5. Effect of emamectin benzoate against non target organisms

While the use of insecticides remains an important component of integrated pest management (IPM), biological suppression of insect pests is also considered as an equally important tool. Hence, the protection and preservation of natural enemies of the pests are essential. Among the various entomophages, coccinellids, spiders, green lacewing and *Trichogramma* sp. are very important in cotton ecosystem. Similarly, honey bees play an important role in boosting the yield of cotton as pollinators. These pollinating bees are exposed directly to insecticides during spraying, as well as to the left over insecticides on the crop.

The indiscriminate use of insecticides has affected the population of biocontrol agents, as all the conventional recommended insecticides are highly toxic to predators and parasitoids (Dhawan *et al.*, 1992 and 1994; Singh, 1994). The population of predators has declined by 68.4 per cent during the last two decades and many parasitoids have been eliminated (Dhawan and Simwat, 1996). The toxicity level of insecticides on parasitoids, predators and honey bees are reviewed hereunder.

2.5.1. Parasitoids

In general, abamectin is less toxic to beneficial arthropods (honey bees, parasitoids and predators), especially when exposure to treated plant occurs beyond one day after application (Hoy and Cave, 1985; Dybas, 1989 and Zhang and Sanderson, 1990). Fein *et al.* (1994) found that abamectin was safer to natural enemies and hence, can be used in conjunction with biological control agents such as *Encarsia formosa* (Gahan), *Aphelinus semiflavus* Howard and *Diaretiella rapae* (M' Intosh). Rajendran and Gopalan (1996) conducted an experiment to test the effect of endosulfan 35 EC, monocrotophos 36 WSC and cypermethrin 10 EC at different concentrations on egg parasitoid *Trichogramma chilonis* Ishii and observed that they were toxic to the parasitoids even at low concentrations. Nian *et al.* (1997) reported that when *T. chilonis* was treated with the most toxic B1 component of abamectin @ 40 mg l⁻¹ concentration, the corrected mortality at 72 h was 11 per cent, indicating that as a biological insecticide, abamectin is relatively safe to *Trichogramma* populations in cotton fields.

Ling (1997) reported that abamectin was toxic to eggs, larvae and pupae of *Trichogramma confusum* (V.). Abamectin + deltamethrin mixture did not have any

measurable impact on the populations of the natural enemies of *Diadegma* spp. or *Apanteles* spp. (Franca *et al.*, 1998). However, Weintraub (1999) found that spray applications of abamectin and cyromazine significantly reduced the eulophid parasitoid, *Diglyphus isaea* (Walker). Aston *et al.* (2001) conducted field and laboratory studies with emamectin on a wide range of beneficial species relevant to both cotton and horticultural crops. Over all selectivity of emamectin makes it a useful tool in IPM systems.

Hazard ratings are based on disruption to population up to 24 h after application (Aston *et al.*, 2001).

Very low disruption	- < 10% population reduction
Low disruption	- 10-20% population reduction
Moderate disruption	- 20-40% population reduction
High to very high disruption	- > 40% reduction

Govindan (2009) observed emamectin benzoate 5 SG did not show harmful effects to *T. chilonis*. Emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ recorded 84.22 and 80.51 per cent parasitism, respectively. Treatment of parasitized eggs with emamectin benzoate 5 SG did not cause any ill effects to the developing parasitoids, adult emergence and emerged adults. Aiswariya (2010) reported that emamectin benzoate was found to have lesser effect on the emergence of *Trichogramma* adults as 86.10 and 83.98 per cent of adults emerged from the recommended dose of emamectin benzoate (9 g a.i. ha⁻¹) treated *Trichogramma* parasitised *Corcyra* eggs.

2.5.2. Egg-larval predator, *Chrysoperla* spp.

Studies conducted by Lingren and Ridgeway (1967) revealed the toxic nature of phosphamidon to the larvae and adults of *Chrysoperla carnea* Stephens. Larval survival, adult emergence, and fecundity of *C. carnea* were unaffected by permethrin, but not by fenvalerate. However, female life span was reduced by permethrin (Rajakulendran and Plapp, 1982). Fluvalinate was less toxic to the predator, *C. carnea* than to *Campoletis sonorensis* (Cameron) (Shour and Crowder, 1980).

Krishnamoorthy (1985) tested the effect of insecticides belonging to different groups on eggs, larvae and adults of *Chrysoperla scelestes* (Banks) and observed that newly hatched larvae were more susceptible to organophosphate, carbamate and pyrethroid groups of insecticides when compared to egg stage. Quinalphos, chlorpyrifos and cypermethrin were highly toxic to larvae and adults. Pirimicarb, bromophos, heptenopos and trichlorfos were categorised as harmless to slightly harmful, while diflubenzuron, fenvalerate, dimethoate, methamidophos and chlorpyrifos were found harmful to second instar larvae of *C. carnea* Hassan *et al.* (1985).

Patel and Vyas (1985) compared the toxicity of ten insecticides to eggs of *C. scelestes* and concluded that carbaryl at 0.15 per cent was the most toxic followed by malathion (0.05%). However, cypermethrin (0.01%), monocrotophos (0.04%), phosalone (0.05%), fenvalerate (0.1%), permethrin (0.0125%) and endosulfan (0.07%) were found to be safe to eggs of *C. scelestes*. Fenvalerate, fluvalinate and other synthetic pyrethroids were generally more toxic to *Chrysopa* sp. than organophosphorus insecticides (Pree and Hagely, 1985).

Triazophos, monocrotophos and fenpropathrin sprayed on cotton had a greater residual toxicity to the larvae of *C. carnea* than endosulfan, cypermethrin and fenvalerate (Kapadia and Puri, 1991). Shukla *et al.* (1995) tested insecticides for the toxicity to eggs of *C. scelestes*, and found that methyl parathion was the safest causing only 23.46 per cent mortality of the predator followed by dimethoate (27.78%). Acetamiprid (NI-25) was safe to majority of natural enemies including coccinellids, *Chrysopa* spp., syrphids, *Aphidoletes* spp. and spiders (Araneae) with coccinellids being the least affected Yequming *et al.* (1996).

Gerling *et al.* (1997) reported that population of *C. carnea* was unaffected by applying monocrotophos. The toxic effects of 34 insecticides, six acaricides and nine fungicides on the first instar larvae of *C. carnea* were investigated in the laboratory using a direct dipping test and a residual contact test by Toda and Kashio (1997). All organophosphatic insecticides showed high toxicity, while nitenpyram, imidacloprid and acetamiprid showed low toxicity in the dipping test but high toxicity in the residual contact test.

Kumar (1998) observed no significant adverse effects of imidacloprid on *C. carnea* egg hatchability. This compound had significant adverse effect on the grubs and adult

longevity of *C. carnea* when fed on treated diet. Safety evaluation tests conducted by Reddy and Divakar (1998) revealed that phosalone (0.05%) and endosulfan (0.07%) were harmless to *C. carnea*, whereas carbaryl, monocrotophos and quinalphos were harmful. Indoxacarb is reported to be highly selective with little impact on beneficial insects (Holloway *et al.*, 1999). Indoxacarb had no or little effects on hemipteran predators (*Geocoris* spp., *Orius* spp. and *Nabis* spp.), hymenopteran parasitoids (*Aphidius* sp., *Cotesia* sp., *Bracon* spp., *Macroplitis* spp. and *Trichogramma* sp.), spiders and predaceous mites and had no or moderate effects on lacewings (*Chrysoperla rufilabris* (Burmeister)) and coccinellids (Studebaker and Kring, 1999).

Srinivasan and Sundarababu (2000) observed that endosulfan (0.07%) and abamectin (0.03%) were the least toxic to *C. carnea*. Emamectin benzoate 5 SG at 13.5 g a.i.ha⁻¹ applied twice, one week apart proved to be very safe to all predator groups and stages (*Orius* and *Campylomma* adults and nymphs, *Chrysoperla* larvae, adults of *Scymnus*, *Coccinella* and *Paederus* and adults and immature stages of spiders) (Sechser *et al.*, 2003). Bueno and Freitas (2004) reported that egg viability of *Chrysoperla externa* (Hagen) was not affected by abamectin. Neonate larvae from abamectin sprayed eggs as well as first, second and third instar larvae when directly treated, developed normally and yielded normal adults. Alagar and Sivasubramanian (2007) observed that endosulfan 0.07 per cent was slightly harmful to first instar grubs of *C. carnea*, whereas dimethoate was harmful to first and third instar grubs of *C. carnea*.

The highest egg hatchability of *C. carnea* was recorded by emamectin benzoate 5 SG @ 7 g a.i. ha⁻¹ (90.33 %) and 9g a.i. ha⁻¹ (85.00 %) when compared to untreated check (96.33 %). The fecundity of the adults decreased as the concentration of emamectin benzoate 5 SG increased (Govindan *et al.* 2012d). Emamectin benzoate 5 WSG was not found to have adverse effect on hatchability of *C. carnea* eggs and highest dose 13 g a.i. ha⁻¹ killed 20.73 per cent of *Chrysoperla* eggs, but it was only 8.33 per cent for the lowest dose of 7 g a.i. ha⁻¹ Aiswariya (2010).

2.5.3 Coccinellid predator

Rajagopal and Kareem (1983) concluded that fenvalerate (0.05%) and methamidophos (0.05%) were toxic to adults and larvae of *Menochilus sexmaculatus*

(Fab.), while dichlorvos (0.05%) was the least toxic and phosalone (0.05%) and dimethoate (0.05%) were comparatively safer to adults and larvae. Acephate at 0.5 kg a.i.ha⁻¹, methamidophos at 0.5 kg a.i.ha⁻¹, and fenvalerate at 50 g a.i.ha⁻¹ had deleterious effect on the predator *M. sexmaculatus* (Rao, 1986). Endosulfan (0.05%) and fenvalerate (0.01%) were non-toxic to aphid predator *M. sexmaculatus* (Rao *et al.*, 1989).

Under laboratory condition, Dhingra *et al.* (1995) evaluated 10 insecticides against adults of *M. sexmaculatus*. Deltamethrin, cypermethrin, phosphamidon, malathion and fenvalerate were 10.18, 3.10, 1.97, 1.55 and 1.05 times more toxic than monocrotophos based on the LC₅₀, respectively, whereas methyl demeton, endosulfan and lindane were less toxic (0.28, 0.04 and 0.02 times, respectively).

Patil and Lingappa (2000) worked out the selective toxicity ratio (STR) for tobacco aphid, *Myzus nicotianae* (Blackman) and its predator, *Cheilomenes sexmaculatus* (Fab.) and reported that acephate recorded the lowest STR, followed by imidacloprid, while endosulfan registered the highest. Avermectins were safe to non-target organisms viz., *Dolycorris bauarum* (L.), *Pentatoma rufipes* (L.), *Coccinella septumpunctata* (L.), *Adalia bipunctata* (L.), *Adonia variegata* Goeze and *Vanessa urticae* Cardui (Chizhov *et al.*, 2000). Acharya *et al.* (2002) suggested that the newer molecules viz., acetamiprid (20 g a.i.ha⁻¹), thiamethoxam (25 g a.i. ha⁻¹), imidacloprid (25 g a.i.ha⁻¹) and abamectin (20 g a.i.ha⁻¹) were relatively safer to the predatory ladybird beetles.

Galvan *et al.* (2002) observed that abamectin showed median selectivity in favour of the predator, *Brachygastera lecheguana* Fabricius and *Protopolybia exigua* (Saussure). Udikeri *et al.* (2004) reported that emamectin benzoate 5 SG is safe to coccinellids in cotton ecosystem. Jyoti and Goud (2008) reported that emamectin benzoate 5 SG was safe to coccinellids, chrysopids and spiders in brinjal ecosystem. Yogesh Patel *et al.* (2009) recorded minimum reduction in population of coccinellids, green lacewings, and chrysopids over control, in plots treated with emamectin benzoate at 8 g a.i.ha⁻¹ followed by emamectin benzoate at 9.8 g a.i. ha⁻¹, spinosad 45 SC at 75 g a.i.ha⁻¹ and spinosad 45 SC at 100 g a.i.ha⁻¹.

Govindan (2009) concluded that emamectin benzoate 5 SG treatments were safer to coccinellids when compared with other standard treatment endosulfan 35 EC. Aiswariya (2010) reported that all the treatments of emamectin benzoate imposed were comparatively less toxic to coccinellids.

Sheeba jasmine and Kuttalam (2011) suggested that emamectin benzoate 5SG and 1.9 EC was found to be safer to coccinellids at different concentrations tested. The highest population was recorded in plots treated with emamectin benzoate @ 7 g a.i. ha⁻¹ followed by emamectin benzoate @ 11 g a.i. ha⁻¹, respectively.

2.5.4. Spiders

Raman and Uthamasamy (1983) observed that carbosulfan was the least toxic to spiders in cotton ecosystem. Mansour *et al.* (1992) stated that fenvalerate 10 EC at 0.3 l ha⁻¹ recorded 57 per cent mortality of *Pardosa* spp. Restabilization of spider population was noticed after 4 - 5 weeks of spraying of deltamethrin and methamidophos (Volkumar and Wetzel, 1993). Cole *et al.* (1997) observed that lambda-cyhalothrin recorded little impact on ground spiders. Diazinon, fenobucarb, carbaryl, dichlorvos and imidacloprid were toxic to spiders in cotton (Nagata *et al.*, 1997) and spiderlings were sensitive even to azadirachtin (Punzo, 1997). Vandenberg *et al.* (1998) found that monocrotophos at 108 g a.i.ha⁻¹ adversely affected the population of *Pardosa* spp. in cotton ecosystem.

Maleque *et al.* (1999) reported that cypermethrin applied at weekly intervals caused population reduction of ladybird beetles and spiders in brinjal ecosystem. Srinivasan and Sundarababu (2000) found that phosphamidon 40 SL at 300 g a.i.ha⁻¹ recorded lower levels of toxicity to spiders in brinjal ecosystem. Thiamethoxam at 25 g a.i ha⁻¹ proved to be safer to the spiders, causing less mortality of 13.5 per cent followed by imidacloprid (18.0%).

Manjunatha and Shivanna (2001) concluded that imidacloprid was toxic to predatory spiders and mirid bugs in rice ecosystem, recording mortality of 30.66 per cent at 100 ml ha⁻¹ and 77.66 per cent at 400 ml ha⁻¹. Neemazal (0.5%) and Neem seed kernel extract (NSKE) (5%) were safer to natural enemies like syrphids and spiders in brinjal ecosystem (Rosaiah, 2001). The insect growth regulator Rimon[®] 10EC (Novaluron) was relatively safe to spiders, coccinellids and *Chrysoperla* sp. in cotton ecosystem (Vichiter and Chander, 2009).

Aiswariya (2010) reported that all the emamectin benzoate treatments were comparatively less toxic to spiders. Emamectin benzoate 5 WSG at 9 g a.i. ha⁻¹ recorded a mean of 4.94 and 6.05 spiders per 10 plants after first and second round of application, respectively. At higher doses, there was a slight, but non-significant reduction in spider population.

Govindan *et al.* (2012e) reported that higher dose of emamectin benzoate 15 g a.i. ha⁻¹ recorded a mean population of 2.67 - 3.93 spiders per 10 plants when compared to lower doses of emamectin benzoate 5 SG at 9 and 11 g a.i. ha⁻¹ which recorded a mean of 3.35 - 6.66 and 3.35 spiders per 10 plants at the end of second experiment, respectively. While the lowest spider population was found in plots treated with endosulfan 35 EC at 350 g a.i. ha⁻¹ that recorded 1.97 - 3.53 per 10 plants.

2.5.5. Honey bees

Usha and Kandasamy (1986) studied the effect of several insecticides and reported diflubenzuron to be the safest with no mortality of honey bees even at 1000 ppm. Panda *et al.* (1989) found that phosphamidon followed by endosulfan and phosalone were the most toxic insecticides to forager bees, while neem oil was the least toxic followed by fenvalerate, deltamethrin and malathion. Lasota and Dybas (1991) found that honey bees were very sensitive to abamectin following direct contact through their food and through treated foliage. Mospilan (acetamiprid) exhibited low toxicity to beneficial insects such as honey bees and bumble bees (Matsuda and Takahashi, 1996).

The honey bees *Apis mellifera* L. and the eulophid parasitoid *Diglyphus isaesae* (Walker) were highly susceptible to fresh residues of emamectin benzoate (Chukwudebe *et al.*, 1997). Acetamiprid has low toxicity levels to mammals, aquatic organisms and wildlife and does not show adverse effects on honey bees or bumble bees (Lacombe, 1999). Dimethoate and carbaryl were highly toxic, inhibiting the development of colonies in the treated area followed by endosulfan, fenvalerate and mancozeb. Fenvalerate was less toxic and neem oil was non toxic (Abrol and Rajiv, 2000). Abrol and Andotra (2000) studied the relative contact and oral toxicity of some insecticides to honey bees, *A. mellifera* and found that monocrotophos (0.01%), phosphamidon (0.025%) and dimethoate (0.03%) caused quick knockdown of bees as more than 90 per cent of them died within one hour of contact with the insecticides.

Aston *et al.* (2001) found that direct application of abamectin caused 100 per cent mortality, but indirect application of abamectin had no effect on *A. mellifera* 24 h after application. Kain and Agnello (2001) also found that abamectin was toxic to bees and predatory mites on contact. Profenofos was reported to be less toxic to honey bees when compared to other insecticides in use in cardamom and cashew (Renuka, 2001). Acetamiprid was relatively safer to honey bees (Jayaprabhavathi, 2005). Kavitha *et al.* (2006) reported that spiromesifen was found to be safe to honey bees three hours after contact, whereas triazophos and dicofol caused more than 50 per cent mortality of bees. Of the seven insecticides tested, chlorpyrifos was found to be slightly toxic to *Apis cerana indica* F. (Muranjan *et al.* 2006).

Seema *et al.* (2007) found that chlorpyrifos repelled honey bees through contact action at 0.04 and 0.02 per cent concentration. Chandramani *et al.* (2008) reported the descending order of oral toxicity of 10 test insecticides to Indian bee, *A. indica* under laboratory was cypermethrin > monocrotophos > endosulfan > dimethoate > thiomethoxam > imidacloprid > spinosad > pungam oil > neem oil > NSKE.

Govindan (2009) found that emamectin benzoate 5 SG at 7, 9, and 11 g a.i. ha⁻¹ caused 3.33, 10.00 and 16.67 per cent mortality, respectively to Indian bees, *Apis cerana indica* Fabricius at 12 HAT, and it increased to 10.00, 13.33 and 29.00 per cent, respectively after 24 HAT. Standard insecticide endosulfan and spinosad recorded increased mortality of 37.67 and 32.68 per cent, respectively.

Studies carried out by Aiswariya (2010) revealed that emamectin benzoate at 9 g a.i.ha⁻¹ was toxic when bees were exposed to dry film of emamectin benzoate registering 86.19, 85.12 and 85.61 per cent mortalities at 24 HAT to *A. indica*, *Apis mellifera* L. and *Apis florea* F., respectively while standard insecticide endosulfan recorded corresponding less mortality of 67.44, 64.50 and 66.67 per cent.

2.5.6. Earthworms

Earthworm populations are drastically influenced by modern agricultural practices. The pesticides applied as soil treatment may affect the non target earthworms due to the left over residues in crop lands (Edwards, 1984). Kring (1969) noticed that there was drastic decline in *Lumbricus terrestris* L. population in carbofuran treated

tobacco field. Among the commonly used insecticides, carbamates are the most toxic and are deadly to earthworms. Even small concentrations at recommended rates of application could severely reduce earthworm population (Finlayson *et al.*, 1975; Martin, 1976; Lebrun *et al.*, 1981 and Medts, 1981). Avermectins displayed very little toxicity to earthworms with LC₅₀ values of 315 and 28 ppm in soil for ivermectin and abamectin, respectively (Halley *et al.*, 1993). Addison and Holmes (1995) reported that *Eudrilus foetida* (Kinberg) and *Dendrobaena octaedra* Savigny were relatively susceptible to fenitrothion, although *D. octaedra* (LC₅₀ = 393.9 ml cm⁻²) was approximately eight times less sensitive than *E. foetida* (LC₅₀ = 54.1 ml cm⁻²).

The LC₅₀ values of abamectin to *Eudrilus eugeniae* (Kinberg) by artificial soil test bioassay method were 33.2, 17.4 and 4.6 mg kg⁻¹ of soil at 2, 7 and 14 days, respectively, The LC₅₀ values of abamectin to *E. eugeniae* at 2, 7 and 14 days by dung test bioassay method were 177.1, 53.3, 35.9 mg kg⁻¹ of dung, respectively whereas, the same to *P. excavatus* were 172.6, 47.2 and 30.5 mg kg⁻¹ of dung, respectively (Sheeba jasmine, 2005).

The LC₅₀ values of flubendiamide to *E. eugeniae* and *P. excavatus* were 215.17 and 241.92 ppm, respectively (Thilagam, 2006). The LC₅₀ values of acetamiprid to *E. eugeniae* and *P. excavatus* were 7.17 and 6.67 mg kg⁻¹ of soil, respectively (Suganyakanna, 2006). The LC₅₀ value of imidacloprid for *E. eugeniae* by artificial soil test bioassay method was 2.864, 1.285 and 0.072 ppm at 1, 2 and 7 days after treatment (DAT) (Preetha, 2007). The LC₅₀ values of spirotetramat 150 OD *E. eugeniae* by artificial soil test bioassay method were 56.91, 31.98 and 9.83 mg kg⁻¹ of soil at 2, 7 and 14 days, respectively, while that of *P. excavatus* were 62.05, 39.25 and 9.06 mg kg⁻¹ of soil, respectively (Vinoth Kumar, 2007). The median lethal concentration of diafenthiuron to earthworms was 72.312 µg g⁻¹ in soil and 236.040 µg g⁻¹ in dung (Stanley, 2007).

Reddy and Reddy (1992) found that application of endosulfan @ 3 ml l⁻¹ reduced cent per cent population of *Drawida willisi* Mich. and *Lampito mauritii* Kinberg. Chlorpyrifos was the least toxic to various earthworms including *E. eugeniae* with higher survival rate at different dosages (Mantur, 1998). The acute toxicity of acetamiprid to earthworms was 9 mg kg⁻¹ (Anonymous, 2003). Awaknavar and Karabhantanai (2004)

observed that endosulfan was highly toxic with respect to weight and carbofuran with regard to survival.

Govindan (2009) observed that LC_{50} value was found to be 16.22 ppm in soil at 2 DAT whereas, the respective LC_{50} value of emamectin benzoate to *E. eugeniae* at 2 days by cowdung test bioassay method was 15.44 ppm.

The LC_{50} value of emamectin benzoate was found to be 16.23 ppm in soil at 2 DAT whereas, the respective LC_{50} value of emamectin benzoate to *E. eugeniae* at 2 days by cowdung test bioassay method was 15.45 ppm (Aiswariya, 2010).

2.6. Persistence of emamectin benzoate

Emamectin benzoate by virtue of its translaminar activity, thereby provided a relatively prolonged residual action. As with abamectin, surface residues were decomposed rapidly in sunlight, resulting in a relatively low toxicity to beneficial insects (McConnell *et al.*, 1989; Feely *et al.*, 1992; Jansson and Dybas, 1996). Abamectin degrades rapidly when exposed to sunlight (Wislocki *et al.*, 1989). Despite its rapid photodecomposition, abamectin provided residual activity in the field due to its translaminar activity (Wright *et al.*, 1985; Dybas, 1989). Cent per cent mortality of *Spodoptera exiqua* was recorded at 17 days after application of emamectin benzoate 5 EC @ 8.4 g a.i ha⁻¹ on pepper plants and chick pea plants in glass house (Jansson *et al.*, 1997b). While emamectin benzoate was susceptible to photodegradation, reservoirs of the compound development in cotton leaf tissue, resulting in long residual activity under field conditions (Dunbar *et al.*, 1998). Brevault *et al.* (2009) reported that the persistence was found to be higher for emamectin benzoate 5 EC @ 10 g a.i ha⁻¹ (10.6 days) followed by spinosad 45 SC @ 36 g a.i ha⁻¹ (8.9 days) and persistence was lower for indoxacarb @ 25 g a.i ha⁻¹ (3.7 days) and endosulfan @ 750 g a.i ha⁻¹ (5.2 days) in cotton plants under simulated rainy condition.

2.7. Residues

Pesticides have become an essential component in cotton and okra production especially with introduction of high yielding varieties and extensive use of fertilizers. Application of pesticides towards the later stages of the crop for the management of

insects may leave toxic residues in harvested produce resulting in deleterious effects. Therefore, the estimation of insecticide residues in the harvested produce may throw light in the optimal use of insecticide in pest management.

2.7.1. Harvest time residues in cotton

Harvest time residues of fenvalerate (0.05%) on cotton seed and lint were 0.62 and 1.20 ppm, respectively, which were above the tolerance limit of 0.2 ppm prescribed by Food and Agriculture Organization (FAO) (Jain *et al.*, 1980). Srivastava *et al.* (1983) determined the residues of deltamethrin and permethrin in cotton lint and seed at below detectable level (BDL), while the residues of cypermethrin were below the recommended tolerance limit. Gupta *et al.* (1984) found that among the treatments viz., flucythrinate at 30 and 50 g a.i. ha⁻¹, fenvalerate 40 and 75 g a.i. ha⁻¹, cypermethrin 40 and 75 g a.i. ha⁻¹ and deltamethrin 10 and 15 g a.i. ha⁻¹, no detectable residues of flucythrinate and deltamethrin was found in seed or lint. Cypermethrin and fenvalerate left less than 0.02 to 0.08 ppm of residues in cotton seed, but were below the maximum residual limit (MRL) as prescribed by FAO.

Agnihotri *et al.* (1987) reported that residues of flucythrinate sprayed at 11 days interval were at BDL in cotton seed. Sharma and Agarwal (1988) stated that no detectable (ND) residue of lamdacyhalothrin was found in seed samples and lint. Raj *et al.* (1990) found that deltamethrin did not leave any detectable residues on cotton seed, oil and lint. Fenvalerate and cypermethrin residue levels were below detectable level in lint. However, in cotton seed oil, fenvalerate residues exceeded maximum residue limit (MRL) of 0.1 ppm in the first picking. Endosulfan residues in cotton seed and oil in the first picking were below the MRL of 0.5 and 0.2 ppm, respectively.

The alphamethrin residues in cotton seeds were below the tolerance limit of 0.5 ppm (Bhuvaneswari and Uthamasamy, 1992). Supervised trials conducted by Manimegalai *et al.* (1994) revealed that the residues of pyraclophos in cotton seed, oil and lint were quite low. In seeds, the residues of imidacloprid were at BDL except one sample that had 0.01 ppm (Kumar, 1995). Valarmathi (1997) reported that the harvest time residues of quinalphos in lint samples from first picking were at detectable levels, but lesser than MRL (0.05 ppm). During the third picking, the harvest time residues were

at BDL in both lint and seed samples. Residues of imidacloprid (applied both as seed and foliar treatment) on cotton were BDL in seed, oil and in lint (Kumar, 1998).

Residues of imidacloprid were at BDL ($< 0.05 \text{ mg kg}^{-1}$) in cotton seed (Gupta *et al.*, 1998; Mukherjee and Gopal, 2001 and Suganthi, 2003). Karthikeyan and Jayakumar (2000) assessed the residues of chlormequat chloride in cotton lint, cotton seed and seed oil and reported chlormequat chloride residues at below detectable limits in all the samples. George *et al.* (2002) studied the persistence and translocation of foliar applied deltamethrin and lindane in cotton boll and reported that the pesticide contamination of seeds is the least when the bolls are closed and maximum when the bolls are partially or fully open.

Battu *et al.* (1999) reported that six applications of betacyfluthrin at seven to ten days interval in cotton at 12.50 and 18.75 g a.i. ha^{-1} left residues in cotton lint samples with an average of 0.30 and 0.40 mg kg^{-1} , respectively, while the residues were BDL in seeds and oil. Kavitha (2003) found that the harvest time residues of spiromesifen at 120 and 240 g a.i. ha^{-1} were at BDL in cotton lint, seed and oil. The harvest time residues of abamectin 1.9 EC at 10.8, 14.5, 18.5, 22.5 and 29.0 g a.i. ha^{-1} were at below detectable level in cotton seed, lint and oil samples (Sheeba Jasmine, 2005). Sheeba Jasmine *et al.* (2005) observed that carbosulfan (Marshal[®]) at 500 and 1000 g a.i. ha^{-1} left residues of 0.042 and 0.054 $\mu\text{g g}^{-1}$ in cotton seed sampled at first harvest while the residues in lint was at below detectable levels.

Dikshit *et al.* (2005) stated that harvest time residues of imidacloprid (Confidor 70[®] WG) were non detectable in cotton lint and seed samples. The harvest time residues of flubendiamide 480 SC applied at 60 and 120 g a.i. ha^{-1} left residues at below detectable levels (BDL) in cotton lint, seed and oil at first and third harvest and in the soil sample at third harvest (Thilagam, 2006). Acetamiprid 20 SP applied at 10, 20, 40 and 80 g a.i. ha^{-1} left residues at below detectable levels in cotton lint, seed and oil at first, third and fifth harvest (Suganyakanna *et al.*, 2007).

Govindan (2009) reported that the harvest time residues of emamectin benzoate 5 WSG at 11 and 22 g a.i. ha^{-1} as foliar spray were at below detectable level (BDL) in cotton lint, seed and oil samples of first and third pickings in the two field experiments. Aiswariya (2010) reported that the harvest time residues of emamectin benzoate 5 WSG at 9 and 18 g

a.i. ha⁻¹ as foliar spray were at below detectable level (BDL) in cotton lint, seed and oil samples of first and third pickings in the two field experiments.

2.7.3. Dissipation of emamectin benzoate in okra

Govindan (2009) reported that emamectin benzoate 5 SG sprayed at 11 and 22 g a.i. ha⁻¹ left an initial deposit of 0.169 and 0.310 µg g⁻¹ in the okra fruits at 0 day. Dissipation of initial deposits was 35.50 (11 g a.i. ha⁻¹) and 40.32 per cent (22 g a.i. ha⁻¹) on day one in the field. The half life of emamectin benzoate applied as foliar treatment at 11 and 22g a.i. ha⁻¹ was 1.28 and 1.47days, respectively. The dissipation studies of emamectin benzoate on okra revealed that emamectin benzoate 5 WSG spray at 9 and 18 g a.i. ha⁻¹ left an initial deposit of 0.095 and 0.302 µg g⁻¹, respectively on first day after treatment and reached BDL after fifth day for both the doses (Aiswariya, 2010).

2.8. Baseline toxicity

2.8.2. Acute toxicity of emamectin benzoate

Leaf dip bioassays had LC₉₀ of 4" epimethyl amino 4" deoxy avermectin B₁ (EMA) in the range of 0.002 to 0.014 ppm to neonate lepidopteran larvae (Dybas and Babu, 1988). In contrast to abamectin, which demonstrated considerably less intrinsic toxicity against economically important species such as *S. frugiperda*, *S. exigua*, *H. zea*, *H. virescens* and *T. ni*, the LC₉₀ values of EMA were 0.01, 0.005, 0.002, 0.003 and 0.014 ppm, respectively (Dybas and Green, 1984; Dybas and Babu, 1988). This indicated 1,166 fold increase in potency over abamectin in the case of *S. eridania* and about a 1,500 fold increase in the case of *S. exigua* (Trumble *et al.*, 1987). Although EMA was less toxic to *Tetranychus urticae* Koch (LC₉₀ = 0.29 ppm) than abamectin (LC₉₀ = 0.03 ppm), EMA was found to be more toxic to colorado potato beetle *Leptinotarsa decemlineata* (Say) (LC₉₀ = 0.032 ppm) (Clark and Argentine, 1994) and Mexican bean beetle *Epilachna varivestis* Mulsant (LC₉₀ = 0.20 ppm). As compared to abamectin, EMA was considerably less toxic to the bean aphid, *Aphis fabae* Scopoli (LC₉₀ = 19.9 ppm) (Lasota and Dybas, 1991).

Studies on the susceptibility of a field strain of *P.gossypiella* to insecticides indicated that pyrethroids were far more toxic to the pest than organophosphates and carbamates (Ayad *et al.*, 1993). Jansson *et al.* (1997a) reported the LC₅₀ and LC₉₀ values of

emamectin benzoate as 0.004 - 0.006 $\mu\text{g ml}^{-1}$ against *H. virescens* and 0.007 - 0.013 $\mu\text{g ml}^{-1}$ for *S. exigua*. Dunbar *et al.* (1998) reported that emamectin benzoate was highly toxic to a broad spectrum of lepidopteran pests with LC_{90} values ranging between 0.001 and 0.02 $\mu\text{g ml}^{-1}$ in leaf dip bioassay for *H. virescens*. The LC_{50} determined for *P.gossypiella* by employing larval dip method for various chemical was 0.0835 for chlorpyrifos, 0.0335 for beta-cyfluthrin, 0.0452 for quinalphos, 0.0086 for cypermethrin, 0.0144 for indoxacarb, 0.0165 for spinosad which revealed that synthetic pyrethroids were effective against pink bollworm (Gopalaswamy *et al.*, 2000).

Martinez-Carrillo and Wright (1998) obtained the base line data for emamectin benzoate against beet army worm (*S. exigua*) as 0.6 $\mu\text{g g}^{-1}$ and the fiducial limits ranged from 0.36 to 1.41 $\mu\text{g g}^{-1}$ in susceptible population, which were similar to those in field collected colonies. LD_{50} and LD_{95} values of emamectin benzoate against *H. armigera* were 0.016 $\mu\text{g larvae}^{-1}$ and 0.175 $\mu\text{g larvae}^{-1}$ (Shobanadevi, 2003) and against *P. xylostella* obtained by leaf dip bioassay were 0.053 and 0.989 ppm (Suganyakanna, 2003). LD_{50} values of emamectin benzoate for F_1 and F_6 generations of *H. armigera* and *S.litura* was found to be 0.00386; 0.00347 $\mu\text{g larvae}^{-1}$ and 0.00105; 0.0099 $\mu\text{g larvae}^{-1}$ respectively (Stanley, 2004; Stanley *et al.*, 2006).

Sampath Kumar *et al.* (2007) reported that susceptibility of abamectin in F_6 generation of *E.vittella* was moderately increasing with an LD_{50} value of 0.00167 $\mu\text{g larva}^{-1}$. The LD_{95} was also found to decrease from 0.02210 (F_1) to 0.01136 $\mu\text{g larva}^{-1}$

2.8.3. Discriminating dose

The information available on base-line data generated for the widely used insecticides in the control of key pests as reviewed by Regupathy and Ayyasamy (2004) are furnished below.

Table 2. Discriminating dose screen of various insecticides for *P. xylostella*

Insecticide	Method	DD (ppm)	Source
Fenvalerate	Vial	115	Chandrasekaran & Regupathy, 1996
	Spray tower	170	
	Larval dip	130	
Quinalphos	Vial	3	
	Spray tower	10	
	Larval dip	10	
Monocrotophos	Vial	140	
	Spray tower	170	
	Larval dip	150	
Cartap hydrochloride	Vial	5	
	Spray tower	10	
	Larval dip	10	
Carbosulfan	Vial	4	
	Spray tower	20	
	Larval dip	15	
Ethion	Leaf dip	2	Lavanya, 2004
Spinosad	Leaf dip	12	

Table 3. Discriminating dose screen of various insecticides for *S. litura*

Insecticide	Method	DD (µg)	Source
Endosulfan	Topical	2.0	Niranjankumar and Regupathy, 2001
Profenofos	Topical	3.0	
Chlorpyrifos	Topical	0.5	
Fenvalerate	Topical	0.25	
Ethion	Leaf dip	0.40	Stanley <i>et al.</i> , 2006
Spinosad	Leaf dip	125	

2.8.4. Detection of insecticide resistance

2.8.4.1. Topical bioassay

Based on the international collaborative study by the FAO panel of experts on pest resistance to pesticides and crop loss assessment, FAO method No.21 was recommended for generating baseline data for monitoring insecticide resistance. This reliable method was followed by El-defrawi *et al.* (1964), Gunning *et al.* (1984), Prasad *et al.* (1985), McCaffery *et al.* (1989), Christie and Wright (1990), Armes *et al.* (1992), Leonard *et al.* (1996), Niranjankumar (2002), Tamilselvi and Regupathy (2002), Chavan and Nimbalkar (2003), Shravankumar *et al.* (2003), (Deepa Rajathi *et al.*, 2006) (Stanley *et al.*, 2006), (Stanley *et al.*, 2007) and (Stanley *et al.*, 2009).

2.8.4.2. Resistance of insect pests to new molecules

Table 4. Pests recorded for their resistance to new molecules

Pest	Pesticide	Reference
<i>P. xylostella</i>	Abamectin	Abro <i>et al.</i> , 1988
<i>Musca domestica</i> L. (Pyrethroid resistant)	Abamectin	Scott, 1989; Scott <i>et al.</i> , 1991
<i>L. decemlineata</i>	Abamectin	Argentine and Clark, 1990
<i>Blatella germanica</i> L. (Multi resistant)	Abamectin	Scott, 1991
<i>Liriomyza huidobrensis</i> (Blanchard) and <i>Liriomyza sativae</i> (Blanchard)	Avermectin 95.2 P Agrimec 1.8 EC Aifunding 1.8 EC	Luo Yan-Jie <i>et al.</i> , 2004
<i>T. urticae</i>	Milbemycin	Yomamoto and Nishida, 1981; Yomamoto <i>et al.</i> , (1982) Campos and Dybas, 1992
<i>M. domestica</i>	Spinosad	Toshio and Scott, 2003
<i>S. exigua</i>	Spinosad	Moulton <i>et al.</i> , 1999

Abro *et al.* (1988) found that, a field strain of DBM (*P. xylostella*) was resistant to abamectin. In topical assays, a highly resistant housefly strain exhibited a resistance more than 60,000 but not in injection assays, revealing decreased cuticular penetration as the primary mechanism of resistance (Scott *et al.*, 1991). The resistance ratio for colorado potato beetle based on LD₅₀ and LD₉₇ values of resistant and susceptible strains was 15-23 and 21-38 fold, respectively. The resistant strain would thrive in doses up to 100 ng abamectin beetle⁻¹, while no survival was reported in susceptible strain even to 10 ng beetle⁻¹ (Argentine and Clark, 1990). Luo Yan-Jie *et al.* (2004) stated that the resistance index of *L. huidobrensis* to avermectin declined with 19 generations and ranged from 0.8520 to 0.4341 ppm. The LC₅₀ of resistant strain before selection and after selection was 0.4047 mg L⁻¹ and 1.1447 mg L⁻¹, respectively. Clark *et al.* (1995) reported that, *T. urticae* showed 900 - fold resistance to abamectin in residual bioassay.

The abamectin resistant strains of houseflies were found to be two fold cross resistant to MK - 244 (4" epimethyl amino avermectin) (Lamine, 1994). LC₅₀ to spinosad field population of *S. exigua* ranged from 0.6 to 14 µg ml⁻¹ which was significantly different from the LC₅₀ of the susceptible reference population (0.20µg ml⁻¹). The resistance ratio obtained was 3-70. Thailand population was found to be more resistant to spinosad with high LC₅₀ and LC₉₅ values of 14 µg ml⁻¹ and 68 µg ml⁻¹ (Moulton *et al.*, 1999). Selection of field collected houseflies with indoxacarb, produced an indoxacarb resistant strain with > 118 fold resistance after three generations (Shono *et al.*, 2004). One strain of oblique banded leafroller, *Choristoneura rosaceana* collected from Michigan exhibited a very high level of resistance of >700 fold resistance to indoxacarb (Ahmad *et al.*, 2002).

Selection of field collected houseflies for spinosad resistance resulted in a strain more than 150 fold resistant to spinosad within 10 generations of selection. Selection for resistance to spinosad did not result in cross resistance to other insecticides (Toshio and Scott, 2003). Studies on several insect strains suggest that strains resistant to organophosphates, organochlorines, or pyrethroids were not cross resistant to abamectin (Argentine and Clark, 1990; Scott *et al.*, 1991) and spinosad (Toshio and Scott, 2003).

Laboratory studies conducted by Stanley *et al.* (2009) revealed that the discriminating doses were fixed based on the LC₉₅ of the susceptible population of *H. armigera* as 0.80 ppm for emamectin and ten ppm for spinosad. Resistance was not observed when the discriminating doses of emamectin and spinosad were applied on field-collected populations of *H. armigera* from two intensive cotton growing areas, Coimbatore and Madurai, India. *H. punctigera* were tested for resistance to either endosulfan, pyrethroids or emamectin benzoate in cotton and other crops. There was less than one per cent resistance detected to each of the three insecticides. Louise Rossiter (2012).

Gamal and Abdu-Allah (2010) reported that based on the LD₅₀ values against 4th instar larvae of cotton leaf worm, *S. littoralis* emamectin benzoate proved to be better than spinetoram by 31516 fold. The persistence/residual efficacy under field conditions was also investigated and emamectin benzoate is one of the best bio-insecticides in controlling cotton leaf worm larvae infestations in cotton field.

Lavanya *et al.*, (2010) found that median lethal doses (LC₅₀) values were found to be 0.066 and 2.12 ppm for emamectin and spinosad to *P. xylostella* respectively. Based on LC₉₅, discriminating doses were fixed at 2 and 10 ppm for emamectin and spinosad. Revalidating the discriminating doses on field collected populations found that there was no resistance among the populations of *P. xylostella* from the three locations - Coimbatore, Ooty and Oddanchatram.

Louise Rossiter (2012) reported that to predict the development of resistance, it required 18.67 and 26.71 generations of *H. armigera* to obtain 5-fold and 10-fold increase of emamectin benzoate in LC₅₀ under selection pressure at 90 per cent mortality for each generation of selection. The bioassay of cross-resistance revealed that the LC₅₀ values of avermectin was 3.962-fold higher in resistance-selected population than that in the homologous control population, suggesting that emamectin benzoate-selected pest had cross-resistance to avermectin.

Doffou *et al.* (2011) reported that LD₅₀ values in *P. gossypiella* and *C. leucotreta* were respectively, 505.98 and 41.36µg/g for cypermethrin, 215.87 and 103.41µg/g for triazophos and 11049.06 and 3798.23µg/g for acetamiprid, respectively.

2.9. Arthropod biodiversity in cotton and okra ecosystem

Arthropods are frequently used as ecological indicators because they represent more than 80 per cent of the global species richness. They fulfill essential roles in ecosystem such as pollination, soil structure and function, decomposition and nutrient recycling, natural enemies of pest species, prey for highly valued vertebrate, etc. (Pettersson *et al.*, 1995). They have short generation times and respond quickly to ecological changes. Further, various arthropod taxa have been used to detect anthropogenic impact on ecosystems including agriculture and climate change (Parmesan, 1996 and Buddle *et al.*, 2000).

2.9.1. Insecta

The insecta have always been regarded as the most speciose class in the Animal Kingdom (Ehrlich and Wilson, 1991; Samways, 1993; Myers *et al.*, 2000). This class also constitutes a substantial proportion of terrestrial species richness and bio mass and plays a significant role in ecosystem functioning (McGeoch, 1998). Even so, known species diversity is only a small fraction of the total species diversity (Ehrlich and Wilson, 1991; Myers *et al.*, 2000).

Cotton, *Gossypium hirsutum* L., is subject to attack by a wide variety of insect pests. Hargreaves (1948) recorded 1326 species as pests. Luttrell (1994) emphasized that the number of species recorded in the crop varied from region to region with five to ten key pests causing significant crop damage. In Thailand, about 33 different species were recorded in cotton of which only 13 species are known to damage cotton each year (Cantelo and Pholboon, 1965 and Nachapong *et al.*, 1989). The abundance of insect pests depends on season length, rainfall, temperature, surrounding vegetation and agronomic practices (e.g., pest management) (Pimentel and Wheeler, 1973; Wilson, 1994).

The performance and effectiveness of natural enemies might also be enhanced by chemical cues from the associated plants (Altieri *et al.*, 1981; Nordlund *et al.*, 1988).

2.9.2. Arachnida

Spiders are the most abundant predators of insects in terrestrial ecosystems (Vanhook, 1971; Moulder and Reichle, 1972; Schaefer, 1974; Edwards *et al.*, 1976) and

form one of the most ubiquitous groups of predaceous organism in the animal kingdom (over 30000 species) (Reichert and Lockley, 1984). Occurrence of seventeen spider species in cotton fields near Shanxi Agricultural University, China (Cai *et al.*, 1999), 17 species belonging to nine families in Cauca valley of Colombia (Bastistas *et al.*, 1993), 17 species belonging to 11 families (Breene *et al.*, 1989), 101 spider species in Germany (Basedow, 1998) and 17 species belonging to eight families in Gujarat, India (Muralidharan and Chari, 1992), 21 species of spiders grouped under 16 genera belonging to eight families (Mathirajan, 2001), 2835 spiders belonging to 9 families, 41 genera and 101 species in cotton at Faisalabad (Shakila *et al.*, 2003) were reported.

The jumping spider, *Oxyopes salticus* Hentz. was the most abundant in Arkansas (Whitcomb *et al.*, 1963) and Texas (Dean *et al.*, 1982) cotton fields. *Misumenops* sp. (Plagens, 1983) and *Tetragnatha laboriosa* Gravely (Dean *et al.*, 1987) were predominant in cotton fields of Arizona. A total of 10,487 individuals from 132 species belonging to 30 families were recorded from black cotton soil habitats of Kenya (Warui *et al.*, 2004).

2.9.3. Pesticide impact on arthropod diversity

Agricultural field that were frequently subjected to pesticides often had lower spider populations (Amalin *et al.*, 2001). A decrease in spider population as a result of pesticide use could result in an out break of pest populations (Holland *et al.*, 2000; Tanaka *et al.*, 2000). Reichert and Lockely (1984) reported that a spider may kill as many as 50 times the number of prey it consumes. In agroecosystems, spiders, as generalist predators, might maintain populations in periods of low pest numbers by preying upon other insects, including harmless and beneficial insects (Nyffeler *et al.*, 1994)

Saminathan and Regupathy (2003) proved the use of untreated okra as a trap crop and application of biorational dust formulations on cotton enhanced the diversion of *Amrasca devastans* Distant (1: 1.5 to 1:3.4), *Aphis gossypii* Glover (1:1.4 to 1:3.6) and *Bemisia tabaci* Russell (1:1.2 to 1:1.9) towards okra. The preference of *A. devastans* and *A. gossypii* was towards okra as a trap crop compared to cotton and the ratio towards cotton: okra varied from 1:1.73 to 1:1.86 and 1:1.04 to 1:1.38, respectively. Use of untreated okra as a trap crop and application of NSKE on cotton increased the preference

ratio in favour of okra. The increased preference ratio towards cotton: okra varied from 1:3.07 to 1:3.13 and 1:1.68 to 1:1.76, for *A. devastans* and *A. gossypii*, respectively (Duraimurugan, 2004).

The cotton ecosystem normally contains beneficial predators and parasites in numbers that frequently provide partial to satisfactory pest control. In order to conserve natural enemies, care should be taken in the selection of appropriate insecticides for pest management to reduce the harmful effects caused by them. Preetha (2007) reported that the recommended dose of imidacloprid 17.8 SL (25 g a.i. ha⁻¹) recorded less toxic effect on the natural enemies especially coccinellids and spiders. Srinivasababu and Sharma (2003) found that imidacloprid at 12.5 g a.i. ha⁻¹ was the safest chemical against coccinellids compared to conventional insecticides like dimethoate and chlorpyrifos.

Spiders have a very significant role to play in the ecology by being exclusively predatory (Wise, 1993) and thereby regulate insect populations. Pesticide use has decreased spider populations in agro-ecosystems, affecting the ability of spiders to control pest species (Reichert and Lockley, 1984; Clausen, 1990; Young and Edwards, 1990). Similar trend was observed in the okra ecosystem. Low toxic effects of phosalone against green lacewing have been reported by Babrikova (1979). All the insecticides, irrespective of the doses, were safer to spiders as 50 per cent reduction in population was considered to be safe (Dhawan, 2000).

Preetha (2007) reported that impacts of imidacloprid on spiders in cotton and okra ecosystem were assessed. A maximum of nine and six species were observed in the cotton and okra ecosystems, respectively. The spider species, *Oxyopes javanus* Thorell, *Oxyopes rufisternum* and *Clubiona* sp (cotton) and *Thomisus* sp, *Phidippus* sp and *Clubiona* sp (okra) were predominant in the ecosystem observed. Though the application of imidacloprid reduced the population of spiders in the treated plots, it did not influence the species richness and their abundance. Suganyakanna (2006) reported that acetamiprid influenced the species richness of spiders in cotton ecosystem. All the insecticidal treatments caused a short term reduction in the spider population of cotton and okra and later they tend to increase. No values were found to be more in the untreated check which indicated the decline in the number of species in the insecticidal treatments. The evenness index (E4) revealed more even distribution of species in okra ecosystem than cotton.

Nadeem and Hamed (2011) reported that weekly data was collected from each replicate of both unsprayed and spinosad and confidor sprayed cotton plants from July to October by observing eggs, larvae and pupae of *C. carnea* from five randomly selected plants. The results showed that count of eggs on unsprayed plants was in increasing trend from 2.8 to 25 per plant, larvae from 1.3 to 6.3 while pupae were recorded as 0.4 to 3.4 per plant from July to October. Few eggs, larvae and pupae of *C. carnea* were observed in insecticide treatment from July to October which showed the survival of naturally resistant strains of this predator. The overall occurrence of *C. carnea* eggs, larvae and pupae was highest in the month of August and September while lowest in June and July.

Studies of Mellet *et al.* (2006) revealed that 945 spiders from Bt-cotton and 1486 from non Bt-cotton (control) plots were collected from the pit traps. Amalin *et al.* (2009) reported that several families in the order hymenoptera were collected in the pitfall traps throughout the sampling periods. In general, more individuals in the families Pompilidae, Scelionidae, Halictidae, Mutilidae, Apidae, and Eulophidae, were sampled in the nonsprayed area than in the sprayed area; however, no difference was observed for the family formicidae.

The most sensitive among the predators were the coccinellids. A number of studies have shown the sensitivity of coccinellids to chemical sprays, particularly broad spectrum insecticides (Ba M'hamed and Chemseddine, 2002; Iperti, 1999; Santos *et al.*, 2007). The spider lycosid was not showing sensitivity to the chemical spray. It was reported by Mansfield *et al.* (2006) that since lycosids are nocturnal and ground-burrowing they might have been less exposed to diurnal foliage sprays. Nevertheless, other studies proved that lycosids were still susceptible to insecticides such as the pyrethroid alphamethrin but less than to other insecticides such as endosulfan (van den Berg *et al.*, 1990).

Amalin *et al.* (2009) observed that higher number of spider mites and chalk mites in the sprayed area and a higher number of armored scales, eriophyid mites, and butterfly and moth larvae in the non-sprayed area. Moreover, the sampling results from both pitfall and sweeping methods showed a higher diversity and more abundant arthropod community in the non-sprayed area than in the sprayed area.

Hakim *et al.* (2011) found that the activities of natural enemies (Predators and parasitoids) were found maximum in control plot followed by neem oil, imidacloprid and profenophos indicating that neem oil (repellent) was the least toxic against natural enemies followed by imidacloprid. Amalin *et al.* (2009) reported that the order Orthoptera, more individuals were collected in the non-sprayed area than the sprayed area, especially from the second sampling period (Feb. 2000) and onward for families Acrididae and Gryllidae. Studies of Rishi Kumar *et al.* (2012) revealed that the population of predators was significantly less disrupted by the stem application method, while foliar sprays were particularly destructive to beneficial pests.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

Research investigations were carried out to evaluate the efficacy of emamectin benzoate 5 SG supplied by M/s Krishi Rasayan Pvt. Ltd., New Delhi, as foliar application against the bollworms viz., American bollworm, *Helicoverpa armigera* (Hubner), spotted bollworm, *Earias vitella* Fabricius and pink bollworm, *Pectinophora gossypiella* (Saunders) in cotton and fruit borers, *Earias vitella* and *H. armigera* in okra and its phytotoxicity, physical and biological compatibility, selective toxicity to beneficial and natural enemies, persistence and residues, resistance monitoring and arthropod diversity. The experiments were conducted both under laboratory and field conditions from December 2010 to November 2012. The laboratory experiments were carried out at the Insectary, Tamil Nadu Agricultural University (TNAU), Coimbatore and field experiments were conducted at Madhampatti, Narasimanayakkan palayam and Tamil Nadu Agricultural University. The various methodologies followed to carry out the laboratory as well as field experiments are explained below in detail.

Properties of emamectin

Chemical name	:	Emamectin benzoate
Empirical formula	:	C ₅₆ H ₈₁ NO ₁₅ (emamectin B _{1a} benzoate) + C ₅₅ H ₇₉ NO ₁₅ (emamectin B _{1b} benzoate)
Formulation	:	5 SG
Molecular weight	:	B1 a: 1008.3 B 1b: 994.2
Colour/appearance	:	Light yellow granules
Melting point	:	141 to 146°C
Content	:	95%

Structural formula

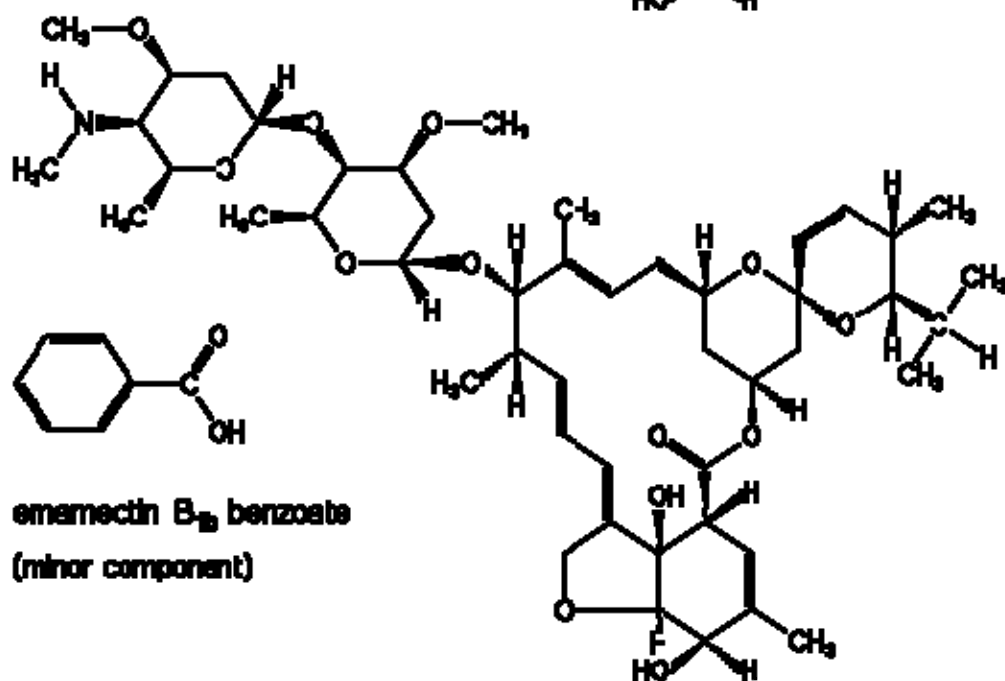
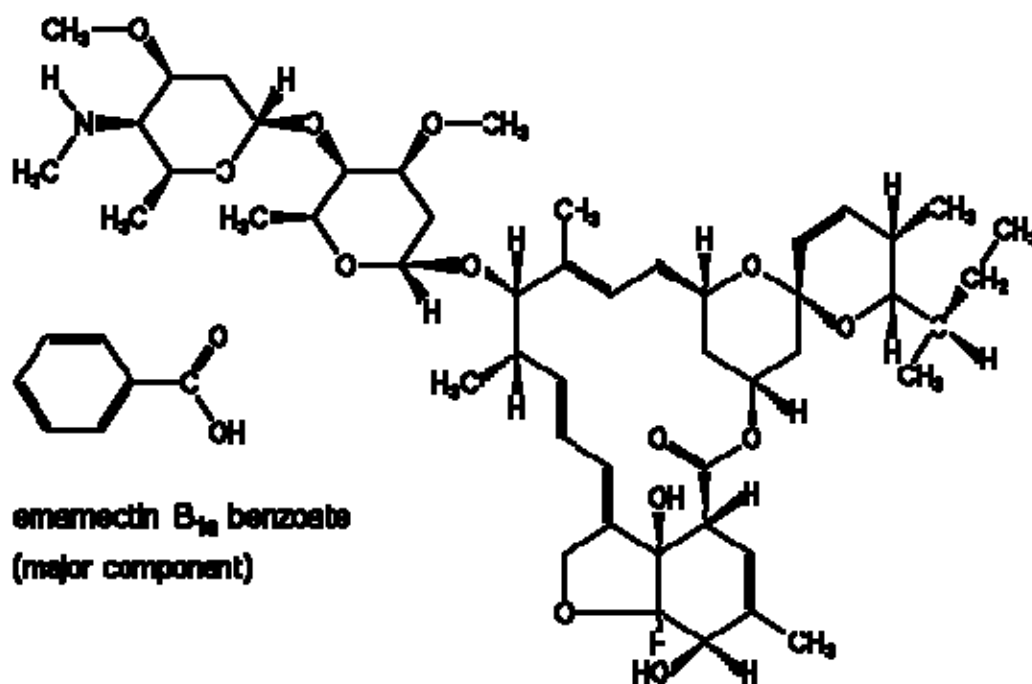


Fig 2. Structure of emamectin benzoate

A. Field experiments

3.1. Evaluation of bioefficacy

3.1.1. Cotton

Two field trials were conducted, one at Madampatti and the second at Narasimanayakkan palayam, Coimbatore district in plots of 3 m × 7 m size in a randomized block design (RBD) with seven treatments replicated thrice. The first trial was conducted from January 2011 to July 2011 using cotton variety Rasi 2000 and the second from February – August 2012 using Surabhi cotton variety, to evaluate the bioefficacy of emamectin benzoate 5 SG (EB) against bollworms in cotton (Plate 1). In the experiment I (Madampatti) two rounds of spray were given, one on 68 days after sowing (DAS) and the other on 82 DAS. Two sprays were given at 14 days interval starting from 65 DAS for experiment II (Narasimanayakkan palayam). Spraying was given with pneumatic knapsack sprayer using 1000 litres of spray fluid per hectare.

3.1.1.1. Treatments details

The insecticides used in the present investigation and their dosages were as follows.

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1.	Emamectin benzoate 5 SG	7
2.	Emamectin benzoate 5 SG	9
3.	Emamectin benzoate 5 SG	11
4.	Emamectin benzoate 5 SG	15
5.	Emamectin benzoate 5 SG (Proclaim®) (Standard check)	11
6.	Spinosad 45 SC	75
7.	Untreated Control (Water spray)	-

3.1.1.2. Methods of assessment

3.1.1.2. a. Bollworms

Observations were made on the larval population of bollworms viz., *H. armigera* and *E. vitella* on the infestation of bollworm complex in green fruiting bodies (flowers, squares, and green bolls) on the day of each spray application and 3, 5, 7 and 14 days after treatment



Plate 1. Bioefficacy of emamectin benzoate 5 SG against cotton bollworms – Field view



Plate 2. Bioefficacy of emamectin benzoate 5 SG against fruit borers of okra – Field view

(DAT) from 10 randomly tagged plants per plot and the mean was worked out as per the method followed by Thilagam (2006). Observations on open boll damage due to bollworm complex were also recorded.

3.1.1.2. b. Natural enemies

In both the field trials, the natural enemies' fauna viz., spiders and coccinellids were recorded and the diversity of spiders was assessed in experiment I and II in insecticide treated plots in cotton ecosystem. The number of spiders and coccinellids were recorded on 10 randomly tagged plants per plot prior to application of insecticides and on 3, 7, 10 and 14 DAT in order to assess the effect of insecticides.

3.1.1.3. Yield

Cotton yield per plot was recorded from each picking and pooled to arrive at the total yield. Finally, it was computed to quintal ha⁻¹ and the same was subjected to statistical analysis.

3.1.2. Evaluation of bioefficacy (Okra)

3.1.2.1. Fruit borers in okra

Two field experiments were conducted one at Madhampatti (September 2010-December 2010) and second at Narasimanayakkan palayam (Aug 2011 – November 2011) to test the efficacy of different doses of emamectin benzoate against okra fruit borers viz., *H. armigera* and *E.vittella* (Plate 2). The experiments were conducted using RBD with seven treatments replicated thrice with a plot size of 4 × 5 m using the variety Mahyco 10.

3.1.2.2. Treatments details

The treatments imposed were as follows:

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1.	Emamectin benzoate 5 SG	4.7
2.	Emamectin benzoate 5 SG	6.7
3.	Emamectin benzoate 5 SG	8.5
4.	Emamectin benzoate 5 SG	11
5.	Emamectin benzoate 5 SG (Proclaim®) (Standard check)	8.5
6.	Spinosad 45SC	75
7.	Untreated Control (Water spray)	-

A second spray was given 14 days after first application or considering the larval population and per cent damage crossing the ETL. The treatments were imposed commencing from 30th day after planting with pneumatic knapsack sprayer using 500 litres of spray fluid per hectare.

3.1.2.2. Methods of assessment

3.1.2.2.a. Fruit borers

The observations on larval population of *H. armigera* and *E. vittella* and their damage on okra fruits were recorded on ten randomly tagged plants per plot before insecticide application and at 3, 7, 10 and 14 days after spraying. The fruit damage was assessed based on bore holes found on the fruit. The total number of fruits and infested fruits in ten randomly selected plants per plot were counted and the per cent fruit damage was worked out as per the method followed by Shobanadevi (2003). The larval population and the yield of fruits were also recorded.

3.1.2.3. b. Natural enemies

Incidence of natural enemy fauna viz., spiders and coccinellids was recorded in both insecticides treated and untreated plots in okra ecosystem, in both the field trials.

The number of spiders and coccinellids was recorded on 10 randomly tagged plants per plot prior to application of insecticides and at 3, 7, 10 and 14 days after spraying in order to assess the effect of insecticides.

3.1.2.4. Yield

Okra yield per plot was recorded from each picking and pooled to arrive at the total yield. Finally, it was computed to kg ha⁻¹ and the same was subjected to statistical analysis.

3.2. Evaluation of phytotoxicity

3.2.1. Cotton

To evaluate the phytotoxicity (if any) caused by emamectin benzoate on cotton, two field experiments were conducted at Madhampatti with variety Rasi 2000 and Narasimanayakkan palayam (cultivar-Surabhi) during January 2011 to July 2011 and February 2012- August 2012, respectively. The experiments were conducted in a randomized block design in a plot size of 3 m × 7 m with five replications.

The treatment details were as follows.

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1	Emamectin benzoate 5 SG	11
2	Emamectin benzoate 5 SG	22
3	Emamectin benzoate 5 SG	44
4	Untreated check	-

3.2.1.1. Method of assessment

The plants were observed on 1,3,5,7, 10 and 14 DAT for the phytotoxic symptoms such as injury to the leaf tip, wilting, necrosis, vein clearing, epinasty and hyponasty on the plants. The extent of phytotoxicity was recorded based on the scale prescribed by Central Insecticide Board and Registration Committee (C.I.B and R.C).

Leaf injury was assessed by visual rating in a 0-10 scale

Rating	Phytotoxicity (%)
0	No phytotoxicity
1	1-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81-90
10	91-100

The per cent leaf injury was calculated using the formula,

$$\text{Per cent leaf injury} = \frac{\text{Total grade points}}{\text{Maximum grade} \times \text{Number of leaves observed}} \times 100$$

3.3.2. Okra

To evaluate the phytotoxicity if any caused by emamectin benzoate on okra, field experiments were conducted at Madhampatti during (September 2010 - December 2010) and second at Narasimanayakkan palayam during (Aug 2011 – November 2011) on F₁ hybrid (Mahyco-10). The experiments were conducted in a randomized block design with five replications. The treatment details were as follows.

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1	Emamectin benzoate 5 SG	8.5
2	Emamectin benzoate 5 SG	17
3	Emamectin benzoate 5 SG	34
4	Untreated check	-

Observations were made as described in cotton under section 3.2.1.1.

3.3. Biological compatibility

3.3.1. Pot culture experiment on cotton

An experiment with the following treatments was conducted in a completely randomized design and replicated thrice to study the biological compatibility using non *Bt* cotton variety *Surabhi* grown in pots.

The recommended level of emamectin benzoate was mixed with water and to this solution, the fungicide and insecticide at recommended concentrations were added and mixed thoroughly. The potted plants were sprayed with these solutions on 30th day after sowing at the rate of 15 ml plant⁻¹. The plants were observed on 3, 7, 10 and 14 days after spraying and the phytotoxic symptoms were observed as under section 3.2.1.1. (Plate 3).



Plate 3. Biological compatibility of emamectin benzoate 5 SG with agrochemicals on cotton



Plate 4. Biological compatibility of emamectin benzoate 5 SG with agrochemicals on okra

The treatment details were as follows.

Sl.No	Treatments	Dose (g a.i. ha ⁻¹)
1	Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	11 + 25
2	Emamectin benzoate 5% SG + Carbendazim 50 WP	11 + 0.1%
3	Emamectin benzoate 5% SG + Buprofezin 25 SC	11 + 200
4	Emamectin benzoate 5% SG + Mancozeb 75 WP	11 + 0.2%
5	Lambda cyhalothrin 5 CS	25
6	Carbendazim 50 WP	0.1%
7	Buprofezin 25 SC	200
8	Mancozeb 75 WP	0.2%
9	Untreated control (Water spray)	-

3.3.1. 1. Field experiment (Cotton)

A field experiment with the treatments described in section 3.3.1. was conducted at Tamil Nadu Agricultural University in RBD and replicated thrice to study the biological compatibility of emamectin benzoate with commonly used pesticides in cotton ecosystem using Surabhi during April- September 2012. The recommended effective dose of emamectin benzoate was mixed with lambda cyhalothrin 5% CS, buprofezin 25 %WP, mancozeb 75 % WP and carbendazim 50% WP at recommended concentrations and mixed thoroughly. Treatments were imposed on 60th day after sowing with pneumatic knapsack sprayer using 1000 litres of spray fluid per hectare and a second spray was given 14 days later. The plants were observed for phytotoxic symptoms, as described in section 3.2.1.1. The plants were also observed larval population as mentioned in section 3.1.1.2. a.

3.3.2. Pot culture experiment on okra

For observing the visible phytotoxic effects of the combination products, F₁ hybrid (Mahyco-10) was grown in pots (Plate 4). The experiment with the following treatments was conducted in a completely randomized design and replicated thrice.

The treatment details were as follows.

Sl.No	Treatments	Dose (g a.i. ha ⁻¹)
1	Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	8.5 + 25
2	Emamectin benzoate 5% SG + Carbendazim 50 WP	8.5 + 0.1%
3	Emamectin benzoate 5% SG + Buprofezin 25 SC	8.5 + 200
4	Emamectin benzoate 5% SG + Mancozeb 75 WP	8.5 + 0.2%
5	Lambda cyhalothrin 5 CS	25
6	Carbendazim 50 WP	0.1%
7	Buprofezin 25 SC	200
8	Mancozeb 75 WP	0.2%
9	Untreated control (Water spray)	-

The recommended level of emamectin benzoate was mixed with water and to this solution, the fungicide and insecticides at recommended concentrations were added and mixed thoroughly. The potted plants were sprayed with these solutions on 30th day after planting at the rate of 15 ml plant⁻¹. The plants were observed on 1,3,5,7, 10 and 14 days after spraying and phytotoxicity symptoms were scored as mentioned in section 3.2.1.1.

3.3.3. Field experiment (Okra)

A field experiment was conducted at Tamil Nadu Agricultural University with the treatments described in section 3.3.2 in RBD and replicated thrice to study the biological compatibility of emamectin benzoate with commonly used pesticides in okra ecosystem using Mahyco 10 during July 2012 – September 2012. The recommended effective dose of emamectin benzoate was mixed with water and to this solution, the insecticides and fungicide at recommended concentrations were added and mixed thoroughly. Treatments were imposed twice: one at 30th day after planting and the second, 14 days later with pneumatic knapsack sprayer using 500 litres of spray fluid per hectare and observations

on phytotoxic symptoms were scored as mentioned in section 3.2.1.1. and observations on pest incidence as mentioned in section 3.1.2.3a.

B. Laboratory experiments

3.4. Culturing of test insects

3.4.1. Cotton bollworms

3.4.1.1. *Pectinophora gossypiella*

Initial culture was developed from fourth instar larvae and pupae collected from freshly harvested cotton from Coimbatore. The larvae that were about to pupate were placed in cotton in a petri dish for pupation. The pupae were collected and placed in oviposition cages. Cotton twig with a square and a leaf kept in glass vial and plugged with cotton served as oviposition substratum (Plate 5). The moths were provided with 10 per cent sucrose solution fortified with a few drops of vitamin mixture (ABDEC drops) to enhance oviposition. Whitish elongate eggs were laid on the under surface of leaves and on squares. The twigs were replaced once in three days with fresh ones. After hatching, the neonate larvae were reared individually on cotton flowers (Sivasubramanian, 1991).

3.4.1.2. American Bollworm, *H. armigera*

The Coimbatore strain of *H. armigera* was cultured in the laboratory using chickpea based diet standardized by Sathiah (2001) (Plate 6).

3.4.1.2 a. Larval rearing

Larvae of *H. armigera* collected were reared separately in semi-synthetic diet till pupation. Chickpea seeds were soaked overnight, boiled in water and blended along with 375 ml of water, yeast (30 g). Agar 13g was melted simultaneously in 375 ml of water. After fine grinding of chickpea seeds, molten agar and the other ingredients were added in to the blender and mixed thoroughly. The hot diet was poured in to sterilized 12 well tissue trays to a depth of 5 mm before solidification using plastic squeeze bottle for rearing larvae. The diet was also poured in to 30 x 15 x 15 cm plastic trays used for neonate larval rearing. The trays containing the diet were kept at room temperature for an hour. Upon solidification, they were covered, inverted and placed inside the biological oxygen demand (BOD) incubator. The 12-well diet trays with larvae for feeding were replaced with fresh ones on alternate days.



A. Oviposition cage



B. Larval rearing

Plate 5. Mass culturing of *P. gossypiella*

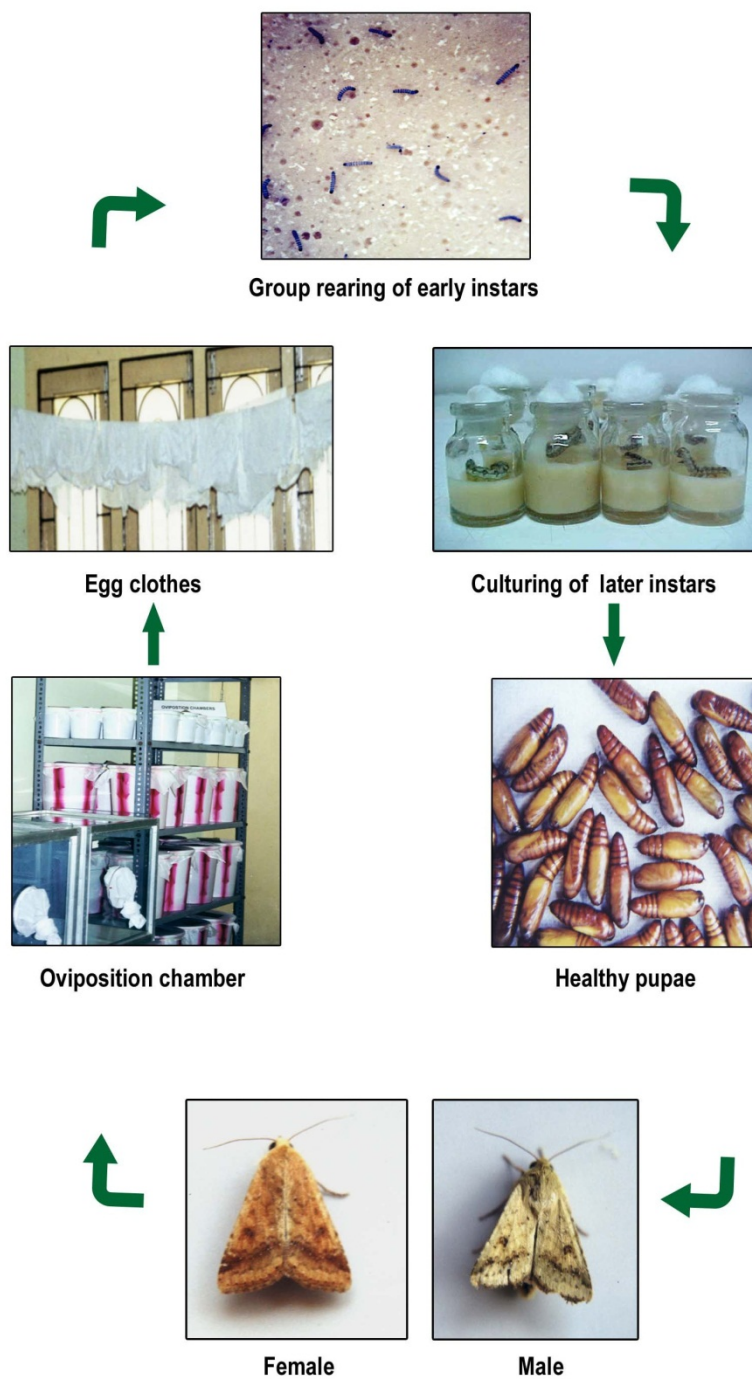


Plate 6. Mass culturing of *Helicoverpa armigera*

The utilized diet trays were cleaned with water and kept in 0.5 per cent sodium hypochlorite solution overnight, rinsed thrice in clean water and allowed to sun dry before reuse.

3.4.1.2 b. Adult rearing

The pupae from the culture were collected and placed in a 30 x 30 x 30 cm adult emergence cage. Five pairs of newly emerged adults were transferred to plastic buckets of seven-litre capacity maintaining the sex ratio of 1:1 for oviposition. Adults were fed with 10 per cent sugar solution enriched with ABDEC® multivitamin solution, provided in a 5ml glass vial with a cotton wool wick filling the mouth to prevent the moths from drowning. The mouth of the bucket was covered with sterile muslin cloth, which served as oviposition substrate. The buckets were kept in a dark place at 25° C and 70-75 per cent relative humidity (RH).

3.4.1.2 c. Egg collection

Muslin cloth laid with eggs was collected from third day onwards, replaced with fresh one daily and placed in plastic container covered with lid, which was kept inside another container with a layer of water to maintain humidity. After formation of distinct germ band in eggs, the egg clothes were surface sterilized with 10 per cent formalin for 10 minutes and washed in running tap water for 20 minutes to prevent the incidence of nucleopolyhedrovirus (NPV) in culture. Egg clothes were shade dried at room temperature (27-32°C) and brought back to another sterile humidified chamber for hatching. Newly hatched larvae were transferred to plastic trays (30 x 15 x 5 cm) having the diet. When the larvae attained second instar they were transferred to 12-well trays individually in order to avoid cannibalism. The reared larvae were used for bioassay and persistent toxicity studies.

3.4.1.3. Spotted bollworm, *E. vittella*

Larvae of different instars were collected from cotton and okra from farmer's field at Deenampalayam and reared on okra fruit. The choice of this food medium was based on earlier findings that development time was the shortest on okra fruit (Vishwapremi and Krishna, 1974; Senapati *et al.*, 1978; Ambegaonkar and Bilapatte, 1984).

Fresh and tender okra fruits were collected from okra plants grown under insecticide free condition. The fruits were cut into pieces of 2.5 cm long and placed in 12-well cavity trays (Plate 7). Using camel hair brush, the larvae were transferred on fruits. Filter paper of same size as that of the tray was placed over the fruits in order to absorb excess moisture thereby preventing rotting of fruits. The tray was then covered using plastic lid and fastened by a rubber band. Fresh fruit pieces were provided on alternate days. The boat shaped cocoons were collected and placed in adult emergence cage (30x30x30 cm). Newly emerged adults were provided with ten per cent sugar solution fortified with ABDEC multivitamin solution in 5 ml glass vial with cotton wool wick placed in mouth to prevent the moths from drowning. Four to five tender okra fruits were kept in cages as oviposition substrates. These fruits were removed the next day of egg laying and observed for hatching of eggs. The newly hatched first instar larvae were provided with cut pieces of okra fruit. This represented F₁ generation. The larva reached third instar on 6-7 days after hatching. Those with weight ranging between 0.0638 and 0.0857 g larva⁻¹ and length of 0.8 to 1.0 cm alone were used for conducting the laboratory experiments (Somasundaram, 1984).

3.5. Assessment of safety of emamectin benzoate 5 SG to natural enemies

Laboratory experiments were conducted with seven treatments replicated three times to assess the safety of emamectin benzoate to the egg parasitoid, *Trichogramma chilonis* Ishii, egg-larval parasitoid, *Chelonus blackburni* Cameron, predatory green lacewing, *Chrysoperla carnea* (Stephens). Insecticidal solutions were prepared by dissolving 0.14, 0.18, 0.22 and 0.6 g of emamectin benzoate 5 SG, 0.22 g of emamectin Benzoate (Proclaim® at the recommended dose of 11 g a.i. ha⁻¹), and 0.16 ml of spinosad 45 SC, each in one litre of water which were equivalent to the field doses.

3.5.1. Effect of emamectin benzoate 5 SG on *T. chilonis* Ishii

3.5.1.1. Mass culturing of host insect

Corcyra cephalonica (Stainton) was reared in the laboratory as per the method described by Navarajanpaul (1973). The adult moths were allowed inside an oviposition cage of 21 x 25 x 20 cm size, with a wire mesh at the bottom for easy collection of eggs and lateral sides for ventilation. Adults were fed with 50 per cent honey solution. Eggs were collected from the oviposition cages daily up to four days and cleaned with sieves



A. Oviposition cage



B. Larval rearing

Plate 7. Mass culturing of *E.vittella*

or egg separator. The cleaned eggs were sprinkled over half ground cumbu grains, at the rate of one cc per 2.5 kg of grains fortified with ten grams of yeast in a plastic basin (45 x 30 x 10 cm) and covered with kada cloth. Care was taken to maintain the culture free of storage mites and diseases by mixing five grams of wettable sulphur (80 WP) and streptomycin sulphate 0.5 per cent, respectively. The emerged adults were collected and used again for culturing both host (*C. cephalonica*) and parasitoid (*T. chilonis*). The culture was maintained at room temperature ($28 \pm 2^\circ\text{C}$ and $80 \pm 5\%$ RH).

3.5.1.2. Mass culturing of *T. chilonis*

The egg parasitoid, *T. chilonis* was mass cultured in the Biocontrol Laboratory on the eggs of rice moth, *C. cephalonica* as per the method described by Prabhu (1991). Fresh *C. cephalonica* eggs collected in the morning were sterilized under UV radiation of 15 W capacity for 20 minutes at a distance of 15 cm, to avoid the emergence of *C. cephalonica* larvae. These eggs were pasted on paper cards of 20 x 30 cm size having thirty, 7 x 2 cm rectangles. These egg cards were placed in polythene bags along with nucleus card at 6:1 ratio for parasitisation by the egg parasitoids. The parasitised egg cards were cut into one cm² bits and three days old 100 per cent parasitised eggs (eggs appearing black and plumpy) were used for the study.

3.5.1.3. Parasitisation study

Corcyra egg cards were sprayed with insecticide solution at different concentrations as given in 3.5. The treated egg cards were cut into bits of 6 x 1 cm² and the parasitized egg cards into 1x1 cm². One bit of treated egg card and one bit of parasitized egg card were put into a test tube (6:1 ratio) (Plate 8) and the number of parasitised eggs (eggs appearing black and plumpy) were recorded after 48 h of *Trichogramma* adult emergence and the per cent parasitisation was worked out using the formula,

$$\text{Per cent parasitisation} = \frac{\text{No. of parasitised eggs}}{\text{Total no. of } \textit{Corcyra} \text{ eggs}} \times 100$$



a. Adult emergence



b. Parasitization

Plate 8. Safety of emamectin benzoate 5 SG against *T. chilonis*

The mortality data was categorized as per method given by Kuttalam, 1999.

Mortality (%)	Category
≤ 50	Harmless
50 – 70	Slightly harmful
80 – 99	Moderately harmful
> 99	Harmful

3.5.1.4. Adult emergence study

The parasitised egg cards having three days old 100 per cent parasitised eggs were cut into one cm² bits and sprayed with insecticides at different concentrations mentioned as in section 3.5. using an atomizer. For untreated check, only distilled water was sprayed. The treated egg cards were shade dried for 10 min and then kept in a test tube of 10 x 1.5 cm size (Plate 8). The number of parasitoids that emerged from each treatment was recorded after 48 h of treatment and per cent emergence was worked out using the formula,

$$\text{Per cent emergence} = \frac{\text{No. of wasps emerged (eggs with emergence slit)}}{\text{Total no. of eggs in 1 cm}^2} \times 100$$

3.5.2. Effect of emamectin benzoate 5 SG on adults of *C. blackburni* - Dry film method

The adults of *C. blackburni* were obtained from Bio Control Laboratory, Department of Agricultural Entomology, T.N.A.U.

3.5.2.1. Safety tests

The bioassay method described by McCutchen and Plapp (1988) for *C. carnea* was adopted with modifications. Glass scintillation vials of 20 ml capacity and 1mm thickness were evenly coated with 0.5 ml of acetone solution containing insecticide formulations as in section 3.5. and dried by rolling for few seconds. Three-day-old adults of *Chilonus blackburni* Cameron were released into the vials at 10 per vial and covered with muslin cloth and secured with a rubber band. After 1h of exposure, they were released in test tubes (15 cm ht x 2.5 cm dia.) and honey solution (20%) was given as feed to the adults. Mortality observations were taken at 6, 12 and 24 h after treatment. For untreated check, only acetone was used. Per cent mortality of the adults was worked out.

$$\text{Per cent mortality} = \frac{\text{No. of adults dead}}{\text{Total number of wasps released}} \times 100$$

3.5.3. Larval parasitoid, *Bracon hebetor* Say

The adults of *B. hebetor* were obtained from Bio Control Laboratory, Department of Agricultural Entomology, T.N.A.U.

3.5.3.1. Selective toxicity of emamectin benzoate on the adults of *B. hebetor*

The bioassay method described by McCutchen and Plapp (1988) for *C. carnea* was adopted with modifications. Different concentrations of insecticide solutions were prepared using acetone and water in the ratio of 80:20.

Glass scintillation vials of 20 ml capacity with 1 mm thickness were evenly coated with 0.5 ml of insecticide formulations dissolved in acetone: water and dried by rotating the vials placed horizontally on the table with palm. The adults of *B. hebetor* were released into the vials at the rate of 10 vial⁻¹, covered with muslin cloth and secured with a rubber band. After an h of exposure, honey solution was provided as feed to the adults. Mortality observations were made at 24 and 48 h after treatment and per cent mortality of the adults was worked out as in 3.5.2.1.

3.5.4. Selective toxicity of emamectin benzoate 5 SG on predators

3.5.4.1. Effect of emamectin benzoate 5 SG on *C. carnea*

Mass rearing of *C. carnea* was done with *C. cephalonica* eggs as feed following the method described by Swamiappan (1996).

3.5.4.1a. Mass rearing of *C. carnea*

Grubs of *C. carnea* were reared in galvanized iron (GI) basins (30 cm dia. x 12 cm ht) at 250 larvae basin⁻¹ covered with kada cloth. The eggs of *C. cephalonica* were provided as feed for the grubs in the laboratory. About 25cc of *C. cephalonica* eggs basin⁻¹ were provided on alternate days. Usually after five feedings, the larvae pupated into white coloured round silken cocoon. The cocoons were collected and transferred into one litre plastic container with wire mesh window for emergence of adults.

The adults were collected and transferred to GI troughs, wrapped inside with brown sheets for collecting the eggs. The trough was covered with nylon cloth and kept firm with the help of a rubber band. Over the cloth covering, two bits of foam sponge (2.5 cm²) dipped in water were kept besides an artificial protein rich diet in the form of semi solid paste was smeared. This diet consisted one part of fructose, one part of honey and one part of Protinex[®] with water to make it just a paste. The adults laid eggs on the brown sheet wrapped inside the trough. The adults were collected daily and allowed into fresh rearing troughs with fresh feed. From the old troughs, the brown paper sheets along with eggs were removed and used for hatchability experiments or for culturing.

3.5.4.1b. Effect of emamectin benzoate 5 SG on green lacewing, *C. carnea*

Laboratory studies were conducted to assess the effect of emamectin benzoate on the eggs of *C. carnea*, as per the method described by Krishnamoorthy (1985). The eggs along with stalk collected on brown paper strips were sprayed with various dilutions as in section 3.5 Using an atomizer (Plate 9). Each treatment was replicated three times with 30 eggs per treatment. Untreated check was maintained by spraying distilled water. The number of grubs hatching from each treatment was recorded and per cent hatchability was worked out by the formula,

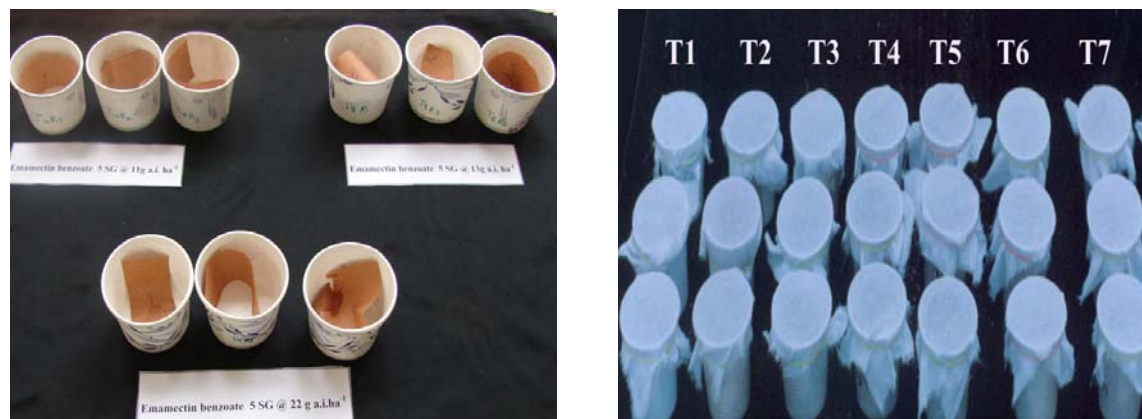
$$\text{Hatchability (\%)} = \frac{\text{No. of grubs hatched}}{\text{Total number of eggs}} \times 100$$

Observations were also made on pupation and adult emergence.

3.5.4.1c. Effect of emamectin benzoate on the Grubs of *C. carnea*

(i). Dry film method

The bioassay method described by McCutchen and Plapp (1988) was adopted with modifications according to Chelladurai (1999). Different concentrations of insecticide solution mentioned in section 3.5. were prepared using acetone. Glass scintillation vials of 20 ml capacity were evenly coated with 0.5 ml of insecticide solution dissolved in acetone and dried by rotating the tube horizontally on a table with palm. Second instar predatory lacewing grubs were released into the vials @ 10 per vial and



a. Effect of emamectin benzoate 5 SG on *C. carnea* Stephens eggs



b. Effect of emamectin benzoate 5 SG on the grubs of *C. carnea* – Dry film method

Plate 9. Safety of Emamectin benzoate 5 SG against *C. carnea*

covered with muslin cloth secured with a rubber band (Plate 9). After 1h exposure of the grubs, they were released in test tubes, 1cc *Corcyra* eggs given as feed and observations on the mortality of the grubs made. Observations were made on the grub mortality (6, 12, and 24 h after treatment), pupation and adult emergence.

$$\text{Per cent grub mortality} = \frac{\text{No. of grubs dead}}{\text{Total number of grubs}} \times 100$$

3.6. Evaluation of toxicity of emamectin benzoate 5 SG to non- target organism

3.6.1 Honeybees

A laboratory experiment was conducted to assess the safety of emamectin benzoate to the workers of Indian bee, *Apis cerana indica* Fab., Rock bee,, *Apis dorsata* Fab. and stingless bee, *Trigona iridipennis* smith. with the bees maintained in Insectary, TNAU, Coimbatore. The experiment consisted of treatments mentioned under section 3.5. and each treatment was replicated three times.

The effect of emamectin benzoate was assessed by contact toxicity method. Different concentrations of emamectin benzoate were prepared using distilled water. Plastic containers with perforations were used for the experiment to allow adequate aeration for the bees (Plate 10). Filter paper discs were wetted with 1 ml of different concentrations of insecticides dissolved in distilled water and allowed to dry by hanging in a string. Shade dried filter paper was placed in the bioassay container and honey bees were released at the rate of 10 per container. Three days old worker honeybees were kept in refrigerator prior to test so as to calm them which helped easier transfer. After exposure for 1 h, honey bees were allowed in a big polythene bag perforated using pins and 40 per cent sucrose solution soaked in cotton wool tied in a twine was provided as feed for the honeybees. The bee mortality was observed after 6, 12 and 24 h of treatment and corrected per cent mortality worked out. Corrections were carried out for mortality in the control.



Plate 10. Safety of emamectin benzoate 5 SG to honey bees

3.6.2. Earthworms

3.6.2.1. Evaluation of emamectin benzoate 5 SG to earthworm *Eudrilus eugeniae* (Kinberg)

The effect of emamectin benzoate on earthworm *E. eugeniae* was tested by following the artificial soil test method proposed by Biologische Bundesanstalt für Land-und Forstwirtschaft, Braunschweig (BBA) as reported by Ganeshkumar (2000). The culture of *E. eugeniae* was obtained from Central farm unit, TNAU, Coimbatore.

One kg each of soil and cow dung separately in tubular pots (18 x 6 cm) was treated with different doses of emamectin benzoate and 15 earthworms washed cleanly in water were placed on the top of the substrate. The tubular pots were covered with perforated polythene cover to prevent the worms from crawling out and to avoid evaporation (Plate 11). The set up was kept under shade. After 7 days, 5 g of finely ground dried cow dung was mixed inside the container and water lost by evaporation was replaced. The numbers of live earthworms were counted. Earthworms were considered dead if they did not respond to a gentle mechanical stimulus (Edwards and Bohlen, 1992).

3.7. Persistent toxicity

3.7.1. Evaluation of persistent toxicity of emamectin benzoate 5 SG to *H. armigera* on cotton

Pot culture experiments were conducted in the glass house in order to assess the persistent toxicity of emamectin benzoate as foliar application against third instar larvae of *H. armigera* with the following treatments in a completely randomized block design (CRD) and replicated thrice.

Insecticidal solutions were prepared as mentioned in 3.5. Non *Bt* cotton plants (Rasi 2000) grown in pots were sprayed with the insecticides at the respective concentrations at 60 days after sowing at the rate of 15 ml per plant using an atomizer. The leaves and shoot portion bearing flowers of cotton were cut after 1, 3, 7, 9, 11, 13, 15, 17, 19, 21 and 23 days after application and brought to the laboratory. Single third instar larva was released into each plastic cups and 10 tubes made one replication. Observations on larval mortality were recorded from each treatment at 24 h interval. For comparing the relative efficacy of different



a. Magnified view of *Eudrilus eugeniae*



**b. Release of earthworms in the pot
Kinberg**



c. Different treatments of emamectin benzoate

Plate 11. Acute toxicity experimental setup to *E.eugeniae*

treatments, index of persistent toxicity values were calculated from mortality data as per the method method given by Pradhan (1967). Persistent toxicity index (PTI) = Period for which toxicity persisted (P) X Average residual toxicity (T).

3.7.2. Evaluation of persistent toxicity of emamectin benzoate 5 SG to *E. vittella* on okra

Pot culture experiments were conducted in the glass house (insectary) in order to assess the persistent toxicity of emamectin benzoate against *E. vittella*. Thirty days old potted okra plants (Mahyco 10) were used for the study. Insecticidal solutions were prepared as mentioned in 3.6. Treated okra fruits were taken from the plants at different time intervals. Single third instar larva was released in to each plastic cup and 10 tubes made one replication.

Observations on larval mortality were recorded from each treatment at 24 h interval. For comparing the relative efficacy of different treatments, index of persistent toxicity values were calculated from mortality data as per the method given by Pradhan (1967).

3.8. Acute toxicity studies

The dilutions required for the insecticidal assays were prepared from technical grade insecticides of known purity diluted with analytical grade acetone and used for topical assays

3.8.1 Topical bioassay for *E. Vittella*, *H.armigera* and *P. gossypiella*

Topical application method was followed. Third instar larvae were assigned to topical application on the dorsal thorax with 1.0 µl of required concentrations of technical insecticides in methanol with a Hamilton repeating dispenser (Plate 12). A minimum of 30 larvae were used per concentration. After treatment, larvae were held individually in their respective diets viz., okra fruit for spotted bollworm and cotton flowers for pink bollworm and synthetic diet for *H.armigera* at 25 (± 2°C) for 24 h when mortality was recorded. Larvae were considered dead if they were unable to move in a co-ordinate manner when prodded.

3.8.2 Establishment of base line data

Preliminary range finding tests were conducted to attain series of doses which gives a range of kills from 10 to 100 per cent. Since, the insecticides used were newer, to

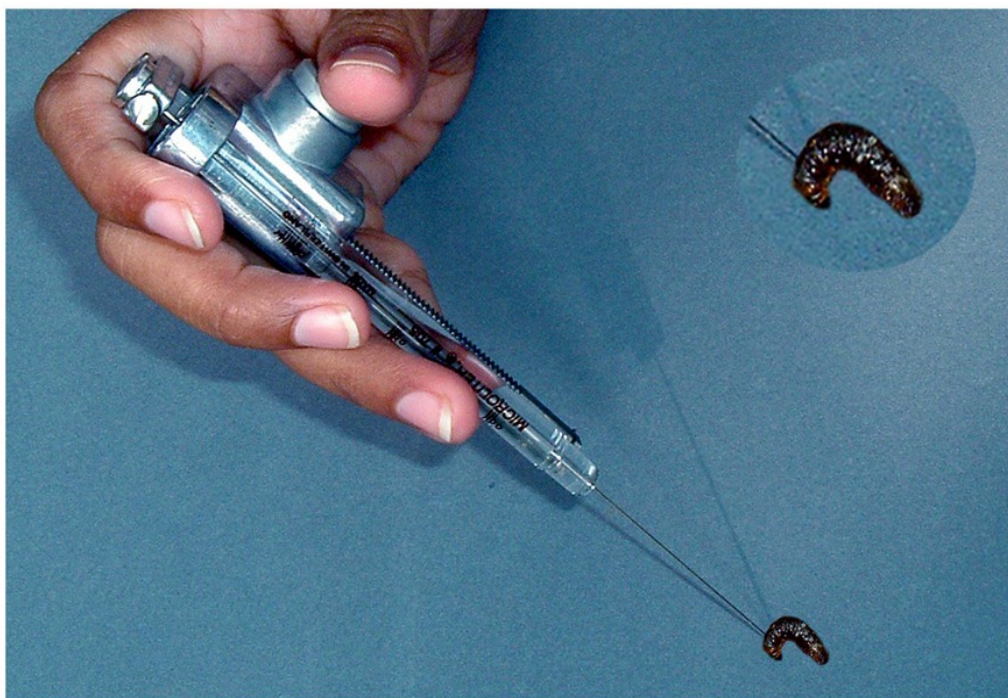
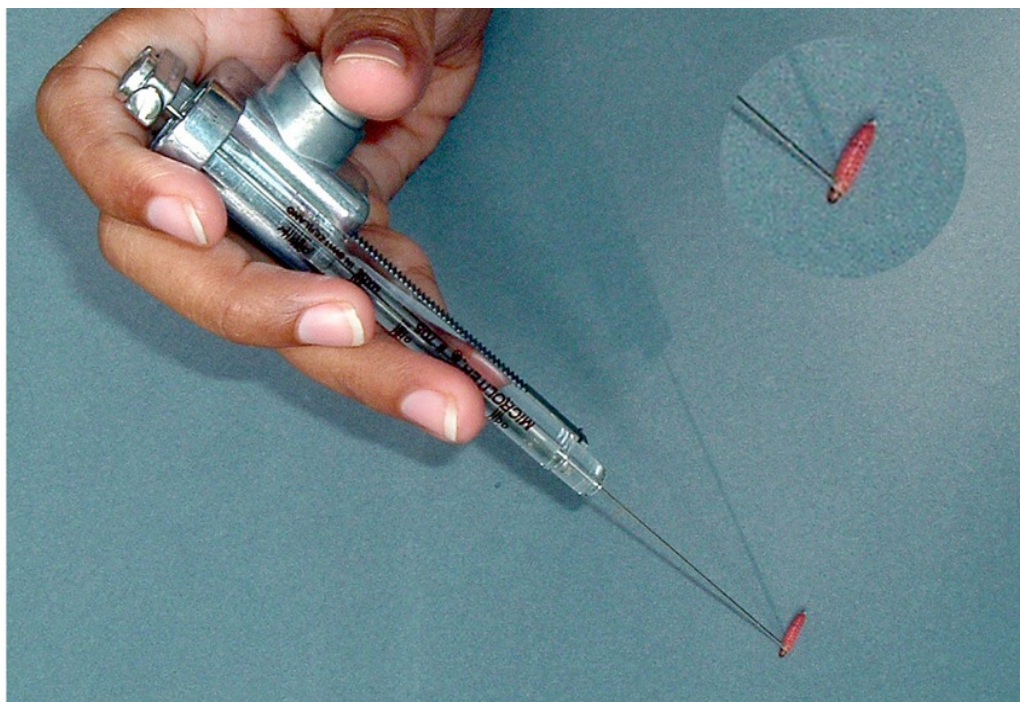


Plate 12. Topical application on *E. vittella* and *P. gossypiella* larvae

generate the base line data, larvae not exposed to insecticides were cultured continuously without any selection pressure through out the generations up to F₉. Bioassay was conducted based on the dosages obtained from the preliminary range finding test to construct log dose probit mortality line for susceptible population.

Discriminating doses of the emamectin benzoate were tentatively fixed based on LD₉₅ values obtained for ninth generation of Coimbatore population.

3.9. Monitoring of emamectin benzoate resistance

Based on Discriminating doses for *H.armigera*, *E.vitella* and *P. gossypiella* was used for monitoring. Field level monitoring of emamectin benzoate resistance were assessed based on the mean mortality of larvae at discriminating dose. The larval populations for monitoring were collected from five districts viz., Coimbatore, Erode, Salem, Madurai and Dharmapuri in Tamil Nadu. Finally, the mean per cent mortality of larvae at 24h and 48 h were arrived for the different districts of Tamil Nadu.

3.9.1. Risk assessment factors

3.9.1.1. Selectivity ratio

Selectivity ratio was calculated as

$$\text{Selectivity ratio} = \frac{\text{LD}_{50}/\text{LC}_{50} \text{ of } X}{\text{LD}_{50} / \text{or } \text{LC}_{50} \text{ of } Y}$$

where X = the beneficial species (µg/g)

Y = the pest species (µg/insect)

3.9.1.2. Probit substitution

This method was used to determine relative toxicities of beneficial species at particular levels of pest mortality. This method involved substituting the log LD₉₀ (µg/insect) and its 95 per cent fiducial limits for the pest species into modified probit equations (Finney, 1971) for each insecticide and beneficial species. The equation used is as follows,

$$Y=5+m(x-[\log \text{LC}_{50} \text{ of beneficial species}])$$

Where, Y = probit value,

m = the slope of the probit line for the beneficial species,

x = log of the fiducial limits for the LD_{90} of the pest species.

Solving for Y gives a probit value which is then converted to percentage of mortality using a conversion table (Finney, 1971).

3.9.1.3. Hazard ratio

The hazard ratio was calculated as given below on the lines of Felton *et al.* (1986). Hazard ratio = recommended field rate (g a.i.ha⁻¹/LC₅₀ (µg/g)

Insecticides with hazard ratio

Less than 50	Harmless
50 to 2,500	slightly to moderately toxic
More than 2,500	Dangerous

3.9.1.4. Sequential testing scheme

Hazards of insecticides to nontargets was assessed using Sequential testing scheme on the lines of (Johansen and Mayer, 1990).

LC ₅₀ (µg/g)	=	> 100 µg/g	=	nontoxic product
LC ₅₀ (µg/g)	=	11-100 µg/g	=	slightly toxic product
LC ₅₀ (µg/g)	=	2 to 10.9 µg/g	=	moderately toxic product
LC ₅₀ (µg/g)	=	< 2 µg/g	=	highly toxic product

3.9.2. Probit analysis

The median lethal dose (LD₅₀) and median lethal concentration (LC₅₀) of insecticide used were determined by Finney's probit analysis (Finney, 1971). The corrected per cent mortality was worked out using the formula (Abbott, 1925).

$$\text{Per cent corrected mortality} = \frac{\text{Percentage test mortality} - \text{Percentage control mortality}}{100 - \text{Percentage control mortality}}$$

3.9.3. Susceptibility index and rate of resistance decline

Susceptibility indices were calculated based on LC₅₀ and LC₉₅ obtained for final generation maintained without insecticidal exposure (Regupathy and Dhamu, 2001).

$$\text{Susceptibility index} = \frac{\text{LC}_{50} \text{ of } F_1}{\text{LC}_{50} \text{ of } F_n} \text{ or } \frac{\text{LC}_{95} \text{ of } F_1}{\text{LC}_{95} \text{ of } F_n}$$

The rate of resistance decline (R) used to quantify the rate of changing LC₅₀ when the selection pressure is stopped was estimated by the formula;

$$R = \frac{\text{Log (final LC}_{50}) - \text{Log (initial LC}_{50})}{N}$$

Where, n is the number of generations not exposed to insecticide,

final LC₅₀ is the LC₅₀ after n generations without selection

initial LC₅₀ is the LC₅₀ of the parental generation before n generations of selection

The number of generations (G) required for ten-fold decrease in the LC₅₀ value was calculated using the formula;

$$G=R^{-1}$$

3.9.4. Resistance Ratio or Resistance Factor

The intensity of resistance of a population or a strain of insects to a particular insecticide, frequently quoted as the Resistance factor (RF) or Resistance ratio (RR) was calculated by the formula:

$$\text{RF or RR at LC}_{50} = \frac{\text{LC}_{50} \text{ of Resistant Strain (RS)}}{\text{LC}_{50} \text{ of susceptibility strain (SS)}}$$

3.9.5. Discriminating dose

Discriminating doses of test insecticides were fixed based on LD₅₀ obtained for the F_n generation of culture population maintained under insecticide free conditions. LD-P lines were constructed for F₁ and subsequent generation.

For each discriminating dose screen, by knowing the total number of larvae dosed and total mortality, per cent survival was calculated by the formula,

$$\text{Percent survival (resistance)} = 1 - \left[\frac{\text{number of dead larvae}}{\text{number of larvae dosed}} \right] \times 100$$

The pooled binomial standard error (Regupathy and Dhamu, 2001) was also calculated as per the formula,

$$\sqrt{P(100-P)/n-1}$$

Where,

P - Percentage of larva surviving at discriminating dose

n - Total number of larva used.

3.10. Compatibility of emamectin benzoate 5 SG

3.10.1. Physical compatibility of emamectin benzoate 5 SG

Physical compatibility of emamectin benzoate 5 SG with fungicides (Mancozeb 75 WP and Carbendazim 50 WP) and insecticides (lambda cyhalothrin 5 CS and Buprofezin 25 SC) were studied in the laboratory condition.

3.10.1.1. Physical compatibility of emamectin benzoate 5 SG with agrochemicals

Physical stability of emamectin benzoate 5 SG was studied individually and in combination with chemicals as detailed below.

3.10.1.2. Preparation of standard hard water

Standard hard water was prepared by dissolving 0.302 g calcium chloride (CaCl₂) and 0.139 g magnesium chloride (MgCl₂) in one liter of distilled water. This solution had hardness equivalent of 342 ppm calcium carbonate.

To 30 ml of the formulated chemical suspension emamectin benzoate prepared, 30ml of the combination chemical (Mancozeb, carbendazim, buprofazin and lambda cyhalothrin) was added separately and transferred to a clean dry graduated cylinder and the volume was made up to 100 ml with standard hard water, shaken well and kept in a thermostat at $30\pm 1^{\circ}\text{C}$ for 1 h without any disturbance. The sediment, if any, at the bottom or creamy layer at the top was observed. The sediment not exceeding 2.0 ml was considered as the criteria for the compatibility.

3.11. Residues of emamectin benzoate 5 SG

3.11.1. Preparation of standards

Emamectin benzoate 5 SG technical material obtained from M/s Krishi Rasayn Pvt. Ltd., New Delhi was utilized to prepare the stock solution of 1000 ppm prepared by dissolving 0.1024 g of technical material (95 % purity) in 100 ml of HPLC grade acetonitrile. From this stock, intermediate stock solutions of 100 ppm and 10 ppm were prepared. Using 10 ppm stock, working standards of 0.1, 0.2, 0.5 and 1 ppm were prepared in acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml triethanolamine (TEA) (Fig. 3).

3.11.2. Recovery studies

Samples were fortified with working standards at 0.1, 0.5 and $1\ \mu\text{g g}^{-1}$ (ppm) level to find out the recovery of emamectin benzoate. The recovery factor worked out was taken for final calculation.

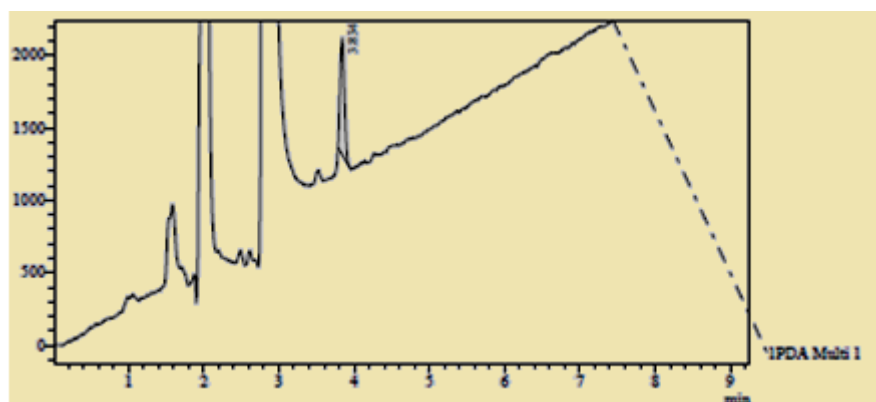
3.11.3. Determination of residues

The residues of emamectin benzoate were determined from field experiments at the time of harvest from soil, seed, lint and oil in cotton and from fruit and soil in okra.

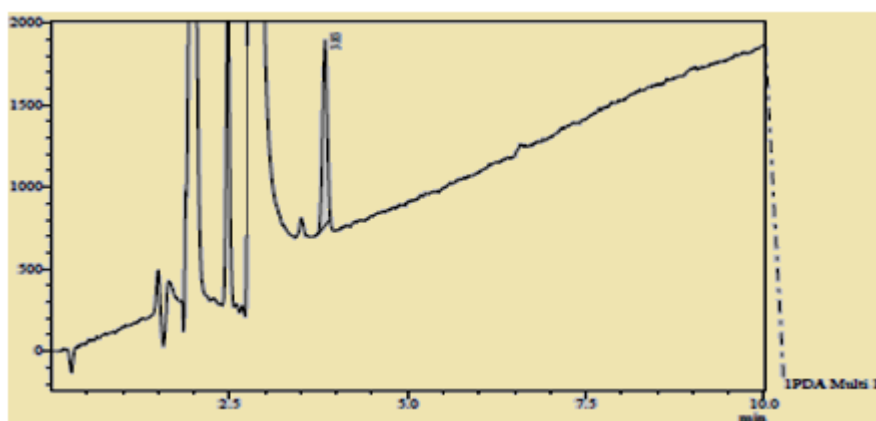
3.11.3.1. Cotton

3.11.3.1.a. Collection of sample

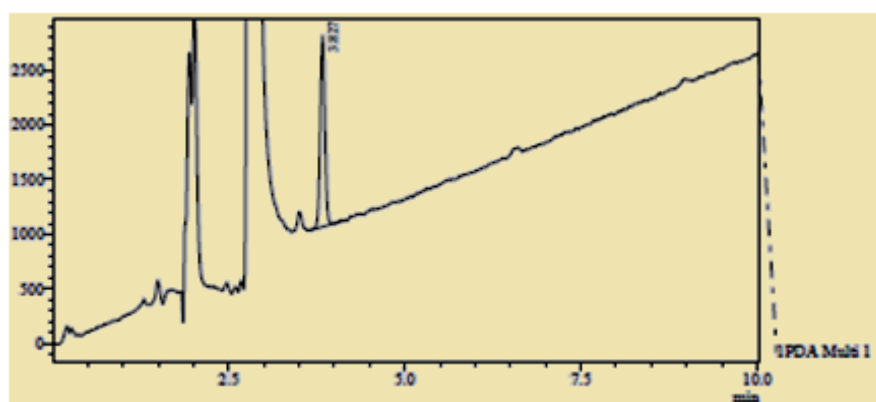
Field experiments were conducted to determine the residues of emamectin benzoate on cotton at Narasimanayakkan palayam during Jan 2011 - July 2012. Experiment was carried out in plots of 3 x 7 m size in a randomized block design with



Emamectin benzoate 0.3 ppm



Emamectin benzoate 0.5 ppm



Emamectin benzoate 1.0 ppm

Fig. 3. Standard chromatogram for emamectin benzoate

three treatments, each replicated five times. The foliar spray commencing from 68 and 60 days after sowing (DAS), respectively at 14 days interval. Cotton plants were sprayed with emamectin benzoate at 11 and 22 g a.i ha⁻¹ with the help of pneumatic knapsack sprayer. For insecticide residue analysis, sampling of cotton kapas was done during first and third pickings. The interval between the last spray and the first harvest and the first harvest to third harvest were 15 and 10 days, respectively. The samples were ginned to analysed pesticide residues in seed, lint and oil. The samples of lint, seed and oil were analyse for insecticide residue using HPLC as detailed below. Soil samples were collected at the time of first and third picking. Control samples were collected from untreated plots.

3.11.3.1.b. Analytical methodology

(i). Lint

Ten grams of cotton lint was soaked in 100 ml acetonitrile for over night. The soaked sample was blended in a blender for approximately five minutes. The mixture was filtered through filter paper and micro filtration unit using filter paper supported on Buchner funnel in to 500 ml vacuum filter flask. This was condensed to near dryness using rotary vacuum flask evaporator. Ten ml of acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml triethanolamine) was then added to this and one ml was then taken and filtered through membrane filter. Twenty microlitres of this sample was directly injected to HPLC (Shimadzu LC - 20 AT model) with a running time of 10 minutes. Prior to this a chromatogram was prepared with standard solution of emamectin benzoate with the same configuration.

(ii). Seed

Twenty grams of cotton seeds was soaked in 50 ml acetonitrile for over night. The soaked sample was blended in a blender for approximately five minutes. The mixture was filtered through filter paper and micro filtration unit using filter paper supported on Buchner funnel in to 500 ml vacuum filter flask. This was condensed to near dryness using rotary vacuum flask evaporator. Twenty ml of acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml triethanolamine (TEA)) was then added to this and one ml was then taken and filtered through membrane filter. Twenty

microlitres of this sample was directly injected to HPLC (Shimadzu LC - 20 AT model) with a running time of 10 minutes. Prior to this a chromatogram was prepared with standard solution of emamectin benzoate with the same configuration.

(iii). Oil

Fifty gram seed was blended, tumbled and placed in Soxhlet apparatus and run for 6-8 h in hexane to extract the oil. Hexane portion was collected, partitioned with acetonitrile saturated with hexane (repeated three times). Hexane layer was discarded, acetonitrile layer collected and condensed to near dryness. To this added 10 ml of acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml TEA) in a 25 ml conical flask and then 1 ml was filtered through membrane filter and twenty microlitres of this sample was directly injected to HPLC (Shimadzu LC - 20 AT model) with a running time of 10 minutes. Prior to this a chromatogram was prepared with standard solution of emamectin benzoate with the same configuration.

(iv). Soil

The soil samples taken from treated plots were air dried. It was ground in a pestle and mortar and passed through 2 mm sieves. Ten gram soil sample was taken in a 100 ml conical flask and mixed with 50 ml acetonitrile and shaken for 1 hour in a mechanical shaker. The solution was filtered, condensed to near dryness and added 10 ml acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml TEA) and then filtered 1 ml through membrane filter and twenty microlitres of this sample was directly injected to HPLC (Shimadzu LC - 20 AT model) with a running time of 10 minutes.

3.11.3.2. Okra

3.11.3.2a. Dissipation studies

For conducting the dissipation studies, the field was laid out with a plot size of 4 × 5 m using Mahyco 10 at Mathampatti during September 2010 – December 2010. Emamectin benzoate was sprayed @ 8.5 g a.i. ha⁻¹ and 17 g a.i. ha⁻¹ with hand operated knapsack sprayer. Each treatment was replicated five times in randomized block design. Fruit samples were collected from each replicate of two treatments at 0 (1 h after spraying), 1, 3, 5, 7 and 10 days after spraying. Control samples were collected similarly

from untreated plots (water spray). Samples from replicated treatments were pooled together and were used for residue analysis.

3.11.3.2b. Analytical methodology

(i) Fruits

In a 250 ml storage bottle weighed sample (fruits - 25g) was soaked in 50 ml acetonitrile for 24 hrs. The soaked fruit sample was blended in a blender for approximately three minutes. The mixture was filtered through filter paper and microfiltration unit using filter paper supported on Buchner funnel in to 500 ml vacuum filter flask. It was then condensed to near dryness using rotary vacuum flash evaporator. To this 25 ml of acetonitrile mixture (750 ml acetonitrile + 250 ml double distilled water + 0.8 ml triethanol amine) was added and from this one ml was taken and filtered through membrane filter. Twenty microlitres of this sample was directly injected to HPLC (Shimadzu LC - 20 AT model) with a retention time of 10 minutes. Prior to this a chromatogram was prepared with standard solution of emamectin benzoate with the same configuration.

(ii) Soil

The soil samples were analysed as per the procedure described in cotton under section 3.13.3.1.b (iii).

(iii). Final quantification

Emamectin benzoate 5 WSG residues were estimated by Shimadzu LC - 20 ATmodel HPLC equipped with SPD - M20A prominence Diode array detector (DAD) fitted with RP-18 e Chromolith[®] column. (Plate 15) The following were the operating parameters.

Column	:	RP- 18e Chromolith [®]
Temperature	:	Ambient temp. (40 ⁰ C)
Detector	:	SPD – DAD (Diode Array Detector)
Mobile phase	:	Acetonitrile + double distilled water + TEA (750 : 250 : 0.8v /v)
Flow rate	:	1 ml min ⁻¹

Wavelength : 254 nm

Total run time : 10 minutes

The amount of residue was determined by comparing the sample response with the response of standard by using the formula,

$$\text{Residues (ppm)} = \frac{A_s}{A_{\text{std}}} \times \frac{W_{\text{std}}}{W_s} \times \frac{V_s}{A_{\text{sj}}}$$

Where,

A_s - Peak area of the sample

A_{std} - Peak area of the standard

W_{std} - Weight of the standard in ng

W_s - Weight of the sample in g

V_s - Volume of the sample (final extract in ml)

A_{sj} - Aliquot of the sample injected in μl

3.12. Arthropod biodiversity in cotton ecosystem

The present investigations were carried out to study the arthropod diversity in cotton ecosystem in TNAU during July 2012 - October 2012. The various methodologies followed for survey and collection of arthropods, preservation and their identification and diversity analysis are described in detail in this objective.

3.12.1. Sampling methods

To develop a package of methods for quantitative sampling of arthropod communities, collections were made using four different methods viz., active searching, net sweeping, pitfall trap and rubbish trap (Plate 13). For carrying out arthropod collection, the plot was divided into 100 quadrats (10 m x 10 m). Five such quadrats were chosen each at random and the entire plot was covered during the sampling period.



Pitfall trap



Rubbish trap



Netsweeping

Plate 13 . Sampling techniques

3.12.2 Collecting devices

3.12.2.1 Active searching

Active searching was done in the early morning or evening hours. Each quadrat was selected at random and they were actively searched for arthropods. Each site was searched for a total of two hours. Spiders were collected by walking diagonally in the fields and care was taken to capture them without injuring and transferred to polythene bags for further studies. Specimens from a single quadrat at each habitat type were pooled for analysis.

3.12.2.2 Net sweeping

Sweeping is very effective for the collection of flying and jumping arthropods at the ground level and under storey vegetation. The nets used in systematic sweeping of the ground level were made of thick cotton cloth with a diameter of 30 cm at the mouth and a bag length of 60 cm.

For carrying out net sweeps, the plot was divided into 100 quadrats, measuring 10 m x 10 m each. Five such quadrats representing the field were chosen at random and the entire ground level vegetation in the chosen quadrat was covered during the sweeping. Net sweeps were always done between 10 am and 12 noon. The arthropods collected from each quadrat were transferred into polythene bags containing cotton dipped in chloroform. Sampling was done from August 2011 to April 2012. The sweeps were made at ground vegetation above one meter height from the ground for collecting insects from shrubs. The contents from the sweep nets were placed in a bucket with a small amount of ethyl alcohol to kill all the arthropods. They were sorted on the same day. Spiders and other arthropods were separated from the vegetation. Soft bodied insects and spiders were later separated from the bag and preserved in vials containing 70 per cent alcohol.

3.12.2.3 Pitfall traps

This method was adopted to collect ground dwelling and nocturnal arthropods. Pitfall traps were set out using a plastic container (15 cm height and 10 cm width) buried in to the soil to a depth of 20 cm. Five pitfall traps were placed in each of five randomly

chosen 10 m x 10 m quadrats. The traps were set up between 6 am and 5 pm and specimens were collected the next morning. In order to stop the receptacle from filling with water or leaf litter and to deter some larger predators like mice, the trap was covered with a flat stone supported by four smaller stones. Teepol (2-3 drops) in water was kept in the traps as trapping fluid. The traps were placed at the rate of 25 per plot. The trapping fluid was changed every week. Observations were recorded daily on the number and type of arthropods trapped in each container.

3.12.2.4 Rubbish traps

These traps were constructed using chicken wire mesh, stuffed with leaf litter (45 cm length and 15 cm width). Five rubbish traps were placed in each of five randomly chosen quadrats. The traps were placed in the field allowing a week for arthropods to take up residence. Every seven days, these traps were removed and brought to the laboratory and arthropods found inside were collected.

3.12.3. Collection and identification of arthropods

The collection of arthropods for biodiversity analysis was carried out in cotton field at different stages of the crop growth. Arthropod fauna were collected on fortnight basis from first fortnight of July 2011 to the last fortnight October 2012 using the methods specified earlier. The collected arthropods were sorted out based on taxon. Soft bodied insects and spider species were preserved in 70 per cent ethyl alcohol in glass vials. Other arthropods were card mounted or pinned. The preserved specimens were photographed and identified based on the taxonomic characters.

All arthropod species were identified to the lowest possible taxon. Insects were identified following Lefroy (1984), Comstock (1984), Richards and Davis (1983), Poorani (2002) and also by comparing with the specimens in the Department of Agricultural Entomology, Tamil Nadu Agricultural University. Spiders were identified with the help of Dr. M. Ganesh Kumar, Professor of Entomology in Coimbatore.

3.13. Diversity analysis of arthropods in cotton ecosystem

3.13.1. Alpha diversity indices

Measures of diversity are frequently seen as indicators of the well being of any ecosystem. They also serve as a measure of the species diversity in the ecosystem. The following indices were used to assess and compare the diversity and distribution of arthropods in cotton Species richness and diversity ii (Pisces Conservation Ltd., www.irchouse.demon.co.uk) (Henderson, 2003) programmes were used to assess and compare the diversity of arthropods in sprayed and unsprayed cotton ecosystems.

3.13.1.1. Species richness

3.13.1.1a. Fishers alpha (Fisher *et al.*, 1943)

This presents the alpha log series parameter for each sample. This is a parametric index of diversity that assumes the abundance of species and follows the log series distribution.

$$\alpha x, \alpha x^2/2, \alpha x^3/3 \dots \alpha x^n/n$$

Where, each term gives the number of species predicted to have 1, 2, 3, ..., n individuals in the sample.

3.13.1.1b. Q Statistic (Kempton and Taylor, 1976)

This presents the interquartile diversity index for each sample. It measures the interquartile slope of the cumulative abundance curve and is estimated by,

$$Q = 1/2 \sum_{R_1} nR + 1/2 \sum_{R_2} nR / \ln (R_2/R_1)$$

Where,

nR = the total number of species with abundance R

R_1 and R_2 = 25% and 75% quartile of the cumulative species curve

nR_1 = the number of individuals in the class where R_1 falls

nR_2 = the number of individuals in the class where R_2 falls

3.13.1.1c. Species number (Magurran, 1987)

This represents the total number of species in each sample.

3.13.1.1d. Margalef's D (Clifford and Stephenson, 1975)

Margalef's D has been a favourite index for many years. It is calculated as species number minus one divided by the logarithm of the total number of individuals. This program uses the natural logarithm.

$$D_{Mg} = (S - 1) / \ln N$$

Where,

S = total number of species recorded

N = the total number of individuals summed overall S species

3.13.1.1e. Shannon diversity index (Batten, 1976)

This represents the Shannon - Weiner (also called as Weaver) diversity index for each sample and is defined as:

$$H' = \sum P_i \ln P_i$$

Where

P_i = the proportion of individuals in the i^{th} species

This program calculates the index using the natural logarithm.

3.13.1.1f. Brillouin diversity index (Magurran, 1987)

The Brillouin index H is calculated as follows:

$$H = \ln N! - \sum_{i=1}^s \ln n_i! / N$$

Where,

N is the total number of individuals in the sample.

n_i is the number of individuals belonging to the i^{th} species and s is the species number.

3.13.1.2. Species Dominance indices

3.13.1.2a. Simpson's index (Simpson, 1949)

Simpson's index describes the probability that a second individual drawn from a population should be of the same species as the first.

$$D = \Sigma [N_i (N_i - 1)] / [N_t (N_t - 1)]$$

Where,

N_i is the number of individuals in the i^{th} species

N_t is the total number of individuals in the sample

So, larger its value, greater the diversity. The statistic $1 - C$ gives a measure of the probability of the next encounter being from another species (Hulbert, 1971).

3.13.1.2b. Berger Parker diversity index (Berger and Parker, 1970)

A simple dominance measure is the Berger parker index. The index expresses the proportional importance of the most abundant species.

$$d = N_{\max} / N$$

Where,

$N_{\max}$ is the number of individuals in the most abundant species

N is the number of individuals in the sample

This simple index was considered by May (1975) to be one of the best. It is simple measure of the numerical importance of the most abundant species.

3.13.1.2c. McIntosh index (McIntosh, 1967)

This index was calculated using the following formula proposed by McIntosh (1967) as

$$D = N - U / N - \sqrt{(N)}$$

Where,

N is the total number of individuals in the sample

U is given by the expression,

$$U = \sqrt{(\Sigma n_i^2)}$$

Where, n_i is the number of individuals belonging to the i^{th} species and the summation is undertaken over all the species.

3.13.1.3. Evenness indices

Evenness (E) is a measure of how similar the abundances of different species or categories are in a community. When all species in a community are equally abundant, the evenness index should be maximum and decrease towards zero as the relative abundances of the species diverge away from evenness closer to zero. It indicates that most of the individuals belong to one or a few species or categories, when the evenness is close to one; it indicates that each species/ category consists of the same number of individuals.

3.13.1.3a. Equitability J (Magurran, 1987)

Equitability or evenness refers to the pattern of distribution of the individuals between the species. This measure of equitability compares the observed Shannon-Weiner index against the distribution of individuals between the observed species which would maximize diversity. If H is the observed Shannon - Weiner index, the maximum value this could take $\log (S)$, where S is the total number of the species in the habitat. Therefore the index is:

$$J = H / \log (S)$$

Results

CHAPTER IV

EXPERIMENTAL RESULTS

The results of the experiments conducted under laboratory and field conditions on the bioefficacy of emamectin benzoate 5 SG against bollworms in cotton and fruit borers in okra, its persistence, acute toxicity, safety to non- target organisms, compatibility with agrochemicals, harvest time residues, baseline toxicity, level of resistance and effect on arthropod biodiversity are presented in this chapter.

A. Field experiments

4.1. Cotton

4.1.1. Bioefficacy of emamectin benzoate 5 SG against cotton bollworms

4.1.1.1. Experiment I – Madampatti

4.1.1.1a. Bollworm, *Helicoverpa armigera* (Hubner)

The pre-treatment observations made before the first spray indicated that larval population varied between 7.10 and 8.10 plant⁻¹ and had crossed the economic threshold level (ETL). On the seven days after treatment (DAT) the higher dose of emamectin benzoate 5 SG (15 g a.i. ha⁻¹) recorded the minimum population of larvae (0.97 plant⁻¹) followed by 11 g a.i. ha⁻¹ (1.93 plant⁻¹) which was on par with emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (2.00 plant⁻¹). The lower dose of emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ recorded larval population of 3.27 and 3.00 plant⁻¹ which was superior to the untreated check (8.67 plant⁻¹) (Table 5). A similar trend was observed on 10 and 14 DAT. The highest larval population was observed in standard check spinosad 45 SC at 75 g a.i. ha⁻¹ (4.97 larvae plant⁻¹) next to untreated check (Table 5).

The results of the second application revealed that, on 7 DAT the larval population was zero larvae plant⁻¹ in emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ followed by emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ (1.07 larvae plant⁻¹) which was on par with emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (1.27 larvae plant⁻¹). Higher mean larval population was observed in emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ (3.45 and 3.16 larvae plant⁻¹) but was superior to spinosad and untreated check. Similar trend was

Table 5. Effect of emamectin benzoate 5 SG on bollworms in cotton– (Location- Madampatti) I season

Treatments	Number of larva per plant*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	7.20	4.10 (2.14) ^{cd}	3.27 (1.94) ^{cd}	4.09 (2.14) ^{cd}	5.20 (2.38) ^{cd}	4.16	51.19	3.70 (2.04) ^{cd}	3.10 (1.89) ^{cd}	3.37 (1.96) ^{cd}	3.73 (2.05) ^{cd}	3.45	61.21
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	7.33	3.59 (2.02) ^c	3.00 (1.87) ^c	3.67 (2.04) ^c	4.79 (2.30) ^c	3.76	56.50	3.47 (1.99) ^c	2.90 (1.84) ^c	3.00 (1.87) ^c	3.29 (1.94) ^c	3.16	64.67
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	7.17	2.50 (1.73) ^b	1.93 (1.55) ^b	2.47 (1.72) ^b	3.19 (1.92) ^b	2.52	70.83	2.20 (1.64) ^b	1.07 (1.25) ^b	1.87 (1.53) ^b	2.03 (1.59) ^b	1.79	80.04
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	7.67	1.37 (1.36) ^a	0.97 (1.21) ^a	1.50 (1.41) ^a	2.13 (1.62) ^a	1.49	82.74	0.93 (1.19) ^a	0.00 (0.70) ^a	0.73 (1.10) ^a	1.00 (1.22) ^a	0.66	92.57
Emamectin benzoate 5 SG (Proclaim®) 11 g a.i.ha ⁻¹	7.10	2.57 (1.75) ^b	2.00 (1.58) ^b	2.59 (1.75) ^b	3.73 (2.05) ^b	2.72	68.52	2.17 (1.63) ^b	1.27 (1.33) ^b	1.90 (1.54) ^b	2.10 (1.61) ^b	1.86	79.24
Spinosad 45 SC 75 g a.i.ha ⁻¹	7.37	5.27 (2.40) ^d	4.97 (2.33) ^d	5.27 (2.40) ^d	5.49 (2.44) ^d	5.25	39.30	3.79 (2.07) ^e	2.27 (1.66) ^e	3.93 (2.10) ^e	4.40 (2.21) ^e	3.59	59.84
Untreated check	8.10	8.27 (2.96) ^f	8.67 (3.02) ^f	8.72 (3.03) ^f	8.97 (3.07) ^f	8.65	-	8.97 (3.07) ^f	8.90 (3.06) ^f	8.98 (3.07) ^f	9.00 (3.08) ^f	8.96	-

PTC- Pre treatment count; % Redn.- Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

observed on 10 and 14 DAT and the order of efficacy was emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ > emamectin benzoate 5 SG 11g a.i. ha⁻¹ = emamectin benzoate 5 SG (Procalim®) at 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 9 g a.i. ha⁻¹ = emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ > spinosad 45 SC at 75 g a.i. ha⁻¹ > untreated check (Table 5).

4.1.1.1. b. Larval population, *Pectinophora gossypiella* Saunders

Since there was no incidence of *P. gossypiella* during the investigation period, data was not obtained in field experiment I.

4.1.1.1 c. Damage to green fruiting bodies

The damage due to bollworm complex before imposing treatments ranged from 23.65 to 24.61 per cent plant⁻¹ (Table 6). The treatment with emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ showed significantly less bollworms damage (5.57 per cent) after 7 DAT. Emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ (7.63 per cent) which was on par with emamectin benzoate 5SG (Procalim®) at 11 g a.i. ha⁻¹ (8.19 per cent). The lower dose of emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ recorded the mean per cent damage of 14.23 and 12.27 per cent, respectively. The highest mean per cent damage was recorded in standard check, spinosad (16.02 per cent) and was found to be superior over untreated check (30.50 per cent).

Similar trend was noticed after second round of application. The results of the second application recorded that, the highest reduction was recorded in plots treated with emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ (84.86 per cent over untreated check) followed by emamectin benzoate 5 SG 11 g a.i. ha⁻¹ which was on par with emamectin benzoate 5 SG (Proclaim®) 11 g a.i. ha⁻¹ (80.06 and 78.62 per cent). The lower dose of emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ recorded 67.67 and 71.32 per cent bollworms damage over untreated control. The highest damage was observed in standard check spinosad 75 g a.i. ha⁻¹ (15.48 %) and untreated check (35.61%) (Table 6). Based on the mean damage per cent, the order of efficacy of different treatments are follows: emamectin benzoate 5 SG at 15g a.i. ha⁻¹ > emamectin benzoate 5 SG 11 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 9 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ > spinosad 45SC at 75 g a.i. ha⁻¹ > untreated check.

Table 6. Effect of emamectin benzoate 5 SG against bollworms damage on cotton – (Location- Madampatti) I season

Treatments	Mean per cent fruit damage per plant*												
	Days after first application						Days after second application						% Redn
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	24.37	14.73 (22.56) ^{cd}	12.89 (21.03) ^d	13.97 (21.94) ^d	15.33 (23.04) ^d	14.23	53.34	12.27 (20.49) ^d	10.33 (18.55) ^d	11.27 (19.60) ^{cd}	12.17 (20.41) ^d	11.51	67.67
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	24.02	12.33 (20.54) ^c	10.57 (18.96) ^c	12.79 (20.95) ^c	13.40 (21.46) ^c	12.27	59.77	10.27 (18.68) ^c	9.00 (17.45) ^c	10.39 (18.82) ^c	11.17 (19.51) ^c	10.20	71.32
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	23.65	9.02 (17.47) ^b	7.63 (16.02) ^b	9.67 (18.10) ^b	11.63 (24.83) ^b	9.48	68.91	7.00 (15.33) ^b	5.73 (13.84) ^b	7.47 (15.85) ^b	8.23 (16.66) ^b	7.10	80.06
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	24.41	7.33 (15.70) ^a	5.57 (13.64) ^a	7.59 (15.98) ^a	9.93 (19.93) ^a	7.60	75.06	5.73 (13.84) ^a	4.10 (11.67) ^a	5.00 (12.91) ^a	6.73 (15.02) ^a	5.39	84.86
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i.ha ⁻¹ .	24.11	10.00 (18.43) ^b	8.19 (16.62) ^b	10.27 (18.68) ^b	12.33 (20.55) ^b	10.19	66.56	7.47 (15.85) ^b	6.00 (14.16) ^b	7.97 (16.39) ^b	9.00 (17.45) ^b	7.61	78.62
Spinosad 45 SC 75 g a.i.ha ⁻¹	24.61	16.37 (26.09) ^d	14.47 (24.68) ^d	15.73 (26.38) ^d	17.53 (27.65) ^d	16.02	47.45	15.83 (25.71) ^e	14.17 (23.70) ^e	15.27 (24.55) ^e	16.67 (25.59) ^e	15.48	56.51
Untreated check	24.45	27.53 (31.64) ^e	28.42 (32.21) ^e	31.97 (34.43) ^e	34.08 (35.71) ^e	30.50	-	34.61 (36.03) ^f	35.17 (36.37) ^f	36.67 (37.26) ^f	36.00 (36.86) ^f	35.61	-

PTC- Pretreatment count; % Redn. - Reduction from control, * Mean of three replications, Figures in parentheses are *arc sine* transformed values; In a column, means followed by a common letter(s) are not significantly different by DMRT (P=0.05).

4.1.1.2. Experiment II – Narasimanayakkan palayam

4.1.1.2. a. Bollworms

The results of the field experiment carried out at Narasimanayakkan palayam are presented in Table 7. Foliar treatments were given when the population of *H. armigera* exceeded two per plant. The pre-treatment larval population varied from 6.67 to 7.29 larvae per plant. Among the insecticidal treatments, the highest reduction (75.66 per cent) was recorded in emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ treated plots. Emamectin benzoate 5 SG 11 g a.i. ha⁻¹ (64.68 per cent) was on par with emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (62.05 Per cent). On 7 DAT, emamectin benzoate 5 SG at 15, 11 and (Proclaim®) 11 g a.i. ha⁻¹ recorded 1.17, 2.00 and 2.50 larvae plant⁻¹. The lower dose of emamectin benzoate 5SG at 7 and 9 g a.i. ha⁻¹ recorded 5.25 and 3.93 mean larval population per plant which was superior over the untreated control (8.63 larvae plant⁻¹).

The population of bollworms prior to second application ranged from 3.16 to 9.00 plant⁻¹. Significant difference was recorded among the treatments after 3, 7, 10 and 14 days of second spray. Among the insecticidal treatments, emamectin benzoate 5SG at 15 g a.i. ha⁻¹ was found consistently and significantly superior up to 14 days. Emamectin benzoate 5SG at 11 g a.i. ha⁻¹ (1.00 larvae plant⁻¹) was on par with the emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (1.37 larvae plant⁻¹) on 7 DAT. On 7 DAT, emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ was better zero larvae plant⁻¹ than other treatments in reducing larval population followed by its recommended dose. A similar trend was observed at 10 and 14 DAT (Table 7). The lowest per cent reduction was observed in spinosad 45 SC (51.18 per cent) treated plots next to untreated check.

4.1.1.2.b. Larval population of *P. gossypiella*

Since there was no incidence of *P. gossypiella* during the investigation period, data was not obtained in field experiment II.

4.1.1.2. c. Damage to green fruiting bodies

The results of field experiments conducted at Narasimanayakkan palayam revealed that all the doses of emamectin benzoate 5 SG recorded a significant reduction in the damage caused by bollworms and the results are presented in Table 8. The damage per cent of

Table 7. Effect of emamectin benzoate 5G against bollworms in cotton (Location- Narasimanayakkan palayam) II season

Treatments	Number of larva per plant*												
	Days after first application							Days after second application					
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate5 SG 7 g a.i.ha ⁻¹	6.67	5.17 (2.38) ^{cd}	4.93 (2.33) ^{cd}	5.27 (2.40) ^{cd}	5.63 (2.47) ^{cd}	5.25	39.16	4.73 (2.28) ^{cd}	3.50 (2.00) ^{cd}	3.73 (2.05) ^{cd}	4.00 (2.12) ^{cd}	3.99	57.10
Emamectin benzoate5 SG 9 g a.i.ha ⁻¹	7.13	4.30 (2.19) ^c	3.30 (1.94) ^c	3.97 (2.113) ^c	4.17 (2.16) ^c	3.93	54.40	3.50 (2.00) ^c	2.97 (1.86) ^c	3.27 (1.58) ^c	3.43 (1.94) ^c	3.29	64.59
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	7.17	3.19 (1.92) ^b	2.00 (1.58) ^{ab}	3.00 (1.87) ^{ab}	4.00 (2.12) ^{ab}	3.04	64.68	1.20 (1.30) ^{ab}	1.00 (1.22) ^{ab}	1.50 (1.41) ^{ab}	2.00 (1.58) ^{ab}	1.42	84.73
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	7.00	2.00 (1.58) ^a	1.17 (1.29) ^a	2.07 (1.60) ^a	3.16 (1.91) ^a	2.10	75.66	0.73 (1.10) ^a	0.00 (0.70) ^a	1.00 (1.22) ^a	1.23 (1.31) ^a	0.74	92.04
Emamectin benzoate 5 SG (Proclaim®) 11 g a.i.ha ⁻¹ .	6.77	3.23 (1.93) ^b	2.50 (1.73) ^b	3.27 (1.94) ^b	4.10 (2.14) ^b	3.27	62.05	1.27 (1.33) ^b	1.37 (1.36) ^b	1.69 (1.47) ^b	2.20 (1.64) ^b	1.63	82.47
Spinosad 45 SC 75 g a.i.ha ⁻¹	6.93	5.10 (2.36) ^{de}	4.97 (2.33) ^{de}	5.10 (2.36) ^{de}	5.37 (2.42) ^{de}	5.13	40.49	4.63 (2.26) ^{de}	4.17 (2.16) ^{de}	4.47 (2.22) ^{de}	4.90 (2.32) ^{de}	4.54	51.18
Untreated check	7.29	7.79 (2.87) ^f	8.78 (3.04) ^f	8.97 (3.07) ^f	9.00 (3.08) ^f	8.63	-	9.17 (3.10) ^f	9.27 (3.12) ^f	9.30 (3.13) ^f	9.47 (23.15) ^f	9.30	-

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

bollworm complex before imposing treatments ranged from 26.93 to 27.97. There was a significant reduction in bollworm damage after spraying emamectin benzoate 5 SG. After first round of application the highest per cent reduction over untreated check in plots treated with emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ (73.05 %) followed by emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ (67.32 %) which were on par with emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (66.35 %). The highest mean damage was observed in spinosad 45 SC (16.51 %) next to emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ (15.85 and 13.01 per cent).

After second round of treatment, emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ recorded minimum mean boll damage per plant (5.67 per cent) followed by emamectin benzoate 5 SG 11 g a.i. ha⁻¹ (7.32 per cent) which was on par with emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (7.48 per cent). The lower mean damage was observed at 7 and 9 g a.i. ha⁻¹ (13.65 and 10.34 per cent), followed by spinosad (16.43 per cent). After second spray, emamectin benzoate 5 SG doses at 11, 15 and Proclaim® 11 g a.i. ha⁻¹ were equally effective in reducing the boll damage than other treatments recording 79.81 to 84.70 per cent boll damage. (Table 8)

4.1.2. Incidence of natural enemies in the field

4.1.2.1. Field trial I

4.1.2.1a. Spiders

The spider population prior to the first application ranged from 5.00 to 5.73 per ten plants (Table 9). The population of spiders among different emamectin benzoate 5 SG treatments ranged from 4.00 to 7.53, 3.67 to 7.33, 3.33 to 7.00, 3.00 to 6.00 and 3.00 to 6.47 per five plants on 3, 7, 10 and 14 DAT, respectively. However, in untreated check the population of spiders was significantly higher and ranged from 6.27 to 7.83 per ten plants throughout the observation period.

During the second application, the mean population of spiders varied from 5.83 to 7.41 per ten plants amongst different treatments of emamectin benzoate 5 SG treatments. While considering the overall mean, next to untreated check (9.58 per ten plants) emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ recorded maximum mean population of 7.41 per ten plants.

Table 8. Effect of emamectin benzoate 5 SG against bollworms damage in cotton – (Location- Narasimanayakkan palayam) II season

Treatments	Mean per cent fruit damage per plant*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	27.97	15.29 (23.01) ^d	13.73 (21.74) ^d	16.27 (23.78) ^d	18.17 (25.22) ^d	15.85	52.08	14.27 (22.28) ^d	12.69 (20.86) ^d	13.67 (21.69) ^d	14.00 (21.91) ^d	13.65	63.16
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	27.42	13.63 (21.66) ^c	11.07 (19.42) ^c	12.60 (20.83) ^c	14.77 (22.60) ^c	13.01	60.70	11.00 (19.36) ^c	9.12 (17.57) ^c	10.00 (18.42) ^c	11.27 (19.78) ^c	10.34	72.10
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	27.86	11.47 (19.78) ^b	9.17 (17.64) ^b	10.67 (19.06) ^b	12.00 (20.26) ^b	10.82	67.32	8.00 (16.42) ^b	6.17 (14.37) ^b	7.00 (15.33) ^{ab}	8.13 (16.55) ^{ab}	7.32	80.24
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	27.09	9.07 (17.52) ^a	7.47 (15.85) ^a	9.00 (17.45) ^a	10.17 (18.60) ^a	8.92	73.05	5.23 (13.21) ^a	4.37 (12.05) ^a	6.10 (14.28) ^a	6.98 (15.31) ^a	5.67	84.70
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i.ha ⁻¹	26.95	11.69 (19.98) ^b	9.53 (17.93) ^b	11.00 (19.36) ^b	12.37 (20.58) ^b	11.14	66.35	8.17 (16.60) ^b	6.23 (14.44) ^b	7.37 (15.74) ^b	8.20 (16.63) ^b	7.48	79.81
Spinosad 45 SC 75 g a.i.ha ⁻¹	26.93	16.47 (26.84) ^e	14.97 (32.55) ^e	16.89 (32.03) ^e	17.72 (33.02) ^e	16.51	50.01	16.67 (25.60) ^e	15.27 (24.55) ^e	16.13 (25.93) ^e	17.67 (27.74) ^e	16.43	55.65
Untreated check	27.09	30.20 ^c (33.33) ^f	31.74 (34.28) ^f	33.97 (35.60) ^f	36.51 (37.14) ^f	33.11	-	36.57 (37.20) ^f	36.89 (37.40) ^f	37.17 (37.56) ^f	37.63 (37.83) ^f	37.06	-

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Figures in parentheses are *arc sine* transformed values; In a column, means followed by a common letter(s) are not significantly different by DMRT (P=0.05).

Table 9. Effect of emamectin benzoate 5 SG on spiders in cotton eco system (Location - Madampatti) I season

Treatments	Number of spiders per ten plants*										
	Days after first application					Days after second application					
	PTC	3	7	10	14	Mean	3	7	10	14	Mean
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	5.00	4.00 (2.12) ^b	5.17 (2.38) ^b	6.53 (2.65) ^b	7.53 (2.83) ^{ab}	5.80	6.00 (2.54) ^b	6.33 (2.61) ^b	8.00 (2.91) ^b	9.33 (3.13) ^{ab}	7.41
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	5.17	3.67 (2.04) ^{bc}	5.33 (2.41) ^b	7.00 (2.73) ^{bc}	7.33 (2.79) ^{ab}	5.83	5.03 (2.35) ^{bc}	6.00 (2.54) ^b	7.33 (2.79) ^{bc}	8.67 (3.02) ^b	6.75
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	5.73	3.33 (1.95) ^{bcd}	5.00 (2.34) ^{bc}	6.67 (2.67) ^{bc}	7.00 (2.73) ^{bc}	5.50	4.67 (2.27) ^c	5.67 (2.48) ^{bc}	7.00 (2.73) ^{cc}	8.33 (2.97) ^{bc}	6.41
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	5.60	3.00 (1.87) ^{cd}	4.33 (2.19) ^c	5.67 (2.48) ^{bc}	6.00 (2.54) ^c	4.75	4.33 (2.19) ^c	5.00 (2.34) ^c	6.33 (2.61) ^d	7.67 (2.85) ^c	5.83
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i.ha ⁻¹	5.37	3.00 (1.87) ^d	4.79 (2.30) ^c	6.33 (2.61) ^c	6.47 (2.64) ^{cd}	5.14	4.50 (2.19) ^c	5.37 (2.34) ^c	6.33 (2.61) ^d	7.67 (2.85) ^c	5.95
Spinosad 45 SC 75 g a.i.ha ⁻¹	5.63	1.33 (1.35) ^e	2.67 (1.78) ^d	4.33 (2.19) ^e	5.00 (2.34) ^d	3.33	2.67 (1.78) ^d	2.67 (1.78) ^e	4.33 (2.19) ^e	7.33 (2.80) ^d	4.25
Untreated check	5.73	6.27 (2.60) ^a	7.17 (2.76) ^a	7.69 (2.86) ^a	7.83 (2.88) ^a	7.24	8.67 (3.02) ^a	9.33 (3.13) ^a	10.00 (3.24) ^a	10.33 (3.29) ^a	9.58

PTC- Pre treatment count; *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

Emamectin benzoate 5 SG at 15 g a.i. ha⁻¹, emamectin benzoate SG at 11 g a.i. ha⁻¹ and emamectin benzoate 5 SG (Proclaim®) at 11 g a.i. ha⁻¹ (5.83 to 6.41 per ten plants) were found to be on par with each other in the mean spider population per ten plants but superior over the standard check, spinosad 75 g a.i. ha⁻¹ (4.25 per ten plants). The highest mean spider population was observed in untreated check (9.58 spiders per ten plants) (Table 9)

4.1.2.1b. Coccinellids

In the count before application, the coccinellid adult population ranged from 8.33 to 9.27 per ten plants. There was a slight reduction in population after spraying. Considering the mean coccinellid population per ten plants, the maximum was observed in untreated check (9.58 / ten plants) followed by the lower dose of emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ (8.19 / ten plants) and emamectin benzoate 5 SG at 9 g a.i. ha⁻¹ (7.25/ ten plants). The higher dose of emamectin bezoate at 15 g a.i. ha⁻¹ reduced the mean coccinellid population to 4.83 per ten plants (Table 10). All the treatments irrespective of doses were found to have more coccinellids population per ten plants when compared with spinosad 45 SC at 75 g a.i. ha⁻¹ (4.25 / ten plants).

Similar trend was observed after the second application. The mean population of coccinellids after second spray with emamectin benzoate 5 SG ranged from 6.91 to 9.24 per ten plants. Untreated check recorded the maximum mean coccinellid population of 12.58 per ten plants followed by emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ (9.24 per ten plants). All the treatments were found superior to the standard check spinosad (2.83 per ten plants) (Table 10).

4.1.2.2. Experiment II

4.1.2.2 a. Spiders

Among the chemicals tested, emamectin benzoate 5 SG at 7 and 9 g a.i.ha⁻¹ were the least toxic to spiders recording a mean of 9.38 and 8.05 spiders, respectively per ten plants after the first round of spraying (Table 11), followed by emamectin benzoate 5 SG at 11 g a.i.ha⁻¹ and standard check (Proclaim®) at 11 g.a.i.ha⁻¹ which recorded 7.45 and 7.35 spiders per ten plants, respectively. The least spider population was observed in plants treated with spinosad at 75 g a.i.ha⁻¹ (3.58 per ten plants)

Table 10. Effect of emamectin benzoate 5 SG on coccinellids in cotton eco system (Location - Madampatti) I season

Treatments	Number of coccinellids per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	3	7	10	14	Mean		
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	9.27	7.10 (2.73) ^b	7.97 (2.91) ^b	8.69 (3.03) ^b	9.00 (3.04) ^b	8.19	7.67 (2.85) ^b	8.67 (3.02) ^b	9.17 (3.10) ^b	11.00 (3.39) ^b	9.24		
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	8.33	6.43 (2.63) ^b	7.00 (2.73) ^b	7.47 (2.82) ^b	8.00 (2.91) ^b	7.25	7.00 (2.73) ^{bc}	8.33 (2.97) ^b	9.17 (3.10) ^b	10.00 (3.24) ^b	8.62		
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	9.13	5.00 (2.34) ^c	6.00 (2.54) ^{bc}	7.10 (2.75) ^{bc}	7.47 (2.82) ^{bc}	6.39	6.00 (2.54) ^c	7.17 (2.76) ^c	8.97 (3.07) ^{bc}	9.33 (3.13) ^{cd}	7.86		
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	9.00	4.00 (2.12) ^{cd}	4.33 (2.19) ^d	5.00 (2.34) ^d	6.33 (2.61) ^c	4.83	5.33 (2.41) ^d	6.67 (2.67) ^d	7.33 (2.79) ^d	8.33 (2.97) ^c	6.91		
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i.ha ⁻¹	8.69	5.13 (2.37) ^c	5.63 (2.47) ^c	6.67 (2.67) ^c	7.67 (2.85) ^{bc}	6.27	5.93 (2.53) ^{cd}	7.00 (2.73) ^c	8.17 (2.27) ^{bc}	8.73 (3.03) ^{cd}	7.45		
Spinosad 45 SC 75 g a.i.ha ⁻¹	8.67	2.33 (1.68) ^e	3.67 (2.04) ^e	5.00 (2.34) ^e	6.00 (2.54) ^d	4.25	2.00 (1.58) ^e	2.37 (1.69) ^e	2.67 (1.78) ^e	4.67 (2.27) ^e	2.83		
Untreated check	8.33	8.67 (3.02) ^a	9.33 (3.13) ^a	10.33 (3.29) ^a	10.00 (3.24) ^a	9.58	11.00 (3.39) ^a	12.67 (3.62) ^a	13.00 (3.67) ^a	13.67 (3.76) ^a	12.58		

PTC- Pre treatment count; * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

Table 11. Effect of emamectin benzoate 5 SG on spiders in cotton eco system (Location - Narasimanayakkan palayam) II season

Treatments	Number of spiders per ten plants*											
	Days after first application						Days after second application					
	PTC	3	7	10	14	Mean	3	7	10	14	Mean	
Emamectin benzoate 5 SG 7 g a.i./ha ⁻¹	9.00	8.17 (2.94) ^b	9.00 (3.08) ^b	9.89 (3.22) ^b	10.47 (3.31) ^b	9.38	9.13 (2.61) ^b	9.83 (2.67) ^b	10.00 (2.85) ^b	10.33 (3.08) ^b	9.82	
Emamectin benzoate 5 SG 9 g a.i./ha ⁻¹	9.73	7.00 (2.73) ^{bc}	7.53 (2.83) ^{bc}	8.37 (2.97) ^{bc}	9.33 (3.13) ^b	8.05	8.00 (2.41) ^b	8.93 (2.54) ^{bc}	9.73 (2.79) ^{bc}	10.00 (3.02) ^b	9.16	
Emamectin benzoate 5 SG 11 g a.i./ha ⁻¹	9.67	6.47 (2.64) ^{cd}	7.00 (2.73) ^{bc}	7.83 (2.88) ^{cd}	8.53 (2.79) ^{bc}	7.45	7.17 (2.27) ^c	8.00 (2.48) ^{cd}	8.43 (2.73) ^{bc}	9.00 (2.97) ^b	8.15	
Emamectin benzoate 5 SG 15 g a.i./ha ⁻¹	9.17	5.93 (1.87) ^{de}	6.00 (2.19) ^d	6.57 (2.61) ^{cd}	7.43 (2.73) ^{bc}	6.48	5.97 (2.19) ^c	6.67 (2.41) ^{cd}	7.00 (2.54) ^d	7.83 (2.79) ^c	6.86	
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i./ha ⁻¹	9.83	6.33 (1.68) ^{ef}	6.97 (1.95) ^d	7.83 (2.67) ^d	8.27 (2.61) ^c	7.35	7.00 (2.27) ^c	7.63 (2.34) ^d	8.00 (2.67) ^{cd}	8.67 (2.79) ^c	7.82	
Spinosad 45 SC 75 g a.i./ha ⁻¹	9.33	3.00 (1.47) ^f	4.17 (1.87) ^d	4.67 (2.27) ^e	5.00 (2.34) ^d	3.58	3.00 (1.87) ^d	3.00 (1.87) ^e	4.33 (2.19) ^e	5.00 (2.34) ^d	4.33	
Untreated check	10.17	10.23 (2.91) ^a	10.97 (2.85) ^a	11.00 (3.02) ^a	11.13 (3.08) ^a	10.83	12.00 (3.08) ^a	12.33 (3.13) ^a	13.67 (3.18) ^a	13.97 (3.24) ^a	12.99	

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

After second round of application, emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ harboured 9.82 mean spiders per ten plants followed by emamectin benzoate 5 SG at 9, 11 and Proclaim[®] 11 g a.i. ha⁻¹ (9.16, 8.15 and 7.82 spiders per ten plants, respectively). High dose of emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ and spinosad recorded 6.86 and 4.33 spiders per ten plants respectively. The highest mean spiders was recorded in untreated check 12.99 per ten plants (Table 11).

4.1.2.2 b. Coccinellids

All the doses of emamectin benzoate 5 SG did not affect the activity of coccinellids. The pre-treatment population of coccinellids varied from 8.33 to 9.33 per ten plants. After first round of spray, emamectin benzoate 5 SG at 7, 9 and 11 g a.i. ha⁻¹ recorded a mean coccinellid population of 7.16, 6.75 and 6.25 per ten plants, respectively, while untreated plots recorded 9.66 per ten plants. The higher dose of emamectin benzoate 5 SG @15 g a.i. ha⁻¹ recorded 5.75 per ten plants which was on par with standard check Proclaim[®]. Whereas spinosad treated plots recorded 4.50 coccinellids per ten plants (Table 12).

After second round of application, maximum population per ten plants was observed in untreated check (12.00) followed by emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ (8.00 and 7.00, respectively). The minimum population of coccinellids was observed in spinosad treated plots with 3.25 coccinellids per ten plants.

Emamectin benzoate 5 SG doses at 15 and Proclaim[®] 11 g a.i. ha⁻¹ were the highly toxic treatments recording a mean population of 4.66 and 5.93 coccinellids per ten plants, respectively (Table 12).

4.1.3. Effect of emamectin benzoate 5 SG on cotton yield

4.1.3.1. Experiment I

The data recorded on the yield of cotton, on the first trial indicated that emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ recorded significantly higher yield (21.46 q ha⁻¹) over rest of the treatments (Table 13) which was on par with 11 g a.i. ha⁻¹ and Proclaim[®] 11 g a.i. ha⁻¹ (20.72 and 20.53 q ha⁻¹). The lower dose of emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ recorded a yield of 18.82 q ha⁻¹ and was superior over untreated check (12.20 q ha⁻¹). The standard check, spinosad recorded lowest yield of 15.29 q ha⁻¹.

Table 12. Effect of emamectin benzoate 5 SG on coccinellids in cotton eco system (Location - Narasimanayakkan palayam) II season

Treatments	Number of coccinellid per ten plants*										
	Days after first application					Days after second application					
	PTC	3	7	10	14	Mean	3	7	10	14	Mean
Emamectin benzoate 5 SG 7 g a.i.ha ⁻¹	8.67	5.00 (2.34) ^b	6.33 (2.61) ^b	8.00 (2.91) ^b	9.33 (3.13) ^b	7.16	6.67 (2.56) ^b	7.33 (2.79) ^b	8.33 (2.97) ^b	9.67 (3.07) ^b	8.00
Emamectin benzoate 5 SG 9 g a.i.ha ⁻¹	9.00	4.67 (2.27) ^{bc}	6.00 (2.54) ^{bc}	7.33 (2.78) ^b	9.00 (2.97) ^{bc}	6.75	5.67 (2.37) ^{bc}	6.67 (2.56) ^b	7.00 (2.73) ^c	8.67 (2.91) ^{bc}	7.00
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	8.33	4.33 (2.19) ^{bcd}	5.67 (2.48) ^{bcd}	6.33 (2.61) ^c	8.67 (3.02) ^{bcd}	6.25	5.33 (2.30) ^{bc}	5.73 (2.49) ^{cd}	6.33 (2.61) ^c	8.33 (2.97) ^c	6.33
Emamectin benzoate 5 SG 15 g a.i.ha ⁻¹	8.67	3.67 (2.04) ^d	5.00 (2.34) ^d	6.00 (2.54) ^c	8.33 (2.20) ^{cd}	5.75	4.33 (2.08) ^d	4.67 (2.16) ^d	4.00 (2.01) ^d	5.67 (2.74) ^d	4.66
Emamectin benzoate 5 SG (Proclaim [®]) 11 g a.i.ha ⁻¹	8.33	4.00 (2.12) ^{cd}	5.33 (2.41) ^{cd}	5.67 (2.48) ^{cd}	8.00 (2.80) ^d	5.75	4.67 (2.27) ^d	5.00 (2.34) ^{cd}	6.17 (2.58) ^c	7.89 (2.89) ^c	5.93
Spinosad 45 SC 75 g a.i.ha ⁻¹	9.33	2.33 (1.68) ^e	3.67 (2.04) ^e	5.00 (2.34) ^d	7.00 (2.62) ^e	4.50	2.33 (1.57) ^e	2.67 (1.67) ^e	3.00 (1.87) ^e	5.00 (2.23) ^e	3.25
Untreated check	8.67	9.00 (3.08) ^a	9.33 (3.13) ^a	10.00 (3.24) ^a	10.33 (3.29) ^a	9.66	10.67 (3.34) ^a	11.33 (3.43) ^a	12.33 (3.58) ^a	13.67 (3.76) ^a	12.00

PTC- Pre treatment count; * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

Table 13. Effect of emamectin benzoate 5 SG on yield of cotton (Location- Madhampatti) I season

Treatments	Doses (g a.i.ha⁻¹)	Kapas Yield (Kg plot⁻¹)*	Kapas Yield (q ha⁻¹)	Per cent increase in yield over untreated check
Emamectin benzoate 5 SG	7	3.76	18.82 ^c	35.17
Emamectin benzoate 5 SG	9	3.88	19.40 ^c	37.11
Emamectin benzoate 5 SG	11	4.14	20.72 ^{ab}	41.11
Emamectin benzoate 5 SG	15	4.29	21.46 ^a	43.15
Emamectin benzoate 5 SG(Proclaim [®])	11	4.10	20.53 ^{ab}	40.57
Spinosad 45 SC	75	3.05	15.29 ^d	20.20
Untreated control	-	2.44	12.20 ^e	-

*Mean of three replications; In a column, means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

4.1.3.2. Experiment II

In the second trial conducted at Narasimanayakkan palayam, the highest dose of emamectin benzoate 5 SG @ 15 g a.i. ha⁻¹ gave significantly more yield (19.96 q ha⁻¹) which was on par with emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹, and (Proclaim®) 11 g a.i. ha⁻¹ (18.77 and 18.85 q ha⁻¹). While emamectin benzoate 5 SG @ 9 g a.i. ha⁻¹ were the next best treatments (17.90 q ha⁻¹), the lowest yield was observed in spinosad (14.42 q ha⁻¹) treated plants next to untreated check (11.70 q ha⁻¹) (Table 14).

4.2. Okra

4.2.1. Bioefficacy of emamectin benzoate 5 SG against okra fruit borers

4.2.1.1. Experiment I - Madhampatti

4.2.1.1.a. Larval population, *E.vittella*

The incidence of larvae ranged from 18.25 to 19.52 ten plants⁻¹ prior to first spray (Table 15). The treatment with emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ showed significantly less population (3.57 larvae per ten plants) after 7 DAT followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ and emamectin benzoate (Proclaim®) @ 8.5 g a.i. ha⁻¹ (5.53 and 6.00 larvae per ten plants, respectively) and was on par. The lower dose of emamectin benzoate 5 SG @ 4.7 and 6.7 g a.i. ha⁻¹ recorded the mean population of 12.31 and 11.13 per ten plants followed by the standard check, spinosad (17.06 / ten plants) was found to be superior over untreated check.

After the second spray, with the lowest mean larval population in emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ (2.86 / ten plants) followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (5.59 / ten plants) which was on par with emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ (5.86 / ten plants). The lower dose of emamectin benzoate 5 SG at 4.7 and 6.7 g a.i. ha⁻¹ (11.94 and 9.25/ ten plants, respectively) were found to be superior over check, Spinosad 45SC @75 g a.i. ha⁻¹ (21.88/ ten plants) and untreated check (30.46/ ten plants) (Table 15). Based on the reduction over control, the order of efficacy of different treatments are given as follows: Emamectin benzoate 5 SG 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 6.7 g a.i. ha⁻¹ = emamectin benzoate 5 SG at 4.7 g a.i. ha⁻¹ > spinosad 45 SC at 75 g a.i. ha⁻¹ > untreated check. (Table 15)

Table 14. Effect of emamectin benzoate 5 SG on the yield of cotton (Location- Narasimanyakkan palayam) II season

Treatments	Dose (g a.i.ha⁻¹)	Kapas Yield (Kg plot⁻¹)*	Kapas Yield (q ha⁻¹)	Per cent increase in yield over untreated check
Emamectin benzoate 5 SG	7	3.35	16.78 ^{cd}	30.27
Emamectin benzoate 5 SG	9	3.58	17.90 ^c	34.60
Emamectin benzoate 5 SG	11	3.75	18.77 ^{ab}	37.66
Emamectin benzoate 5 SG	15	4.00	19.96 ^a	41.30
Emamectin benzoate 5 SG (Proclaim [®])	11	3.77	18.85 ^{ab}	37.90
Spinosad 45 SC	75	2.88	14.42 ^e	18.80
Untreated control	-	2.34	11.70 ^f	-

* Mean of three replications; In a column, means followed by a common letter(s) are not significantly different by DMRT(P=0.05)

Table 15. Effect of emamectin benzoate 5 SG on larval population of *Earias vittella* in okra (Location- Madhampatti) I season

Treatments	Number of larva per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	18.25	12.00 (3.53) ^d	9.00 (3.08) ^c	13.00 (3.67) ^d	17.00 (4.18) ^d	12.31	48.60	11.00 (3.39) ^d	8.50 (3.00) ^d	12.25 (3.57) ^d	13.13 (3.69) ^{cd}	11.94	60.80
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	19.00	10.25 (3.27) ^c	8.50 (3.00) ^c	11.00 (3.39) ^c	14.00 (3.80) ^c	11.13	53.52	9.00 (3.08) ^c	7.25 (2.78) ^c	9.50 (3.16) ^c	11.25 (3.42) ^c	9.25	69.63
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	18.50	7.17 (2.76) ^b	5.53 (2.45) ^b	7.50 (2.82) ^b	10.97 (3.38) ^b	7.79	67.47	6.00 (2.54) ^b	4.00 (2.12) ^b	5.10 (2.36) ^b	7.27 (2.78) ^b	5.59	81.64
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	18.27	5.52 (2.45) ^a	3.57 (2.01) ^a	6.50 (2.64) ^a	9.00 (3.08) ^a	6.52	72.77	3.33 (1.95) ^a	2.17 (1.63) ^a	2.97 (1.86) ^a	3.00 (1.87) ^a	2.86	90.61
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i.ha ⁻¹	19.00	7.23 (2.78) ^b	6.00 (2.54) ^b	7.63 (2.85) ^b	11.00 (3.39) ^b	7.96	66.76	6.25 (2.59) ^b	4.20 (2.16) ^b	5.70 (2.48) ^b	7.30 (2.79) ^b	5.86	80.76
Spinosad 45 SC 75 g a.i.ha ⁻¹	19.26	13.00 (3.67) ^e	14.20 (3.84) ^d	19.00 (4.41) ^e	22.00 (4.74) ^e	17.06	28.76	18.00 (4.30) ^e	19.00 (4.41) ^e	24.00 (4.94) ^e	26.50 (5.19) ^e	21.88	28.16
Untreated check	19.52	22.00 (4.74) ^f	23.27 (4.87) ^e	24.51 (5.00) ^f	26.00 (5.14) ^f	23.95	--	27.67 (5.30) ^f	29.67 (5.49) ^f	31.00 (5.61) ^f	33.50 (5.83) ^f	30.46	--

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

4.2.1.1.b. Larval population *H.armigera*

The larval population of *H.armigera* prior to first application was 5.93 to 6.90/ ten plants (Table 16). Significant difference was recorded among the treatments after 3, 7, 10 and 14 days of first spray. Among the insecticidal treatments, emamectin benzoate 5 SG at 8.5 and 11 g a.i. ha⁻¹ was found consistently and significantly superior up to 14 days. The recommended dose of emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (2.10 larvae / ten plants) was on par with the emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ (2.00 larvae / ten plants) on 3 DAT. After 7 DAT emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ was better (0.73 larvae/ ten plants) than other treatments in reducing larval population. The lower dose of emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ recorded (3.00 larvae / ten plants) and emamectin benzoate 5 SG at 4.7 g a.i. ha⁻¹ recorded 3.79 larvae/ ten plants. The spray of standard check spinosad was significantly different from untreated check (6.97 larvae/ ten plant).

Similar trend of efficacy was observed after the second spray (Table 16). Considering the per cent reduction over untreated check, the order of efficacy of the given treatments against *H. armigera* are as follows: emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ > emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ > emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ > spinosad 45SC @ 75 g a.i. ha⁻¹ > untreated check.

4.2.1.1. c. Fruit borer damage on okra fruits

All the insecticidal treatments were significantly effective in suppressing the fruit borer damage as compared to untreated control (Table 17). Among the treatments, emamectin benzoate 5 SG at the dose of 11 g a.i. ha⁻¹ was significantly superior over other treatments with 8.33, 7.57, 9.50, and 11.93 per cent damage per ten plants, respectively at 3, 7, 10 and 14 DAT. Similarly, emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ gave 10.02, 8.63, 10.57, and 13.63 which was on par with emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ (10.90, 9.00, 11.00, and 14.00) respectively on 3, 7, 10 and 14 DAT. However, the lower dose of emamectin benzoate 5 SG @ 4.7 and 6.75 g a.i. ha⁻¹ were comparatively less effective in reducing the damage.

Table 16. Effect of emamectin benzoate 5 SG on larval population of *Helicoverpa armigera* in okra (Location - Madhampatti) I season

Treatments	Number of larva per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	6.27	4.17 (2.16) ^c	3.79 (2.07) ^c	4.00 (2.12) ^c	4.33 (2.19) ^c	4.07	42.35	3.77 (2.06) ^{cd}	2.70 (1.78) ^{cd}	3.00 (1.87) ^{cd}	3.70 (1.78) ^{cd}	3.29	55.66
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	6.67	3.40 (1.97) ^c	3.00 (1.87) ^c	3.37 (1.96) ^c	3.97 (2.11) ^c	3.43	51.34	3.10 (1.89) ^c	2.53 (1.74) ^c	2.70 (1.78) ^c	3.00 (1.87) ^c	2.83	61.18
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	6.33	2.10 (1.44) ^b	1.37 (1.36) ^{ab}	1.93 (1.55) ^{ab}	2.47 (1.99) ^{ab}	1.96	72.23	1.90 (1.54) ^b	1.00 (1.22) ^{ab}	1.27 (1.33) ^{ab}	1.33 (1.35) ^{ab}	1.37	81.53
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	6.00	1.00 (1.22) ^a	0.73 (1.10) ^a	1.10 (1.26) ^a	1.49 (1.72) ^a	1.87	73.51	1.00 (1.22) ^a	0.33 (0.91) ^a	0.70 (1.27) ^a	0.63 (1.06) ^a	0.79	89.35
Emamectin benzoate 5 SG (Proclaim [®]) 8.5 g a.i.ha ⁻¹	5.93	2.00 (1.58) ^b	1.43 (1.38) ^{ab}	2.07 (1.60) ^b	2.73 (1.79) ^b	2.05	70.96	2.00 (1.58) ^b	1.13 (1.27) ^{ab}	1.37 (1.36) ^{ab}	1.53 (1.42) ^{ab}	1.53	79.38
Spinosad 45 SC 75 g a.i.ha ⁻¹	6.90	5.63 (2.47) ^d	4.17 (2.16) ^d	5.97 (2.54) ^d	5.27 (2.40) ^e	5.26	25.37	3.97 (2.11) ^d	3.20 (1.92) ^d	3.17 (1.91) ^d	3.93 (2.10) ^d	3.41	54.04
Untreated check	6.67	6.73 (2.68) ^e	6.97 (2.73) ^e	7.17 (2.76) ^e	7.37 (2.80) ^f	7.06	-	7.10 (2.75) ^e	7.37 (2.80) ^e	7.40 (2.81) ^e	7.83 (2.88) ^e	7.42	-

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

Table 17. Effect of emamectin benzoate 5 SG against fruit borers damage in okra (Location - Madhampatti) I season

Treatments	Mean per cent fruit damage per ten plants*													
	Days after first application							Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn	
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	25.37	16.72 (24.11) ^d	14.89 (22.70) ^d	18.95 (25.80) ^d	23.33 (28.88) ^d	18.47	39.44	15.39 (23.08) ^d	12.53 (20.72) ^d	13.67 (21.69) ^d	14.23 (28.07) ^d	13.95	67.50	
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	26.02	15.34 (23.05) ^c	13.52 (21.58) ^c	16.79 (24.19) ^c	20.42 (26.86) ^c	16.52	48.84	13.57 (21.61) ^c	10.63 (19.01) ^c	11.43 (19.75) ^c	12.37 (26.98) ^c	12.00	72.27	
Emamectin benzoate 5 SG8.5 g a.i.ha ⁻¹	24.65	10.02 (21.95) ^b	8.63 (20.82) ^{ab}	10.57 (22.41) _{ab}	13.63 (24.83) ^b	10.07	64.88	9.81 (18.24) ^b	6.59 (14.86) ^b	7.63 (16.02) ^b	8.38 (24.20) ^b	8.10	81.12	
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	25.41	8.33 (18.75) ^a	7.57 (18.01) ^a	9.50 (19.79) ^a	11.93 (21.92) ^a	9.33	70.00	6.63 (14.91) ^a	3.77 (11.18) ^a	4.42 (12.33) ^a	5.23 (21.30) ^a	6.02	85.97	
Emamectin benzoate 5 SG (Proclaim [®]) 8.5 g a.i.ha ⁻¹ .	26.11	10.90 (21.95) ^b	9.00 (21.62) ^b	11.00 (24.04) ^b	14.00 (26.81) ^b	11.22	63.20	10.45 (18.85) ^b	7.00 (15.33) ^b	8.07 (16.49) ^b	8.79 (24.53) ^b	8.57	80.00	
Spinosad 45 SC 75 g a.i.ha ⁻¹	25.61	19.37 (26.09) ^E	27.45 (31.59) ^e	25.75 (30.49) ^e	29.55 (32.93) ^e	25.53	16.30	25.35 (30.23) ^e	26.64 (31.06) ^e	27.59 (31.68) ^e	28.71 (34.69) ^e	27.07	36.91	
Untreated check	26.45	27.53 (31.64) ^F	28.42 (32.21) ^f	31.97 (34.43) ^f	34.08 (35.71) ^f	30.50	-	41.76 (40.25) ^f	42.59 (40.73) ^f	43.05 (41.00) ^f	44.23 (40.21) ^f	42.91	-	

PTC- Pretreatment count; % Redn. - Reduction over control, * Mean of three replications, Figures in parentheses are *arc sine* transformed values; In a column, means followed by a common letter(s) are not significantly different by DMRT (P=0.05).

A similar trend was noticed during second spray also (Table 17) in which, emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ recorded a mean damage of 6.02 per cent per ten plants followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (8.10 % per ten plants) which was on par with emamectin benzoate 5 SG (Proclaim[®]) @ 8.5 g a.i. ha⁻¹ (8.57 % per ten plants). The lower dose of emamectin benzoate 5 SG @ 4.7 and 6.7 g a.i. ha⁻¹ recorded 13.95 and 12.00 per cent damage per ten plants and standard check, spinosad @ 75 g a.i. ha⁻¹ recorded 27.07 per cent damage per ten plants. Based on the per cent reduction over untreated check, the order of efficacy of different treatments were as follows: emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim[®]) at 8.5 g a.i. ha⁻¹ > emamectin benzoate 5 SG 6.7 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 4.7 g a.i. ha⁻¹ > spinosad 75 g a.i. ha⁻¹ > untreated check.

4.2.1.2. Experiment II –Narasimanyakkan palayam

4.2.1.2 a. Larval population, *E. vittella*

The mean larval population prior to first spray ranged from 19.50 to 22.00 per ten plants (Table 18). Emamectin benzoate 5 SG @11 g a.i. ha⁻¹ recorded the highest reduction at 3,7,10 and 14 DAT with larval population of 7.25, 5.50, 8.00 and 10.00 larvae per ten plants, respectively. Emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ recorded the mean larval population of 9.73 per ten plants which was on par with Proclaim[®] (10.10 larvae per ten plants), while lowest doses of emamectin benzoate 5 SG @ 4.7 and 6.7 g a.i. ha⁻¹ recorded 12.18 and 11.73 mean larval population per ten plants. The highest larval population was observed in spinosad with 17.00 larvae per ten plants, next to untreated check (24.06 larvae per ten plants).

However, after the second spray, the maximum larval reduction was recorded in emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ (83.60 %) and emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ (81.37 %) which were on par with Proclaim[®] (79.60 %) followed by emamectin benzoate 5 SG @ 6.7g a.i. ha⁻¹ recorded (63.32 %). Emamectin benzoate 5 SG at 4.7 g a.i. ha⁻¹ and standard check spinosad recorded 56.34 and 43.64 per cent reduction and were superior to untreated check. (Table 18).

Table 18. Effect of emamectin benzoate 5 SG on larval population of *Earias vittella* in okra (Location- Narasimanayakkan palayam) II season

Treatments	Number of larva per ten plants*													
	Days after first application							Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn	
Emamectin benzoate5 SG 4.7 g a.i.ha ⁻¹	20.50	14.00 (3.80) ^d	12.50 (3.60) ^d	12.67 (3.62) ^d	15.23 (3.96) ^d	12.18	49.37	11.23 (3.42) ^d	10.57 (3.32) ^c	11.53 (3.46) ^d	11.20 (3.42) ^c	11.13	56.34	
Emamectin benzoate5 SG 6.7 g a.i.ha ⁻¹	19.50	12.00 (3.53) ^c	10.23 (3.27) ^c	11.50 (3.46) ^c	13.20 (3.70) ^c	11.73	51.24	9.23 (3.11) ^{bc}	8.10 (2.93) ^b	9.50 (3.16) ^c	10.00 (3.24) ^b	9.20	63.32	
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	22.00	10.50 (3.31) ^b	8.17 (2.94) ^b	9.60 (3.17) ^b	10.67 (3.34) ^b	9.73	59.55	5.00 (2.34) ^b	4.00 (2.12) ^{ab}	4.50 (2.23) ^{ab}	5.50 (2.44) ^{ab}	4.75	81.37	
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	21.00	7.25 (2.78) ^a	5.50 (2.44) ^a	8.00 (2.91) ^a	10.00 (3.24) ^a	7.93	67.04	3.00 (1.87) ^a	2.27 (1.66) ^a	3.50 (2.00) ^a	5.00 (2.34) ^a	2.19	83.60	
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i.ha ⁻¹ .	20.25	10.93 (3.38) ^b	8.50 (3.00) ^b	10.00 (3.24) ^b	11.00 (3.39) ^b	10.10	58.02	5.20 (2.38) ^b	4.50 (2.23) ^b	5.00 (2.34) ^b	6.13 (2.57) ^b	5.20	79.60	
Spinosad 45 SC 75 g a.i.ha ⁻¹	21.50	16.50 (4.12) ^e	14.00 (3.80) ^e	16.00 (4.02) ^e	18.00 (4.30) ^e	17.00	29.34	11.00 (3.39) ^e	12.50 (3.60) ^e	15.00 (3.93) ^e	19.00 (4.41) ^e	14.37	43.64	
Untreated check	22.00	24.00 (4.94) ^f	25.00 (5.04) ^f	25.25 (5.02) ^f	22.00 (4.73) ^f	24.06	--	23.00 (4.84) ^f	24.50 (5.00) ^f	26.25 (5.17) ^f	28.25 (5.36) ^f	25.50	--	

PTC- Pre treatment count; Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

4.2.1.2. b. Larval population, *H. armigera*

The perusal of the data (Table 19) indicated that all insecticidal treatments were significantly effective over untreated control in reducing larval population. Observations recorded at 10 and 14 DAT showed that emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ was effective in reducing the larval population (1.87 and 2.39 per ten plants) which was on par with emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (2.67 and 3.17 per ten plants). The lower dose of emamectin benzoate @ 4.7 g a.i. ha⁻¹ recorded 4.97 larvae per ten plants. Emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ was found to be superior over spinosad (4.33 larvae / ten plants) and untreated check (8.37 larvae/ ten plants).

After second spray, emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ gave maximum control of larvae with 0.23 / ten plants at 7 DAT, followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (1.23/ ten plants) which was on par with emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ (1.30/ ten plants). However, the lower dose of emamectin benzoate 5 SG at 4.7 g a.i. ha⁻¹ (3.67 larvae / ten plants) and emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ (2.90 larvae/ ten plants) were better than untreated check (Table 19).

Based on the per cent reduction over untreated check, the order of efficacy of different treatments were as follows: emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ > emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim®) @ 8.5 g a.i. ha⁻¹ > emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ > emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ > spinosad 45 SC @ 75 g a.i. ha⁻¹ > untreated check.

4.2.1.2. c. Fruit borer damage on okra fruits

The damage per cent due to fruit borers before imposing treatments ranged from 28.03 to 29.09 per cent (Table 20). There was a significant reduction in damage after first round of application, on 7 DAT. The lowest mean damage was recorded in emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ (12.60%) followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (16.38 %) which was on par with Proclaim® @ 8.5 g a.i. ha⁻¹ (16.72 %). Among the insecticidal treatments, the highest boll damage was recorded in plots treated with spinosad (26.81 %). After first round of application, the highest reduction was recorded in plots treated with emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ (61.95 %) followed by emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (50.53 %).

Table 19. Effect of emamectin benzoate 5 SG on larval population of *Helicoverpa armigera* in okra (Location - Narasimanayakkan palayam) II season

Treatments	Number of larva per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	6.70	5.10 (2.36) ^{cd}	4.17 (2.16) ^{cd}	4.97 (2.33) ^{cd}	5.47 (2.44) ^{cd}	4.92	39.46	4.10 (2.14) ^{cd}	3.67 (2.04) ^{cd}	3.73 (2.05) ^{cd}	3.97 (2.11) ^{cd}	3.86	56.91
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	6.17	4.27 (2.18) ^c	3.97 (2.11) ^c	4.33 (2.19) ^c	4.90 (2.32) ^c	4.36	47.62	3.97 (2.11) ^c	2.90 (1.84) ^c	3.27 (1.94) ^c	3.40 (1.97) ^c	3.26	63.61
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	6.00	3.00 (1.87) ^b	2.13 (1.62) ^{ab}	2.67 (1.78) ^{ab}	3.17 (2.91) ^{ab}	2.74	66.59	2.00 (1.58) ^{ab}	1.23 (1.31) ^{ab}	1.57 (1.43) ^{ab}	1.79 (1.51) ^{ab}	1.64	81.64
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	6.23	1.90 (1.54) ^a	1.00 (1.22) ^a	1.87 (1.53) ^a	2.39 (1.70) ^a	1.79	78.19	1.00 (1.22) ^a	0.23 (0.85) ^a	0.77 (1.12) ^a	1.00 (1.22) ^a	0.75	85.37
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i.ha ⁻¹	6.37	3.10 (1.89) ^b	2.40 (1.70) ^b	2.83 (1.82) ^b	3.47 (1.99) ^b	2.95	64.06	2.20 (1.64) ^b	1.30 (1.34) ^b	1.69 (1.47) ^b	1.97 (1.57) ^b	1.79	80.02
Spinosad 45 SC 75 g a.i.ha ⁻¹	6.40	5.17 (2.38) ^{de}	4.27 (2.18) ^{de}	4.60 (2.25) ^{de}	4.93 (2.33) ^{de}	4.74	42.26	4.00 (2.12) ^{de}	3.97 (2.11) ^{de}	4.37 (2.20) ^{de}	4.67 (2.27) ^{de}	4.25	52.56
Untreated check	7.77	7.89 (2.89) ^f	8.37 (2.97) ^f	8.27 (2.96) ^f	8.33 (2.97) ^f	8.21	-	8.61 (3.01) ^f	8.97 (3.07) ^f	9.00 (3.08) ^f	9.27 (3.12) ^f	8.96	-

PTC- Pre treatment count; % Redn. - Reduction from control, * Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values, In a column means followed by a common letter(s) are not significantly different by DMRT (P=0.05)

**Table 20. Effect of emamectin benzoate 5 SG against fruit borers damage in okra (Location - Narasimanayakkan palayam)
II season**

Treatments	Mean per cent fruit damage per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	28.97	18.79 (25.68) ^e	16.99 (24.33) ^d	20.74 (27.08) ^d	25.00 (29.99) ^e	20.38	38.45	11.23 ^e (19.57)	10.53 ^c (18.92)	11.40 ^d (19.72)	13.23 ^d (21.32)	11.59	72.42
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	28.42	17.68 (24.85) ^d	15.08 (22.84) ^{bc}	18.65 (25.58) ^c	21.75 (27.79) ^d	18.29	44.76	9.57 ^c (18.01)	8.67 ^b (17.11)	10.47 ^c (18.87)	11.13 ^c (19.48)	9.46	77.52
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	28.86	15.43 (23.12) ^c	13.00 (21.12) ^b	15.93 (23.52) ^b	18.65 (25.58) ^b	16.38	50.53	7.53 ^b (15.91)	5.47 ^b (13.51)	6.33 ^b (14.56)	8.37 ^{bc} (16.80)	6.92	83.55
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	28.09	12.09 (20.34) ^a	10.37 (18.78) ^a	13.65 (21.67) ^a	14.29 (22.20) ^a	12.60	61.95	4.59 ^a (12.35)	3.17 ^a (10.23)	4.10 ^a (11.67)	4.87 ^a (12.73)	4.18	90.00
Emamectin benzoate 5 SG (Proclaim [®]) 8.5 g a.i.ha ⁻¹	28.95	15.52 (23.19) ^b	13.97 (21.94) ^c	16.00 (23.57) ^c	19.00 (25.83) ^c	16.72	49.50	7.73 ^b (16.13)	6.59 ^b (14.86)	7.13 ^b (15.47)	9.07 ^b (17.52)	7.63	81.86
Spinosad 45 SC 75 g a.i.ha ⁻¹	28.03	24.42 (26.85) ^f	28.97 (32.55) ^e	28.14 (32.03) ^e	29.72 (33.03) ^f	26.81	19.03	26.50 ^f (30.97)	25.27 ^d (30.17)	28.87 ^e (32.49)	30.30 ^e (33.39)	27.73	34.12
Untreated check	29.09	30.20 ^c (33.33) ^g	31.74 (34.28) ^f	33.97 (35.64) ^f	36.51 (37.17) ^g	33.11	-	40.03 ^g (39.24)	41.50 ^e (40.10)	42.63 ^f (40.75)	44.17 ^f (41.64)	42.08	-

PTC- Pretreatment count; % Redn. - Reduction over control, * Mean of three replications, Figures in parentheses are *arc sine* transformed values; In a column, means followed by a common letter(s) are not significantly different by DMRT (P=0.05).

After second round of application, emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ registered a mean reduction of 90 per cent damage over untreated check followed by emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ (83.55 %), Proclaim® (81.86 %), emamectin benzoate 5 SG at 6.7 g a.i. ha⁻¹ (77.52 %), emamectin benzoate 5 SG at 4.7 a.i. ha⁻¹ (72.42 %) and spinosad (34.12 %) (Table 20).

4.2.2. Population of natural enemies

4.2.2.1. Experiment I

4.2.2.1 a. Spiders

The population of spiders before the first application varied from 5.00 to 5.97 per ten plants (Table 21). There was slight reduction in the population of spiders after spraying. The higher dose of emamectin benzoate (11 g a.i. ha⁻¹) recorded minimum population of spiders (4.86/ ten plants). Emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ was on par with Proclaim® @ 8.5 g a.i. ha⁻¹ (5.83 and 5.59/ ten plants) , while standard check spinosad recorded a mean population of 3.19 per ten plants and was found to be more toxic to spiders than other insecticidal treatments. The population was the highest in untreated check (7.33 nos./ ten plants) followed by lower dose of emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (6.37 nos. / ten plants).

The spider population varied from 4.67 to 8.67 per ten plants prior to second spray (Table 21). Considering the mean spider population among the insecticidal treatments, emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ recorded maximum population of spiders (8.00 nos./ ten plants) and the standard check spinosad recorded the least population of spiders (4.27nos./ ten plants). The population of spiders slowly recovered during the subsequent period after treatment. Emamectin benzoate 5 SG @ 6.7g a.i. ha⁻¹ harboured 7.67 spiders per ten plants followed by emamectin benzoate 5 SG @8.5 g a.i. ha⁻¹ (7.33/ ten plants) and Proclaim® 11 g a.i. ha⁻¹ (6.97/ ten plants) whereas, untreated check recorded a mean of 9.58 spiders per ten plants.

4.2.2.1 b. Coccinellids

The population of coccinellids was uniform (8.33 to 9.00 nos. per ten plants) in the okra crop prior to commencement of insecticidal treatment. The mean population of

Table 21. Effect of emamectin benzoate 5 SG on spiders in okra eco system (Location - Madhampatti) I season

Treatments	Number of spiders per ten plants*										
	Days after first application						Days after second application				
	PTC	3	7	10	14	Mean	3	7	10	14	Mean
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	5.00	4.00 (2.12) ^b	5.17 (2.38) ^b	7.67 (2.85) ^a	8.67 (3.02) ^a	6.37	7.00 (2.73) ^b	7.33 (2.79) ^b	8.00 (2.91) ^b	9.67 (3.18) ^{ab}	8.00
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	5.27	3.73 (2.05) ^{bc}	4.93 (2.33) ^b	6.00 (2.54) ^b	8.33 (2.97) ^{ab}	5.74	6.03 (2.55) ^{bc}	7.00 (2.73) ^b	8.33 (2.97) ^{bc}	9.33 (3.13) ^b	7.67
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	5.73	3.33 (1.95) ^{bc}	5.00 (2.34) ^{bc}	7.00 (2.75) ^{bc}	8.00 (2.91) ^{ab}	5.83	5.67 (2.48) ^{bc}	6.67 (2.67) ^{bc}	8.00 (2.91) ^{bc}	9.00 (3.08) ^{bc}	7.33
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	5.33	3.00 (1.87) ^d	4.13 (2.15) ^{cd}	5.00 (2.34) ^c	7.33 (2.79) ^b	4.86	5.33 (2.41) ^c	6.00 (2.54) ^c	7.33 (2.79) ^c	8.67 (3.02) ^c	6.83
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i.ha ⁻¹	5.97	3.33 (1.95) ^{bc}	4.33 (2.19) ^{cd}	6.73 (2.68) ^{bc}	8.00 (2.91) ^{ab}	5.59	5.00 (2.34) ^c	6.33 (2.61) ^c	7.67 (2.85) ^{bc}	8.89 (3.06) ^{bc}	6.97
Spinosad 45 SC 75 g a.i.ha ⁻¹	5.23	2.67 (1.78) ^e	2.10 (1.61) ^e	3.33 (1.95) ^d	4.67 (2.27) ^c	3.19	3.00 (1.87) ^d	3.90 (2.09) ^d	4.67 (2.27) ^d	5.53 (2.45) ^d	4.27
Untreated check	5.73	6.00 (2.54) ^a	6.73 (2.68) ^a	7.93 (2.90) ^a	8.67 (3.02) ^a	7.33	9.67 (3.18) ^a	10.00 (3.24) ^a	10.33 (3.29) ^a	10.67 (3.34) ^a	9.58

PTC- Pre treatment count; *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

coccinellid predators was highest in the treatment sprayed with emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (7.87 nos. / ten plants) followed by emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ (7.20 nos./ ten plants). Emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (6.84 nos./ ten plants) was on par with emamectin benzoate 5 SG (Proclaim®) @ 11 g a.i. ha⁻¹ (6.58 nos./ ten plants) (Table 22). The least population of coccinellids was recorded in the standard check, spinosad @ 75 g a.i. ha⁻¹ (4.37 nos. / ten plants) followed by the higher dose of emamectin benzoate @ 11 g a.i. ha⁻¹ (5.61 nos./ ten plants).

The coccinellids population before second round of spray varied from 5.63 to 10.60 per ten plants (Table 22). Among the insecticidal treatments, the highest mean population of coccinellids was recorded by emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (8.83 nos. / ten plants) followed by emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ (7.57 nos./ ten plants), emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (7.29 nos./ ten plants) and emamectin benzoate 5 SG @ (Proclaim®) 8.5 g a.i. ha⁻¹ (7.00 nos./ ten plants). On comparison with untreated check, all the insecticidal treatments showed decline in the population of coccinellids but it was clear that after initial decline there occurred a slow progressive increase in the number of coccinellids.

4.2.2. Incidence of natural enemies

4.2.2.2. Experiment II

4.2.2.2 a. Spiders

Among the chemicals tested, emamectin benzoate 5SG doses @ 4.7 and 6.7 a.i.ha⁻¹ were the least toxic to spiders recording a mean of 8.01 and 7.34 spiders, respectively per ten plants after the first round of spraying (Table 23).

After second round of application, emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ harboured 8.30 spiders per ten plants followed by emamectin benzoate 5 SG at 6.7, 8.5 and Proclaim® @ 8.5 a.i. ha⁻¹ (7.59, 7.13 and 6.84 spiders / ten plants), whereas higher dose of emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ and spinosad at 75 g a.i. ha⁻¹ harboured 6.63 and 4.16 spiders per ten plants respectively as against 9.72 spiders per ten plants in untreated check (Table 23).

Table 22. Effect of emamectin benzoate 5 SG on coccinellids in okra eco system (Location- Madhampatti) I season

Treatments	Number of coccinellids per ten plants*												
	Days after first application						Days after second application						
	PTC	3	7	10	14	Mean	3	7	10	14	Mean		
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	9.00	5.63 (2.47) ^b	7.03 (2.74) ^b	9.17 (3.10) ^{ab}	9.67 (3.18) ^{ab}	7.87	7.63 (2.85) ^b	8.63 (3.02) ^b	9.07 (3.09) ^b	10.00 (3.24) ^b	8.83		
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	8.33	5.37 (2.42) ^b	6.37 (2.62) ^{bc}	8.07 (2.92) ^b	9.00 (3.08) ^b	7.20	6.63 (2.67) ^{bc}	7.37 (2.80) ^{bc}	7.63 (2.85) ^c	8.67 (3.02) ^c	7.57		
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	9.00	5.27 (2.40) ^b	6.37 (2.62) ^{bc}	7.57 (2.87) ^c	8.17 (2.94) ^{bc}	6.84	6.70 (2.68) ^{bc}	7.00 (2.73) ^c	7.33 (2.79) ^c	8.13 (2.93) ^c	7.29		
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	8.67	4.33 (2.19) ^c	5.00 (2.34) ^{de}	6.13 (2.57) ^d	7.00 (2.73) ^c	5.61	4.63 (2.26) ^d	5.00 (2.34) ^d	5.63 (2.47) ^d	7.63 (2.85) ^d	5.72		
Emamectin benzoate 5 SG (Proclaim [®]) 8.5 g a.i.ha ⁻¹ .	9.00	5.33 (2.41) ^{bc}	5.67 (2.48) ^{cd}	7.33 (2.79) ^c	8.00 (2.91) ^{bc}	6.58	6.27 (2.60) ^{bc}	6.79 (2.70) ^c	7.00 (2.73) ^d	7.96 (2.90) ^c	7.00		
Spinosad 45 SC 75 g a.i.ha ⁻¹	8.67	3.37 (1.96) ^{cd}	4.00 (2.12) ^e	5.00 (2.34) ^e	5.63 (2.47) ^d	4.37	3.10 (1.89) ^e	3.73 (2.05) ^e	3.77 (2.06) ^e	4.07 (2.13) ^e	3.66		
Untreated check	8.33	9.33 (3.13) ^a	9.67 (3.18) ^a	10.33 (3.29) ^a	10.60 (3.33) ^a	9.98	12.00 (3.53) ^a	12.67 (3.62) ^a	14.00 (3.80) ^a	14.67 (3.89) ^a	13.33		

PTC- Pre treatment count; *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

Table 23. Effect of emamectin benzoate 5 SG on spiders in okra eco system (Location - Narasimanayakkan palayam) II season

Treatments	Number of spiders per ten plants*											
	Days after first application						Days after second application					
	PTC	3	7	10	14	Mean	3	7	10	14	Mean	
Emamectin benzoate 5 SG 4.7 g a.i.ha ⁻¹	8.37	7.00 (2.73) ^b	7.27 (2.78) ^b	8.63 (3.02) ^b	9.17 (3.10) ^b	8.01	7.30 (2.79) ^b	7.69 (2.86) ^b	8.63 (3.02) ^b	9.60 (3.17) ^{ab}	8.30	
Emamectin benzoate 5 SG 6.7 g a.i.ha ⁻¹	8.00	6.33 (2.61) ^{bc}	7.00 (2.73) ^b	7.37 (2.80) ^{bc}	8.67 (3.02) ^b	7.34	6.37 (2.62) ^b	7.00 (2.73) ^b c	8.00 (2.91) ^{bc}	9.00 (3.08) ^b	7.59	
Emamectin benzoate 5 SG 8.5 g a.i.ha ⁻¹	8.67	5.00 (2.34) ^{cd}	6.33 (2.61) ^{bc}	7.00 (2.73) ^c	8.00 (2.91) ^{bc}	6.58	5.60 (2.46) ^c	6.63 (2.70) ^c	8.00 (2.91) ^{bc}	8.30 (2.96) ^{bc}	7.13	
Emamectin benzoate 5 SG 11 g a.i.ha ⁻¹	8.33	4.00 (2.12) ^d	5.30 (2.40) ^c	6.13 (2.57) ^c	7.27 (2.78) ^c	5.67	5.60 (2.46) ^c	6.00 (2.54) ^c	7.33 (2.79) ^c	7.63 (2.85) ^c	6.63	
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i.ha ⁻¹	8.63	4.83 (2.30) ^{cd}	6.00 (2.54) ^d	7.00 (2.73) ^c	7.93 (2.90) ^{bc}	6.44	5.30 (2.40) ^c	6.37 (2.62) ^c	7.70 (2.54) ^c	8.00 (2.91) ^c	6.84	
Spinosad 45 SC 75 g a.i.ha ⁻¹	8.63	2.67 (1.78) ^e	3.47 (1.99) ^e	4.67 (2.27) ^d	5.00 (2.34) ^d	3.95	3.00 (1.87) ^d	3.33 (1.95) ^d	4.33 (2.19) ^d	6.00 (2.54) ^d	4.16	
Untreated check	8.97	9.00 (3.08) ^a	8.63 (3.02) ^a	9.63 (3.18) ^a	10.00 (3.24) ^a	9.35	9.43 (3.15) ^a	9.67 (3.18) ^a	9.80 (3.20) ^a	10.00 (3.24) ^a	9.72	

PTC- Pre treatment count; *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

4.2.2.2b. Coccinellids

In the pre-treatment count, the coccinellid population ranged from 5.33 to 6.13 per ten plants. There was a slight reduction in population after spraying. Considering the mean coccinellids population per ten plants, the maximum population was observed in untreated check (9.91 nos. /ten plants) followed by the lower dose of emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (6.29 nos. / ten plants), while emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ and Proclaim® @ 8.5 g a.i. ha⁻¹ recorded a mean population of 5.33 and 5.11 coccinellids per ten plants, respectively. The higher dose of emamectin benzoate 5 SG @11 g a.i. ha⁻¹ reduced the mean coccinellids population to 4.80 per ten plants (Table 24). All the treatments irrespective of doses were found to have more coccinellid population per ten plants when compared to standard check spinosad 45 SC at 75 g a.i. ha⁻¹.

Similar trend was observed after the second application. The mean population of coccinellids prior to second spray ranged from 4.17 to 10.67 per ten plants. Untreated check recorded the maximum mean coccinellid population of 11.97 per ten plants followed by emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (7.38 nos. /ten plants). All the treatments were found to be superior to the standard check spinosad (4.22 nos. / ten plants) (Table 24).

4.2. Effect of emamectin benzoate 5 SG on okra fruit yield

4.2.3. Experiment I

The data recorded on the yield of bhendi, on the first trial indicated that emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ (8100.50 kg ha⁻¹) exhibited significantly higher yield over rest of the treatments (Table 25). Emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ (7690.50 kg ha⁻¹) was on par with (Proclaim®) @ 8.5 g a.i. ha⁻¹ (7345.00 kg ha⁻¹). The lower dose of emamectin benzoate 5 SG @ 6.7 g a.i. ha⁻¹ recorded yield of 6915.00 kg ha⁻¹. The standard check, spinosad recorded a lower fruit yield of 5726.50 kg ha⁻¹ and was found to be better than untreated check (4936.00 kg ha⁻¹).

4.2.3.2 Experiment II

In the second trial, emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ gave significantly more yield over the rest and other treatments, viz., Whereas emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ (7500.00kg ha⁻¹) was on par with Proclaim® (7340.00 kg ha⁻¹) and

Table 24. Effect of emamectin benzoate 5 SG on coccinellids in okra eco system (Location - Narasimanayakkan palayam)
II season

Treatments	Number of coccinellids per ten plants*										
	Days after first application						Days after second application				
	PTC	3	7	10	14	Mean	3	7	10	14	Mean
Emamectin benzoate 5 SG 4.7 g a.i./ha ⁻¹	5.17	4.27 (2.18) ^b	5.73 (2.49) ^b	7.17 (2.76) ^b	8.00 (2.91) ^b	6.29	6.00 (2.54) ^b	7.17 (2.76) ^b	8.00 (2.91) ^b	8.37 (2.97) ^b	7.38
Emamectin benzoate 5 SG 6.7 g a.i./ha ⁻¹	5.00	4.00 (2.12) ^{bc}	5.13 (2.37) ^{bc}	6.93 (2.72) ^{bc}	7.69 (2.86) ^b	5.93	5.87 (2.52) ^{bc}	7.00 (2.73) ^b	7.67 (2.85) ^c	8.00 (2.91) ^b	7.13
Emamectin benzoate 5 SG 8.5 g a.i./ha ⁻¹	6.13	3.47 (1.99) ^{bc}	4.53 (2.24) ^{bc}	6.00 (2.54) ^c	7.33 (2.79) ^c	5.33	6.13 (2.57) ^c	6.63 (2.67) ^c	7.13 (2.76) ^d	8.00 (2.91) ^b	6.97
Emamectin benzoate 5 SG 11 g a.i./ha ⁻¹	5.79	3.00 (1.87) ^c	4.27 (2.18) ^c	5.13 (2.37) ^{cd}	6.83 (2.70) ^c	4.80	5.67 (2.48) ^{cd}	5.37 (2.42) ^d	4.00 (2.12) ^f	6.67 (2.67) ^c	5.42
Emamectin benzoate 5 SG (Proclaim®) 8.5 g a.i./ha ⁻¹	5.33	3.39 (2.34) ^{bc}	4.27 (2.18) ^{bc}	5.79 (2.50) ^d	7.00 (2.73) ^c	5.11	6.00 (2.54) ^d	6.60 (2.66) ^d	7.00 (2.73) ^e	7.70 (2.86) ^{bc}	6.82
Spinosad 45 SC 75 g a.i./ha ⁻¹	5.63	3.37 (1.97) ^d	3.00 (1.87) ^d	4.00 (2.12) ^{cd}	4.17 (2.16) ^d	3.63	3.37 (1.96) ^e	3.87 (2.09) ^e	4.00 (2.12) ^f	5.67 (2.48) ^d	4.22
Untreated check	6.00	9.33 (3.13) ^a	9.67 (3.18) ^a	10.00 (3.24) ^a	10.67 (3.34) ^a	9.91	10.60 (3.33) ^a	11.37 (3.44) ^a	12.37 (3.58) ^a	13.60 (3.75) ^a	11.97

*Mean of three replications; PTC- Pre-treatment count, Values in parentheses are $\sqrt{x + 0.5}$ transformed values
 In a column means followed by a common letter are not significantly different by DMRT(P=0.05)

Table 25. Effect of emamectin benzoate 5 SG on the yield of okra (Location- Madhampatti) I season

Treatments	Dose (g ai/ha)	Yield* (Kg/ha)	Per cent increase in yield over untreated check
Emamectin benzoate5 SG	4.7	6050.00 ^d	38.77
Emamectin benzoate5 SG	6.7	6915.00 ^c	50.22
Emamectin benzoate 5 SG	8.5	7690.20 ^b	55.81
Emamectin benzoate 5 SG	11.00	8100.50 ^a	64.11
Emamectin benzoate 5 SG (Proclaim [®])	8.5	7345.00 ^b	48.81
Spinosad 45 SC	75	5726.30 ^e	16.01
Untreated check	-	4936.00 ^f	-

*Mean of four replications; In a column, means followed by a common letter(s) are not significantly different by DMRT(P=0.05)

6.7 g a.i.ha⁻¹ was the next best. When compared to spinosad (5603.33 kg ha⁻¹), the lowest dose of emamectin benzoate 5 SG @ 4.7 g a.i. ha⁻¹ (5948.33 kg ha⁻¹) recorded significantly higher yield (Table 26).

4.3. Phytotoxicity studies

4.3.1. Phytotoxicity of emamectin benzoate 5 SG on cotton

The phytotoxicity of emamectin benzoate as foliar treatments in the field trial I (Madampatti) with variety *Rasi* 2000 and II trial at Narasimanayakkan palayam with Surabhi was assessed by recording visual observations, viz., injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty (Table 27). The results indicated that emamectin benzoate 5 SG at 11, 22 and 44g a.i. ha⁻¹ did not cause any visual phytotoxic symptoms during both the seasons of experimentation.

4.3.2. Phytotoxicity of emamectin benzoate 5 SG on okra

The results of the field experiments conducted at Madhampatti and Narasimanayakkan palayam to assess the phytotoxic effect of emamectin benzoate on var. Mahyco10, revealed that okra plants sprayed with emamectin benzoate at 8.5 (x), 17 (2x) and 34 g a.i.ha⁻¹ (4x) doses did not show any phytotoxic effects like injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty at 1, 3, 5, 7, 10 and 14 days after spraying (Table 28).

4.4. Compatibility of emamectin benzoate 5 SG with agrochemicals

4.4.1. Physical compatibility of emamectin benzoate 5 SG with agrochemicals

The results of the investigations on the physical compatibility to assess the compatibility of emamectin benzoate 5 SG (11 g a.i. ha⁻¹) with lambda cyhalothrin 5CS (25 g a.i. ha⁻¹), carbendazim (0.1%), buprofezin 25 SC (200 g a.i. ha⁻¹) and mancozeb 75 WP (0.2%) revealed that no sediment was observed at the bottom or more than 2ml creaming matter at the top, which was considered as the criteria for compatibility. The results confirmed that emamectin benzoate 5 SG is physically compatible with the pesticides used in the present study (Table 29).

Table 26. Effect of emamectin benzoate 5 SG on the yield of okra (Location- Narasimanyakkan palayam) II season

Treatments	Dose (g ai/ha)	Yield* (Kg/ha)	Per cent increase in yield over untreated check
Emamectin benzoate 5 SG	4.7	5948.33 ^d	35.91
Emamectin benzoate 5 SG	6.7	6796.67 ^c	47.12
Emamectin benzoate 5 SG	8.5	7500.00 ^b	53.32
Emamectin benzoate 5 SG	11.00	8090.00 ^a	65.38
Emamectin benzoate 5 SG (Proclaim [®])	8.5	7340.00 ^b	48.01
Spinosad 45 SC	75	5603.33 ^e	14.55
Untreated check	-	4891.67 ^f	-

*Mean of four replications; In a column, means followed by a common letter(s) are not significantly different by DMRT(P=0.05)

Table 27. Phototoxic effect of emamectin benzoate in cotton– I and II season

Treatments	Dose g a.i/ha	Phytotoxicity ratings*					
		Leaf injury	Wilting	Vein clearing	Necrosis	Epinasty	Hyponasty
Emamectin benzoate 5 SG	11	0	0	0	0	0	0
Emamectin benzoate 5 SG	22	0	0	0	0	0	0
Emamectin benzoate 5 SG	44	0	0	0	0	0	0
Untreated check	-	0	0	0	0	0	0

*Observed on 1, 3, 5, 7, 10 and 14 days after treatment

Table 28. Phytotoxic effect of emamectin benzoate 5 SG on okra I and II season

Treatments	Dose g a.i/ha	Phytotoxicity ratings*					
		Leaf injury	Wilting	Vein clearing	Necrosis	Epinasty	Hyponasty
Emamectin benzoate 5 SG	8.5	0	0	0	0	0	0
Emamectin benzoate 5 SG	17	0	0	0	0	0	0
Emamectin benzoate 5 SG	34	0	0	0	0	0	0
Untreated check	-	0	0	0	0	0	0

*Observed on 1, 3, 5, 7, 10 and 14 days after treatment

Table 29. Physical compatibility of emamectin benzoate 5 SG with agrochemicals

S.No	Treatments	Dose (g a.i. ha ⁻¹)	Creaming matter at the top (ml)	Sediment at the bottom (ml)
1	Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	ED + 25	Nil	Nil
2	Emamectin benzoate 5% SG + Carbendazim 50 WP	ED + 0.1%	Nil	Nil
3	Emamectin benzoate 5% SG + Buprofezin 25 SC	ED + 200	Nil	Nil
4	Emamectin benzoate 5% SG + Mancozeb	ED+ 0.2%	Nil	Nil
5	lambda cyhalothrin 5 CS	25	Nil	Nil
6	Carbendazim 50 WP	0.1%	Nil	Nil
7	Buprofezin 25 SC	200	Nil	Nil
8	Mancozeb 75 WP	0.2%	Nil	Nil
9	Untreated control (Water spray)	-	Nil	Nil

EB- effective dose

4.5. Biological compatibility of emamectin benzoate 5 SG with other agrochemicals

4.5.1. Cotton

4.5.1.1. Phytotoxicity

The results of laboratory and field experiments conducted to assess the biological compatibility of emamectin benzoate 5 SG effective dose (ED) with Lambda cyhalothrin 5 SC (25 g a.i. ha⁻¹), carbendazim (0.1%), buprofezin 25 SC (200 g a.i. ha⁻¹) and mancozeb 75 WP (0.2%) as foliar application showed that none of the combination treatments caused any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty (Table 30).

4.5.1.2. Bioefficacy

4.5.1.2. a. Larval population of *H. armigera* Hubner

The results on the investigations conducted to find out the bioefficacy of emamectin benzoate in combination with other agrochemicals in reducing the larval population and bollworm incidence are presented in Table 31. The results revealed that the larval population of *H. armigera* before imposing treatments ranged from 4.97 to 6.00 larvae ten plants⁻¹. The highest per cent reduction was recorded by emamectin benzoate 5 SG + lambda cyhalothrin (68.15%) which was on par with emamectin benzoate 5 SG + carbendazim (65.01 %), emamectin benzoate 5 SG + mancozeb (66.10 %) and emamectin benzoate 5 SG + buprofezin (63.39%).

Second spray data (Table 31) revealed that there was significant reduction in larval population of *H. armigera* after the application of emamectin benzoate 5 SG combination, compared to untreated check. Plots treated with all emamectin benzoate 5 SG combination treatments recorded more than eighty per cent reduction of larval population, whereas the lowest per cent reduction in larval population was found in buprofezin (14.91 %), carbendazim (18.30 %) and mancozeb (18.10 %) treated plots.

4.5.1.2. b. Damage to green fruiting bodies

The results on the investigations conducted to find out the efficacy of emamectin benzoate 5 SG in combination with other agrochemicals in reducing the bollworm damage are presented in Table 32. The pre-treatment damage caused by bollworms

Table 30. Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on cotton and okra (Laboratory and field experiment)

Treatments	Dose (g a.i. ha ⁻¹)	Phytotoxicity rating*				
		Leaf tip injury	Wilting	Vein clearing	Necrosis	Epinasty
Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	ED + 25	0	0	0	0	0
Emamectin benzoate 5% SG + Carbendazim 50 WP	ED + 0.1%	0	0	0	0	0
Emamectin benzoate 5% SG + Buprofezin 25 SC	ED + 200	0	0	0	0	0
Emamectin benzoate 5% SG + Mancozeb	ED+ 0.2%	0	0	0	0	0
lambda cyhalothrin 5 CS	25	0	0	0	0	0
Carbendazim 50 WP	0.1%	0	0	0	0	0
Buprofezin 25 SC	200	0	0	0	0	0
Mancozeb 75 WP	0.2%	0	0	0	0	0
Untreated control (Water spray)	-	0	0	0	0	0

EB- effective dose , *Observed on 1, 3, 5, 7, 10 and 14 days after treatment

Table 31. Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on larval population of *H. armigera* in cotton (Location - TNAU)

Treatments	Dosage g a.i./ha ⁻¹	Number of larva per five plants*												
		Days after first application							Days after second application					
		PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	11 + 25	4.97	2.00 (1.58) ^a	1.13 (1.27) ^a	2.10 (1.61) ^a	3.00 (1.87) ^a	2.05	68.15	1.00 (1.22) ^a	0.73 (1.10) ^a	1.13 (1.27) ^a	1.79 (1.51) ^a	1.16	84.75
Emamectin benzoate 5% SG + Carbendazim 50 WP	11 +0.1%	5.30	2.20 (1.64) ^a	1.37 (1.36) ^a	2.30 (1.67) ^a	3.17 (1.91) ^a	2.26	65.01	1.27 (1.33) ^{ab}	1.00 (1.22) ^{ab}	1.37 (1.36) ^{ab}	1.90 (1.54) ^a	1.38	81.86
Emamectin benzoate 5% SG + Buprofezin 25 SC	11 + 200	5.27	2.29 (1.67) ^{ab}	1.46 (1.30) ^{ab}	2.97 (1.86) ^{ab}	3.30 (1.94) ^{ab}	2.50	63.39	1.40 (1.37) ^{ab}	1.27 (1.33) ^{ab}	1.63 (1.45) ^{ab}	2.00 (1.58) ^{ab}	1.57	79.36
Emamectin benzoate 5% SG + Mancozeb75WP	11 +0.2%	5.17	2.17 (1.40) ^a	1.20 (1.30) ^{ab}	2.29 (1.67) ^{ab}	3.10 (1.89) ^{ab}	2.19	66.10	1.30 (1.34) ^{ab}	1.17 (1.29) ^{ab}	1.43 (1.38) ^{ab}	1.83 (1.52) ^b	1.43	81.20
lambda cyhalothrin 5 CS	25	5.37	2.30 (1.67) ^{ab}	1.57 (1.43) ^a	2.97 (1.89) ^a	3.47 (1.99) ^a	2.57	60.10	1.39 (1.37) ^{ab}	1.20 (1.30) ^a	1.40 (1.37) ^a	1.87 (1.53) ^a	1.46	80.74
Carbendazim 50 WP	0.1%	5.16	5.43 (2.43) ^c	5.89 (2.52) ^c	6.00 (2.54) ^{cd}	6.29 (2.60) ^c	5.89	8.82	6.37 (2.62) ^c	6.59 (2.66) ^c	6.80 (2.70) ^c	6.97 (2.73) ^c	6.68	18.30
Buprofezin 25 SC	200	4.97	5.00 (2.34) ^c	5.30 (2.40) ^c	5.49 (2.44) ^c	5.97 (2.54) ^c	5.44	15.20	6.27 (2.60) ^c	6.67 (2.67) ^c	6.89 (2.71) ^c	7.00 (2.73) ^c	6.70	18.10
Mancozeb 75 WP	0.2%	5.67	5.89 (2.52) ^c	6.10 (2.56) ^{cd}	6.49 (2.64) ^{cd}	6.80 (2.70) ^{cd}	6.32	2.1	6.87 (2.71) ^c	6.90 (2.72) ^c	7.00 (2.73) ^c	7.10 (2.75) ^c	6.96	14.91
Untreated control	-	6.00	6.10 (2.56) ^{cd}	6.57 (2.62) ^d	6.50 (2.64) ^{cd}	6.89 (2.71) ^d	6.46	-	7.17 (2.73) ^{cd}	7.43 (2.75) ^{cd}	7.87 (2.78) ^{cd}	8.00 (2.81) ^{cd}	7.61	-

PTC- Pre treatment count, *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

Table 32. Biological compatibility of emamectin benzoate 5 SG with other agrochemicals against bollworms damage on cotton (Location- TNAU)

Treatments	Dosage g a.i./ha ⁻¹	Number of larva per five plants*												
		Days after first application						Days after second application						
		PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	11 + 25	28.17	12.27 (20.49) ^a	10.30 (18.71) ^a	10.47 (18.87) ^a	11.27 (19.60) ^a	11.07	66.41	6.60 (14.87) ^a	5.20 (13.16) ^a	5.97 (14.12) ^a	6.27 (14.48) ^a	6.01	84.30
Emamectin benzoate 5% SG + Carbendazim 50 WP	11 +0. 1%	29.23	12.40 (20.61) ^a	10.67 (19.05) ^a	10.90 (19.27) ^a	11.47 (19.79) ^a	11.36	65.00	6.87 (15.18) ^b	5.47 (13.51) ^b	6.00 (14.16) ^b	6.97 (15.29) ^b	6.32	83.47
Emamectin benzoate 5% SG + Buprofezin 25 WP	11 + 200	28.27	13.00 (21.12) ^{ab}	12.63 (20.81) ^b	11.30 (19.63) ^{ab}	12.00 (20.26) ^{ab}	12.23	62.90	7.17 (15.52) ^b	6.00 (14.16) ^b	7.33 (15.70) ^b	8.00 (16.42) ^b	7.12	81.38
Emamectin benzoate 5% SG + Mancozeb 75WP	11 +0.2%	29.19	12.37 (20.58) ^a	13.70 (21.71) ^a	11.00 (19.47) ^a	11.37 (19.70) ^a	12.11	63.28	6.90 (15.22) ^b	5.60 (13.67) ^b	6.20 (14.58) ^b	7.10 (15.44) ^b	6.45	83.15
lambda cyhalothrin 5 CS	25	28.93	13.67 (21.69) ^{ab}	13.00 (21.12) ^{ab}	11.49 (20.17) ^{ab}	11.90 (20.23) ^{ab}	12.51	62.06	7.20 (15.55) ^a	6.33 (14.56) ^a	7.67 (16.07) ^a	8.37 (16.81) ^a	7.39	80.68
Carbendazim 50 WP	0.1%	29.73	24.70 (29.80) ^c	25.73 (30.47) ^c	26.97 (31.28) ^c	28.17 (32.05) ^c	26.40	19.95	29.49 (32.88) ^c	30.47 (33.50) ^c	30.63 (33.60) ^c	31.10 (33.89) ^c	30.42	20.53
Buprofezin 25 SC	200	28.23	25.10 (30.06) ^c	25.80 (30.52) ^c	26.47 (30.95) ^c	28.00 (31.94) ^c	26.34	20.13	29.70 (33.01) ^c	30.67 (33.62) ^c	30.83 (33.72) ^c	31.37 (34.06) ^c	30.64	19.95
Mancozeb 75 WP	0.2%	28.29	24.97 (29.97) ^c	25.60 (30.39) ^c	26.37 (30.89) ^c	28.10 (32.01) ^c	26.26	20.37	29.97 (33.18) ^c	30.40 (33.45) ^c	30.97 (33.81) ^c	31.67 (34.24) ^c	30.75	20.64
Untreated control	-	29.17	31.70 (34.26) ^d	32.17 (34.55) ^d	33.74 (35.51) ^d	34.33 (35.86) ^d	32.98	-	36.79 (37.33) ^d	37.93 (38.01) ^d	38.67 (38.44) ^d	39.73 (39.06) ^d	38.28	-

PTC- Pre treatment count, *Mean of three replications; In a column means followed by a common letter are not significantly different by DMRT (P=0.05), * Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

ranged from 28.17 to 29.73 per cent. After treatment, there was significant reduction in damage caused by bollworms at 7 DAT. The lowest mean damage was recorded by combination treatments viz., emamectin benzoate 5 SG + lambda cyhalothrin (11.07 %) which was on par with all the emamectin benzoate 5 SG combination treatments. All the combination treatments recorded mean per cent damage of 11.07- 12.23 as against 32.98 per cent damage in untreated check. Lambda cyhalothrin alone was found to be on par with all the emamectin benzoate 5 SG combination treatments.

The per cent damage after second application (Table 32) revealed that emamectin benzoate 5 SG combination with lambda cyhalothrin + carbendazim and mancozeb combination was highly effective and reduced the mean per cent boll damage. Emamectin benzoate 5 SG + lambda cyhalothrin (6.01%) was on par with emamectin benzoate 5 SG+ carbendazim (6.32%) and emamectin benzoate 5 SG+ mancozeb (6.45 %) and highest damage was recorded in untreated plot (39.73 per cent) after 14 days of second spray .

4.6.2. Okra

4.6.2.1. Phytotoxicity

The results of laboratory and field (TNAU) experiment conducted to assess the biological compatibility of emamectin benzoate 5 SG @ 8.5g a.i. ha⁻¹ with Lambda cyhalothrin 5SC (25 g a.i. ha⁻¹), carbendazim (0.1%), buprofezin 25 SC(200 g a.i. ha⁻¹) and mancozeb 75 WP (0.2%) as foliar application showed that none of the combination treatments caused any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty (Table 30).

4.6.2.2. Bioefficacy

4.6.2.2. a. Larval population of *H. armigera*

The results on the investigations conducted to find out the bioefficacy of emamectin benzoate 5 SG in combination with other agrochemicals in reducing the larval population are presented in Table 33. The results of field experiments conducted at TNAU revealed that the larval population of *H. armigera* before imposing treatments ranged from 4.00-5.00 larvae per five plants At 7 DAT, the lowest larval population of *H. armigera* was recorded by combination treatments viz., emamectin benzoate 5 SG +

Table 33. Biological compatibility of emamectin benzoate 5 SG with other agrochemicals on larval population of *H. armigera* in okra (Location- TNAU)

Treatments	Dosage g a.i./ha ⁻¹	Number of larva per five plants*												
		Days after first application							Days after second application					
		PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn
Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	8.5 + 25	4.7	2.00 (1.58) ^a	1.10 (1.26) ^a	2.10 (1.61) ^a	2.90 (1.84) ^a	2.02	66.85	1.20 (1.30) ^a	0.73 (1.10) ^a	1.00 (1.22) ^a	1.17 (1.29) ^a	1.02	85.29
Emamectin benzoate 5% SG + Carbendazim 50 WP	8.5 + 0.1%	4.17	2.33 (1.68) ^{ab}	1.47 (1.40) ^{ab}	2.16 (1.63) ^{ab}	2.83 (1.82) ^{ab}	2.19	64.03	1.27 (1.33) ^a	0.93 (1.19) ^a	1.13 (1.27) ^a	1.27 (1.33) ^a	1.15	83.50
Emamectin benzoate 5% SG + Buprofezin 25 SC	8.5 + 200	4.00	2.47 (1.72) ^{ab}	1.57 (1.43) ^{ab}	2.19 (1.64) ^{ab}	2.90 (1.84) ^{ab}	2.25	63.17	1.47 (1.40) ^a	1.00 (1.22) ^a	1.33 (1.35) ^a	1.47 (1.40) ^a	1.31	81.10
Emamectin benzoate 5% SG + Mancozeb 75WP	8.5 +0.2%	4.19	2.53 (1.74) ^{ab}	1.67 (1.47) ^{ab}	2.23 (1.65) ^{ab}	2.97 (1.86) ^{ab}	2.35	61.53	1.33 (1.35) ^a	1.00 (1.22) ^a	1.43 (1.38) ^a	1.37 (1.36) ^a	1.28	81.60
lambda cyhalothrin 5 CS	25	4.16	3.17 (1.91) ^a	2.27 (1.66) ^a	2.70 (1.78) ^a	3.29 (1.94) ^a	2.85	53.35	2.79 (1.81) ^a	2.93 (1.85) ^{ab}	1.79 (1.51) ^a	1.60 (1.44) ^a	2.02	71.01
Carbendazim 50 WP	0.1%	4.27	4.77 (2.29) ^c	4.90 (2.32) ^c	5.20 (2.38) ^c	5.67 (2.48) ^c	5.13	16.00	5.70 (2.48) ^b	5.89 (2.52) ^c	6.00 (2.54) ^b	6.30 (2.60) ^b	5.97	18.5
Buprofezin 25 SC	200	4.10	4.17 (2.16) ^c	4.77 (2.29) ^c	5.27 (2.40) ^c	5.40 (2.42) ^c	4.90	19.80	5.97 (2.54) ^b	6.17 (2.58) ^c	6.47 (2.64) ^b	6.83 (2.70) ^b	6.36	8.75
Mancozeb 75 WP	0.2%	4.60	4.67 (2.16) ^c	4.90 ^c (2.32)	5.37 (2.42) ^c	5.47 (2.44) ^c	5.10	16.53	5.67 (2.48) ^b	5.90 (2.52) ^c	6.10 (2.56) ^b	6.67 (2.67) ^b	6.08	12.77
Untreated control	-	5.00	5.70 (2.48) ^{cd}	5.97 (2.59) ^{cd}	6.17 (2.58) ^{cd}	6.60 (2.66) ^{cd}	6.11	-	6.89 (2.71) ^c	6.90 (2.72) ^{cd}	7.00 (2.73) ^c	7.10 (2.75) ^c	6.97	-

EB- Emamectin benzoate, PTC- Pre treatment count; *Mean of three replications, Values in parentheses are $\sqrt{x + 0.5}$ transformed values; In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

lambda cyhalothrin (1.10 larvae/five plants), emamectin benzoate 5 SG + carbendazim (1.47 larvae/five plants), emamectin benzoate 5 SG + buprofezin (1.57 larvae/five plants), emamectin benzoate 5 SG + mancozeb (1.67 larvae/five plants), which were on par with lambda cyhalothrin alone (2.27 larvae/five plants).

Second spray data (Table 33) revealed that after the application of emamectin benzoate 5 SG combinations, there was significant reduction in larval population of *H. armigera* compared to untreated check. Plots treated with all emamectin benzoate 5 SG combination treatments recorded more than eighty per cent reduction of larval population, whereas the lowest per cent reduction in larval population was found in carbendazim (18.50 %), buprofezin (8.75 %) and mancozeb (12.77 %) alone treated plots.

4.6.2.2. b. Effect on fruit borer damage to okra fruits

The damage due to fruit borers before imposing treatments ranged from 22.50 to 24.00 per cent (Table 34). After treatment, there was significant reduction in damage caused by fruit borers. All the combination treatments recorded mean per cent damage of 11.09 to 12.11 as against 26.11 per cent damage in untreated check. Untreated plot as well as carbendazim, buprofezin and mancozeb alone treated plots recorded higher damage (>26.00 per cent) than combination after 14 days of first spray.

After second spray, there was significant reduction in damage caused by fruit borers (Table 34). Lower damage was recorded by combination treatments effecting > 80 per cent reduction from the untreated check. The highest mean fruit damage after 14 DAT was recorded by untreated plot (37.27 %) which was followed by carbendazim (23.73 %), mancozeb (23.59 %) and buprofezin (23.71 %) alone treated plots.

B. Laboratory experiments

4.7. Persistent toxicity of emamectin benzoate 5 SG

4.7.1. *H. armigera*

The persistent toxicity of emamectin benzoate against *H. armigera* in cotton was evaluated and the results indicated that cent per cent mortality was observed up to 7 DAT in emamectin benzoate at 15 g a.i.ha⁻¹ whereas, in emamectin benzoate @ 11 g a.i.ha⁻¹ and Proclaim® @ 11 g a.i.ha⁻¹ cent per cent was observed up to 5 DAT. More than 50 per cent

Table 34. Biological compatibility of emamectin benzoate 5 SG on the damage caused by fruit borers in okra (Location- TNAU)

Treatments		Dosage g a.i./ha ⁻¹	Number of larva per five plants*													
			Days after first application							Days after second application						
			PTC	3	7	10	14	Mean	% Redn	3	7	10	14	Mean	% Redn	
Emamectin benzoate 5% SG + lambda cyhalothrin 5 CS	8.5 + 25	23.00	11.00 ^a (19.36)	10.00 ^a (18.42)	11.17 ^a (21.35)	12.20 ^a (20.43)	11.09	66.95	5.00 ^a (12.90)	4.50 ^a (12.22)	6.27 ^a (14.48)	7.60 ^a (15.99)	5.84	84.43		
Emamectin benzoate 5% SG + Carbendazim 50 WP	8.5 +0.1%	22.50	11.29 ^b (19.62)	10.33 ^b (18.74)	11.30 ^b (19.51)	12.37 ^{ab} (20.58)	11.32	66.27	5.27 ^b (13.25)	4.77 ^b (12.60)	6.63 ^b (14.91)	7.80 ^b (16.20)	6.11	83.85		
Emamectin benzoate 5% SG + Buprofezin 25 SC	8.5 + 200	23.10	12.67 ^b (20.84)	10.97 ^{ab} (19.66)	11.93 ^b (19.63)	12.87 ^{ab} (21.01)	12.11	63.92	5.83 ^b (13.96)	5.40 ^b (13.42)	6.97 ^b (15.29)	7.93 ^b (16.34)	6.53	82.47		
Emamectin benzoate 5% SG + Mancozeb 75WP	8.5 +0.2%	23.20	11.33 ^a (19.66)	10.57 ^{ab} (18.96)	11.47 ^b (19.57)	12.67 ^b (20.84)	11.51	65.71	5.30 ^b (20.35)	5.00 ^b (12.10)	6.73 ^b (15.02)	7.83 ^b (21.66)	6.21	83.34		
lambda cyhalothrin 5 CS	25	23.50	12.97 ^c (21.11)	12.07 ^{ab} (20.32)	12.37 ^a (21.44)	13.77 ^a (21.77)	12.79	61.88	10.93 ^a (19.29)	7.90 ^a (16.31)	10.37 ^a (18.78)	10.73 ^a (19.11)	9.98	73.22		
Carbendazim 50 WP	0.1%	23.00	25.17 ^{cd} (30.11)	25.37 ^{cd} (30.24)	26.70 ^{cd} (31.10)	26.83 ^{cd} (31.19)	26.01	22.52	27.10 ^c (31.66)	28.13 ^c (31.88)	28.73 ^c (32.40)	29.67 ^c (33.00)	28.40	23.73		
Buprofezin 25 SC	200	24.00	25.17 ^{cd} (30.11)	25.40 ^{cd} (30.26)	26.77 ^{cd} (31.15)	26.97 ^{cd} (31.28)	26.07	22.34	27.73 ^c (31.84)	27.90 ^c (31.88)	28.97 ^c (32.55)	29.13 ^c (32.66)	28.43	23.71		
Mancozeb 75 WP	0.2%	24.00	25.40 ^e (30.26)	25.70 ^{cd} (30.45)	26.97 ^{cd} (31.28)	27.00 ^{cd} (31.30)	26.26	21.77	27.60 ^c (31.69)	28.10 ^c (32.01)	28.93 ^c (32.53)	29.29 ^c (32.76)	28.48	23.59		
Untreated control	-	23.00	23.97 (29.30) ^{cd}	25.00 (29.99) ^{cd}	26.27 (30.82) ^{cd}	29.23 (32.72) ^d	26.11	-	34.53 ^d (35.98)	36.63 ^d (37.24)	38.83 ^d (38.54)	39.10 ^d (38.69)	37.27	-		

PTC- Pre treatment count, *Mean of three replications; In a column means followed by a common letter are not significantly different by DMRT (P=0.05), * Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

mortality was observed up to 11 DAT in emamectin benzoate @ 15 g a.i.ha⁻¹ and emamectin benzoate (Proclaim®) @ 11 g a.i.ha⁻¹ up to 9 DAT. The mortality of *H. armigera* was found to be reduced as the DAT increased and the effect of emamectin benzoate persisted for 17 days (15 g a.i.ha⁻¹), 15 days (9 and 11 g a.i.ha⁻¹) and 13 days for 7 g a.i.ha⁻¹. The order of relative efficacy (ORE) of the insecticides based on the persistent toxicity index (PTI) values was emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ > emamectin benzoate at 11 g a.i. ha⁻¹ > Proclaim® > emamectin benzoate at 9 g a.i. ha⁻¹ > emamectin benzoate at 7 g a.i. ha⁻¹ > spinosad. (Table 35)

4.7.2. *E. vittella*

Cent per cent mortality of *E. vittella* was caused by emamectin benzoate up to 7 DAT in 11 g a.i.ha⁻¹ and 5 DAT in 8.5 g a.i.ha⁻¹ and Proclaim® @ 8.5 g a.i.ha⁻¹. The persistence of the chemical was up to 17 days in emamectin benzoate @ 11 g a.i.ha⁻¹ and 15 days in emamectin benzoate @ 8.5 g a.i.ha⁻¹ and Proclaim® @ 8.5 g a.i.ha⁻¹. The lower doses of emamectin benzoate @ 4.7 and 6.7 g a.i.ha⁻¹ persisted for 13 and 15 days, respectively. (Table 36)

The ORE of the insecticides based on PTI values was emamectin benzoate at 11 g a.i. ha⁻¹ > emamectin benzoate at 8.5 g a.i. ha⁻¹ > Proclaim® > emamectin benzoate 6.7 g a.i. ha⁻¹ > emamectin benzoate at 4.7 g a.i. ha⁻¹ > spinosad.

4.8. Assessment of safety of emamectin benzoate 5 SG to natural enemies

4.8.1. Influence of emamectin benzoate 5 SG against the egg parasitoid, *Trichogramma chilonis* Ishii

The effect of emamectin benzoate 5 SG on the adult emergence and parasitization of *T. chilonis* (Table 37) indicated that all the doses of emamectin benzoate 5 SG exerted lesser impact on the emergence of adults. The adult emergence percentage ranged from 78.50 to 92.50 among the insecticidal treatments. The lowest doses of emamectin benzoate 5 SG at 7 and 9 g a.i.ha⁻¹ recorded 92.50 and 90.00 per cent adult emergence next to untreated check (98.50 %). The emamectin benzoate 5 SG at 11 g a.i.ha⁻¹ recorded 87.50 per cent which was on par with Proclaim® (88.50 %). The higher dose of

Table 35. Persistent toxicity of emamectin benzoate 5 SG to *H. armigera* in cotton

Treatments	Per cent larval mortality at different exposure periods														PTI	T	P	23	21	19	17	15	13	11	9	7	5	3	1	ORE
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Emamectin benzoate 5 SG @ 7g a.i. ha ⁻¹	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Emamectin benzoate 5 SG @ 9 g a.i. ha ⁻¹	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Emamectin benzoate 5 SG @ 11 g a.i. ha ⁻¹	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Emamectin benzoate 5 SG @ 15 g a.i. ha ⁻¹	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹ (Proclaim [®])	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Spinosad 45 SC @ 75 g a.i. ha ⁻¹	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

P – Period for which toxicity persisted (days), T – Average residual toxicity, PTI- Persistent toxicity index, ORE- Order of relative efficacy

Table 37. Effect of emamectin benzoate 5 SG on *Trichogramma chilonis* Ishii

Treatments	Dose (g a.i.ha ⁻¹)	Adult emergence (%)*	Parasitized (%)*
Emamectin benzoate 5SG	7	92.50 (74.11) ^b	90.63 (72.18) ^{ab}
Emamectin benzoate 5SG	9	90.00 (71.56) ^{bc}	88.59 (70.25) ^b
Emamectin benzoate 5SG	11	87.50 (69.29) ^c	87.60 (69.38) ^b
Emamectin benzoate 5SG	15	85.00 (67.21) ^c	72.30 (58.24) ^c
Emamectin benzoate 5SG	11	88.50 (70.17) ^{bc}	85.37 (67.51) ^{bc}
Spinosad 45 SC	75	78.50 (62.37) ^d	64.17 (53.23) ^d
Untreated check	-	98.50 (83.08) ^a	93.63 (75.39) ^a

In a column, means followed by a common letter are not significantly different by DMRT (P = 0.05)

* Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

emamectin benzoate 5 SG (15 g a.i.ha⁻¹) reduced the adult emergence to some extent by recording 85.50 per cent when compared to spinosad (78.50 %).

The other doses of emamectin benzoate 5 SG (7, 9 and 11 g a.i.ha⁻¹) and Proclaim[®] recorded per cent parasitization of 90.63, 88.59, 87.60 and 85.37, respectively. The lowest per cent parasitization was recorded in spinosad (64.17 %).

4.8.2. Influence of emamectin benzoate 5 SG against *Chelonus blackburnii* Cameron

The toxicity studies of emamectin benzoate to the adults of *C. blackburni* revealed that adult mortality increased gradually at different interval in all the insecticidal treatments and all the insecticides were toxic to *C. blackburni*. The least mortality of *C. blackburni* adults was observed in the lower dose of emamectin benzoate 5 SG (7 g a.i.ha⁻¹) which showed 13.33, 23.33 and 33.33 per cent mortality at 6, 12 and 24 HAT, while the recommended dose of emamectin benzoate 5 SG (11 g a.i.ha⁻¹), emamectin benzoate 5 SG Proclaim[®] (11 g a.i.ha⁻¹), and emamectin benzoate (9 g a.i.ha⁻¹) recorded the per cent adult mortality of 23.33, 33.33 and 43.33, at 6 HAT, 26.67, 36.67 and 46.67 at 12 HAT and 16.33, 26.67 and 40.00 at 24 HAT, respectively. Among the emamectin benzoate 5 SG treatments, the highest mortality was accounted by emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ to the extent of 36.33, 40.00 and 50.00 per cent, respectively at 6, 12 and 24 HAT. While the check, spinosad at 75 g a.i.ha⁻¹ registered the mortality percentage of 36.67, 46.67 and 56.67 at 6, 12 and 24 HAT, respectively (Table 38).

4.8.3. Influence of emamectin benzoate 5 SG against *Bracon hebetor* Say

All the insecticides were significantly toxic to *B. hebetor* (Table 39). The higher dose 15 g a.i.ha⁻¹ of emamectin benzoate caused 40 and 60 per cent adult mortality at 24 and 48 HAT, respectively. It was followed by emamectin benzoate 5 SG at the recommended dose 11 g a.i.ha⁻¹ (26.66 and 40.00 per cent) and the standard check, Proclaim[®] @ 11 g a.i.ha⁻¹ (30 and 50 per cent) at 24 and 48 HAT. The lower doses of emamectin benzoate 5 SG @ 7 and 9 g a.i.ha⁻¹ recorded mortality of 10.00 and 23.33 at 24 HAT and 23.33 and 26.67 at 48 HAT, respectively. Fifty three per cent mortality of *B. hebetor* adults were observed at 24 HAT and sixty three per cent mortality at 48 HAT in the check spinosad 45 SC @ 75 g a.i.ha⁻¹. No mortality observed in the untreated check.

Table 38. Effect of emamectin benzoate 5 SG against egg larval parasitoid, *Chelonus blackburnii* Cameron

Treatments	6 HAT		12 HAT		24 HAT	
	Mortality %	Corrected % mortality	Mortality %	Corrected % mortality	Mortality %	Corrected % mortality
Emamectin benzoate 5 SG @ 7g a.i. ha ⁻¹	13.33 (21.40) ^a	13.33	23.33 (28.87) ^b	20.65	33.33 (35.25) ^b	31.03
Emamectin benzoate 5 SG @ 9g a.i. ha ⁻¹	16.33 (23.83) ^b	16.33	26.67 (31.08) ^c	24.14	40.00 (39.22) ^c	37.93
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹	23.33 (28.88) ^c	23.33	33.33 (35.25) ^d	31.03	43.33 (41.16) ^c	41.37
Emamectin benzoate 5 SG @ 15g a.i. ha ⁻¹	36.33 (37.72) ^e	36.33	40.00 (39.22) ^e	37.93	50.00 (44.99) ^d	48.97
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹ (Proclaim [®])	26.67 (31.08) ^d	26.67	36.67 (37.11) ^d	34.48	46.67 (43.08) ^{cd}	43.39
Spinosad 45 SC@ 75 g a.i. ha ⁻¹	36.67 (37.06) ^e	36.67	46.67 (43.08) ^f	43.34	56.67 (48.83) ^e	55.17
Untreated control	-	-	3.33 ^a	-	3.33	-

HAT- Hour after treatment In a column, means followed by a common letter are not significantly different by DMRT (P = 0.05)

* Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

Table 39. Effect of emamectin benzoate 5 SG against larval parasitoid, *Bracon hebetor* Say

Treatments	24 HAT	48 HAT
	Mortality %	Mortality %
Emamectin benzoate 5 SG @ 7g a.i. ha ⁻¹	10.00 (17.95) ^a	23.33 (28.87) ^a
Emamectin benzoate 5 SG @ 9g a.i. ha ⁻¹	23.33 (28.88) ^b	26.67 (31.08) ^b
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹	26.66 (31.08) ^b	40.00 (38.56) ^c
Emamectin benzoate 5 SG @ 15g a.i. ha ⁻¹	40.00 (39.22) ^c	60.00 (50.76) ^e
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹ (Proclaim [®])	30.00 (33.20) ^{bc}	50.00 (45.00) ^d
Spinosad 45 SC@ 75 g a.i. ha ⁻¹	53.00 (46.71) ^d	63.33 (52.73) ^f
Untreated control	-	-

In a column, means followed by a common letter are not significantly different by DMRT (P = 0.05)

* Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

4.8.4. Influence of emamectin benzoate 5 SG against predatory green lacewing, *Chrysoperla carnea* Stephens

4.8.4.1. Egg hatchability and mortality

The least egg mortality was observed in untreated check (3.33 per cent) and emamectin benzoate 5 SG @ 7 g a.i.ha⁻¹ (3.33 per cent) followed by emamectin benzoate 5 SG @ 9 g a.i.ha⁻¹ (6.33%), emamectin benzoate 5 SG @ 11 g a.i.ha⁻¹ (16.33%), emamectin benzoate (Proclaim[®]) @ 11 g a.i.ha⁻¹ (20.00 %), emamectin benzoate 5 SG @ 15 g a.i.ha⁻¹ (20.00 %) and spinosad @ 75 g a.i.ha⁻¹ (23.33%) . The per cent egg hatchability observed in untreated check was 98.00 followed by emamectin benzoate SG at 7 g a.i.ha⁻¹ (96.67 %) and emamectin benzoate 5 SG @ 9 g a.i.ha⁻¹ (93.67%). The recommended dose of emamectin benzoate 5 SG @ 11 g a.i.ha⁻¹(83.67 %) which was on par with standard check Procalim[®] 11 @ g a.i.ha⁻¹ (80.00 %) and emamectin benzoate @ 15 g a.i.ha⁻¹ recorded 80.00 per cent egg hatchability. The least egg hatchability was recorded by spinosad @ 75 g a.i.ha⁻¹ (76.67 %) (Table 40).

4.8.5. Influence of emamectin benzoate 5 SG on the grubs of *C. carnea*

4.8.5.1. Dry film method

All the treatments affected the grub mortality, pupation and adult emergence significantly in the dry film method (Table 41). Among the treatments, emamectin benzoate 5 SG at 7 g a.i.ha⁻¹ emerged as the least toxic by registering 0.00, 6.66 and 10.00 per cent mortality of grub at 12, 24 and 48 HAT, respectively. The recommended dose of emamectin benzoate 5 SG @ 11 g a.i.ha⁻¹ and Proclaim[®] recorded the per cent mortality of 23.33 and 23.67 (12HAT), 36.66 and 43.33 per cent (24HAT), respectively. Spinosad @ 75 g a.i.ha⁻¹ was found to be highly toxic to the grub of *C. carnea* which recorded 58.69 per cent (24 HAT).

The pupation and adult emergence were found to be 100 per cent in untreated check which was on par with emamectin benzoate 5 SG @ 7 g a.i.ha⁻¹ followed by emamectin benzoate SG @ 9 g a.i.ha⁻¹ (96.00 and 90.10 per cent), respectively. Emamectin benzoate 5 SG @ 11 g a.i.ha⁻¹ and Proclaim[®] at 11 g a.i.ha⁻¹ recorded 86.43 and 85.00 per cent pupation, 85.65 and 80.24 per cent adult emergence , respectively.

Table 40. Effect of emamectin benzoate 5 SG on the eggs of *Chrysoperla carnea* Stephens

Treatments	Dose (g a.i.ha ⁻¹)	Eggs*		
		Egg mortality (%)	Corrected Mortality (%)	Egg hatchability (%)
Emamectin benzoate 5SG	7	3.33 (10.48) ^a	0.00	96.67 (79.51) ^a
Emamectin benzoate 5SG	9	6.33 (14.56) ^b	3.13	93.67 (75.43) ^b
Emamectin benzoate 5SG	11	16.33 (23.83) ^c	13.56	83.67 (66.16) ^c
Emamectin benzoate 5SG	15	20.00 (26.56) ^{cd}	17.39	80.00 (63.43) ^{cd}
Emamectin benzoate 5SG	11	20.00 (26.56) ^{cd}	17.39	80.00 (63.43) ^{cd}
Spinosad 45 SC	75	23.33 (28.88) ^d	20.87	76.67 (61.16) ^d
Untreated control	-	3.33 (10.48) ^e	-	98.00 (83.05) ^a

In a column, means followed by a common letter are not significantly different by DMRT (P = 0.05)

* Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

Table 41. Effect of emamectin benzoate 5 SG on the grubs of *C. carnea*

Treatments	6 HAT	12 HAT	24HAT	Adult emergence (%)	
	Mortality %	Mortality %	Mortality %	Pupation (%)	Adult emergence (%)
Emamectin benzoate 5 SG @ 7g a.i. ha ⁻¹	0.00 (0.19)	6.66 (14.94) ^{ab}	10.00 (18.42) ^b	96.29 (78.94) ^b	90.17 (72.56) ^a
Emamectin benzoate 5 SG @ 9g a.i. ha ⁻¹	3.33 (10.48) ^b	13.33 (21.40) ^b	23.33 (28.88) ^c	90.00 (72.53) ^b	89.33 (71.89) ^b
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹	10.00 (18.42) ^c	23.33 (28.88) ^c	36.66 (37.26) ^d	86.43 (68.14) ^c	85.00 (67.39) ^b
Emamectin benzoate 5 SG @ 15g a.i. ha ⁻¹	13.00 (21.12) ^d	36.66 (37.26) ^d	50.00 (44.99) ^f	82.35 (65.23) ^c	70.00 (56.49) ^c
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹ (Proclaim [®])	10.00 (18.42) ^c	23.67 (29.10) ^c	43.33 (41.63) ^e	85.00 (67.39) ^c	80.24 (62.97) ^c
Spinosad 45 SC@ 75 g a.i. ha ⁻¹	23.33 (28.87) ^e	40.00 (39.22) ^d	60.00 (50.76) ^g	71.43 (57.72) ^d	63.33 (56.74) ^d
Untreated control	0.00 (0.19) ^a	0.00 (0.19) ^a	0.00 (0.19) ^a	100.00 (85.00) ^a	100.00 (85.00) ^a

In a column, means followed by a common letter are not significantly different by DMRT (P = 0.05)

* Values in the parentheses are arc sine $\sqrt{\text{per cent transformed values}}$

Whereas the value for higher dose of emamectin benzoate 5 SG at 15 g a.i.ha⁻¹ showed 82.35 and 72.00 per cent. Spinosad @ 75 g a.i.ha⁻¹ recorded least pupation and adult emergence per cent of 71.43 and 63.33, respectively.

4.8.6. Evaluation of toxicity of emamectin benzoate 5 SG to honey bees

The insecticides tested were significantly toxic to Indian bees (Table 42). The higher dose of emamectin benzoate SG @ 15 g a.i.ha⁻¹ recorded per cent mortality of bees ranging between from 16.67 to 30.00 at 6, 12 and 24 HAT respectively. Emamectin benzoate SG @ 11 g a.i.ha⁻¹ which was on par with Proclaim® @ 11 g a.i.ha⁻¹ at 6, 12 and 24 HAT. Whereas in the standard check spinosad per cent mortality of 30 to 36.66 at 6, 12 and 24 HAT, respectively.

Similar trend was observed in little bee also. Emamectin benzoate at 11 g a.i.ha⁻¹ registered mortality of 13.33, 16.67 and 20.00 per cent which was on par with the Proclaim® @ 11 g a.i.ha⁻¹ (16.7, 20.00 and 23.33) at 6, 12 and 24 HAT, respectively. The lowest dose of emamectin benzoate 5 SG (7 g a.i.ha⁻¹) recorded mortality ranged from 0.00 to 10.00 per cent at 6, 12 and 24 HAT, respectively where as standard check spinosad recorded highest mortality per cent at 24 HAT (36.66 %). Based on the italian bee per cent mortality over untreated check, the order of different treatments were as follows: emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ = emamectin benzoate 5 SG (Proclaim®) @ 11 g a.i. ha⁻¹ > emamectin benzoate SG at 9 g a.i. ha⁻¹ > emamectin benzoate 5 SG at 7. g a.i. ha⁻¹ > spinosad 75 g a.i. ha⁻¹ > untreated check.

There was no significant per cent mortality observed in all the three species of honey bees.

4.8.7. Earth worm, *Eudrilus eugeniae* (Kinberg)

The acute toxicity study results indicated that the LC₅₀ value of emamectin benzoate for *E. eugeniae* by artificial soil test bioassay method was 17.22 ppm in soil at 2 DAT. Whereas, the respective LC₅₀ value of emamectin benzoate 5 SG to *E. eugeniae* at 2 days by cowdung test bioassay method was 16.47 ppm (Table 43 and 44).

Table 42. Effect of emamectin benzoate 5 SG on three species of honey bees

Treatments	Mortality (%)* (HAT)									
	Indian bee			Little bee			CM (%)	Italian bee		
	6	12	24	CM (%)	6	12	24	6	12	24
Emamectin benzoate 5 SG @ 7g a.i. ha ⁻¹	0.00 (0.19) ^a	3.33 (6.15) ^a	10.00 (15.00) ^a	6.89	0.00 (0.19) ^a	3.33 (6.15) ^a	10.00 (13.29) ^b	0.00 (0.19) ^a	3.33 (12.29) ^a	13.33 (15.00) ^b
Emamectin benzoate 5 SG @ 9 g a.i. ha ⁻¹	0.00 (0.19) ^a	6.67 (15.00) ^b	16.67 (21.14) ^b	13.79	0.00 (0.19) ^a	6.67 (6.15) ^a	16.67 (20.14) ^b	6.67 (11.29) ^b	10.00 (15.00) ^b	16.66 (25.07) ^c
Emamectin benzoate 5 SG @ 11 g a.i. ha ⁻¹	10.00 (23.86) ^b	16.67 (26.07) ^c	23.33 (37.14) ^c	20.68	13.33 (27.78) ^b	16.67 (36.14) ^b	20.00 (38.15) ^c	13.33 (32.00) ^c	20.00 (38.15) ^c	23.33 (40.15) ^d
Emamectin benzoate 5 SG @ 15 g a.i. ha ⁻¹	16.67 (24.86) ^{cd}	23.33 (26.07) ^d	30.00 (38.14) ^d	27.58	20.00 (20.14) ^d	26.67 (27.78) ^d	33.33 (38.15) ^d	20.00 (27.78) ^e	26.67 (32.00) ^{de}	36.67 (45.00) ^e
Emamectin benzoate 5 SG @ 11g a.i. ha ⁻¹ (Proclaim [®])	13.00 (27.78) ^c	16.67 (33.00) ^c	26.67 (33.15) ^{cd}	24.14	16.67 (26.07) ^{bc}	20.00 (34.00) ^{bc}	23.33 (40.15) ^{bc}	16.67 (26.07) ^c	23.33 (30.00) ^{cc}	26.67 (43.08) ^c
Spinosad 45 SC @ 75 g a.i. ha ⁻¹	30.00 (27.29) ^e	33.33 (33.00) ^d	36.66 (33.15) ^e	34.44	23.33 (30.00) ^e	30.00 (33.15) ^{de}	36.66 (40.15) ^e	26.66 (27.00) ^d	30.00 (38.14) ^d	40.00 (45.00) ^d
Untreated check (water spray)	0.00 (0.19) ^a	0.00 (0.19) ^a	3.33 (6.15) ^a	-	0.00 (0.19) ^a	0.00 (0.19) ^a	0.00 (0.19) ^a	0.00 (0.19) ^a	0.00 (0.19) ^a	3.33 (6.15) ^a
										-

HAT – Hours after treatment, * Mean of three replications, CM- Corrected mortality
 In a column, means followed by a common letter(s) are not significantly different by DMRT (P = 0.05)
 Values in the parentheses are arc sine $\sqrt{\text{per cent}}$ transformed values

Table 43. Acute toxicity of emamectin benzoate 5 SG to earthworm, *Eudrilluse eugeniae* (Kinberg) in soil

Organism	n	LC ₅₀ (ppm)	95 per cent fiducial limit		LC ₉₅ (ppm)	95 per cent fiducial limit		Regression equation	χ^2
			LL	UL		LL	UL		
<i>Eudrillus eugeniae</i>	15	17.22	13.99	26.94	57.71	16.64	206.02	Y= 1.0445+3.2676X	0.177

All lines are significantly a good fit ($p < 0.05$).

Table 44 . Acute toxicity of emamectin benzoate 5 SG to earthworm, *E. eugeniae* in cow dung

Organism	n	LC ₅₀ (ppm)	95 per cent fiducial limit		LC ₉₅ (ppm)	95 per cent fiducial limit		Regression equation	χ^2
			LL	UL		LL	UL		
<i>Eudrillus eugeniae</i>	15	16.47	13.73	22.43	51.12	14.19	217.95	Y= 1.3554 + 3.0658x	0.2746

All lines are significantly a good fit ($p < 0.05$).

4.9. Residues of emamectin benzoate 5 SG

The mean recovery was more than 85.00 per cent from samples fortified at 0.4, 0.5 and 1.0 ppm level (Table 45). The minimum detection limit of the instrument was 0.1 ppm and the determinability level in the sample was $0.04 \mu\text{g g}^{-1}$ considering the weight of the sample (bhendi fruit) as 25 g and final volume of the extract as 1 ml, and $0.01 \mu\text{g g}^{-1}$ considering the weight of the sample as 10 g (cotton lint) and final volume of the extract as 1ml.

4.9.1. Residues of emamectin benzoate 5 SG on bhendi fruits and soil

The initial deposit of emamectin benzoate 5 SG @ 8.5 and 17.0g a.i ha⁻¹ was 0.1521 and 0.2626 $\mu\text{g g}^{-1}$ respectively which dissipated to below detectable level on five days after spraying (Table 46). More than 85 per cent of the residues were dissipated on third day after spraying. The decline behaviour of the persistent residues was computed following seven transformations and the best fit was selected among them. Based on the coefficient of determination, the best fit observed was first order reaction for both the doses (Table 47). The various statistical parameters like intercept(a), slope of regression lines(b or k_1) and half-life ($t_{0.5}$) with confidence limits are presented in tables 48 a and b. The half-life worked out was one day for the recommended dose and double the recommended dose.

Since the emamectin benzoate 5 SG residues were found at below detectable levels on 5th day after application and five days could be suggested as waiting period. The residues in the soil at both the doses were at below detectable levels at both the doses (Table 49).

4.9.2. Harvest time residues

4.9.2.1. Cotton

In the field experiments conducted during 2010 - 2011 at Madampatti and Narasimanayakkan palayam, the harvest time residues of emamectin benzoate 5 SG @ 11 and 22 g a.i.ha⁻¹ as foliar spray were at below detectable level (BDL) in cotton lint, seed, oil and soil samples of first and second pickings in both the field experiments (Table 50 and 51).

Table 45. Recovery of emamectin benzoate

Crop	Matrix/substrate	Amount fortified (ppm)	% Recovered	Average recovery (%)
Cotton	Lint	0.4	91.50	92.50
		0.5	96.00	
		1.00	90.00	
	Seed	0.4	94.50	92.88
		0.5	92.50	
		1.00	91.65	
	Oil	0.4	90.60	90.08
		0.5	89.00	
		1.00	92.80	
	Soil	0.4	91.00	89.93
		0.5	86.00	
		1.00	89.00	
Okra	Fruit	0.4	90.60	85.20
		0.5	78.00	
		1.00	87.00	
	Soil	0.4	92.00	87.00
		0.5	88.00	
		1.00	81.00	

Table . 46. Dissipation of emamectin benzoate 5 SG on okra fruit

Days Elapsed	X (Dose) 8.5 g a.i.ha ⁻¹				2X (Dose) 17.0 g a.i.ha ⁻¹			
	RI	RH	RIII	Mean	RI	RH	RIII	Mean µg/g
0	0.1483	0.1540	0.1540	0.1521	0.2702	0.2663	0.2514	0.2626
1	0.0699	0.0808	0.0682	0.0730	0.1289	0.1433	0.1298	0.1340
3	0.0224	0.0210	0.0154	0.0196	0.0309	0.0290	0.0451	0.0350
5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL – Below Detectable Limit

Table 47. Correlation coefficient for emamectin benzoate 5 SG residues okra fruit by different methods of transformation of residue data

Function	X dose (8.5 g a.i.ha ⁻¹)				2x dose (17.0 g a.i.ha ⁻¹)			
Function	R	r sq	Modi r sq		R	r sq	Modi r sq	
First order	-0.9984	0.9968	0.99		-0.9997	0.9994	1	
1.5 th order	0.9974	0.9948	0.97		0.9975	0.995	0.94	
2 nd order	0.981	0.9624	-0.43		0.9313	0.8673	-1.22	
RF first order	-0.9904	0.9809	0.97		-0.9854	0.971	0.94	
RF 1.5 first order	0.9655	0.9322	0.63		0.9613	0.9241	0.53	
Rf 2 nd order	0.9334	0.8912	-17.55		0.8838	0.7811	-26.9	
Inverse P L	0.9359	0.8759	0.61		0.9239	0.8536	0.54	

RF- Root function
Inverse PL- Inverse Power Law
Modi r sq- Modified 'r' square

Table 48 (a). Dissipation pattern for emamectin benzoate 5 SG (x) on okra fruit with statistical parameters

Function	a	UCL	LCL	b	UCL	LCL	T Half	UCL	LCL
First order	5.0474	5.9648	4.13	-0.6907	-0.1888	-1.1926	1.0035	1.7327	0.2743
1.5 th order	0.0725	0.1551	-0.0101	0.0498	0.0955	0.0041	0.603	1.4854	-0.2794
2 nd order	0.0022	0.0734	-0.069	0.0155	0.0536	-0.0226	0.1419	4.7446	-4.4608
RF first order	5.5629	9.3442	1.7816	-1.4364	1.1112	-3.984	0.2328	1.0586	-0.593
RF 1.5 first order	0.0379	0.4432	-0.3674	0.1011	0.448	-0.2458	0.0643	1.5087	-1.380
Rf 2 nd order	-0.008	0.1686	-0.1846	0.0309	0.1821	-0.1203	0.067	3.0971	-2.9631
Inverse P L	-0.1322	6.1484	-6.4128	0.5537	3.2028	-2.0955	3.4968	24.4395	-17.4459

RF- Root function
Inverse PL- Inverse Power Law
Modi r sq- Modified 'r' square

Table 48 (b). Dissipation pattern for emamectin benzoate 5SG (2x) on okra fruit with statistical parameters

Function	a	UCL	LCL	b	UCL	LCL	T Half	UCL	LCL
First order	5.6186	6.0265	5.2107	-0.6907	-0.4671	-0.9143	1.0035	1.3284	0.6786
1.5 th order	0.0542	0.1165	-0.0081	0.0377	0.072	0.0034	0.5959	1.4682	-0.2772
2 nd order	0.0011	0.0824	-0.0802	0.0089	0.0534	-0.0356	0.1236	9.2817	-9.0345
RF first order	6.1247	10.7814	1.468	-1.4271	1.7113	-4.5655	0.2359	1.2735	-0.8017
RF 1.5 first order	0.0283	0.3536	-0.297	0.0762	0.3545	-0.2021	0.0637	1.6001	-1.4727
Rf 2 nd order	-0.0047	0.1351	-0.1445	0.0177	0.1371	-0.1017	0.0705	4.3701	-4.2291
Inverse P L	-0.1434	6.667	-6.9538	0.5459	3.4175	-2.3257	3.5599	27.3351	-20.2153

RF- Root function
Inverse PL- Inverse Power Law
Modi r sq- Modified 'r' square

Table 49. Harvest time residues of emamectin benzoate 5 SG in okra soil

Treatments	Residues of emamectin benzoate 5 SG($\mu\text{g g}^{-1}$)		
	R1	R2	R3
Emamectin benzoate 5 SG@ 8.5 g a.i ha ⁻¹	BDL	BDL	BDL
Emamectin benzoate 5 SG@ 17 g a.i ha ⁻¹	BDL	BDL	BDL
Control	BDL	BDL	BDL

BDL – Below Detectable Limit (LOQ - 0.04 $\mu\text{g g}^{-1}$)

Table 50. Harvest time residues of emamectin benzoate 5 SG in cotton

Treatments	Dose (g a.i. ha ⁻¹)	Residues of emamectin benzoate 5 SG (in ppm)						
		Lint		Seed		Oil		Soil
		I picking	III picking	I picking	III picking	I picking	III picking	I picking
Emamectin benzoate 5 SG	11	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Emamectin benzoate 5 SG	22	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Control	-	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL - Below detectable Limit

Table 51 . Harvest time residues of emamectin benzoate 5 SG in cotton soil

Treatments	Residues of emamectin benzoate 5 SG(µg g ⁻¹)		
	R1	R2	R3
Emamectin benzoate 5 SG@ 11 g a.i ha ⁻¹	BDL	BDL	BDL
Emamectin benzoate 5 SG@ 22 g a.i ha ⁻¹	BDL	BDL	BDL
Control	BDL	BDL	BDL

BDL – Below Detectable Limit (LOQ - 0.04 µg g⁻¹)

4.10. Acute toxicity

4.10.1. *P. gossypiella*

The LD₅₀ and LD₉₅ values for nine generations of *P. gossypiella* are presented in Table 52.

The median lethal dose (LD₅₀) of emamectin benzoate 5 SG for *P. gossypiella* was found to be 0.4282 µg larva⁻¹ for F₁ generation and 0.1802 µg larva⁻¹ for F₉ generation. The LD₉₅ was found to decrease from 3.3760 (F₁) to 1.1564 µg larva⁻¹ (F₉) (Table 52).

The susceptibility index to emamectin benzoate 5 SG based on LD₅₀ was 2.37 and 3.03 based on LD₉₅ (Table 53).

The rate of resistance decline (R) when selection pressure was stopped was -0.0417. With regard to number of generations required for 10-fold decrease in LD₅₀, it was calculated as 27.77 (Table 53).

4.10.2. Discriminating doses

As the discriminating dose (DD) can kill 95 per cent of the subjected normal population, based on lethal concentration obtained for emamectin benzoate 5 SG on F₁ population of *P. gossypiella*, tentative discrimination dose of 1.1µg larvae⁻¹ for emamectin benzoate 5 SG based on the acute toxicity studies (Table 52).

4.11. Assessing the level of resistance

Monitoring was done as one time survey in cotton and bhendi fields of Coimbatore, Erode, Salem, Dharmapuri and Madurai districts in Tamil Nadu. The resistance in field population of *H. armigera*, *E. vitella* (already fixed) and *P. gossypiella* to emamectin benzoate 5 SG was monitored using discriminating doses (DD) (0.8µg larvae⁻¹, 0.02 µg larvae⁻¹ and 1.1µg larvae⁻¹).

4.11.1. *H. armigera*

When the discriminating dose of emamectin benzoate 5 SG (0.8µg larvae⁻¹) were applied to field collected *H. armigera*, it was found that the per cent resistance of *H. armigera* in five districts ranged from 3.33 to 10.00. The highest per cent resistance

Table 52. Acute toxicity of Emamectin benzoate to *P. gossypiella* by topical application

Generation	Regression Equation	Chi square χ^2	LD ₅₀ µg/µl	Fiducial limits		LD ₉₅ µg/µl	Fiducial limits	
				LL	UL		LL	UL
1	$Y = -1.6103 + 2.5469x$	1.9732	0.4282	0.3263	0.5620	3.3760	1.5488	7.3588
2	$Y = -1.3275 + 2.4506x$	2.5250	0.3381	0.2556	0.4472	2.3751	1.2461	4.5271
3	$Y = -1.2945 + 2.4486x$	1.4193	0.2833	0.2082	0.3853	2.0291	1.0867	3.7890
4	$Y = -1.6016 + 2.6138x$	3.3995	0.2340	0.1679	0.3261	1.6811	0.9463	2.9864
5	$Y = -0.9981 + 2.4250x$	4.4295	0.2081	0.1458	0.2970	1.5314	0.8662	2.7072
6	$Y = -0.7309 + 2.3479x$	5.0766	0.1853	0.1266	0.2712	1.3476	0.7643	2.3759
7	$Y = -0.4818 + 2.2589x$	2.9291	0.1808	0.1165	0.2474	1.1171	0.6854	1.8205
8	$Y = -0.4103 + 2.5469x$	2.9732	0.1807	0.1042	0.2461	1.1565	0.6829	1.9585
9	$Y = -0.4219 + 2.5860x$	2.9667	0.1802	0.1041	0.2391	1.1564	0.6803	1.9483

Table 53. Susceptibility index and rate of resistance decline of emamectin benzoate 5 SG against *P. gossypiella*

Insecticide	Susceptibility Index		Rate of resistance decline	
	LD ₅₀ /LD ₅₀	LD ₉₅ / LD ₉₅	R	G
Emamectin benzoate 5 SG	2.37	3.03	-0.0417	27.77

(10 %) was recorded in Coimbatore district followed by Dharmapurai population. The lowest per cent levels of larval resistance observed in Salem, Erode and Madurai ranged from 3.33 to 6.66 (Table 54).

4.11.2. *E. vitella*

The survivability of fruit and shoot borer varied from 6.66 to 15.00 per cent for emamectin benzoate 5 SG. In case of Erode population was found to be highly susceptible which was evident from 0.00 per cent survival during monitoring whereas, it was 15.00 per cent for Coimbatore population followed by Salem, Madurai and Dharmapuri population (6.66 to 13.13) (Table 55).

4.11.3. *P. gossypella*

The per cent survival of pink bollworms varied from 3.33 to 6.66 per cent for emamectin benzoate 5 SG at $1.1\mu\text{g larvae}^{-1}$. The larval population of Coimbatore and Dharmapuri registered a per cent survival of 6.66 which was followed by Erode, Salem and Madurai (3.33%). All the district population showed the lowest level of resistance (Table 56).

4.12. Collection and identification of arthropods under cotton ecosystem

Arthropods collected at fortnightly intervals from July (2012) to October (2012) in sprayed and unsprayed cotton fields were documented, identified up to the lowest taxonomic level possible and various biodiversity indices were worked out. The survey yielded a wide array of 4232 individuals of arthropods from 51 families and 14 orders of spiders and insects (Tables 57).

4.12.1. Occurrence of arthropods in sprayed and unsprayed cotton field

The class insecta was the most common followed by arachnida. Totally, ten families of Araneae were collected with the majority of individuals falling under the family lycosidae, salticidae and araneidae in both sprayed and unsprayed cotton fields. under insecta, endopterygotes were the largest group represented by five orders while exopterygotes though represented by seven orders were lesser in occurrence. Among endopterygotes, maximum individuals were from hymenoptera while hemiptera was predominant in terms of individuals of exopterygota. The nine families of hemipterans,

Table 54. Mean resistance of *H. armigera* against emamectin benzoate 5 SG in five district of Tamil Nadu.

Location	No. of insect dosed	No. dead	% Resistance $\pm$ SE
Coimbatore	60	54	10 $\pm$ 3.91
Erode	60	58	3.33 $\pm$ 2.34
Salem	60	57	5 $\pm$ 2.84
Madurai	60	56	6.66 $\pm$ 3.25
Dharmapuri	60	55	8.33 $\pm$ 3.60

Table 55. Mean resistance of *E. vitella* against emamectin benzoate 5 SG in five district of Tamil Nadu.

Location	No. of insect dosed	No. dead	% Resistance $\pm$ SE
Coimbatore	60	51	15 $\pm$ 4.96
Erode	60	60	0.00
Salem	60	52	13.3 $\pm$ 4.57
Madurai	60	53	11.6 $\pm$ 4.18
Dharmapuri	60	56	6.66 $\pm$ 3.25

Table 56. Mean resistance of *P. gossypiella* against emamectin benzoate 5 SG in five district of Tamil Nadu.

Location	No. of insect dosed	No. dead	% Resistance $\pm$ SE
Coimbatore	30	28	6.66 $\pm$ 3.25
Erode	30	29	3.33 $\pm$ 3.25
Madurai	30	29	3.33 $\pm$ 5.51
Dharmapuri	30	28	6.66 $\pm$ 4.43
Salem	30	29	3.33 $\pm$ 5.21

Table 57. Diversity of arthropods in sprayed and unsprayed cotton field

Order	Family	Geneus	Sprayed	Unsprayed	Total
Araneae	Araneidae	<i>Argiope sp.</i>	17	20	37
		<i>Eriovixia excels</i> (Simon)	3	5	8
		<i>Argiope anasuja</i> (Thorell)	6	5	11
		<i>Neoscona muckerjei</i> (Tikader)	12	15	27
		<i>Neoscona theisi</i> (Walckenaer)	16	17	33
		<i>Neoscona bengalensis</i> (Tikader and bal)	11	16	27
	Clubionidae	<i>Clubiona sp</i>	14	19	33
	Gnaphosidae	<i>Drassyllus sp.</i>	4	7	11
	Tetragnathidae	<i>Leucauge decorate</i> (Blackwall)	2	1	3
	Lycosidae	<i>Hippasa greenalliae</i> (Blackwall)	5	6	11
		<i>Pardosa birmanica</i> (Simon)	22	29	51
	Salticidae	<i>Myrmarachne orientales</i> Tikader)	14	12	26
		<i>Plexippus paykulli</i> (Audouin)	6	9	15
		<i>Salticus sp.</i>	9	14	23
		<i>Rhene flavicomans</i> (Simon)	1	2	3
		<i>Telamonia dimidiate</i> (Simon)	3	6	9
	Oxyopidae	<i>Oxyopes sp.</i>	22	28	50
		<i>Peucetia viridana</i> (Stoliczka)	11	6	17
	Sparassidae	<i>Olios millet</i> (Pocock)	3	3	6
	Oxyopidae	<i>Oxyopes ratnae</i> (Tikader)	12	17	29
	Thomisidae	<i>Thomisus andamanensis</i> (Tikader)	6	3	9
Acarina	Tetranychidae	<i>Tetranychus urticae</i>	127	143	270
Odonata	Libellulidae	<i>Pantalt flavescens</i> (Fabricius)	6	11	17
Orthoptera	Acrididae	<i>Aeolopus affinis</i> (Bolivar)	5	15	20
		<i>Acrida exaltata</i> (Walker)	11	16	27
	Tettigonidae	<i>Conocephalus sp</i>	3	7	10
	Gryllidae	<i>Gryllus sp.</i>	13	18	31
Dermaptera	Forficulidae	<i>Forficula auricularia</i> (Linnaeus)	16	22	38
	Labiduridae	<i>Labidura riparia</i> (Pallas)	14	20	34
Dictyoptera	Blattidae	<i>Blatta germanica</i> (Linnaeus)	19	29	48
	Mantidae	<i>Odontomantis micans</i> (Saussure)	7	14	21
		Unidentified sp. (1)	6	8	14
		Unidentified sp. (2)	6	11	17

Order	Family	Geneus	Sprayed	Unsprayed	Total
Isoptera	Termitidae	<i>Odontotermes obesus</i> (Rambur)	79	86	165
Hemiptera	Reduviidae	<i>Acanthaspis siva</i> (Distant)	1	0	1
	Lygaeidae	<i>Geocoris</i> sp.	62	81	143
		<i>Oxycarenus hyalinipennis</i> (Costa)	102	122	224
	Pyrhrocoridae	<i>Dysdercus cingulatus</i> (Fabricius)	84	96	180
		<i>Dysdercus olivaceus</i> (Fabricius)	18	23	41
	Pentatomidae	<i>Halyomorpha picus</i> (Fabricius)	3	11	14
		<i>Dolycoris indicus</i> (Stal)	13	17	30
		<i>Nezara viridula</i> (Linnaeus)	31	35	66
	Membracidae	<i>Leptocentrus taurus</i> (Fabricius)	29	31	60
	Cicadellidae	<i>Amrasca devastans</i> (Distant)	123	164	287
	Aphididae	<i>Aphis gossypii</i> (Glover)	106	116	222
	Aleyrodidae	<i>Aleurodicus disperses</i> (Russell)	83	89	172
	Pseudococcidae	<i>Paracoccus marginatus</i> (Williams and Willink)	167	173	340
		<i>Phenacoccus solenopsis</i> (Tinsley)	96	113	209
Thysanoptera	Thripidae	<i>Thrips tabaci</i>	69	72	141
Neuroptera	Chrysopidae	<i>Chrysoperla carnea</i> (Stephens)	6	9	15
Lepidoptera	Noctuidae	<i>Earias vitella</i> (Sherborn)	16	26	42
		<i>Helicoverpa armigera</i> (Hubner)	10	19	29
		<i>Spodoptera litura</i> (Fabricius)	27	36	63
	Gelechiidae	<i>Pectinophora gossypiella</i> (Saunders)	7	18	25
	Pyraustidae	<i>Sylepta derogate</i> (Fabricius)	4	6	10
	Hesperiidae	<i>Pelopidas sinensis</i> (Mabille)	3	3	6
Diptera	Syrphidae	<i>Syrphus</i> sp.	6	8	14
	Scarcophagidae	<i>Sarcophaga lineaticollis</i>	7	10	17
	Muscidae	<i>Musca domestica</i> (Linnaeus)	9	13	22
Hymenoptera	Ichneumonidae	<i>Gotra</i> sp.	2	1	3
	Trichogrammatidae	<i>Trichogramma</i> sp.	4	6	10
	Eumenidae	<i>Eumenes dimidiatipennis</i> (Saussure)	4	3	7
	Formicidae	<i>Oecophylla smaragdina</i> (Fabricius)	62	67	129

Order	Family	Geneus	Sprayed	Unsprayed	Total
	Apidae	<i>Apis cerana indica</i> (Fabricius)	46	49	95
	Vespidae	<i>Ropalidia spatulata</i> (Van der Vecht)	18	20	38
Coleoptera	Carabidae	<i>Pheropsophus bimaculatus</i> (Linnaeus)	7	10	17
		<i>Scarites mahratta</i> (Andrewes)	9	13	22
	Coccinellidae	<i>Cheilomenes sexmaculata</i> (Fabricius)	46	52	98
		<i>Coccinella transversalis</i> (Fabricius)	67	72	139
		<i>Cryptolaemus montrouzieri</i> (Mulsant)	7	2	9
		<i>Illeis cincta</i> (Fabricius)	19	23	42
	Scarabaeidae	<i>Onthophagus laevigatus</i> (Fabricius)	12	16	28
	Curculionidae	<i>Alcidodes</i> sp.	4	6	10
		<i>Myllocerus</i> sp.	16	22	38
	Meloidae	<i>Mylabris pustulata</i> (Thunberg)	7	6	13
	Cetoniidae	<i>Oxycetonia versicolor</i> (Fabricius)	3	7	10
	Grand Total		1926	2306	4232

collected, majority of the individuals were pseudococcidae followed by cicadellidae, aphididae, lygaeidae, aleyrodidae, pyrrhocoridae, pentatomidae, membracidae, and reduviidae (Table 57).

In case of order thysanoptera, 72 individuals of *Thrips tabaci* (thripidae) were collected with majority of individuals from unsprayed cotton. Dermaptera was represented as two families viz., forficulidae (*Forficula auricularia*) and labiduridae (*Labidura riparia*) with majority of individuals from unsprayed cotton field. The single family represented under the order isoptera was termitidae with 86 individuals of *Odontotermes obsesus*. The order Hymenoptera was represented by six families. The maximum number of individuals belonged to family formicidae (129), followed by apidae (95) and vespidae (38) in both sprayed and unsprayed cotton.

Lepidoptera was represented by four families with majority of individuals collected falling under noctuidae (195) followed by gelechiidae (25), pyraustidae (10) and hesperiidae (6). Majority of species under Noctuidae belonged to the genus *Spodoptera* with (63) (Table 57). Under coleoptera six families were collected with majority of individuals belonging to coccinellidae (248). Only 28 individuals of curculionidae were collected.

4.13. Biodiversity indices

From the collection, 14 orders of arthropods were recorded (Plate 14-21). Based on this primary arthropod data, two different sets of indices namely alpha diversity indices and beta diversity indices were calculated.

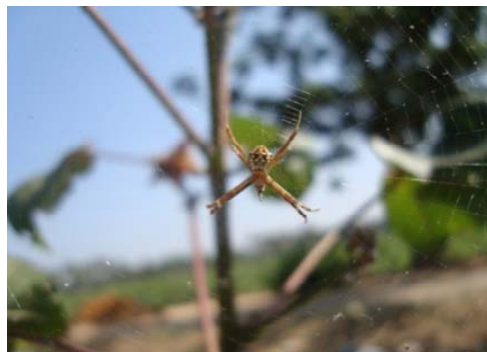
4.13.1. Alpha diversity indices at ordinal, family, generic and species level

The species number calculated based on the generic level varied between a minimum of 53 during the second fortnight of July to a maximum of 71 during the month of October second fortnight in unsprayed cotton. In sprayed cotton, the maximum (62) was during the second fortnight of October and minimum during the second fortnight of July (49) (Table 58).

Based on ordinal level and species level analysis, the species richness not clear variation in the fisher's alpha index values. At generic level and familial level, the value



Argiope sp.



Argiope sp.



Argiope anasuja Thorell



Neoscona muckerjei Tikader



Neoscona bengalensis Tikader and Bal



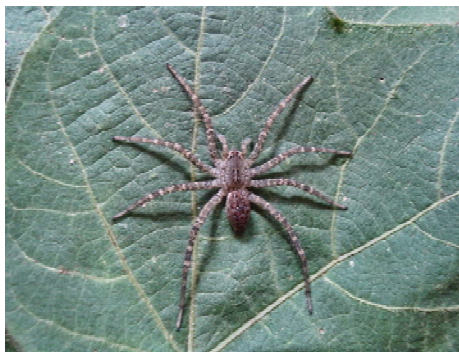
Neoscona theisi (Walckenaer) male



Clubiona sp.



Drassyllus sp.



Hippasa greenalliae (Blackwall)



Leucauge decorata (Blackwall)



Myrmarachne orientales Tikader



Olios milleti (Pocock)



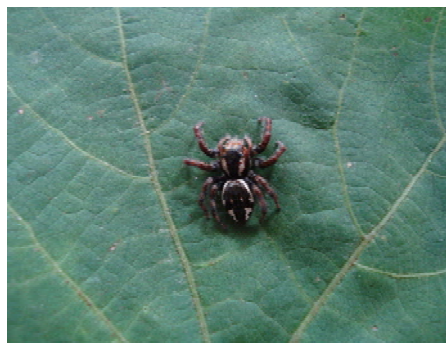
Pardosa birmanica Simon female



Oxyopes ratnae Tikader



Salticus sp.



Plexippus paykulli (Audouin)



Pardosa birmanica Simon male



Telamonia dimidiata (Simon) female



Telamonia dimidiata (Simon) male



Thomisus andamanensis Tikader

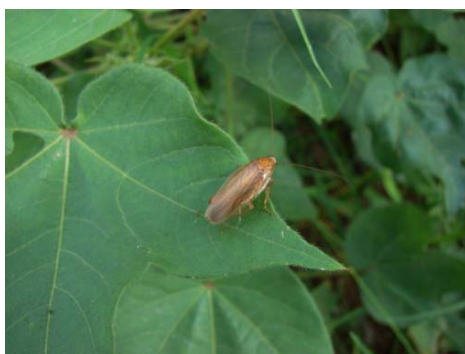
Plate 14c. Arthropods observed in cotton ecosystem (Order: Araneae)



Unidentified sp.



***Pantala flavescens* (Fabricius)**



***Blatta germanica* (Linnaeus)**



Unidentified sp.



***Mantis religiosa* (Linnaeus)**



Unidentified sp.



***Labidura riparia* (Pallas)**

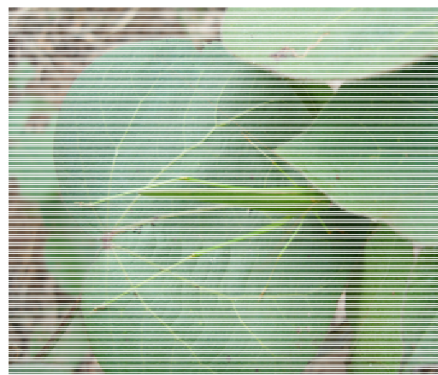


***Forficula auricularia* (Linnaeus)**

**Plate 15. Arthropods observed in cotton ecosystem
(Order: Odonata, Dermaptera and Dictyoptera)**



Aeolopus affinis (Bolivar)



Conocephalus sp.



Gryllus sp.



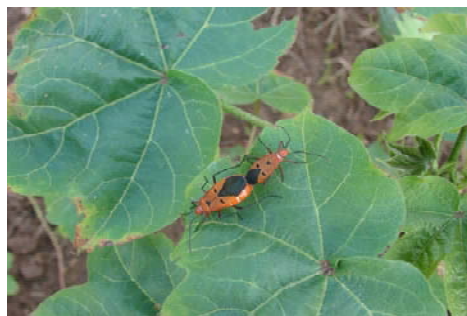
Cyrtacanthacris tatarica (Linnaeus)



Acanthaspis siva (Distant)



Dysdercus olivaceus (Fabricius)



Dysdercus cingulatus (Fabricius) adult



Dysdercus cingulatus (Fabricius) nymph

**Plate 16. Arthropods observed in cotton ecosystem
(Order: Orthoptera and Hemiptera)**



Cyclopelta siccifolia (Westwood)



Nezara viridula (Linnaeus) nymph



Dolycoris indicus (Stal)



Chrysocoris stockerus (Linnaeus)



Halyomorpha picus (Fabricius)



Scutellera nobilis (Fabricius)



Nezara viridula (Linnaeus) adult



Solenothethium rubropunctatum

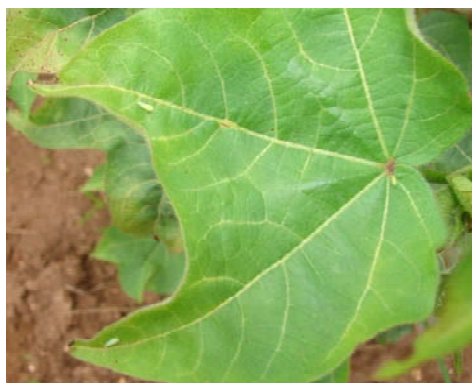
Plate 17. Arthropods observed in cotton ecosystem (Order: Hemiptera)



Leptocentrus taurus (Fabricius)



Aphis gossypii (Glover)



Amrasca devastans (Distant)



Aphis gossypii (Glover)



Aleurodicus dispersus (Russell)



Paracoccus marginatus (Williams and Willink)



Aphis gossypii (Glover)



Phenacoccus solenopsis (Tinsley)

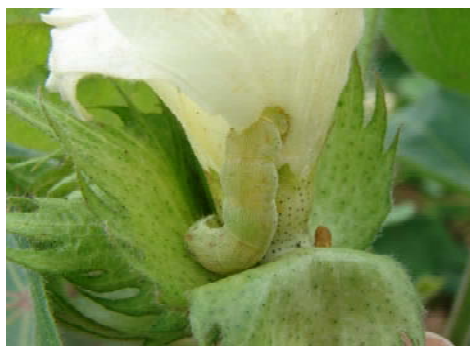
Plate 17a. Arthropods observed in cotton ecosystem (Order: Hemiptera)



Earias vitella (Sherborn)



Sylepta derogata (Fabricius)



Helicoverpa armigera (Hubner)



Diacrisia obliqua (Walker)



Spodoptera litura (Fabricius)



Unidentified sp.



Tarache nitidula (Fabricius)



Pelopidas sinensis (Mabille)

Plate 18. Arthropods observed in cotton ecosystem (Order: Lepidoptera)



Chrysoperla carnea (Stephens) adult



Chrysoperla carnea (Stephens) egg



Syrphus sp.



Idvia sp.



Heliophilus sp.



Sarcophaga lineaticollis (Abasa)

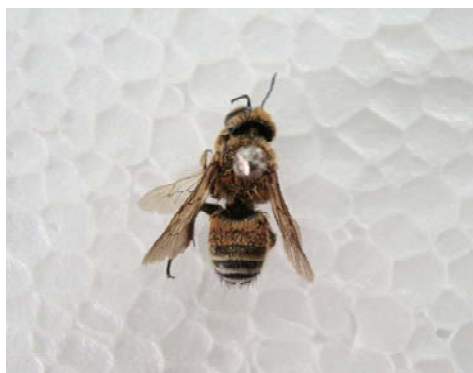


Promachus heteropterus (Macquart)



Hermetia illucens (Linnaeus)

Plate 19. Arthropods observed in cotton ecosystem (Order: Diptera and Neuroptera)



Megachile lanata (Fabricius)



Ropalidia spatulata (van der Vecht)



Xylocopa sp.



Chrysis angolensis (Radoszkowski)



Xylocopa aestuanus (Linnaeus)



Megachile vestita (Smith)



Megachile mendica (Cresson)



Mutilla sp.



Macrochilus bensoni (Hope)



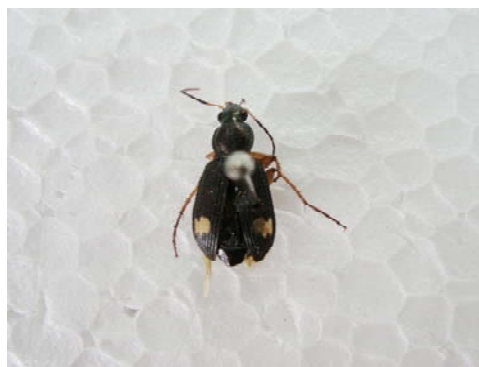
Cheilomenes sexmaculata (Fabricius)



Coccinella transversalis (Fabricius)



Harmonia octomaculata (Fabricius)



Chlaenius bimaculatus (Macleay)



Scarites mahratta (Andrewes)



Cheilomenes sexmaculata (Fabricius)



Harmonia octomaculata (Fabricius)

Plate 21. Arthropods observed in cotton ecosystem (Order: Coleoptera)

Table 58. Arthropod diversity in cotton ecosystem – Alpha diversity (Species number)

Month	Sampling fortnight	Species richness indices (Species number)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level		Ordinal level	Familial level	Generic level	Species level	
July	First fortnight	14	41	57	46		14	45	64	46	
	Second fortnight	13	37	49	43		13	39	53	47	
August	First fortnight	12	38	60	56		14	41	64	58	
	Second fortnight	13	40	51	54		14	42	56	57	
September	First fortnight	13	38	57	55		13	38	65	58	
	Second fortnight	12	39	57	58		14	40	62	59	
October	First fortnight	13	39	61	57		14	42	71	62	
	Second fortnight	12	37	62	56		13	39	62	59	

was highest in the first fortnight of July in sprayed (35.091 & 14.548) and unsprayed cotton (36.180 & 16.108) (Table 59).

From table 60 it could be seen that the Margelef D value based on Generic level varied between a minimum of 9.318 during the second fortnight of August and maximum of 11.284 in the first fortnight of July in sprayed cotton. In unsprayed cotton, the index value was highest during the first fortnight of July (12.185) and lowest during the second fortnight of July (9.5669).

Analysis of data using Q statistic is presented in table 61. The index value based on Ordinal and familial recorded no significant variance in both sprayed and unsprayed cotton. On the generic level, the value was maximum in the first fortnight of July (25.032) and minimum in the second fortnight of September (14.791) in sprayed cotton. In unsprayed cotton, the value was highest in the first fortnight of July (28.673) and lowest in the second fortnight of August (16.831).

From the table 62 it could be seen from Brillouin diversity index recorded there was minimum variation in the index value on analysis based on Ordinal, Generic, Familial and Species level between the sprayed and unsprayed cotton.

The Shannon –Weiner calculated based on the four taxonomic level are presented in table 63. The index value based on Ordinal, Generic, Familial and Species in sprayed cotton was equal to unsprayed filed.

The simpson's index calculated based on ordinal level revealed maximum during the first fortnight of July (6.1195) and minimum during the first fortnight of October (3.3210) in unsprayed cotton. In sprayed cotton, the maximum was during the first fortnight of August (4.4160) and minimum during the second fortnight of October (2.6773). Analysis of values based on generic level showed that the value was highest during the first fortnight of July and lowest during the second fortnight of October both in sprayed and unsprayed cotton. (Table 64)

McIntosh index also observed no clear variation in index values on the four taxonomic levels in both sprayed and unsprayed cotton are presented in the (Table 65).

Table 59.Arthropod diversity in cotton ecosystem – Alpha diversity (Fishers alpha)

Month	Sampling fortnight	Species richness indices (Fishers alpha)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	3.1174	14.548	35.091	19.687	3.4435	16.108	36.180	22.990		
	Second fortnight	2.9977	11.749	25.189	18.336	3.0016	12.766	28.125	19.659		
August	First fortnight	3.1961	12.358	26.390	21.250	3.3275	13.188	30.522	23.541		
	Second fortnight	2.9831	13.175	21.189	20.057	3.0727	13.812	21.427	21.502		
September	First fortnight	2.8135	11.879	22.850	20.394	2.9977	12.315	24.894	21.187		
	Second fortnight	3.0376	11.969	20.884	20.952	3.2918	14.271	21.268	22.220		
October	First fortnight	2.8272	13.770	23.177	21.759	3.0376	14.334	26.602	22.835		
	Second fortnight	2.9521	12.427	23.024	22.013	3.1289	13.150	23.811	22.584		

Table 60. Arthropod diversity in cotton ecosystem – Alpha diversity (Margalef's D)

Month	Sampling fortnight	Species richness indices (Margalef's D)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	2.3130	7.3614	11.284	8.6291	2.4583	7.9864	12.185	9.0173		
	Second fortnight	2.2120	6.4651	10.284	8.1501	2.2113	6.8432	9.5669	8.7237		
August	First fortnight	2.3494	6.6772	10.849	9.7921	2.4082	7.0898	11.700	10.301		
	Second fortnight	2.2488	7.0087	9.3182	9.4299	2.2462	7.2996	9.8177	9.9195		
September	First fortnight	2.1243	6.5705	10.113	9.5712	2.2120	6.6678	11.132	9.9588		
	Second fortnight	2.2846	6.6661	9.8238	10.007	2.3925	7.2247	10.311	10.116		
October	First fortnight	2.1310	7.0454	10.525	9.9573	2.2752	7.4043	11.909	10.564		
	Second fortnight	2.2336	6.7569	10.592	9.9830	2.2713	6.7698	10.778	10.175		

Table 61.Arthropod diversity in cotton ecosystem – Alpha diversity (Q Statistic)

Month	Sampling fortnight	Species richness indices (Q Statistic)							
		Sprayed field				Unsprayed field			
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level
July	First fortnight	3.5133	12.772	25.032	15.627	5.5883	13.618	28.673	18.755
	Second fortnight	5.6075	11.150	17.312	13.674	6.6531	14.066	24.576	15.348
August	First fortnight	5.2960	9.9888	23.444	16.464	6.9364	11.378	24.526	17.729
	Second fortnight	3.9674	10.468	16.464	17.860	5.1584	11.150	16.831	18.139
September	First fortnight	3.6067	9.9888	17.301	17.580	6.5481	14.564	22,368	19.014
	Second fortnight	3.7923	10.339	14.791	17.860	4.4925	10.563	19.271	18.757
October	First fortnight	2.8991	10.099	19.883	15.417	3.8012	12.022	24.853	18.500
	Second fortnight	2.9192	8.6859	23.444	16.105	3.5196	10.426	25.608	18.243

Table 62.Arthropod diversity in cotton ecosystem – Alpha diversity (Brillouin diversity index)

Month	Sampling fortnight	Species richness indices (Brillouin diversity index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	1.8018	3.0012	3.1453	3.0312	1.9769	3.0251	3.3793	3.1090		
	Second fortnight	1.8483	2.9938	3.1214	2.9636	1.9535	2.9801	3.1463	3.0957		
August	First fortnight	1.8394	2.9262	3.2519	3.1832	1.9289	3.0232	3.287	3.2192		
	Second fortnight	1.6237	2.9525	3.1261	3.1904	1.7418	2.9669	3.2513	3.2452		
September	First fortnight	1.7135	2.9141	3.2214	3.2499	1.8102	3.0196	3.3438	3.3008		
	Second fortnight	1.7638	2.8183	3.2126	3.1722	1.7786	2.8624	3.3487	3.2981		
October	First fortnight	1.5904	2.8384	3.1882	3.173	1.6437	2.9273	3.3297	3.3259		
	Second fortnight	1.4769	2.7987	3.1873	3.1346	1.9834	2.9324	3.2467	3.2724		

Table 63.Arthropod diversity in cotton ecosystem – Alpha diversity (Shannon- Weiner index)

Month	Sampling fortnight	Shannon- Weiner index									
		Sprayed field					Unsprayed field				
		Ordinal level		Familial level			Ordinal level		Familial level		
		H	Variance H	H	Variance H	H	H	Variance H	H	Variance H	Variance H
July	First fortnight	1.8927	0.0051419	3.2653	0.0042869	2.0968	0.0043091	3.2925	0.003499		
	Second fortnight	1.9510	0.0054001	3.2287	0.0030805	2.0579	0.0043766	3.2066	0.002939		
August	First fortnight	1.9467	0.0056715	3.1542	0.0032618	2.0273	0.0043147	3.2498	0.002923		
	Second fortnight	1.7016	0.0065922	3.2001	0.0033272	1.8477	0.0054583	3.1795	0.003375		
September	First fortnight	1.7963	0.0055067	3.1396	0.0033458	1.9111	0.0050291	3.2406	0.002638		
	Second fortnight	1.8634	0.0060522	3.0700	0.0048317	1.8661	0.0048057	3.0644	0.003493		
October	First fortnight	1.6702	0.0055499	3.0893	0.0044994	1.7227	0.0050222	3.1701	0.004098		
	Second fortnight	1.5466	0.0052473	3.0505	0.0043978	2.0956	0.0035510	3.1518	0.003225		

Table 63. (Contd...)

Month	Sampling fortnight	Shannon- Weiner index									
		Sprayed field					Unsprayed field				
		Generic level		Species level		H	Generic level		Species level		Variance H
		H	Variance H	H	Variance H		H	Variance H	H	Variance H	
July	First fortnight	3.8399	0.0045265	3.4331	0.0061697	3.6209	0.0075282	3.4545	0.0042838		
	Second fortnight	3.5373	0.0053027	3.2976	0.0055276	3.5734	0.0061687	3.4272	0.004339		
August	First fortnight	3.6276	0.0052903	3.4930	0.0043053	3.6408	0.0042934	3.5101	0.0036887		
	Second fortnight	3.4527	0.0046456	3.5323	0.003348	3.5469	0.0034061	3.4716	0.0035729		
September	First fortnight	3.5304	0.0037881	3.5324	0.0030833	3.6382	0.0034104	3.5792	0.0029831		
	Second fortnight	3.4837	0.0032865	3.4594	0.0041125	3.6007	0.0026315	3.5643	0.0029758		
October	First fortnight	3.4680	0.0039002	3.4590	0.0040172	3.6072	0.0034963	3.6052	0.0031168		
	Second fortnight	3.4606	0.0038757	3.4422	0.0048299	3.5232	0.0035972	3.5576	0.0034791		

Table 64.Arthropod diversity in cotton ecosystem – Alpha diversity (Simpson’s index)

Month	Sampling fortnight	Species dominance indices (Simpson’s index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	3.9420	18.777	30.767	26.694	6.1195	21.956	44.380	27.645		
	Second fortnight	4.4049	19.821	29.438	21.500	5.2812	20.228	31.901	26.234		
August	First fortnight	4.4160	18.861	28.259	24.905	5.0115	20.350	30.166	25.612		
	Second fortnight	3.0239	18.669	24.375	24.934	3.8423	19.148	27.779	27.368		
September	First fortnight	3.6041	18.125	27.533	28.180	4.2462	20.929	28.065	28.559		
	Second fortnight	3.8305	15.528	25.827	23.222	3.9234	16.067	27.889	27.046		
October	First fortnight	3.1270	16.929	23.786	23.238	3.3210	17.491	25.769	27.936		
	Second fortnight	2.6773	17.336	23.197	21.471	6.5267	18.253	25.056	26.053		

Table 65.Arthropod diversity in cotton ecosystem – Alpha diversity (McIntosh index)

Month	Sampling fortnight	Species dominance indices (McIntosh index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	0.52528	0.81278	0.87501	0.85990	0.63575	0.83202	0.90027	0.86125		
	Second fortnight	0.55701	0.81799	0.86905	0.83543	0.60064	0.82061	0.87705	0.85364		
August	First fortnight	0.55800	0.81271	0.85863	0.84339	0.58665	0.81965	0.86368	0.84469		
	Second fortnight	0.44804	0.81009	0.84440	0.85071	0.52253	0.81405	0.85293	0.84191		
September	First fortnight	0.50055	0.80780	0.85131	0.85358	0.54760	0.82301	0.85325	0.85342		
	Second fortnight	0.51665	0.78557	0.84403	0.83427	0.52674	0.79568	0.84792	0.84694		
October	First fortnight	0.45988	0.80241	0.83561	0.83453	0.47654	0.80368	0.84079	0.85044		
	Second fortnight	0.40964	0.80669	0.83206	0.82811	0.64939	0.80746	0.83996	0.84490		

Berger Parker diversity index was calculated based on the four taxonomic levels. The index value was higher in unsprayed cotton than sprayed field (Table 66).

The maximum number arthropod was observed in unsprayed cotton than sprayed field. The maximum diversity of arthropods occurred in the month of July in most of the diversity index.

Table 66.Arthropod diversity in cotton ecosystem – Alpha diversity (Berger parker diversity index)

Month	Sampling fortnight	Species dominance indices (Berger parker diversity index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial Level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	0.31818	0.12664	0.0625	0.081522	0.47101	0.15789	0.09090	0.088435		
	Second fortnight	0.38326	0.12595	0.08609	0.087179	0.43805	0.12791	0.11460	0.127170		
August	First fortnight	0.39526	0.12157	0.08695	0.094545	0.43439	0.13121	0.10550	0.106720		
	Second fortnight	0.47847	0.13091	0.08118	0.077739	0.55556	0.13793	0.12617	0.097826		
September	First fortnight	0.44493	0.10394	0.09055	0.08156	0.49648	0.14397	0.13235	0.084967		
	Second fortnight	0.47162	0.13837	0.07692	0.085106	0.47973	0.15719	0.11253	0.096429		
October	First fortnight	0.52145	0.12636	0.08361	0.086957	0.54122	0.14961	0.10084	0.104690		
	Second fortnight	0.28426	0.10680	0.09841	0.090301	0.59347	0.13504	0.11480	0.149800		

Table 67. Arthropod diversity in cotton ecosystem – Alpha diversity (Equitability J)

Month	Sampling fortnight	Evenness indices (Equitability J)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Species level
July	First fortnight	0.71719	0.83903	0.83609	0.80808	0.79406	0.84601	0.88667	0.81312		
	Second fortnight	0.73926	0.82393	0.81678	0.77619	0.77978	0.82962	0.82512	0.80669		
August	First fortnight	0.73764	0.81048	0.83763	0.82218	0.76818	0.83503	0.84070	0.82619		
	Second fortnight	0.64477	0.81697	0.79725	0.81713	0.70014	0.82225	0.81901	0.83142		
September	First fortnight	0.68066	0.80673	0.81520	0.83145	0.72415	0.83267	0.84008	0.84247		
	Second fortnight	0.70711	0.78739	0.80441	0.81426	0.70610	0.78884	0.83142	0.83896		
October	First fortnight	0.63289	0.79380	0.80080	0.81416	0.65276	0.81455	0.83293	0.84858		
	Second fortnight	0.58605	0.78382	0.79907	0.81021	0.79454	0.80986	0.81355	0.83737		

Discussion

CHAPTER V

DISCUSSION

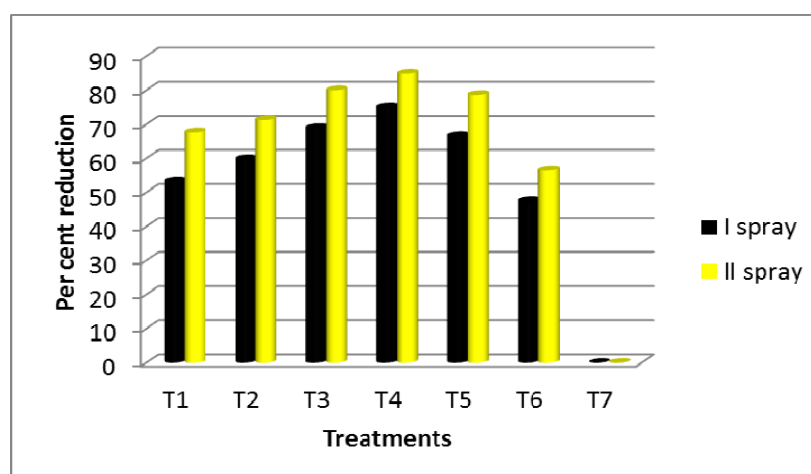
Indiscriminate use of insecticides related resistance development by insects and ill effects on environment have opened the new era of eco-friendly insecticides having novel mode of action with higher bioefficacy against target insects. One such insecticide is emamectin benzoate that belongs to avermectin group. This novel group showed increased efficacy against lepidopteran caterpillars and is relatively safe to non-target organisms. Hence, detailed investigations were carried out with this insecticide during September 2010 to December 2012 at the Department of Agricultural Entomology, Tamil Nadu Agricultural University, and Coimbatore. The results on the evaluation of bioefficacy of emamectin benzoate 5 SG against bollworms in cotton and fruit borers in okra and its persistence, phytotoxicity, safety to natural enemies, compatibility with other agrochemicals, residues, level of resistance in target pests monitoring and arthropod biodiversity in cotton are discussed in this chapter.

5.1. Cotton

5.1.1. Bioefficacy of emamectin benzoate 5SG against cotton bollworms

The results of the field experiments on cotton revealed that emamectin benzoate 5 SG effected marked reduction in the damage caused by bollworm complex. Emamectin benzoate 5 SG at 15 g a.i. ha⁻¹ recorded 92.57 and 92.04 per cent reduction of bollworms in the first and second field experiments, respectively (Figs. 4-5). The higher dose was superior to all other treatments. The lowest larval population was recorded in plots sprayed with emamectin benzoate 5 SG at 11 and 15 g a.i. ha⁻¹ having 2.00 and 1.17 larvae plant⁻¹ respectively, at 7 days after first spray in the second field experiment, while at 7 DAT was 1.00 and 0.00 larvae plant⁻¹ respectively, 7 days after second. The increase in larval population at 10 DAT could be due to the foliage growth that dilutes the non- systemic insecticide deposits on the leaf surface and also that the new leaves might act as insecticide free refuges to the insects that decrease the mean efficacy of insecticides, as reported by Wilson *et al.* (1983). Emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ resulted in 75.66 and 92.04 per cent reduction of larval population at the end of first and second spray respectively, in second field trial. This might be due to the fact that the insecticide

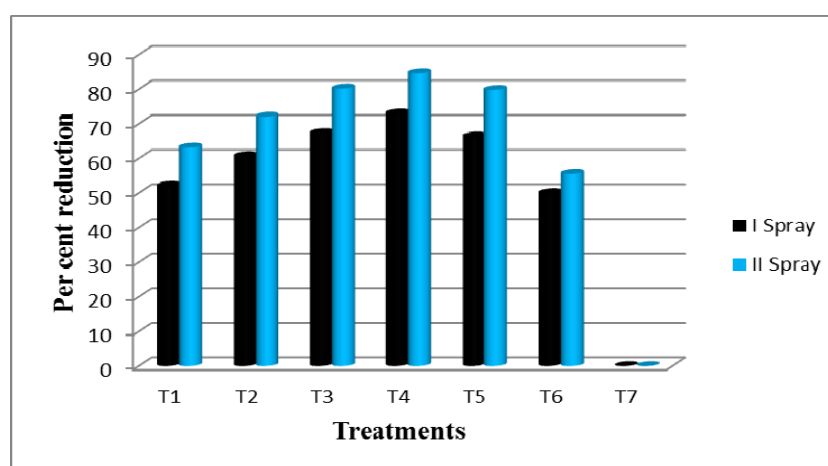
Fig. 4. Effect of emamectin benzoate 5G against bollworms damage in cotton - I season



T1 - Emamectin benzoate 7g a.i. ha⁻¹
 T3 - Emamectin benzoate 11g a.i. ha⁻¹
 T5- Proclaim® 11 g a.i. ha⁻¹
 T7- Untreated check

T2 - Emamectin benzoate 9g a.i. ha⁻¹
 T4 - Emamectin benzoate 15g a.
 T6 - Spinosad 75g a.i. ha⁻¹

Fig. 5. Effect of emamectin benzoate 5G against bollworms damage in cotton - II season



T1 - Emamectin benzoate 7g a.i. ha⁻¹
 T3 - Emamectin benzoate 11g a.i. ha⁻¹
 T5- Proclaim® 11 g a.i. ha⁻¹
 T7- Untreated check

T2 - Emamectin benzoate 9g a.i. ha⁻¹
 T4 - Emamectin benzoate 15g a.i. ha⁻¹
 T6 - Spinosad 75g a.i. ha⁻¹

efficacy depends on the initial activity of the active ingredient on the target pest and its residual activity (persistence) as reported by Mulrooney and Elmore (2000). These results are in line with Prakash and Tomar (2009) where they observed that emamectin benzoate 5 SG @ 11g a.i ha⁻¹ recorded the lowest larval population of *H. armigera* in cotton.

Brevault *et al.* (2009) stated that emamectin benzoate 5 EC @ 10 g a.i ha⁻¹ was effective in causing 85.40 per cent mortality against fifth instar larvae of *H. armigera* in cotton. According to Achallke *et al.* (2009) emamectin bezoate 5 SG @ 12 g a.i ha⁻¹ is effective in suppressing larval population and boll damage of *H. armigera* in cotton. Similar results were obtained by Gupta *et al.*, (2005), Sontakke *et al.* (2007b), Srinivasan *et al.* (2007), Kulkarni and Adsule (2007) and Raghuraman *et al.* (2008). Aiswariya *et al.*(2010) which revealed that emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ was effective in checking the larval population of bollworm viz., *Helicoverpa armigera* Hubner. The same dose (11 g a.i. ha⁻¹) resulted in 60.09 and 75.46 per cent boll damage over untreated check in the first and second field experiments. Likewise, the lower dose of emamectin bezoate 5 SG at 9 g a.i. ha⁻¹ caused 64.67 and 64.59 per cent reduction of larvae population after second spray in the first and second experiments, respectively. Similar result was reported for foliar application of lower dose of emamectin benzoate 5 SG @ 6.75 g a.i ha⁻¹ which was effective in controlling the *H. armigera* in cotton (Gaikwad *et al.*, 2009). This shows that emamectin benzoate is effective even at lower doses. Singh and Chander (2009) found that the plots treated with emamectin benzoate 5 SG @ 9.8 g a.i ha⁻¹ reduced the bollworm damage and increased the seed cotton yield.

The plots treated with emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ recorded 80.06 per cent reduction of boll damage after second spray of first season experiment. In the case of second season field experiment, 80.24 per cent reduction of boll damage was recorded. This increased efficacy might be due to penetration of emamectin benzoate through leaf tissues by translaminar movement delaying its degradation under field conditions as reported by Tomlin (2003). The results are in line with Prakash and Tomar (2009) who reported that emamectin benzoate 5 SG @ 11g a.i ha⁻¹ recorded the lowest infestation of bollworm damage on square basis (10.1 and 9.2%), green boll basis (8.2 and 7.4%) and open boll basis (4.5 and 4.6%). According to Bheemanna *et al.* (2005) foliar application of emamectin benzoate @ 11 g a.i. ha⁻¹ recorded the lowest boll

damage and was effective against cotton bollworms. The results agree with the findings of Ishaaya *et al.* (2002) who reported earlier that emamectin benzoate showed promising efficacy against bollworms by protecting the reproductive structures.

In emamectin benzoate 5 SG at 11 g a.i.ha⁻¹ treated plots, the mean damage to bolls by bollworms in second spray of first and second experiment was in the range of 7.10 and 7.32, respectively. Similar results were also reported by Gaikwad *et al.* (2009) with foliar application of emamectin benzoate 5 SG @ 6.75 g a.i ha⁻¹ which was effective in controlling the bollworms and reducing shed material, locule infestation and bad kapas. Raghuraman *et al.* (2008) found that the plots treated with emamectin benzoate 5 EC @11g a.i ha⁻¹ was effective in reducing the boll damage. According to Udikeri *et al.* (2004) emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ recorded significantly less damage to fruiting bodies (4.17 %). Jansson *et al.* (1997a) reported that emamectin benzoate 5 SG at 8.4 g a.i. ha⁻¹ was very effective in controlling cotton bollworm *Helicoverpa zea* Boddie, when sprayed at 0.0075 - 0.015 lb a.i. ha⁻¹ (Dunbar *et al.*, 1998). Ishaaya *et al.* (2002) found that emamectin benzoate 5 SG at 25 mg a.i.l⁻¹ registered 90 per cent suppression of *H. armigera* larvae up to 28 days after treatment (DAT) on cotton.

Efficacy of Proclaim® 5 SG at 11g a.i. ha⁻¹ against cotton bollworms was on par with emamectin benzoate 5 SG at 11g a.i. ha⁻¹ recording 80.04 and 79.24 per cent reduction of larval population in the first field experiments and 84.73 and 82.47 per cent in the second field experiment. This is in conformity with finding of Duraimurugan *et al.* (2007) who stated that application of Proclaim® @ 11 and 9.5 g a.i. ha⁻¹ recorded the highest reduction of larval population of *H. armigera* (84.60%). Proclaim® 5 SG @ 7.5 g a.i. ha⁻¹ was found more effective against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee (Stanley *et al.*, 2007). Proclaim® @ 200 g a.i. ha⁻¹ (Balikai and Patil, 2007) and 11g a.i. ha⁻¹ (Kulkarni and Adsule, 2007) were found to be effective against grape vine thrips. Prasad kumar and Devappa (2006a) reported that Proclaim 5 SG @ 200 g a.i ha⁻¹ was effective against cabbage diamond back moth and brinjal shoot and fruit borer. Proclaim® @11 g a.i.ha⁻¹ and emamectin benzoate SWG @11 g a.i.ha⁻¹ (Aiswariya, 2010) were found to be effective against *H. armigera* in cotton. Govindan *et al.*, (2012a) who stated that application of Proclaim® @11 g a.i.ha⁻¹ and emamectin benzoate @

11 g a.i.ha⁻¹ recorded the highest reduction of larval population of *H. armigera* (90.31 and 86.65 per cent) after second application.

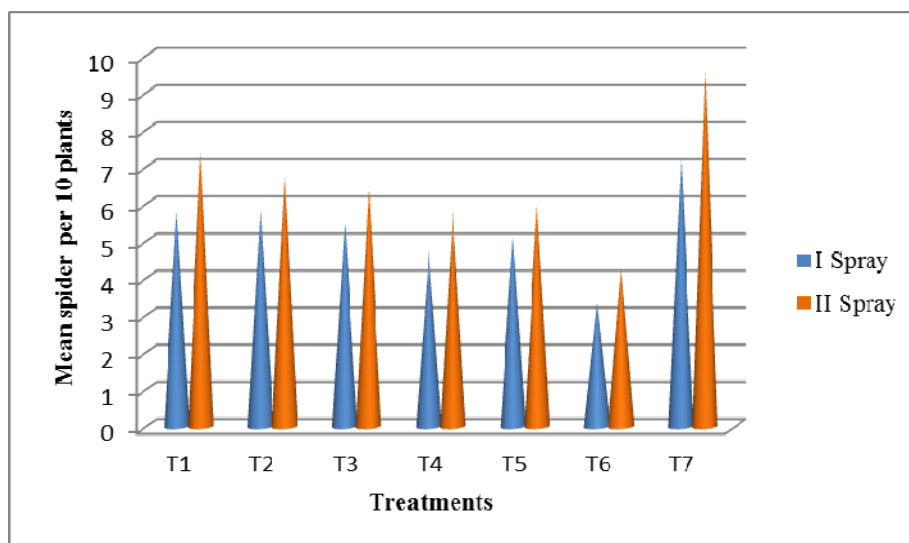
5.1.2. Safety of emamectin benzoate 5 SG to natural enemies in cotton

The effect of emamectin benzoate on spiders revealed that after end of first and second field trials, spider population was maximum in untreated control which was followed by emamectin benzoate 5 SG at 7g a.i ha⁻¹ on three days after application (Figs. 6 and 7). The observations on 7 and 10 DAT showed the recolonization of spiders in all the treatments irrespective of doses tested Balikai and Patil (2007) stated that emamectin benzoate 5 SG (Proclaim®) at 8 g a.i ha⁻¹ recorded a mean of 0.5 spiders per grape vine compared to control. Sansone and Minzenmayer (2000) reported that spinosad had the least impact on spiders as compared to indoxacarb (Steward®) and emamectin benzoate (Denim®). All the insecticides, irrespective of the doses, were safe to spiders as less than 50 per cent reduction in population was considered to be safer as reported by Dhawan (2000).

Emamectin benzoate 5 SG at higher dose (15 g a.i. ha⁻¹) recorded mean of 4.75 and 5.83 spiders per 10 plants respectively, after first and second round of application during first field experiment. Emamectin benzoate 5SG at recommended dose (11 g a.i.ha⁻¹) recorded mean of 7.45 and 8.15 spiders per 10 plants respectively, after first and second round of application during the second field experiment. All the emamectin benzoate treatments were comparatively less toxic to spiders. Sheeba Jasmine (2005) reported abamectin 10.8 g a.i.ha⁻¹ treated cotton plots showed 12.8 spiders per 10 plants. Govindan (2012e) reported that emamectin benzoate 5 SG at higher dose (15 g a.i. ha⁻¹) recorded mean of 3.59 and 3.99 spiders per 10 plants, respectively after first and second round of application during first field experiment. All the emamectin benzoate treatments were comparatively less toxic to spiders.

Balikai and Patil (2007) stated that higher dose of emamectin benzoate 5 SG (Proclaim®) at 22g a.i ha⁻¹ treated plots showed no spiders in grape vine. The observations on 10 DAT showed an increase in the number of coccinellids in plots treated with emamectin benzoate compared to initial population. Similar trend was observed in the current study.

Fig. 6. Effect of emamectin benzoate 5 SG on spiders of cotton eco system –I season



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

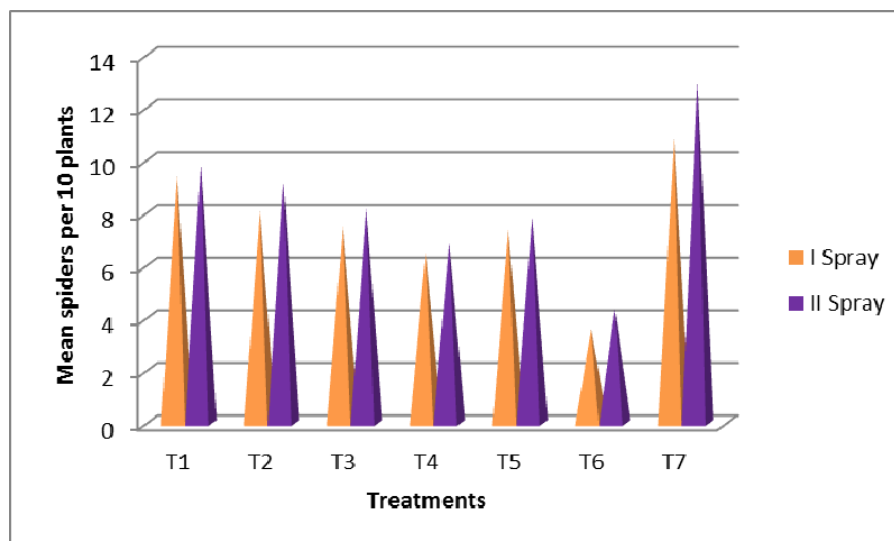
T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim[®] 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Fig. 7. Effect of emamectin benzoate 5 SG on spiders of cotton eco system –II season



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim[®] 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

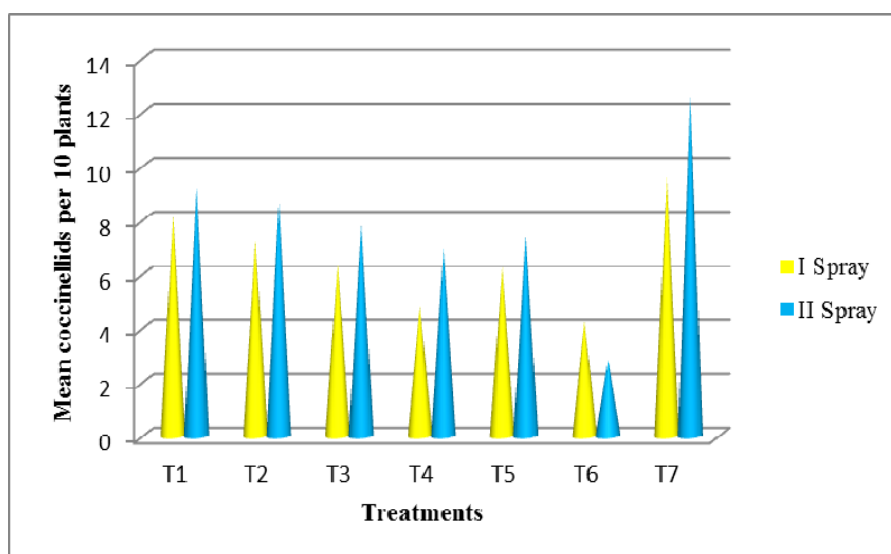
The results on the effect of emamectin benzoate against coccinellids showed that emamectin benzoate 5 SG at 7g a.i ha⁻¹ treated plots recorded a mean population of 8.00 per 10 plants during end of second field experiment (Fig.8). These findings are in conformity with the results of Tilman and Mulrooney (2000) who reported that emamectin benzoate with novel mode of action is generally more selective and require lower rates than conventional insecticides and has low to moderate impact on beneficial insects. The results reported by Acharya *et al.* (2002) revealed that abamectin was safer to lady bird beetles. Similarly, Udikeri *et al.* (2004) reported that Proclaim® is safe to coccinellids in cotton ecosystem. All the emamectin benzoate 5 SG doses were safe to coccinellids compared to standard check spinosad in the first field experiments (2.83 coccinellids 10 plants⁻¹) and second field experiment (3.25 coccinellids 10 plants⁻¹) (Figs.9). Govindan (2009) found that all the emamectin benzoate treatments irrespective of the doses were found to have only a little impact on coccinellids. Population of coccinellids declined immediately after the spray and started increasing gradually.

Aiswariya (2010) reported that observations on 14 DAT showed an increase in the number of coccinellids in plots treated with emamectin benzoate compared to initial population. Similar trend was observed in the present study also emamectin benzoate 5 WSG at 7 g a.i ha⁻¹ treated plots recorded a mean population of 6.39 per ten plants during end of first field experiment.

5.1.3. Effect of emamectin benzoate 5 SG on yield of cotton

Increased seed cotton yield was observed in all the emamectin benzoate treated plots and the yield ranged from 18.82 to 21.46 q ha⁻¹ and 16.78 to 19.96 q ha⁻¹ in experiment I (Madhampatti) and II (Narasimanayakkan palayam), respectively (Fig. 10). This clearly indicates the effectiveness of emamectin benzoate in controlling the bollworms of cotton which resulted in higher yield. Similar results with foliar application of emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ recording higher yield (24.74 q ha⁻¹) were reported by Gupta *et al.* (2005), Prakash and Tomar (2009), (15.65 - 16.42 q ha⁻¹), Singh and Chander, 2009 (21.53 q ha⁻¹) and Srinivasan *et al.* (2007) (19.54 q ha⁻¹) in cotton. Increased seed cotton yield was observed in all the emamectin benzoate treated plots and the yield ranged from 16.00 to 19.60 q ha⁻¹ and 16.80 to 19.88 q ha⁻¹ in experiment I and II, respectively (Govindan, 2009) .

Fig. 8. Effect of emamectin benzoate 5 SG on coccinellids of cotton eco system –I season



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

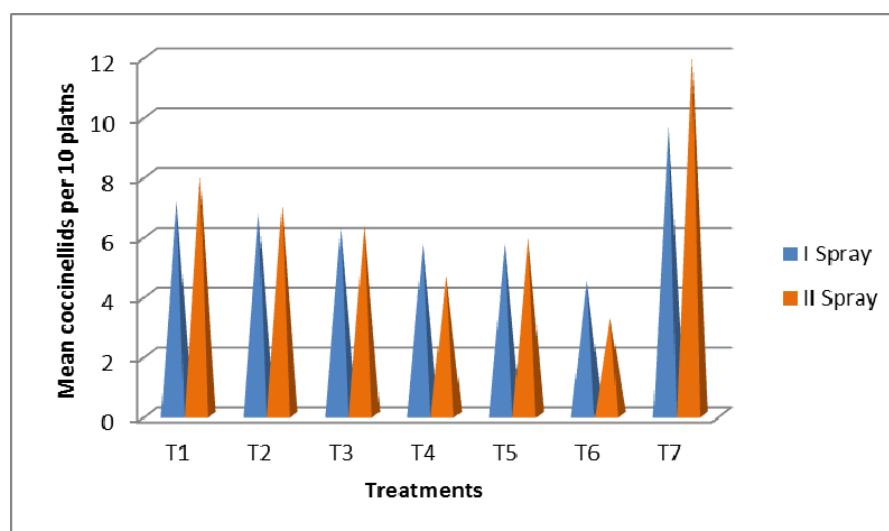
T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Fig. 9. Effect of emamectin benzoate 5 SG on coccinellids of cotton eco system –II season



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

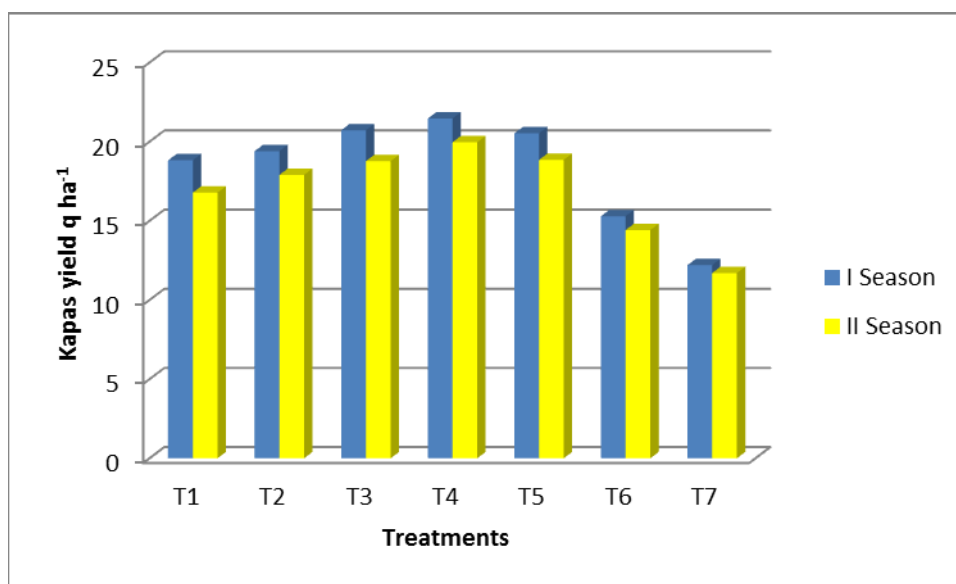
T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Fig. 10. Effect of emamectin benzoate 5 SG on seed cotton yield



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

T5- Proclaim[®] 11 g a.i. ha⁻¹

T7- Untreated check

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T4 - Emamectin benzoate 15g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

Aiswariya (2010) reported that all the insecticidal treatments were superior over untreated check which recorded 8.65 and 9.62 q ha⁻¹ seed cotton yield in the first and second trials, respectively. The emamectin benzoate treated plots registered increased seed cotton yield in both the seasons. Udikeri *et al.* (2004) reported that emamectin benzoate 5 SG recorded a yield of 15.93 q ha⁻¹. Similarly, Wright *et al.* (1985) reported that cotton plants sprayed with abamectin at 28.3 g a.i. ha⁻¹ against *Heliothis virescens* F. increased the seed cotton yield compared to untreated plants.

5.2. Okra

5.2.1. Bioefficacy of emamectin benzoate 5 SG against okra fruit borers

Application of emamectin benzoate 5 SG caused significant reduction in the larval population of okra fruit borers. Emamectin benzoate at 11 g a.i ha⁻¹ reduced larval population of *H. armigera* up to 89.35 and 85.37 per cent in the first and second season field trials, respectively. The emamectin benzoate at 8.5 g a.i. ha⁻¹ recorded 81.53 and 81.64 per cent reduction of *H. armigera* larval population on 14 DAT in first and second season trials, respectively. This finding reflected that emamectin has a remarkable knockdown effect on *H. armigera* larvae, which could be due to the innate nature of emamectin to interfere with chloride ion permeability and GABA receptors and it has been demonstrated well by Fritz *et al.* (1979), Albrecht and Sherman (1987), Mellin *et al.* (1983) and Scott and Dwe (1985).

H. armigera was checked effectively in the field by emamectin benzoate 5SG @ 10 g a.i. ha⁻¹ in okra and chillies (Shobanadevi, 2003) and in tomato (Suganyakanna *et al.*, 2005). Bheemanna *et al.* (2005) stated that foliar application of emamectin benzoate 5SG @ 8.50 and 11 g a.i. ha⁻¹ recorded lower fruit damage against okra fruit borers. Several workers studied the efficacy of emamectin benzoate @ 11 g a.i ha⁻¹ and found that it was effective against *H. armigera* in crops like pigeon pea (Meena *et al.*, 2006) and chick pea (Raghvani and Poshia, 2006). Murugaraj *et al.* (2006) reported that emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ was highly effective in reducing the larval population and fruit damage as well as increasing the tomato yield.

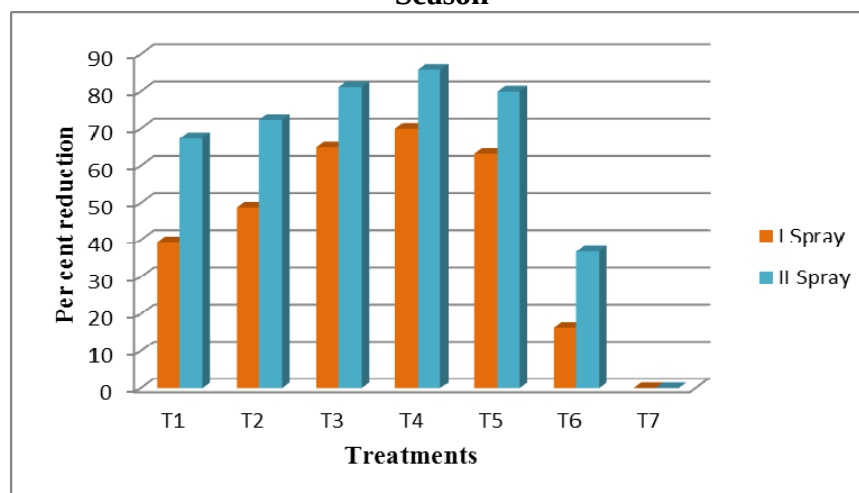
Proclaim® @ 6.7 g a.i ha⁻¹ caused 61.18 and 63.61 per cent reduction from control in *H. armigera* larval population in the first and second field experiments, respectively.

Similarly, Shobanadevi (2003) found that foliar spray of Proclaim® @ 11 g a.i ha⁻¹ reduced the larval population and fruit damage caused by *H. armigera* in okra and chilli. Stanley *et al.* (2007) reported that Proclaim® @ 7.5 g a.i. ha⁻¹ was effective against brinjal shoot and fruit borer, *L. orbonalis*. The plots treated with spinosad 45 EC at 75 g a.i. ha⁻¹ recorded the highest larval population of *H. armigera*, next to control in first and second season experiments. The results were in accordance with the findings of Prakash and Tomar (2009) and Yadav (2009) in chick pea.

The plots treated with emamectin benzoate 5 SG @ 11 g a.i. ha⁻¹ recorded 72.77 and 90.61 per cent reduction in *Earias vittella* (Fabricius) larval population after first and second sprays, respectively in first season trial. In the first and second field experiments after second spray of emamectin benzoate 5 SG @ 8.5 g a.i ha⁻¹ recorded 81.64 and 81.37 per cent reduction in larval population of *E. vittella*, respectively. Sontakke *et al.* (2007a) observed that emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ was effective in controlling the fruit borer in okra. The results are in accordance with the findings of Kuttalam *et al.* (2008) who found that emamectin benzoate 5 EC @ 13 and 15g a.i ha⁻¹ was found be effective in suppressing the larval population of *E. vittella* in okra. Govindan (2012a) found that results obtained on bioefficacy of emamectin benzoate against fruit damage on okra revealed that the plots treated with emamectin benzoate 5 SG at 13 g a.i. ha⁻¹ resulted in 67.67 and 75.49 per cent reduction of fruit damage at the end of first and second field trials, respectively. Application of emamectin benzoate 5 WSG caused significant reduction in the larval population of okra fruit borers. Emamectin benzoate at 13 g a.i ha⁻¹ reduced larval population of *H. armigera* up to 93.48 and 91.89 per cent in the first and second season field trials, respectively (Aiswariya, 2010).

Emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ resulted in 85.97 and 90.00 per cent reduction in fruit damage at the end of first and second field trials, respectively (Fig. 11 and 12). Among the treatments, the emamectin benzoate SG at 8.5 and 11 g a.i. ha⁻¹ exhibited nearly similar effects on insects showing identical damage intensity, without any significant difference. The results are in line with Bheemanna *et al.* (2005) who found that foliar application of emamectin benzoate 5 SG @ 8.5 g a.i. ha⁻¹ recorded lower fruit borer damage and higher fruit yield. Prakash and Tomar (2009) stated that emamectin benzoate 5 SG @ 11g a.i ha⁻¹ recorded the lowest boll damage in cotton. Meena *et al.* (2006) found that

Fig. 11. Effect of emamectin benzoate 5 SG against fruit borers damage in okra- I Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

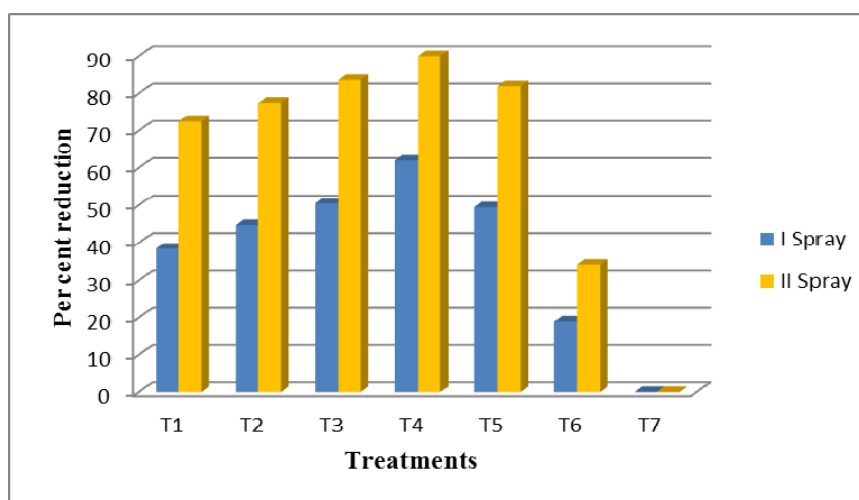
T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

Fig. 12. Effect of emamectin benzoate 5 SG against fruit borers damage in okra- II Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

emamectin benzoate 5 SG @ 11g a.i ha⁻¹ was effective in reducing pod and grain damage in pigeonpea. Similarly, Murugaraj *et al.* (2006) proved that emamectin benzoate 5 SG @ 11g a.i ha⁻¹ caused 2.47 per cent fruit damage effecting 91.46 per cent reduction over untreated check in tomato. The reduced efficacy of insecticides after 10 DAT and the subsequent increase in larval population might be due to the influence of environmental factors like sunlight and temperature which were responsible for the decay of insecticides, as reported by Wilson *et al.* (1986).

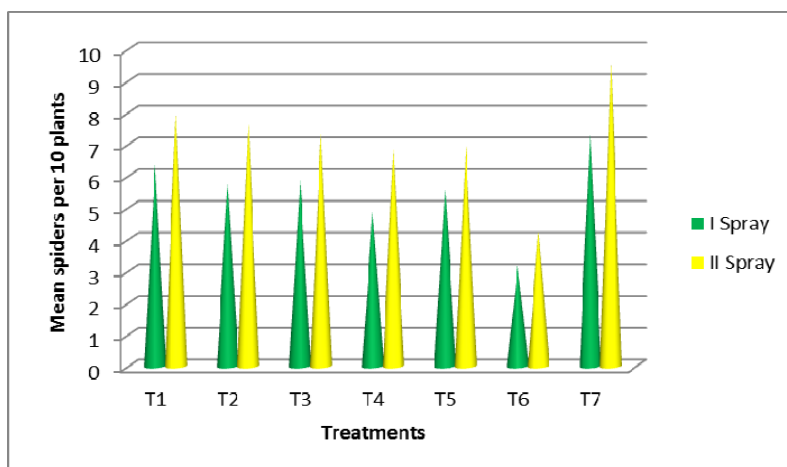
5.2.2. Safety of emamectin benzoate to natural enemies in okra

Field experiments to evaluate the safety of emamectin benzoate 5 SG against spiders revealed that emamectin benzoate 5 SG at lower dose (4.7 g a.i. ha⁻¹) was comparatively less toxic to the natural enemies than higher doses. The present study revealed that standard check spinosad brought down the predatory population to very low levels than other treatments. Among the chemicals tested, emamectin benzoate 5 SG was comparatively safer to the predatory spider population. The findings are in conformity with the results of Aiswariya (2010) and Govindan (2009) who showed that there was considerable decrease in coccinellid population initially in all the treatments (Fig.14). Later, it started increasing, but was less than the population recorded in untreated check. Fitt *et al.* (2004) and Horowitz and Ishaaya (2004) who reported that bio-rational insecticides are less disruptive to beneficial populations.

The emamectin benzoate 5 SG evaluated for toxicity against coccinellids in okra ecosystem showed that there was considerable decrease in coccinellid population initially in all the treatments (Fig.16). Later, it started increasing, but it was less than the population recorded in untreated check. The safety of avermectins to natural enemies was studied and reported by Acharya *et al.* (2002). As per the safety norms described by Udikeri *et al.* (2004), emamectin benzoate 5 WSG was found to be safe to predatory coccinellids.

Emamectin benzoate 5 SG treatments were safer to coccinellids when compared with standard treatment spinosad 45 SC. Although an emamectin benzoate reservoir with the mesophyll layer of leaf tissues is accessible to phytophagous insects, the parasitic and predatory arthropods continue to proliferate because of the short lived surface residues.

Fig. 13. Effect of emamectin benzoate 5 SG on spiders of okra eco system –I Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

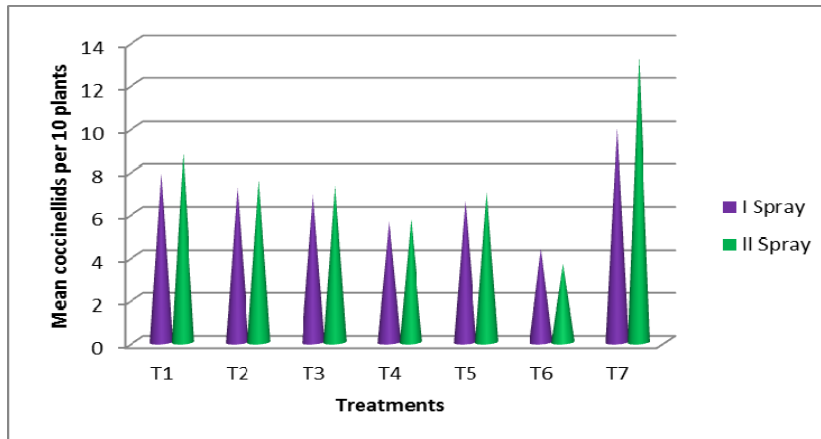
T7 - Untreated check

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T4 - Emamectin benzoate 11g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

Fig. 14. Effect of emamectin benzoate 5 SG on coccinellids of okra eco system –I Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

T7 - Untreated check

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T4 - Emamectin benzoate 11g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

Therefore, the application of emamectin benzoate could be less harmful to the important natural enemies in okra fields.

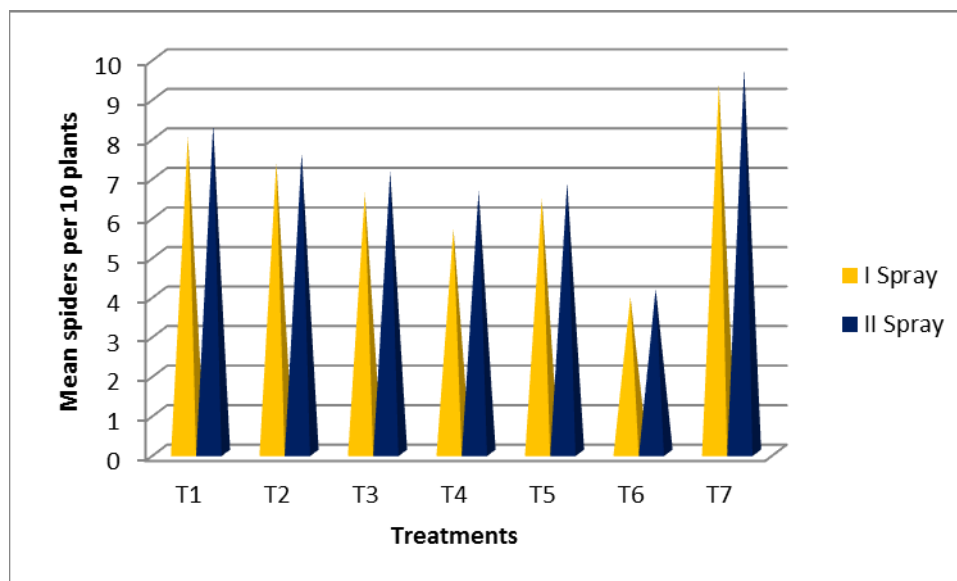
Among the emamectin benzoate doses tested, higher dose of 11 g a.i. ha⁻¹ recorded cumulative mean of 5.67 and 6.63 spiders per 10 plants after first and second round of applications, respectively in the second experiment. All the doses of emamectin benzoate were comparatively less toxic to the spiders (Fig. 13 and 15). These findings are in conformity with the earlier report of Giribabu *et al.* (2002) which concluded that abamectin at 15 g a.i. ha⁻¹ was found to be relatively safer to predatory spiders. Emamectin benzoate had no effects on the beneficial arthropods viz., *Geocoris* sp., *Orius albidipennis* (Reut.), spiders, lady beetles, *C. carnea* and *Solenopsis invicta* (Buren) (Dunbar *et al.*, 1998).

Irrespective of the insecticides used, immediately after the application of insecticides the natural enemy population in the okra ecosystem was reduced in the field. This could be the sole reason that chemicals have lethal effects on natural enemies. On the other hand, there are a few chances that the spiders may move from the treated plants to the untreated check for want of food, since the treated plants harbour lesser number of insects (Stanley, 2004).

5.2.3. Effect of emamectin benzoate 5 SG on yield of okra

Yield data obtained from the field experiments showed that there was an yield increase in the emamectin benzoate sprayed crop, as against the untreated control. The increase in okra fruit yield in emamectin benzoate 5 SG treated plots was in the range of 6050.00 - 8100.50 kg ha⁻¹ and 5948.33 - 8090.00 kg ha⁻¹ during first (Madampatti) and second (Narasimanayakkan palayam) season, respectively (Fig.17). Whereas in the standard check, spinosad 45 SC @ 75 g a.i. ha⁻¹ treated crop it was 5726.50 and 5603.33 kg ha⁻¹ in first and second field experiments, respectively, and Proclaim® @ 8.5 g a.i. ha⁻¹ treated crop it was 7345.00 - 7340.00 kg ha⁻¹ in both season field experiments. Untreated check recorded 4936.00 and 4891.67 kg ha⁻¹ in both first and second field experiments, respectively. The present investigation is in agreement with the findings of Govindan (2009) and Aiswariya (2010) who reported that even though increase in yield was recorded at higher concentrations of emamectin benzoate the difference in per cent increase was not so significant. Hence, the dose of emamectin benzoate 5 WSG at 9

Fig. 15. Effect of emamectin benzoate 5 SG on spiders of okra eco system –II Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

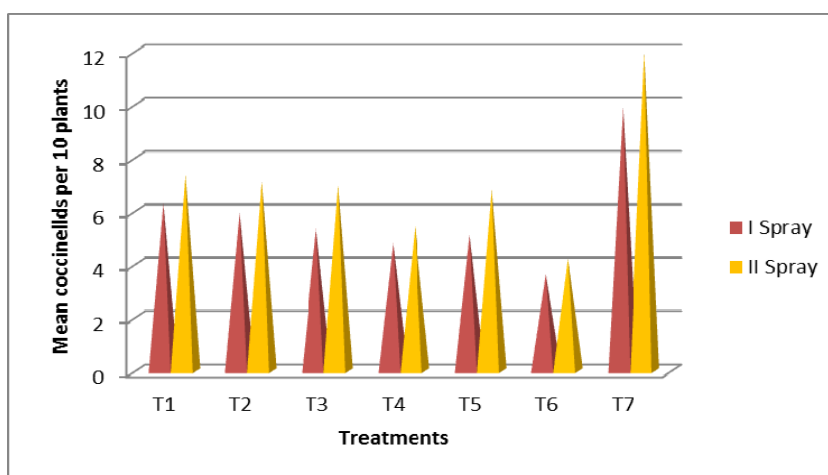
T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

Fig 16. Effect of emamectin benzoate 5 SG on coccinellids of okra eco system –II Season



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

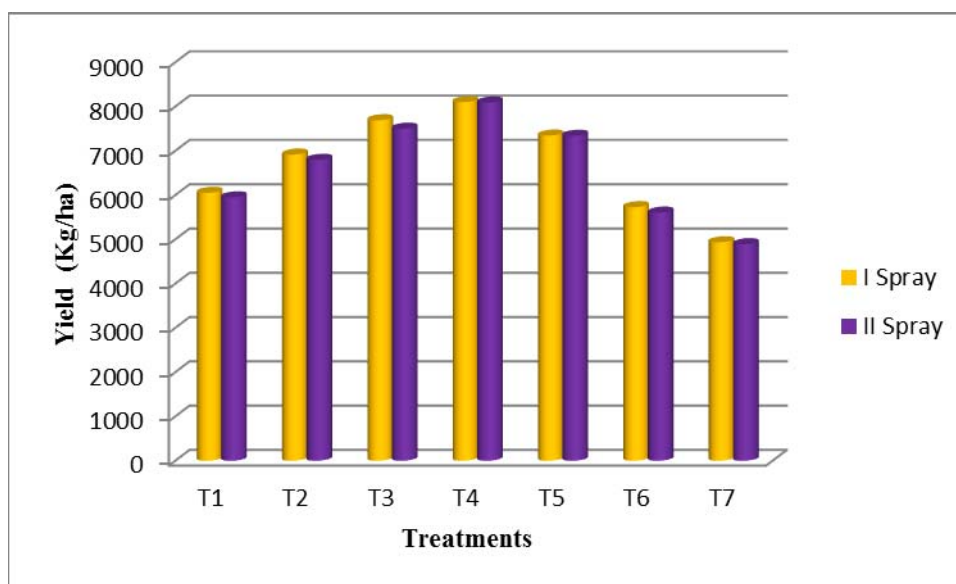
T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim® 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

Fig 17. Effect of emamectin benzoate 5 SG on okra fruit yield



T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim[®] 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

T1 - Emamectin benzoate 4.7g a.i. ha⁻¹

T2 - Emamectin benzoate 6.7g a.i. ha⁻¹

T3 - Emamectin benzoate 8.5g a.i. ha⁻¹

T4 - Emamectin benzoate 11g a.i. ha⁻¹

T5 - Proclaim[®] 8.5 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7 - Untreated check

g a.i. ha⁻¹ may be recommended for the management of borers as it was effective against okra fruit borers viz., *H. armigera* and *E. vittella* and also recorded higher yield. The yield recorded on emamectin benzoate 5 SG at 8.5 g a.i. ha⁻¹ was on par with yield recorded on Proclaim 11g a.i. ha⁻¹. Hence, the dose of emamectin benzoate 5 SG at 11 and 8.5 g a.i. ha⁻¹, which showed good efficacy against okra fruit borers viz., *H. armigera* and *E. vittella* and also recorded higher yield could be considered appropriate and economical. The effectiveness of emamectin benzoate 5 SG on yield increase is in agreement with Shobanadevi (2003), Aslam *et al.* (2004), Bheemanna *et al.* (2005) and Sontakke *et al.* (2007a) on okra, Suganyakanna *et al.* (2005) and Prasad kumar and Devappa (2006a) on cabbage, Kulkarni and Adsule, (2007) on grapes, Meena *et al.* (2006) on pigeonpea and Raghavani and Poshia, (2006) on chickpea. The present findings are in tune with the earlier report of Kuttalam *et al.* (2008) who found that that foliar application of emamectin benzoate 5 SG 5 EC at 15, 13, 11 and 9 g a.i. ha⁻¹ treated okra plots recorded 8100.90, 7590.67, 7215 and 6750 kg ha⁻¹, respectively.

5.3. Phytotoxicity

5.3.1. Phytotoxicity of emamectin benzoate 5 SG on cotton

It was obvious, from the field experiments conducted on cotton (Madhampatti and Narasimanayakkan palayam), that emamectin benzoate 5 SG did not cause any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty on cotton. Doses of 22 and 44 g a.i. ha⁻¹, which were two and four times higher than that of normal dose (11 g a.i. ha⁻¹), also did not show any phytotoxic symptoms. Similar results were reported by Raghuraman *et al.*, (2008) who stated that emamectin benzoate 5 SG 5 EC applied @ 11 and 22 g a.i ha⁻¹ was found to show no phytotoxic effects on cotton plants, and also Sontakke *et al.* (2007b) who reported that emamectin benzoate 5 SG 5 SG @ 8.5 g exhibited no phytotoxic effects on cotton plants. Govindan (2009) reported that emamectin benzoate 5 SG @ 11 and 22 g a.i ha⁻¹ was found to show no phytotoxic effects on cotton plants, and also Aiswariya (2010) reported that emamectin benzoate 5 WSG 11 and 22 g a.i.ha⁻¹ exhibited no phytotoxic effects on cotton plants.

5.3.2. Phytotoxicity of emamectin benzoate 5 SG on okra

Foliar application of emamectin benzoate 5 SG on okra under field conditions revealed that x ($8.5 \text{ g a.i. ha}^{-1}$), 2x ($17 \text{ g a.i. ha}^{-1}$) and 4x ($34 \text{ g a.i. ha}^{-1}$) doses did not exhibit any noticeable phytotoxicity and adverse effects on the crop. The present findings are in conformity with the earlier reports of Sontakke *et al.* (2007a) who found that emamectin 5 SG @ $8.5 \text{ g a.i. ha}^{-1}$ was without exhibiting any phytotoxic effects on okra plants. Prasad Kumar and Devappa (2006a) reported no phytotoxicity on brinjal crop when sprayed with Proclaim® @ 100, 200, 300 and 400 g a.i ha⁻¹. Suganyakanna (2003) found that emamectin benzoate 5 SG at $22 \text{ g a.i. ha}^{-1}$ had no phytotoxic symptom on cabbage and tomato plants and also Shobanadevi, (2003) reported that emamectin benzoate sprayed at 5.0, 10.0 and 20.0 g a.i.ha⁻¹ showed no phytotoxicity on okra and chillies. Govindan (2009) reported that emamectin benzoate 5 SG @ 11, 22 and 44 g a.i ha⁻¹ was found to show no phytotoxic effects on okra plants, and also Aiswariya (2010) who reported emamectin benzoate 5SWG 9 ,18 and 36 g a.i.ha⁻¹ exhibited no phytotoxic effects on cotton plants

5.4. Persistent toxicity

The residual toxicity resulting from foliar spray of insecticides could be of great significance in indicating an effective period over which an insecticide could persist in biologically active stage under field conditions.

The persistent toxicity tests with emamectin benzoate 5 SG ($15 \text{ g a.i. ha}^{-1}$) recorded complete mortality of third instar larvae of *H. armigera* on cotton and was observed up to 7 DAT, while it was single day for spinosad treated plants. More than 50 per cent mortality was observed up to 11 DAT in emamectin benzoate $15 \text{ g a.i. ha}^{-1}$ treatment, followed by emamectin benzoate 5 SG at $11 \text{ g a.i. ha}^{-1}$ (42.6 per cent), Proclaim® (40.1 per cent) and spinosad (30.3 per cent). In the case of spinosad no mortality was observed at 11 DAT. There was a progressive reduction in the mortality of *H. armigera* larvae as the time increased.

The results are in corroboration with the findings of Aiswariya (2010) who reported that persistent toxicity tests with emamectin benzoate 5 WSG ($13 \text{ g a.i. ha}^{-1}$) recorded complete mortality of third instar larvae of *H. armigera* on cotton and that was

observed up to 7 DAT, while it was single day for Proclaim[®] and endosulfan treated plants. More than 50 per cent mortality was observed up to 13 DAT in emamectin benzoate at 13 g a.i. ha⁻¹ treatment, followed by emamectin benzoate at 11 g a.i. ha⁻¹ (46.5 per cent) while emamectin benzoate at 9 g a.i. ha⁻¹ registered cent percent mortality of larvae up to 3 DAT. Govindan (2009) reported that persistent toxicity tests with emamectin benzoate 5 SG (13 g a.i. ha⁻¹) recorded complete mortality of third instar larvae of *H. armigera* on cotton and that was observed up to 9 DAT, while it was single day for spinosad and endosulfan treated plants. More than 50 per cent mortality was observed at 15 DAT in emamectin benzoate at 15 g a.i. ha⁻¹ treatment, followed by emamectin benzoate at 11 g a.i. ha⁻¹ (49.2%)

Persistent toxicity of emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ was observed complete mortality of *E. vittella* larvae up to 7 DAT indicating no change in the persistent period. However, there was significant variation in mortality at various levels of emamectin benzoate at 8.5 g a.i. ha⁻¹ (15 days) and 11 g a.i. ha⁻¹ (17 days). In the effective dose of emamectin benzoate at 8.5 g a.i. ha⁻¹, mortality was observed up to 15 DAT, with cent per cent mortality only up to 5 DAT. These results were in conformity with that of Aiswariya (2010) who reported that when emamectin benzoate at 9 g a.i. ha⁻¹ was applied, there was complete mortality of *E. vittella* larvae up to 7 DAT indicating no change in the persistent period. However, there was significant variation in mortality at various levels of emamectin benzoate at 11 g a.i. ha⁻¹ (15 days) and 13 g a.i. ha⁻¹ (17 days). In the effective dose of EB at 9 g a.i. ha⁻¹, mortality was observed up to 15 DAT. Govindan (2009) revealed that When EB 5 SG at 13 g a.i. ha⁻¹ was applied, there was complete mortality of *E. vittella* larvae up to 9 DAT indicating no change in the persistent period. However, there was significant variation in mortality at various levels of emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ (19 days) and 13 g a.i. ha⁻¹ (21 days).

Brevault *et al.* (2009) reported that the persistence was found to be higher for emamectin benzoate 5 EC @ 10 g a.i ha⁻¹ (10.6 days) followed by spinosad 45 SC @ 36 g a.i ha⁻¹ (8.9 days) and indoxacarb @ 25 g a.i ha⁻¹ (5.2 days) in cotton plants. Jansson *et al.* (1997b) proved that cent per cent mortality of *Spodoptera exigua* (Hubner) was recorded at 17 days after application of emamectin benzoate 5 EC @ 8.4 g a.i ha⁻¹ on pepper plants and chickpea plants in glass house. Ishaaya *et al.* (2002) reported that emamectin benzoate at 25 mg a.i.l⁻¹ provided 90 per cent suppression of *H.armigera* up to 28 days. Translaminar movement

of avermectin insecticides is the reason for the prolonged residual efficacy observed in a variety of crops under glass house and field conditions (Jansson and Dybas, 1996). According to Jansson *et al.* (1996), excellent efficacy of emamectin benzoate was found up to 14-17 days after application when applied at a rate as low as 0.084 g a.i. ha⁻¹ under glass house condition. But this could not be expected in the field as it is very susceptible to photodegradation.

5.5. Compatibility study

5.5.1 Physical compatibility of emamectin benzoate 5 SG

Compatibility of pesticides with other agrochemicals is essential which enables farmers to combine different agro chemicals for reducing the cost of application. The results obtained from the physical compatibility (wettability test) studies revealed that emamectin benzoate 5 SG was physically compatible with lambda cyhalothrin, carbendazim, mancozeb and buprofezin . Emamectin benzoate 5 SG in combination with lambda cyhalothrin, carbendazim, mancozeb did not produce any submergence after 2 minutes indicating its compatibility with other agrochemicals tested.

5.5.2. Biological compatibility of emamectin benzoate 5 SG on cotton and okra

The results of emamectin benzoate 5 SG at 11 and 8.5 g a.i. ha⁻¹ with agrochemicals commonly used in cotton and okra ecosystem revealed that emamectin benzoate 5 SG was highly compatible with the chemicals tested and did not exhibit any phytotoxic symptoms on cotton and okra plants in the laboratory and field conditions. In the present study the lowest larval population of *H. armigera* was recorded by combination treatments viz., plots treated with all emamectin benzoate combination treatments recorded more than eighty per cent reduction of larval population, whereas the lowest reduction of larval population was found in carbendazim alone (18.30 larvae/ ten plants), buprofezin alone (18.10 larvae/ten plants) and mancozeb (14.91 larvae/ ten plants) treated plots as against 7.87 larvae per ten plants in untreated check at ten days after second spray. The lowest mean per cent boll damage was recorded by all the emamectin benzoate 5 SG combination treatments after second spray and was in the range of 6.01 to 7.12 per cent, whereas carbendazim, buprofezin and mancozeb alone recorded higher per cent damage than combination (20.53, 19.95 and 20.64 % respectively). The present findings are in tune with

earlier reports of Govindan (2009). All emamectin benzoate combination treatments recorded the boll damage in the range of 3.67- 4.37 per cent per plant. Whereas, endosulfan 35 EC, urea and carbendazim 50 WP alone recorded higher per cent damage than combination (13.83, 22.40 and 23.00 per cent, respectively). This is supported by Aiswariya (2010) who reported that cotton plots treated with all the emamectin benzoate combination treatments recorded more than eighty per cent reduction of larval population. The studies on biological compatibility of emamectin benzoate 5 SG on okra showed that it was biologically compatible with carbendazim, buprofezin and mancozeb.

The highest reduction of larval population was recorded in okra plots sprayed with emamectin benzoate 5 SG combination treatments viz., emamectin benzoate 5 SG + lambda cyhalothrin 5 CS, emamectin benzoate 5 SG + carbendazim 50 WP, emamectin benzoate 5 SG + buprofezin 25 SC and emamectin benzoate 5 SG + mancozeb 75WP effecting 85.29, 83.50, 81.10 and 81.60 per cent reduction, respectively after 14 days of second spray. The lowest fruit damage was recorded by all the emamectin benzoate combination treatments that were in the range of 5.84 to 6.53 per cent, while the highest mean per cent fruit damage was recorded by untreated plot (37.27 %) which was followed by carbendazim (23.73 %), buprofezin (23.71%) and mancozeb (23.59 %). The present findings are in tune with earlier reports of Ahmed *et al.* (2003) who reported that ULV application of Novaster® @ 56 EC (abamectin + bifenthrin) at 500 ml ac⁻¹ was the best for controlling early instars of *H. armigera*.

Franca *et al.* (1998) reported that cabbage yield was 42 per cent more in the abamectin + deltamethrin mixture than in deltamethrin or abamectin applied alone and this combination did not have any measurable impact on the populations of *Diadegma* sp. This is supported by Rui (2001) who found that abamectin (1.5 per cent + Bt WP) at a dilution rate of 1:750 and 1500 effected a control of 90.9 per cent in *P. xylostella* on 7 DAT. High efficacy of GCSC – BtA (Abamectin + Bt) against *P. xylostella* and low toxicity to its parasitoid, *Apanteles plutellae* L. were also observed (Sengonca *et al.*, 2001; Sengonca and Liu, 2001). This was supported by Govindan (2009). In okra, all the emamectin combination treatments recorded 2.50 - 1.33 larvae per five plants, respectively. The highest larval population was observed in the plots treated with urea (15.60 larvae ten plants⁻¹), carbendazim (15.83 larvae ten plants⁻¹) and endosulfan (4.97

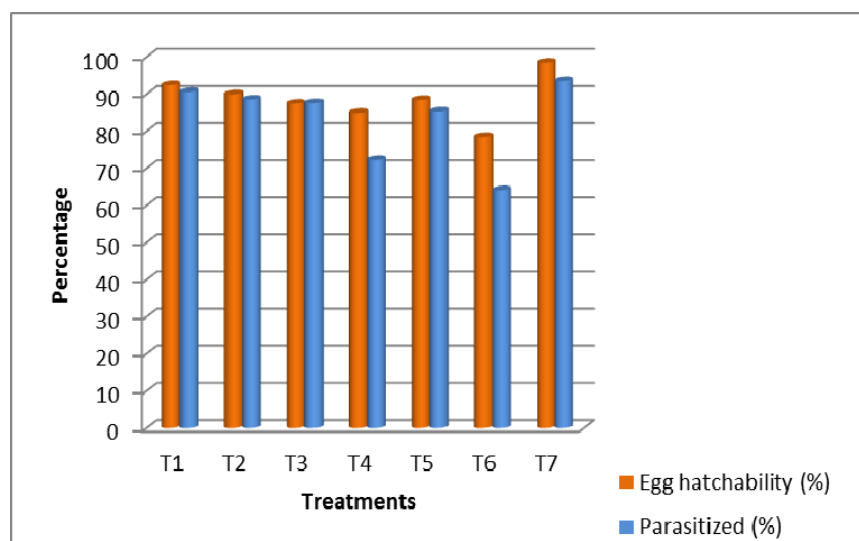
larvae ten plants⁻¹) alone whereas, untreated check recorded 16.00 larvae per ten plants. Fruit damage in all emamectin benzoate combination treatments recorded 67.42 to 74.71 per cent reduction over untreated check. Aiswariya (2010) reported that all the emamectin benzoate combination treatments recorded 1.99 – 2.70 larvae per five plants in okra. The highest larval population was observed in the plots treated with imidacloprid (14.08 larvae five plants⁻¹), mancozeb (13.93 larvae five plants⁻¹) and endosulfan (5.66 larvae five plants⁻¹) alone, whereas untreated check recorded 14.56 larvae per five plants. Fruit damage recorded in all emamectin benzoate combination treatments showed 70.16 to 75.14 per cent reduction from untreated check,

5.6. Toxicity to non target insects

5.6.1 Parasitoids and predators

Laboratory experiments were conducted to study the safety of emamectin benzoate 5 SG against *Trichogramma chilonis* Ishii, *Chelonus blackburnii* Cameron, and *Chrysoperla carnea* Stephens. The insecticides could be classified as harmless (<50 per cent mortality), slightly harmful (50-79 per cent mortality), moderately harmful (80 - 89 per cent mortality) and harmful (>90 per cent mortality) (Nasreen *et al.*, 2000). In the present study, emamectin benzoate 5 SG did not show harmful effects to *T. chilonis*. Emamectin benzoate 5 SG at 7 and 9 g a.i. ha⁻¹ recorded 90.63 and 88.59 per cent parasitism, respectively (Fig. 18). Treatment of parasitized eggs with emamectin benzoate 5 SG did not cause any ill effects to the developing parasitoids, adult emergence and emerged adults. Govindan (2009) reported that emamectin benzoate 5 SG did not cause any adverse effects on the adult emergence and parasitization of *Trichogramma chilonis* Ishii. The present finding is in tune with the findings of Nian *et al.* (1997) who reported that even the most toxic B₁ component of abamectin recorded only 21 per cent mortality. Dhawan (2000) reported that the use of abamectin was safe to *T. chilonis* when compared to chlorpyrifos, methyl demeton and quinalphos. According to Aston *et al.* (2001) *Trichogramma* exposed to 9 h lapsed residues of emamectin benzoate showed no effect on the population, but showed a mortality of 18 per cent on direct application. In the present study also, the mortality was within this limit and it is in conformity with the results reported by the aforesaid authors. Safety of abamectin to parasitoids and predators to be also reported by Morse *et al.* (1987), Chizhov *et al.* (2000), Ping *et al.* (2004) and Sheeba Jasmine (2005).

Fig. 18. Selective toxicity of emamectin benzoate 5 SG on *Trichogramma chilonis* Ishii



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

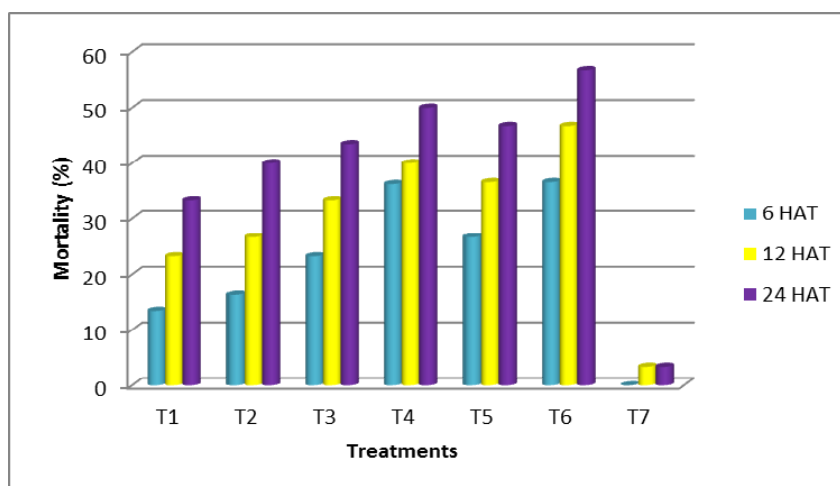
T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Fig. 19. Selective toxicity of emamectin benzoate 5 SG on *Chelonus blackburnii* Cameron



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Among the insecticidal treatments, maximum percentage of adult emergence was noticed in emamectin benzoate at 7 g a.i. ha⁻¹ (92.50 %). The lowest percentage of adult emergence was noticed in higher dose of emamectin benzoate 5 SG at (15 g a.i. ha⁻¹) treated tricho card (85.00). In untreated check 98.50 per cent adult emergence was recorded. Results of present investigations are in accordance with the findings of Aston *et al.* (2001), Shobanadevi (2003) and Udikeri *et al.* (2004) who reported that emamectin was far safe to egg parasitoid *T. chilonis*. Present study revealed that emamectin benzoate lower dose was less toxic to *T. chilonis*. This is supported by Aiswariya (2010) who reported that emamectin benzoate 5 WSG did not cause any adverse effects on the adult emergence and parasitization of *T. chilonis*. The recommended dose of emamectin benzoate at 9 g a.i. ha⁻¹ recorded 77.29 and 83.98 per cent parasitization and adult emergence, respectively.

Emamectin benzoate 5 SG 11 and 15 g a.i. ha⁻¹ recorded 33.30 and 40.00 per cent mortality of *C. blackburni* at 12 hours after treatment (HAT) and had no adverse effect on the mortality of adults (Fig. 19). However, it was relatively safe compared to standard check spinosad (46.67 %) and among the insecticidal treatments, the lowest per cent adult mortality was recorded by emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ at 6 HAT, whereas spinosad 45 SC at 75g a.i. ha⁻¹ recorded the highest adult mortality (56.67 %) at 24HAT. This was in agreement with Govindan (2009) who recorded that lower dose of emamectin benzoate 5 SG at 7, 9 and 11 g a.i. ha⁻¹ caused 13.33, 13.33 and 14.33 per cent mortality respectively, to *C. blackburni* at 24 HAT. All the emamectin benzoate 5 SG doses were less toxic to *C. blackburni* adults compared to standard insecticides.

Thilagam (2006) stated that flubendiamide at 60 g a.i. ha⁻¹ was safe to *C. blackburni*. Suganyakanna (2006) reported that acetamiprid 20 SP caused significant adverse effect on the mortality of *C. blackburni* adults. In contrast imidacloprid was found to be slightly toxic to *C. blackburni* (Preetha, 2007). Aiswariya (2010) revealed that emamectin benzoate 5 WSG at the recommended dose of 9 g a.i. ha⁻¹ caused 33.33 per cent mortality at 48 h after treatment. All the emamectin benzoate doses were less toxic to *C. blackburni* adults compared to standard insecticides. All the emamectin benzoate

treatment were observed no adverse effect on the mortality of adults hence, it was found to be harmless to *B. hebetor* (<50% mortality).

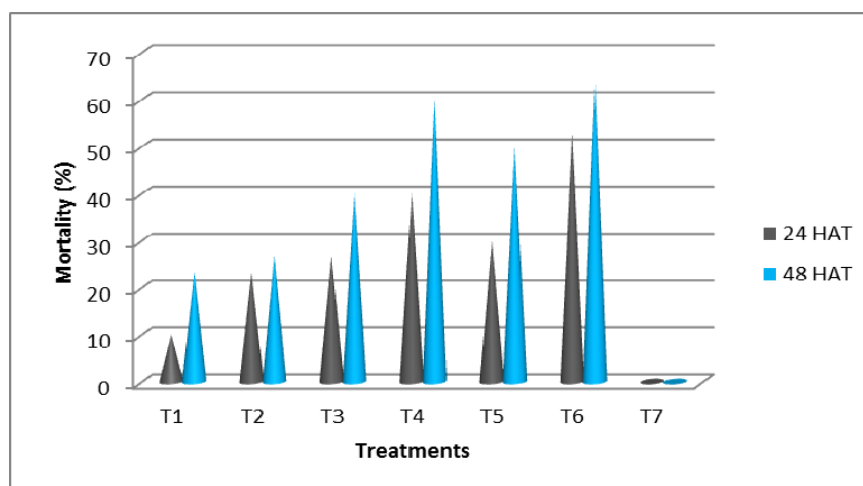
The highest egg hatchability of *Chrysoperla carnea* Stephens was recorded by emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ (96.67 per cent) and 9 g a.i. ha⁻¹ (93.67 per cent) when compared to untreated check (98.00 per cent) (Fig.21). The fecundity of the adults decreased as the concentration of emamectin benzoate 5 SG increased. Per cent pupation of emamectin benzoate 5 SG at 9 and 11 g a.i. ha⁻¹ was on par with standard insecticides. The lowest dose of emamectin benzoate at 7 g a.i. ha⁻¹ resulted in 90.17 per cent adult emergence. All emamectin benzoate treatment caused no adverse effect on the mortality of adults emergence. The lowest adult emergence was observed in spinosad 45 SC at 75 g a.i. ha⁻¹. This is supported by Govindan *et al.* (2012d) who indicated that in all the emamectin benzoate treatments, hatchability of *C. carnea* eggs ranged between 62.26 to 90.33 per cent. Among them, the toxic effect was the least for emamectin benzoate treatments. In the larval feeding method, emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ recorded very high pupation of 88.50 per cent and higher dose of emamectin benzoate (13g a.i. ha⁻¹) recorded a pupation of 62.33 per cent.

Aiswariya (2010) reported that in all the emamectin benzoate treatments, the per cent hatchability of *C. carnea* eggs ranged between 79.27 and 91.67 per cent and was found to have the least toxic effect, and the egg mortality was less when compared to endosulfan (33.11per cent).

Badawy and Arnaouty (1999) reported that abamectin was safer than all tested conventional insecticides to *Chrysoperla* eggs at the recommended dose. It caused only seven per cent mortality of third instar larvae of *C. carnea*. Spinosad was safe to predators (predatory bugs, spider and green lace wing) and parasitoids (*T. chilonis*), whereas conventional insecticides caused higher mortality (Dhawan, 2000).

In the present study, standard spinosad recorded 60.00 per cent mortality of grubs at 24 HAT, besides reduced fecundity. This finding is in conformity with the results of Krishnamoorthy (1985) who reported that the newly hatched larvae of *C. carnea* were more susceptible to organophosphates, carbamates and pyrethroids when compared to the egg stage.

Fig. 20. Selective toxicity of emamectin benzoate 5 SG on *Bracon hebetor* Say



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

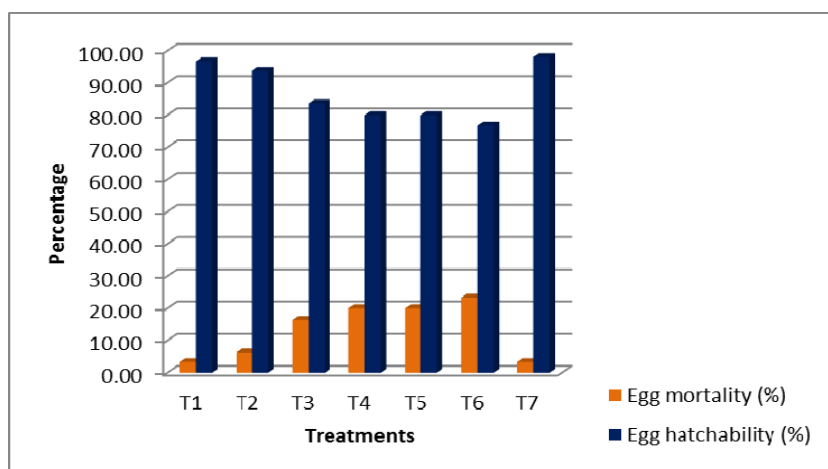
T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

Fig. 21. Selective toxicity of emamectin benzoate 5 SG on the eggs and adults of *Chrysoperla carnea* Stephens



T1 - Emamectin benzoate 7g a.i. ha⁻¹

T2 - Emamectin benzoate 9g a.i. ha⁻¹

T3 - Emamectin benzoate 11g a.i. ha⁻¹

T4 - Emamectin benzoate 15g a.i. ha⁻¹

T5- Proclaim® 11 g a.i. ha⁻¹

T6 - Spinosad 75g a.i. ha⁻¹

T7- Untreated check

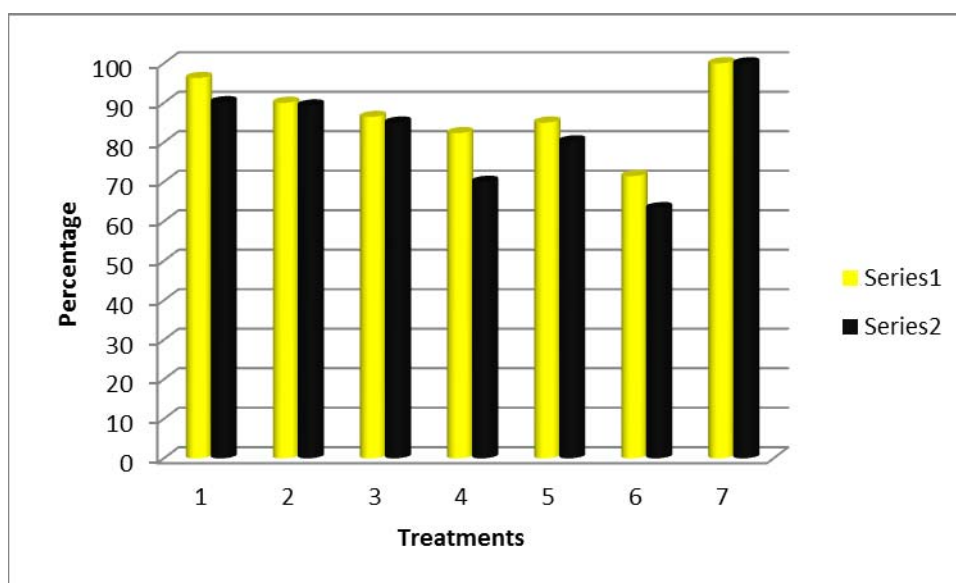
Test by dry film method revealed that all the doses of emamectin 5 SG at 7, 9, 11, and 15 g a.i. ha⁻¹ recorded 6.66, 13.33, 23.33 and 36.66 per cent mortality, respectively at 12 HAT and standard insecticides viz., Proclaim® @ 11 g a.i. and spinosad 45 SC @ 75g a.i.ha⁻¹ ha⁻¹ recorded 20.82 and 37.54 per cent mortality (Fig.22). Emamectin benzoate 5 SG @ 7, 9, 11, and 15g a.i. ha⁻¹ recorded 70.00 to 90.17 per cent pupation as against the standard checks, Proclaim® (80.24 per cent), spinosad (63.33 per cent). The same trend was observed in adult emergence also. This was in agreement with Ameta and Bunker (2007) who stated that spinosad 45 @ 18.75 and indoxcarb 14.5 % SC @ 25 g a.i.ha⁻¹ were less toxic to *C. carnea*.

5.6.2. Honeybees

Emamectin benzoate 5 SG at 7, 9, and 11g a.i. ha⁻¹ caused 3.33, 6.67 and 16.67 per cent mortality, respectively to Indian bees, *Apis cerana indica* F. at 12 HAT, and it increased to 10.00, 16.67 and 23.33 per cent, respectively after 24 HAT. Standard insecticide spinosad recorded increased mortality of 33.33 and 36.66 per cent, respectively (Fig.23). Similar trend was observed with Italian bees and little bees. Hence, emamectin benzoate 5 SG could be considered highly safer to all the species of honey bees than standard insecticides. This is comparable with the results of Govindan (2009) who reported that emamectin benzoate 5 SG was relatively safer to honey bees (Indian bees, *Apis cerana indica* F., little bees, *Apis florea* F. and Italian bees, *Apis mellifera* Linn.) than endosulfan and spinosad. However, the present study does not agree with Aiswariya (2010), who revealed that emamectin benzoate 5 WSG was toxic to honey bees (Indian bees, *Apis cerana indica* F., little bees, *Apis florea* F. and Italian bees, *Apis mellifera* Linn.) than endosulfan. Emamectin benzoate at the field recommended dose of 9 g a.i. ha⁻¹ registered 86.19, 85.12 and 85.61 per cent mortalities at 24 HAT against in *A. cerana indica*, *A. mellifera* and *A. florea*, respectively.

Lasota and Dybas (1991) found that abamectin residues rapidly depleted and did not affect the bees after 24 to 48 h of treatment. The results were in agreement with Anderson and Atkins (1968) who reported that endosulfan was moderately toxic to honey bees. On contrary, Panda *et al.* (1989) stated that phosphamidon followed by endosulfan and phosalone were the most toxic insecticides to *A. cerana indica*. Cleveland *et al.* (2002)

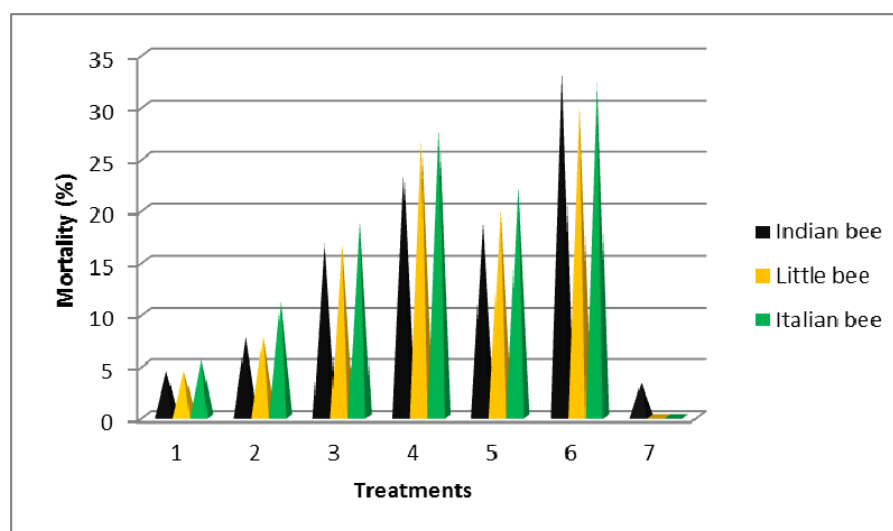
Fig 22 .Selective toxicity of emamectin benzoate 5 SG on the grubs of *C. carnea*



T1 - Emamectin benzoate 7g a.i. ha⁻¹
 T3 - Emamectin benzoate 11g a.i. ha⁻¹
 T5- Proclaim® 11 g a.i. ha⁻¹
 T7- Untreated check

T2 - Emamectin benzoate 9g a.i. ha⁻¹
 T4 - Emamectin benzoate 15g a.i. ha⁻¹
 T6 - Spinosad 75g a.i. ha⁻¹

Fig 23 .Selective toxicity of emamectin benzoate 5 SG on three species of honey bees



T1 - Emamectin benzoate 7g a.i. ha⁻¹
 T3 - Emamectin benzoate 11g a.i. ha⁻¹
 T5- Proclaim® 11 g a.i. ha⁻¹
 T7- Untreated check

T2 - Emamectin benzoate 9g a.i. ha⁻¹
 T4 - Emamectin benzoate 15g a.i. ha⁻¹
 T6 - Spinosad 75g a.i. ha⁻¹

reported that spinosad was acutely toxic to bees under lab conditions, but field studies indicated that the impact on bees was minimal.

Since cotton is cross pollinated crop and rich in pollen, emamectin benzoate will be useful in managing bollworms effectively with minimal hazards to honeybees.

5.6.3. Acute toxicity of emamectin benzoate 5 SG to earthworm

Earthworms are an important part of the soil ecosystem which occupies 80 per cent of the animals, by weight. Therefore the toxicity of emamectin benzoate to earthworms, *Eudrilus eugeniae* (Kinberg) was assessed and the LC₅₀ value was found to be 17.22 ppm in soil at 2 DAT (Fig.24). Whereas, the respective LC₅₀ value of emamectin benzoate 5 SG to *E. eugeniae* at 2 days by cowdung tests bioassay method was 16.47 ppm (Fig.25). These findings are in agreement with the earlier report of Halley *et al.* (1993) which indicated that avermectins were unlikely to be toxic to earthworms in soil. According to Edwards and Bohlen (1992), the earthworms were not affected by the avermectin in the dung pits. However, earthworms treated with avermectin ranging from 2, 4, 8, 12, 16, 20 and 60 mg kg⁻¹ weight loss compared to the untreated earthworms. Govindan *et al.* (2012b) revealed that LC₅₀ value of emamectin benzoate 5SG to earthworm, *E. eugeniae* was 16.22 ppm in soil and 15.44 ppm in cowdung at 2 DAT. Aiswariya (2010) reported that LC₅₀ value of emamectin benzoate 5 SG to earthworm, *E. eugeniae* was 16.23 ppm in soil and 15.45 ppm in cowdung at 2 DAT.

5.7. Harvest time residues

5.7.1. Cotton

The harvest time residues of emamectin benzoate 5 SG at 11 and 22 g a.i. ha⁻¹ as foliar spray were at below detectable level (BDL) in cotton lint, seed and oil samples of first and third pickings in the two field experiments (Madhampatti and Nrasimanayakkan palayam). Similar results were obtained by Sheeba Jasmine (2005) who found that the residues of abamectin in cotton lint, seed, oil and soil at below detectable levels. Govindan (2009) and Aiswariya (2010) also found that the residue of emamectin benzoate in cotton lint, seed, oil and soil at below detectable levels. The present results also agree with the findings of Kavitha (2003), Suganyakanna (2006) and Thilagam (2006) who reported no detectable residues of spiromesifen, acetamiprid

Fig. 24. Log concentration probit mortality curve for emamectin benzoate to *Eudrilus eugeniae* (Kinberg) at 2 DAT in soil

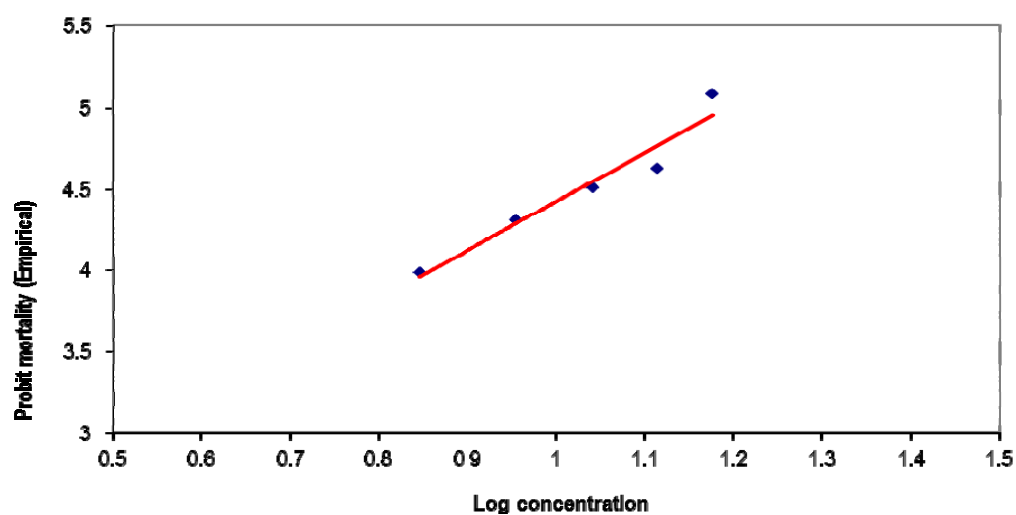
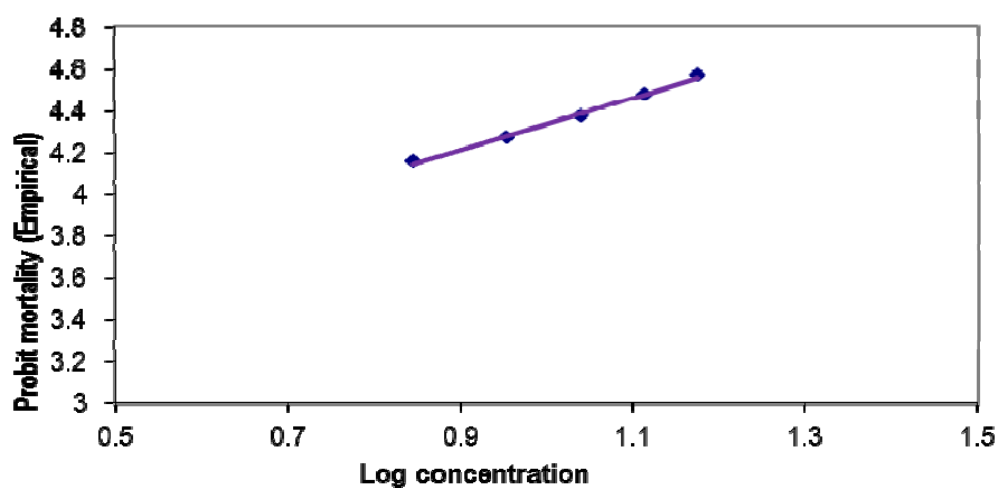


Fig. 25. Log concentration probit mortality curve for emamectin benzoate to *Eudrilus eugeniae* (Kinberg) at 2 DAT in cowdung



and flubendiamide, respectively in samples of lint, seed and oil in cotton with the sensitivity of the instrument being 0.1ppm.

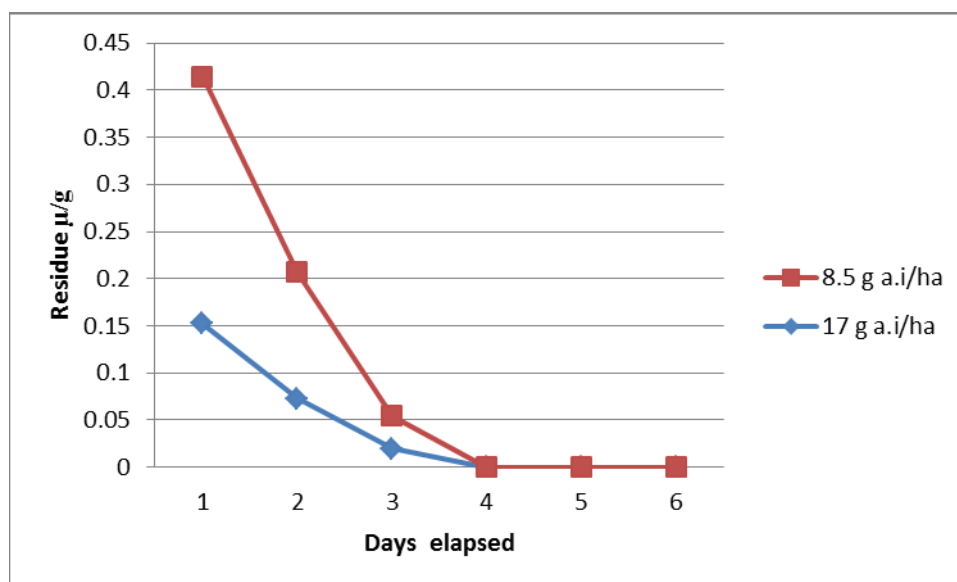
5.7.2. Okra

The initial deposit of emamectin benzoate 5 SG @ 8.5 and 17.00g a.i ha⁻¹ was 0.1521 and 0.2626 µg g⁻¹ respectively, which dissipated to below detectable level on five days after spraying (Fig.26). More than 85 per cent of the residues dissipated on third day after spraying. The half life worked out was one day for the recommended dose and the double the recommended dose respectively. Since, the emamectin benzoate residues were found at below detectable levels on 5th day after application and five days could be suggested as waiting period. The residues in the soil at both the doses were at below detectable levels at both the doses. The present results agree with the findings of Aiswariya (2010) who revealed that emamectin benzoate 5 WSG spray at 9 and 18 g a.i. ha⁻¹ left an initial deposit of 0.095 and 0.302 µg g⁻¹, respectively on first day after treatment and reached BDL after fifth day for 9 g a.i. ha⁻¹ and 18 g a.i.ha⁻¹. Govindan (2009) reported short residual effect of emamectin benzoate at 11 and 22 g a.i.ha⁻¹. Abamectin dissipated rapidly and these results were comparable with the study of Banhawy and Bagoury (1985) who reported the short residual effect of abamectin. Lasota and Dybas (1990) stated that abamectin residues in/on crops were very low, recording less than 0.025 ppm. Kain and Agnello (2001) reported that abamectin residue dissipated quickly. Dinesh (2004) concluded that the residues of abamectin at 0.00045, 0.0009 and 0.0012 per cent reached BDL on 3 DAT on okra fruits. The present study falls in line with the findings of Diserens and Henzelin (1999) who spiked abamectin at three levels with test portions of apples, pears and tomatoes (10, 20 and 30 µg kg⁻¹). The recoveries ranged from 88 to 106 per cent and the repeatability was satisfactory.

5.8. Acute toxicity

Acute toxicity studies aim not only for the detection and measurement of resistance but for the evaluation of bioefficacy of chemicals also. For evaluating the acute toxicity of insecticides, various methods *viz.*, topical application (Fabellar *et al.*, 1988; Tevapucham, 1991), Potter's tower spray (Das and Nair, 1974), leaf dip method (Endo and Masuda, 1981; Stanley *et al.*, 2006) and foliar application (Jena *et al.*, 1992; Naik *et al.*, 1993) are available. Among them topical application was preferred by

Fig 26. Dissipation of emamectin benzoate 5SG on okra fruit



Ramasubramanian and Regupathy (2004), Niranjan Kumar (2002), Sumathi and Regupathy (2003), Stanley (2004) for *H. armigera*, (Niranjan Kumar and Regupathy, (2001); Stanley *et al.*, (2006) for *S. litura* and Deepa Rajathi *et al.* (2006) for *E. vittella* and *P. gossypiella*.

In the present study same method was followed for *P. gossypiella* eventhough it has some drawbacks like being labour intensive and requirement of specialized skill and tools. It was selected because the chance of behavioral resistance or avoidance of treated surface is not possible and the amount of insecticide used for exposing each insect is exact which is not possible in other methods.

The LD₅₀ for emamectin benzoate 5SG against *P. gossypiella* arrived in the present study by topical assay was between 0.1802 and 0.4282 and 95 per cent of the population were killed (LD₉₅) at 1.51564 to 3.3760 µg larvae⁻¹. The LD₅₀ values of abamectin to *E. vittella* was less when compared to the LD₅₀ values of abamectin on *S. littoralis* and it was 1.17, 10.6, 41.7 and 0.36 µg insect⁻¹ for third, fourth, fifth and sixth in stars, respectively (Christie and Wright, 1990). For *S. exigua* it was 0.814 µg ml⁻¹ (Moar and Trumble, 1987) and for pink boll worm *P. gossypiella* it was found in the range of 0.032 to 0.044 µg insect⁻¹ (Bariola, 1984; Bariola and Lingren, 1984). The LC₅₀ value for abamectin on *H. armigera* was 0.64 µg g⁻¹ (Wang *et al.*, 1998, 1999).

The susceptibility of *P. gossypiella* population was tested with relaxation of selection pressure to pesticides by continuously rearing the population in laboratory for nine generations (Fig.27-35). The results indicated that susceptibility gradually increased with succeeding generations as evident from decline in LD₅₀ value from 0.4282 (F₁) to 0.1802 µg larva⁻¹ (F₉) and LD₉₅ from 3.3760 (F₁) to 1.1564 µg larva⁻¹ (F₉). (Fig 27-35)

The LC₅₀ determined for *P. gossypiella* by employing larval dip method for various chemicals were 0.0835 for chlorpyrifos, 0.0335 for beta-cyfluthrin, 0.0452 for quinalphos, 0.0086 for cypermethrin, 0.0144 for indoxacarb, 0.0165 for spinosad and it revealed that synthetic pyrethroids were effective against pink bollworm (Gopalaswamy *et al.*, 2000). The susceptibility of field strains of *P. gossypiella* to insecticides indicated that pyrethroids were far more toxic to the pest than organophosphates and carbamates (Ayad *et al.*, 1993)

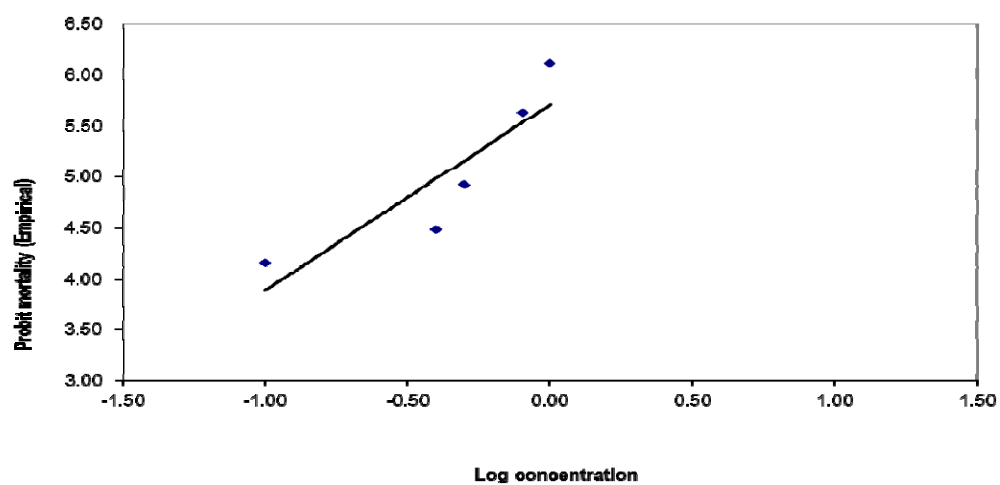


Fig 27. Log Concentration Probit Mortality line for *P.gossypiella* F₁ generation

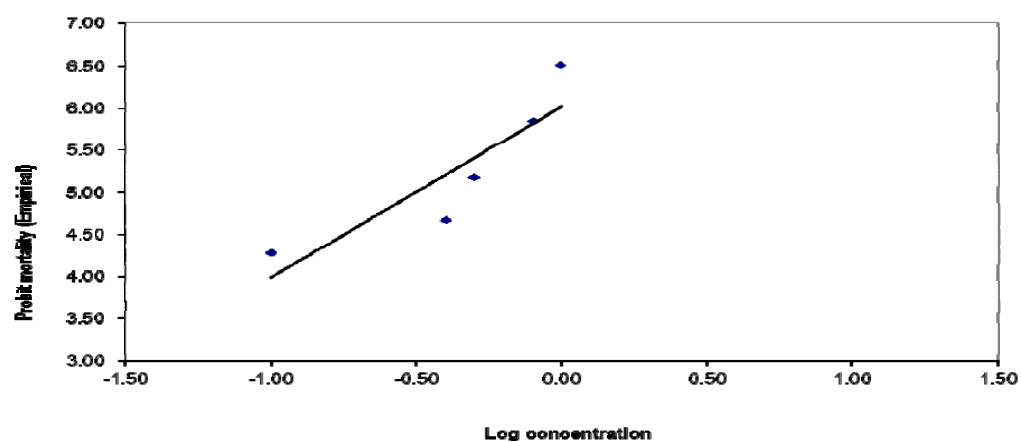


Fig 28. Log Concentration Probit Mortality line for *P.gossypiella* F₂ generation

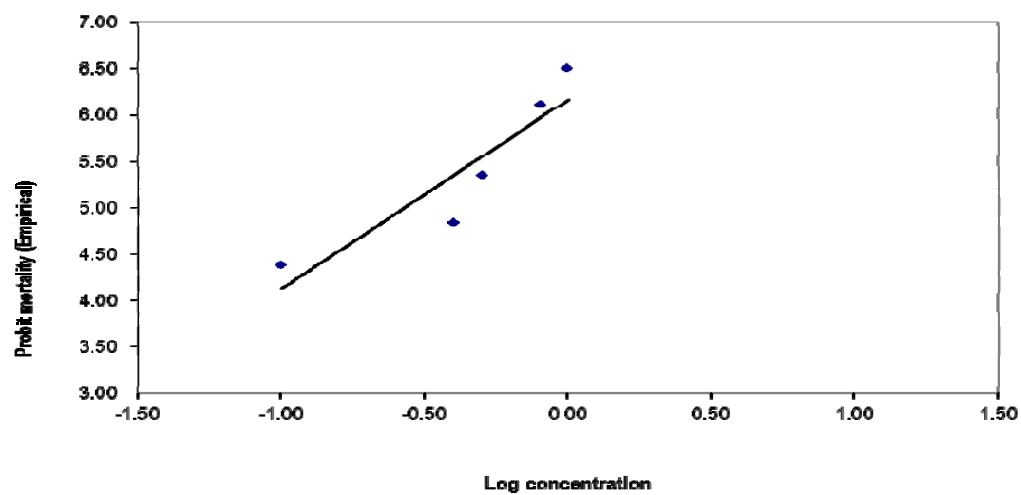


Fig 29. Log Concentration Probit Mortality line for *P.gossypiella* F₃ generation

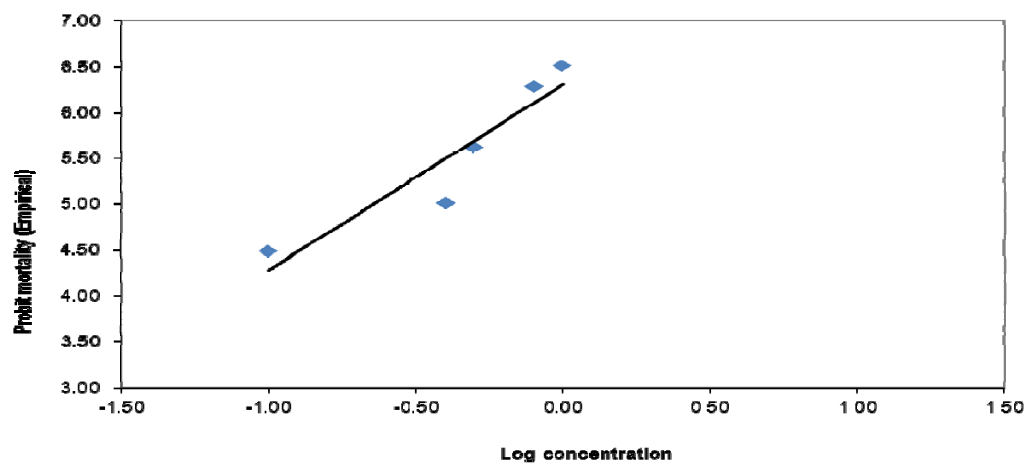


Fig 30.Log Concentration Probit Mortality line for *P.gossypiella* F₄ generation

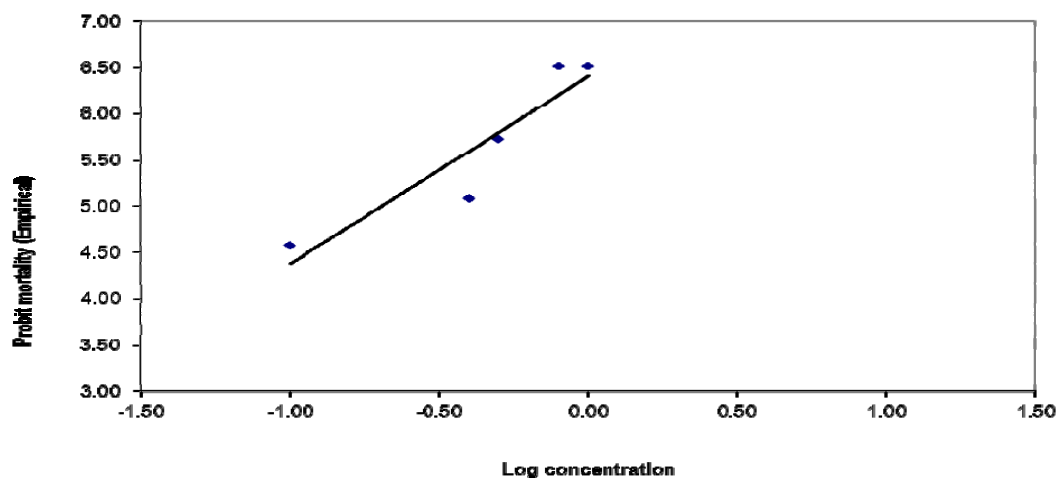


Fig 31.Log Concentration Probit Mortality line for *P.gossypiella* F₅ generation

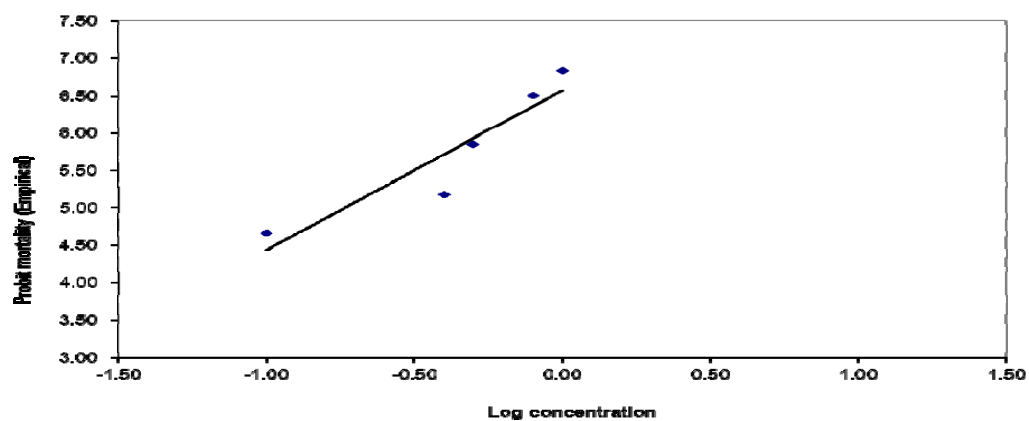


Fig 32.Log Concentration Probit Mortality line for *P.gossypiella* F₆ generation

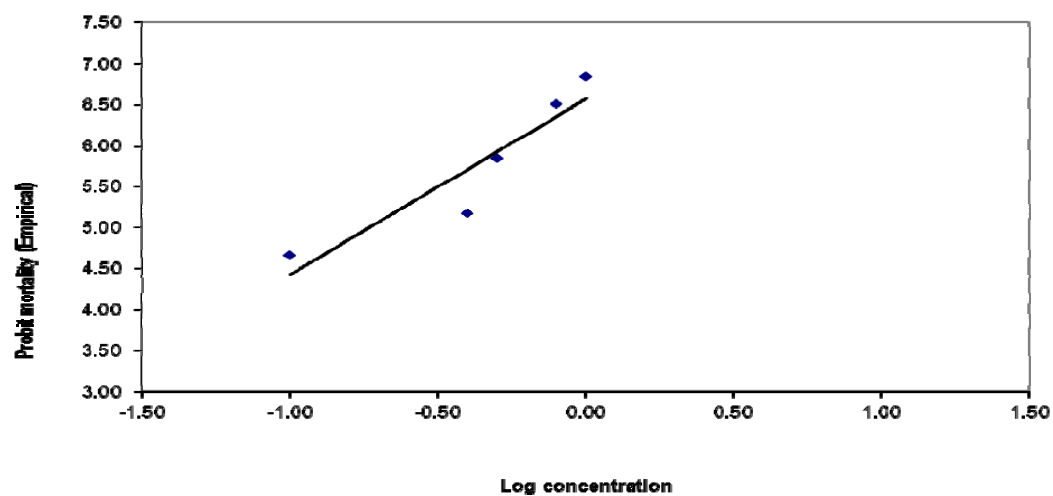


Fig 33. Log Concentration Probit Mortality line for *P.gossypiella* F₇ generation

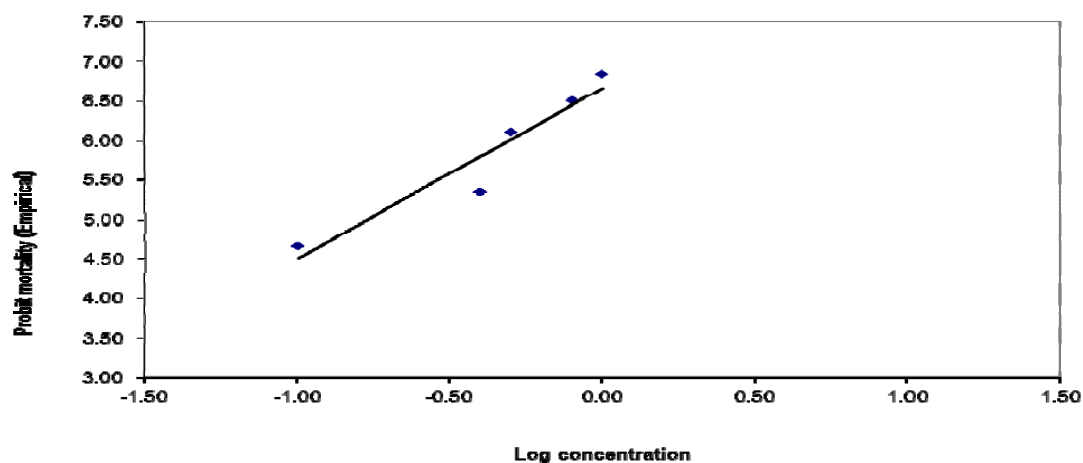


Fig 34. Log Concentration Probit Mortality line for *P.gossypiella* F₈ generation

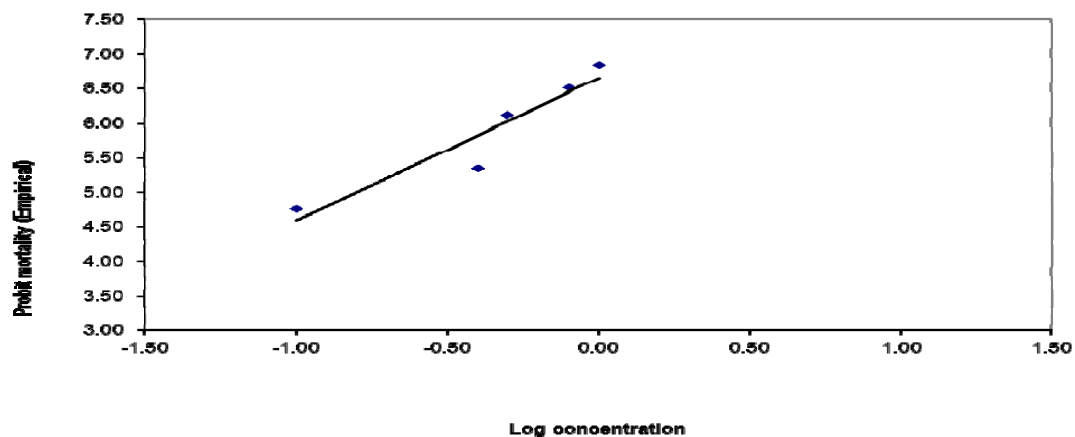


Fig 35. Log Concentration Probit Mortality line for *P.gossypiella* F₉ generation

The LD₅₀ and LD₉₅ value for subsequent generations tested were found to be slightly decreasing with succeeding generations, thus increasing the susceptibility of the pest. LD₅₀ and LD₉₅ values of emamectin benzoate value being 0.016 µg larvae⁻¹ and 0.175 µg larvae⁻¹ (Shobanadevi, 2003), 3.862×10^{-3} and 19.475×10^{-3} µg larvae⁻¹ (Stanley, 2004), 10.499×10^{-3} µg larvae⁻¹ and 81.858×10^{-3} µg larvae⁻¹ against *S. litura* (Stanley *et al.*, 2006). LC₅₀ and LC₉₅ values for *P. xylostella* was found to be 0.053 ppm and 0.989 ppm (Suganyakanna, 2003), 0.092 µg ml⁻¹ and 0.765 µg ml⁻¹ for *H. armigera* (Stanley, 2004) and 0.005 to 0.0218 µg ml⁻¹ for *H. virescens* (Argentine *et al.*, 2002).

The susceptibility index at LD₅₀ was 2.37 and the number of generations required for 10- fold decrease at LC₅₀ was 27.77. The rate of resistance decline was negative indicating that the susceptibility increased with succeeding generation. The tentative discriminating dose (DD) arrived at based on LD₉₅ of emamectin benzoate for F₉ generation of laboratory cultured population of *P. gossypiella* was 1.1 µg larva⁻¹. Sampath kumar *et al.* (2007) reported that tentative discriminating dose (DD) arrived at based on LD₉₅ of emamectin benzoate for F₆ generation of laboratory cultured population of *E. vittella* was 0.02 µg larva⁻¹.

5.9. Assessing the level of resistance

Resistance monitoring techniques play an integral role in resistance management programme and therefore, it is important to detect resistance when it is at incipient levels and monitor its increase and geographical spread so that appropriate measures could be initiated to delay resistance development and thereby preserve the potentiality of new insecticide molecule. The chief objective in resistance monitoring is to exaggerate the differences between susceptible and resistant individuals such that the frequency of misclassification is greatly reduced (French and Villarreal, 1990). This is fulfilled by fixing discriminating doses. Since the chemicals under study are newer ones, the LC₉₅ of the respective chemicals for the respective insecticides is considered as a discriminating dose for monitoring the field populations for their resistance to these insecticides. For new insecticides, without well established baseline data, LC₉₅ can be taken as the discriminating dose (Senthilkumar and Regupathy, 2004).

When the discriminating dose of emamectin benzoate ($0.8\mu\text{g larvae}^{-1}$) was applied to field collected *H.armigera* in the present investigation, the highest per cent resistance (10%) was recorded in Coimbatore district followed by Dharmapurai population. The lowest per cent levels of larval resistance was observed in Salem and Erode in the range of 3.33 to 6.66 which might be due to the lower usage of insecticide with new chemistries. This is comparable with the results of Stanley *et al.* (2009) who revealed that resistance was not observed when the discriminating doses of emamectin and spinosad were applied on field-collected populations of *H. armigera* from two intensive cotton growing areas, Coimbatore and Madurai, India. According to Louise Rossiter (2012). When *H. punctigera* was tested for resistance to either endosulfan, pyrethroids or emamectin benzoate in cotton and other crops, there was less than 1 % resistance detected to each of the three insecticides.

The survivability of fruit and shoot borer varied from 6.66 to 15.00 per cent for emamectin benzoate. Erode population was found to be highly susceptible which was evident from 0.00 per cent survival during monitoring, whereas, it was 15.00 per cent for Coimbatore followed by Salem, Madurai and Dharmapuri population. The level of survivability obtained for the emamectin benzoate was very low when compared to the conventional insecticide against bollworms. The per cent survival of pink bollworm varied from 3.33 to 6.66 per cent for emamectin benzoate at $1.1\mu\text{g larvae}^{-1}$. All the five district populations showed the lowest level of resistance.

Based on LC_{95} , discriminating doses for *P. xylostella* were fixed at 2 ppm and 10 ppm for emamectin and spinosad by Lavanya *et al.* (2010). Revalidating the discriminating doses on field collected populations revealed that there was no resistance among the populations of *P. xylostella* recorded from the three locations of Coimabtoe, Ooty and Oddanchatram areas. Louise Rossiter (2012) reported that to predict the development of resistance, it required 18.67 and 26.71 generations of *H. armigera* to obtain 5-fold and 10-fold increase of emamectin benzoate in LC_{50} under selection pressure at 90 per cent mortality for each generation of selection. From the present investigation, it could be seen that there are chances for the development of resistance in

insect pests which is evident from the low level of resistance detected for *H.armigera* and *E.vittella* in Coimbatore and Dharmapuri field collected larval population.

5.10. Occurrence of arthropods in sprayed and unsprayed cotton field

The present investigation yielded 4232 individuals of arthropods belonging to 51 families and 14 orders in both sprayed and unsprayed cotton field. The class Insecta was the most common followed by Arachnida. Totally, 10 families of Araneae were collected with the majority of individuals grouped under the family Lycosidae, Salticidae, Oxyopidae and Araneidae. Under Insecta, endopterygotes were the largest group represented by five orders while exopterygotes though represented by seven orders were lesser in occurrence. Among endopterygotes, maximum individuals were collected from Hymenoptera while, Hemiptera was predominant in terms of individuals of exopterygota. The reason for the dominance of Hymenoptera was due to the preponderance of ants in the collection. Similarly, with reference to Hemiptera maximum individuals belonged to Cicadellidae ((leaf hopper) and Pseudococcidae (mealybugs).

5.10.1. Comparison of abundance and diversity of arthropods in cotton ecosystem

The results of the present study revealed that arthropod diversity was greater in case of unsprayed cotton compared to sprayed cotton field. Biodiversity is a measurement of ecological complexity, and is expected to be higher in less disturbed ecosystems; overall, biodiversity is highly threatened by modern agriculture (Amman, 2005). The most significant decline in arthropod density was found in the rice fields where broad-spectrum insecticides were applied (Yun 1997).

Agricultural intensification through use of pesticides is significantly correlated to reduction in various taxonomic levels. Arthropod diversity in agricultural landscapes was found to be higher in less intensely cultivated habitats. (Amman, 2005).

In the present study ten families of Araneae were collected from both sprayed and unsprayed areas with more in the non-sprayed area than in the sprayed area. This is supported by Men *et al.* (2004) who reported that the spider populations were significantly depressed by pesticide treatments on nontransgenic cotton and on *Bt* cotton, probably due to a direct contact effect of insecticides. However, insecticides could also kill spiders by accumulating on their webs and poisoning them directly on the webs or

repelling them from the webs, thereby exposing them to predation and contaminated leaf surfaces. There were more spiders on *Bt* cotton with no pesticide treatments than on nontransgenic cotton with no pesticides in 1999 and 2000. Earlier studies have indicated that spiders of the family Lycosidae were susceptible to insecticides such as the pyrethroid and alphamethrin, but less so than to other insecticides such as endosulfan (Van Den Berg *et al.*, 1990).

Spiders were particularly susceptible to organo-synthetic insecticides such as carbamates and organophosphates, while fungicides, herbicides and natural insecticides such as *Bt* had little or no toxicity for spiders (Stark *et al.* 1995).

Yoo *et al.* (1984) reported that the dust formulation was more toxic than wettable powders or emulsions. Carbofuran was one of the most toxic chemicals to dominant spiders such as *P. subpiraticus* and *Gnathonarium dentatum* in laboratory tests (Yoo *et al.*, 1993). In his study, the application of carbofuran GR did not disturb the build-up of spider populations in the early season. The application of granular insecticides in the early season might not directly reduce the spider population. In tropical rice fields, several foliar sprays in the early season resulted in the destruction of predators and outbreaks of insect pests (Cohen *et al.*, 1994, Settle *et al.*, 1996).

In present study, totally three families of Orthoptera were collected from both sprayed and unsprayed cotton fields. More individuals were collected in the non-sprayed area than the sprayed area. Amalin *et al.* (2009) indicated that most of the orthopterans collected belonged to Acarididae and Gryllidae.

In the order hemiptera, totally nine families were collected. The abundance of *Oxycarenus hyalinipennis*, *Dysdercus cingulatus* and *Geocoris* sp. was higher in unsprayed field than in sprayed cotton field. In the order Heteroptera, the family Lygaeidae was more abundant in the sprayed area during the first month of sampling and then more were recorded in the non-sprayed area than in sprayed area in the succeeding sampling periods. Men *et al.* (2004) reported that aphid populations were significantly affected by pesticides on both non transgenic and *Bt* cottons. No insecticide application was needed against seeding aphids on *Bt* cotton in 2001. Most probably, insecticide application against other pests kept aphid densities under the action threshold. Amalin *et al.* (2009) revealed that when compared to the arthropod density in the untreated field,

density in the treated field was reduced by 48.4 per cent for total arthropods, by 55.2 per cent for filter feeders/ detritivores by 44.0 per cent for herbivores and by 39.7 per cent for spiders.

In present study, totally six families of coleopterans were collected from both sprayed and unsprayed fields. Coccinellide was abundant in unsprayed cotton field than sprayed field. Men *et al.* (2004) reported that the insecticides did not reduce ladybeetle populations significantly. Even when affected by pesticides; ladybeetles could survive the insecticides or ladybeetles in neighboring plots could emigrate in a short time to the plots where pesticides are sprayed. There were no significant differences in ladybeetle populations on *Bt* cotton and on nontransgenic cotton in 1999 or 2000, but in 2001 the populations were greater on nontransgenic cotton than on *Bt* cotton (Men *et al.* 2004).

Among the hemiptera families, lygaeidae, pyrrhocoridae, pentatomidae, cicadellidae, aphididae, aleyrodidae, pseudococcidae, yielded the maximum no of individuals. Among the coleoptera maximum number of individuals belonged to coccinellidae.

The abundance of dermapterans, lepidopterans, neuropterans, dictyoptera, diptera and odonata was very low on both systems and the impact of the chemical application might be misleading.

5.10.2. Biodiversity indices

Biodiversity is a function of species present (species richness), the evenness with which the individuals are distributed among these species (species evenness) and the interaction component of richness and evenness (Ludwig and Reynolds, 1988). As complete counts of organisms are impractical, indirect solutions that are practical, rapid and inexpensive are necessary and hence, diversity indices have gained importance. In the present study, the data on the arthropods collected were subjected to alpha or within habitat diversity and beta or between habitat diversity of sprayed and unsprayed cotton fields.

In current study, alpha diversity was estimated based on Species number, Fishers alpha index, Margalef's D index, Q statistic, Brillouin index and Shannon-Weiner index while dominance was based on Simpson's index, McIntosh index and Berger parker index. In both instances, the analysis was subjected to four levels of classification viz., based on order, family, genus and species. The use of higher taxa typically families as

surrogate for species has been suggested by Williams and Gaston (1994). Hughes (1978) concluded that the taxonomic level of identification is one of the most important factors influencing the value of the Shannon index.

The species richness indices based on Species number, Fishers Alpha index, Margalef's D index, Q Statistic, Brillouin diversity index and Shannon - Weiner index was higher in unsprayed cotton, of the different dominance indices viz., Simpson's index, McIntosh index and Berger Parker index, expressed higher arthropods diversity in unsprayed cotton field and lower was observed in unsprayed field (Fig.36-45).

The current biodiversity study demonstrated that the chemicals applied in the sprayed area had a negative effect on the arthropod community as a whole. The current findings on the sensitivity of certain taxa to chemical sprays could contribute in the identification of bioindicators for environmental stress due to pesticide usage in the cotton field. Therefore, the use of best management practices should be taken into serious consideration in controlling the pests in the agricultural areas to reduce the negative impacts on biodiversity and continuously provide natural ecological services such as biological control.

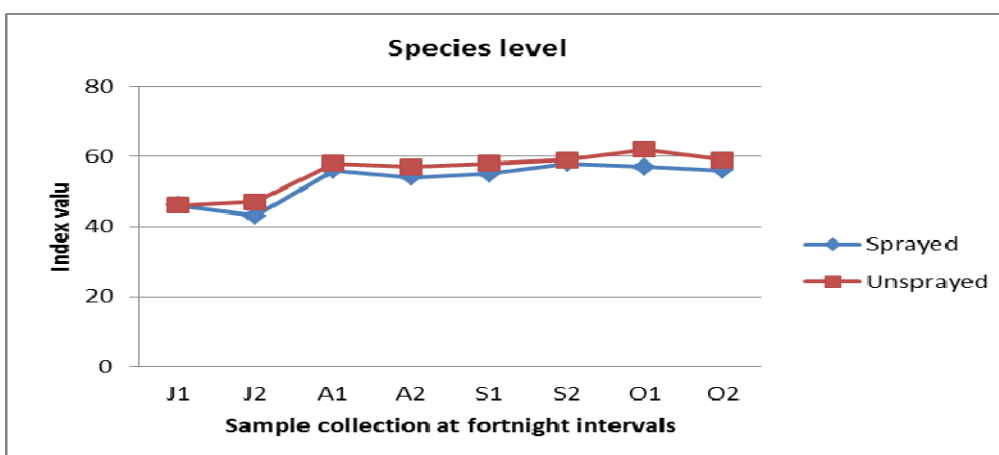
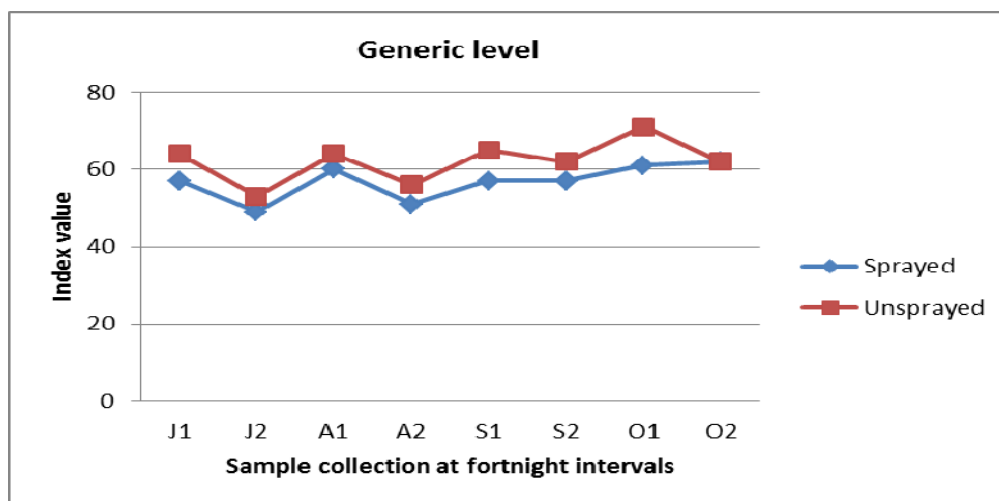
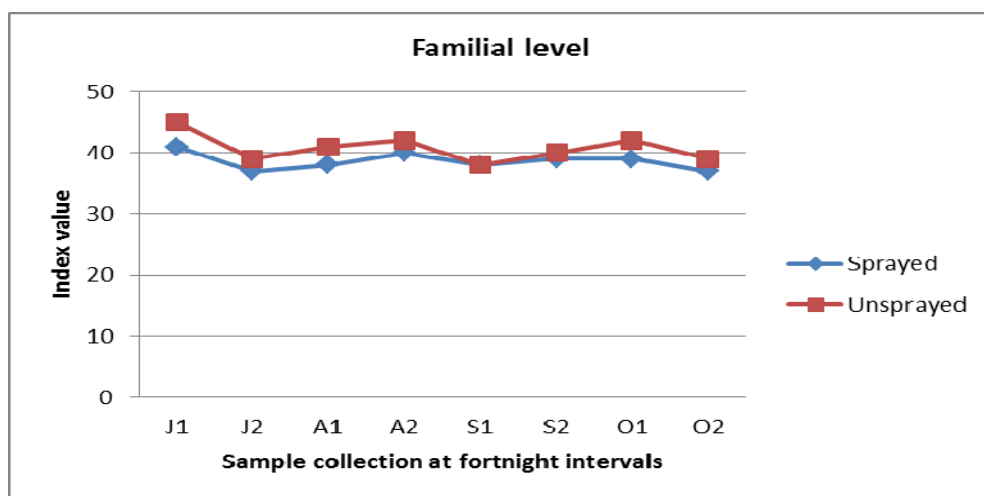


Fig 36. Arthropod diversity based on Species number in cotton ecosystem

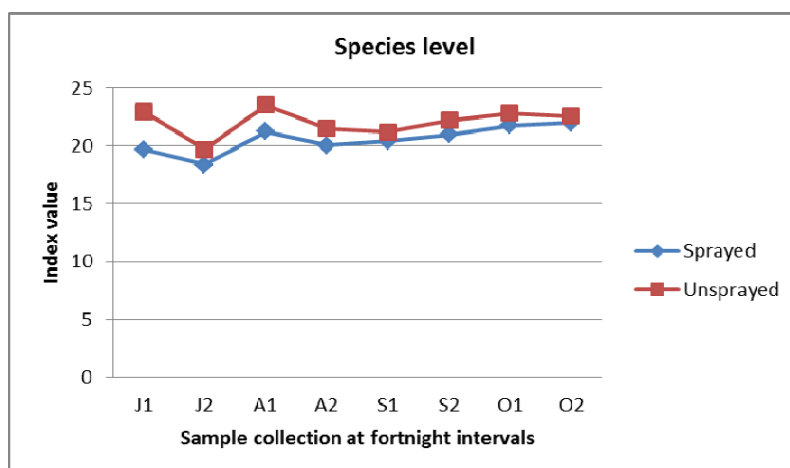
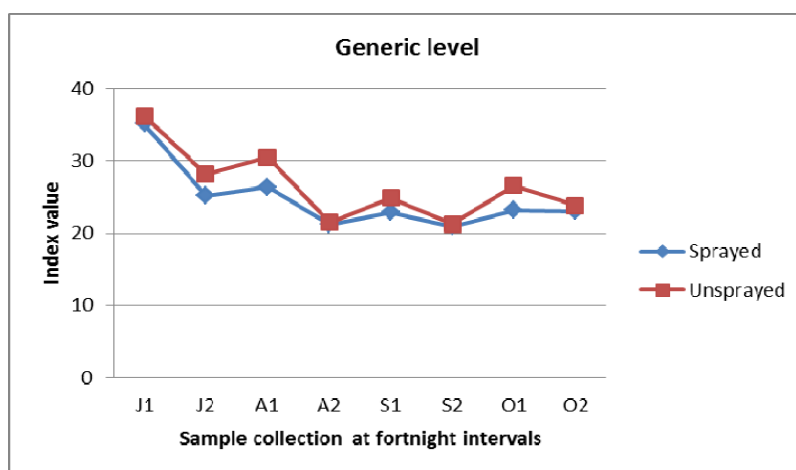
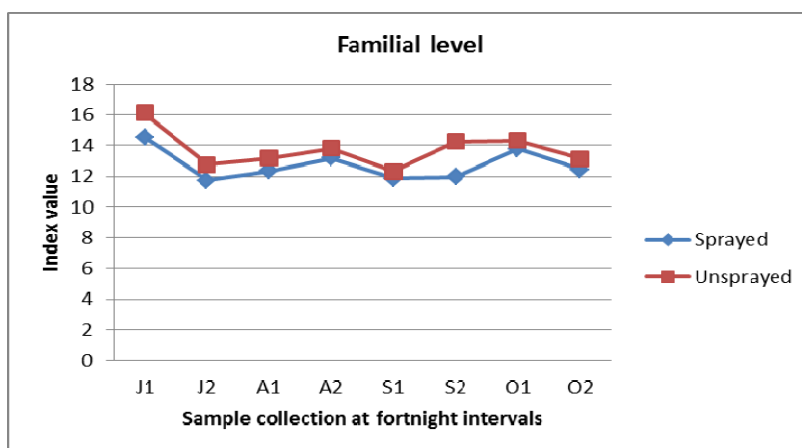


Fig 37. Arthropod diversity based on Fisher's alpha index in cotton ecosystem

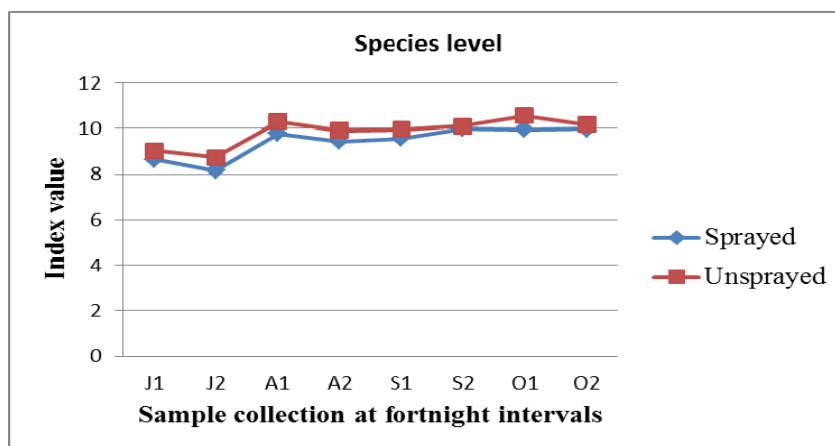
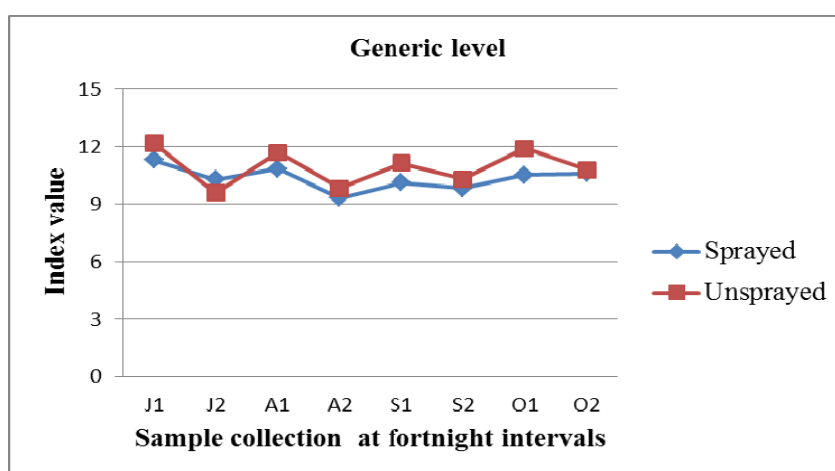
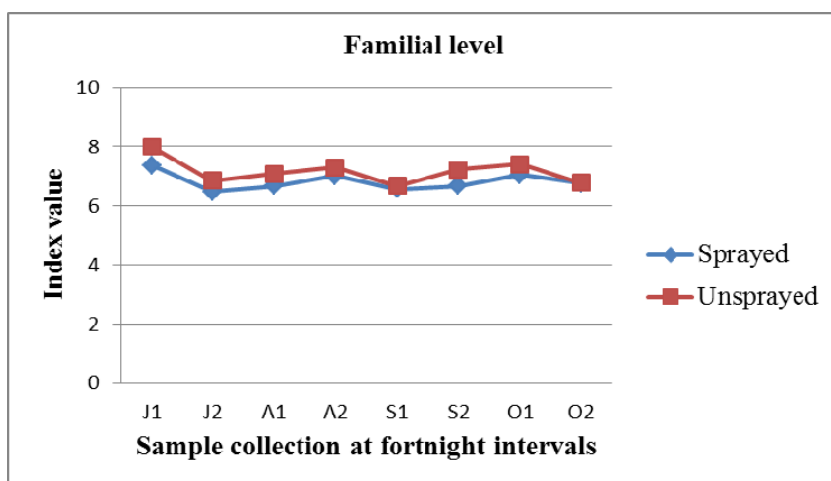


Fig. 38. Arthropod diversity based on Margalef's D index in cotton ecosystem

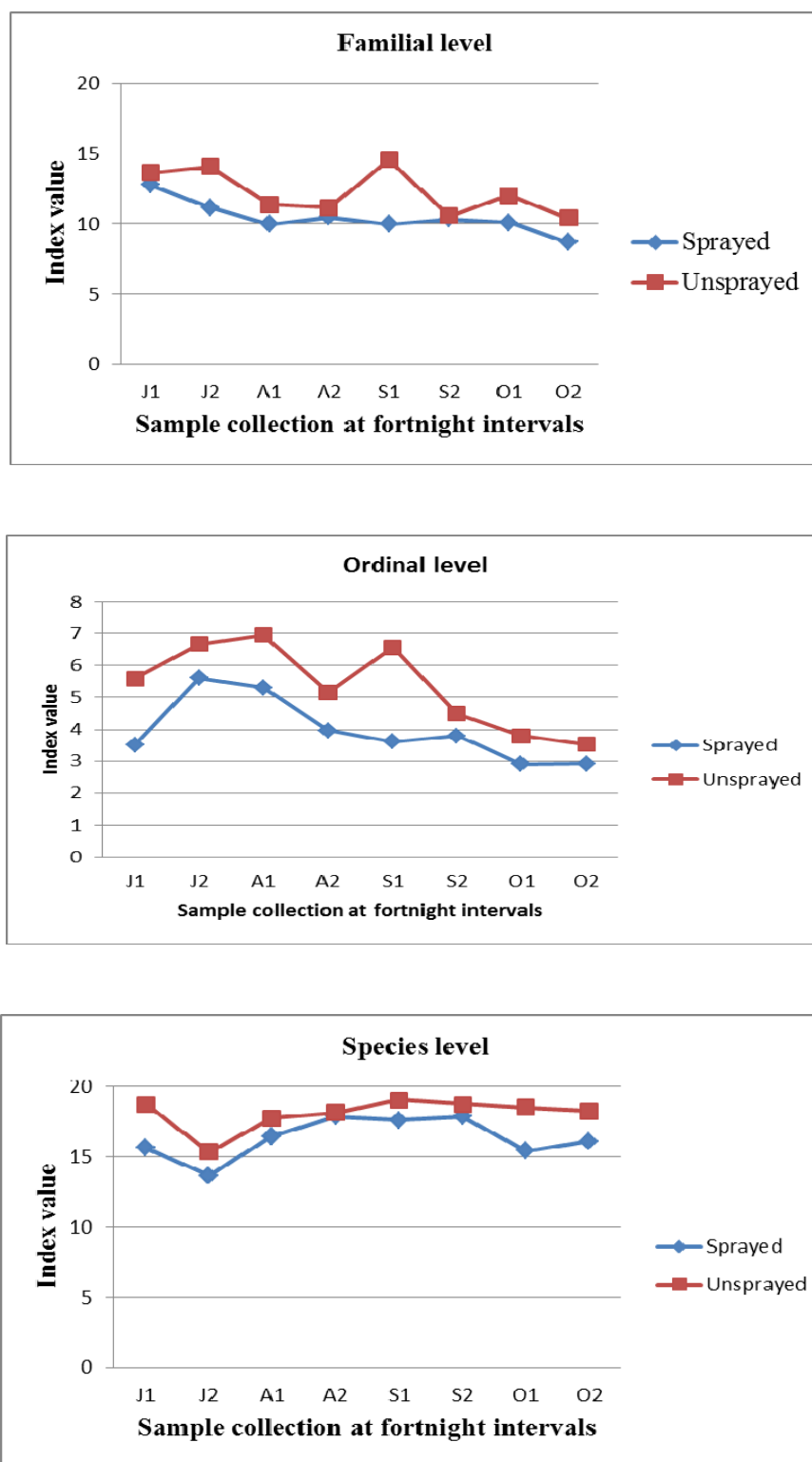


Fig. 39. Arthropod diversity based on Q Statistic in cotton ecosystem

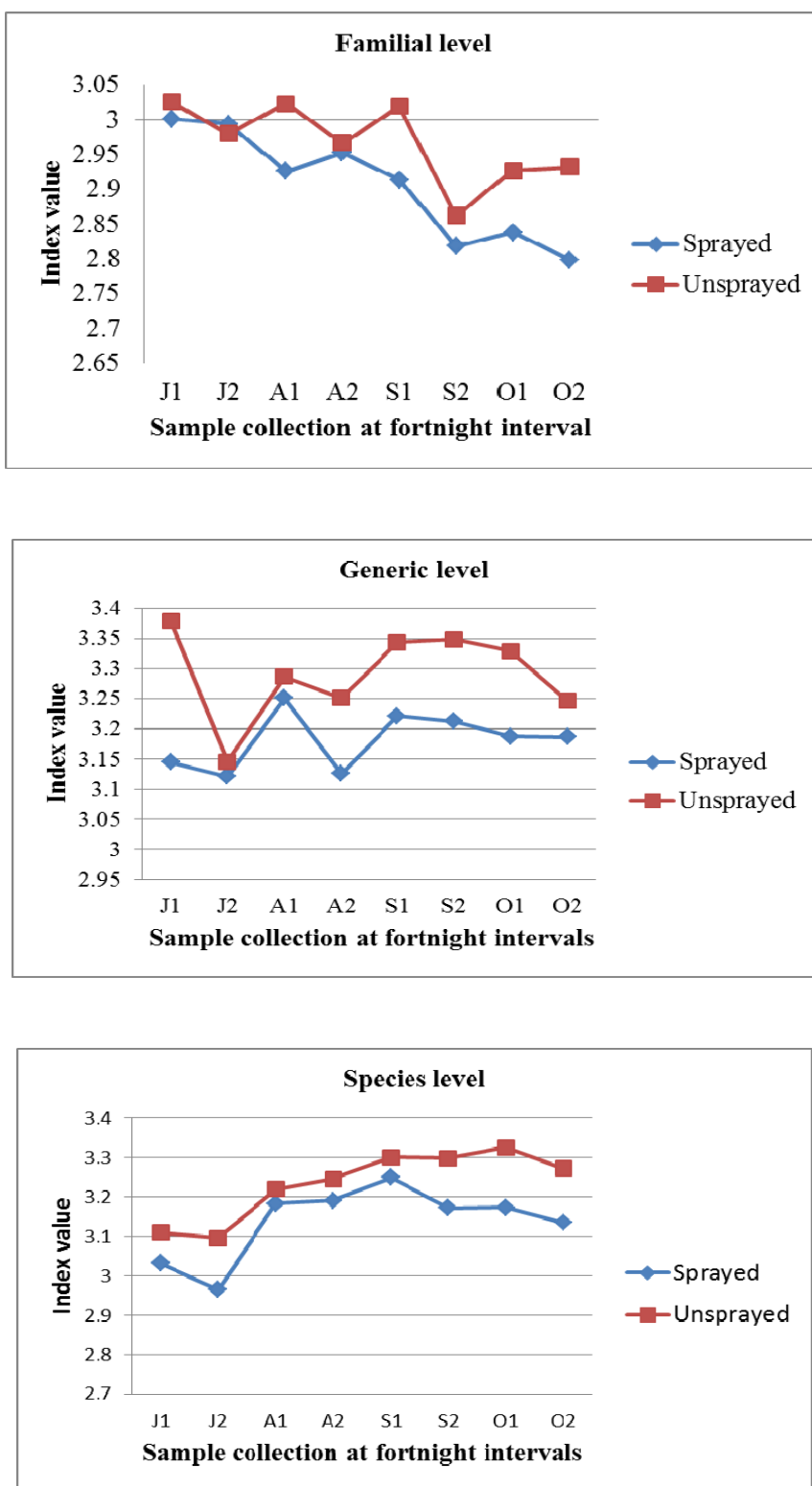


Fig. 40. Arthropod diversity based on Brillouin diversity index in cotton ecosystem

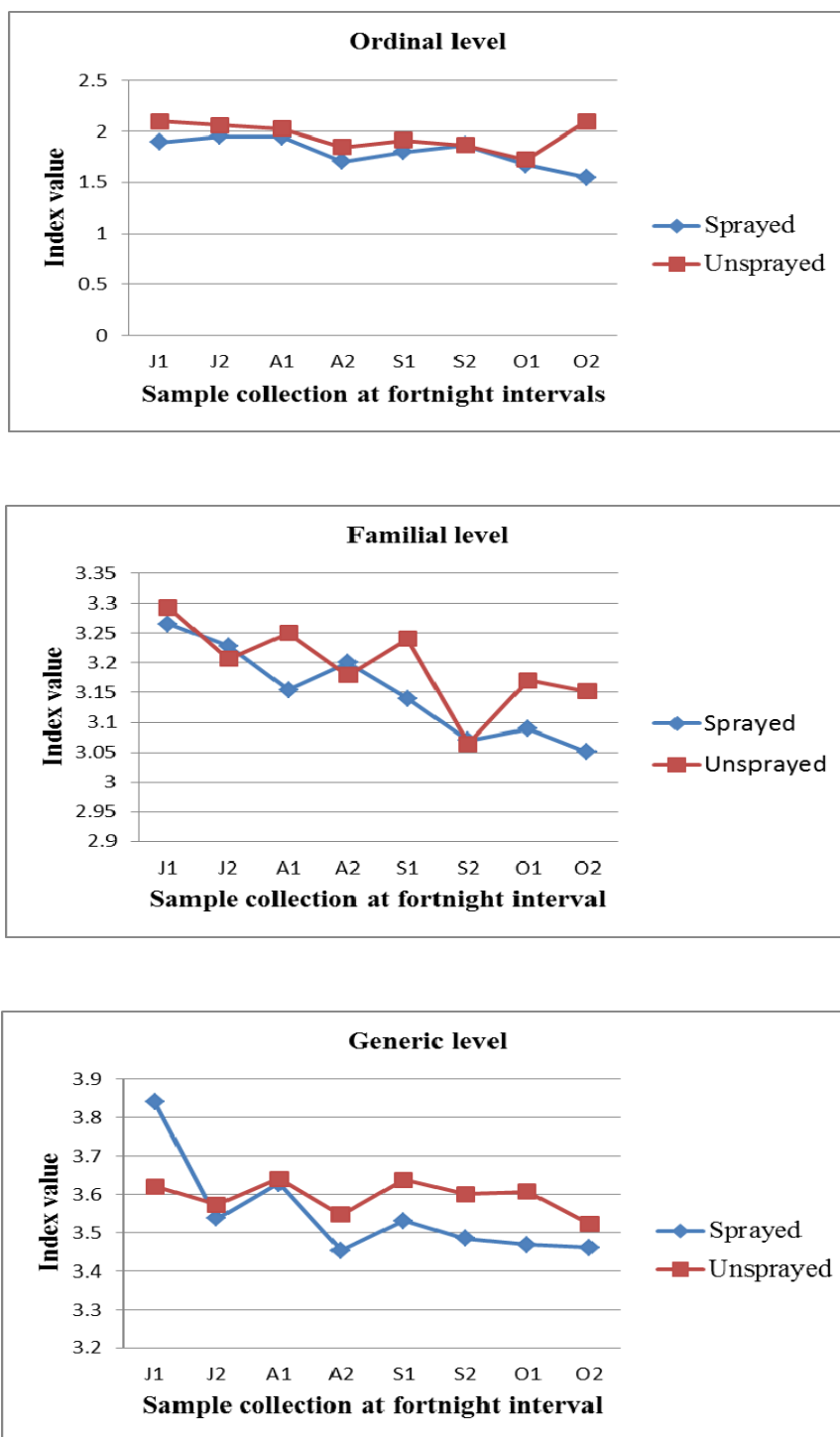


Fig. 41. Arthropod diversity based on Shannon- Weiner index in cotton ecosystem

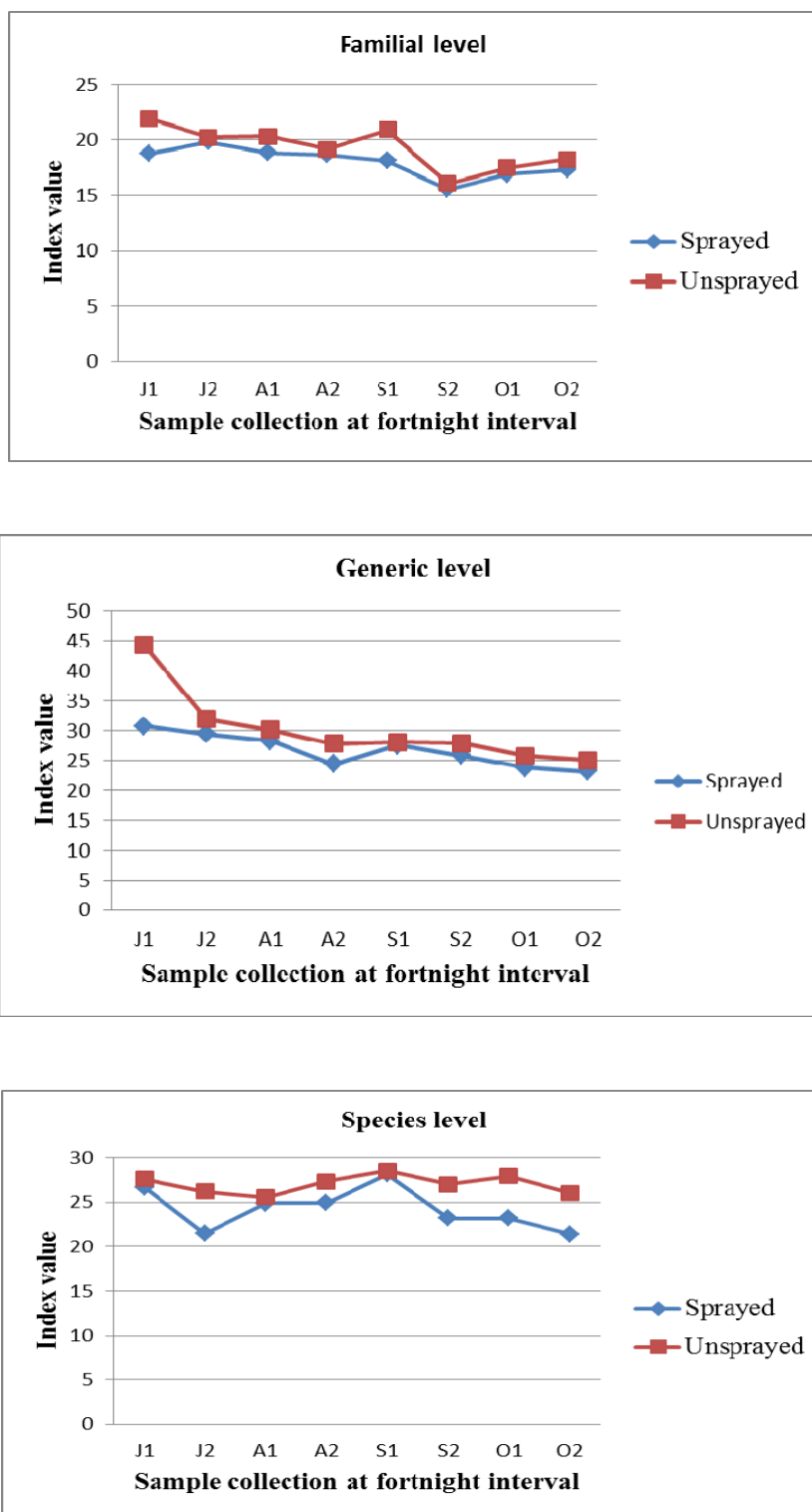


Fig. 42. Arthropod diversity based on Simpson's index in cotton ecosystem

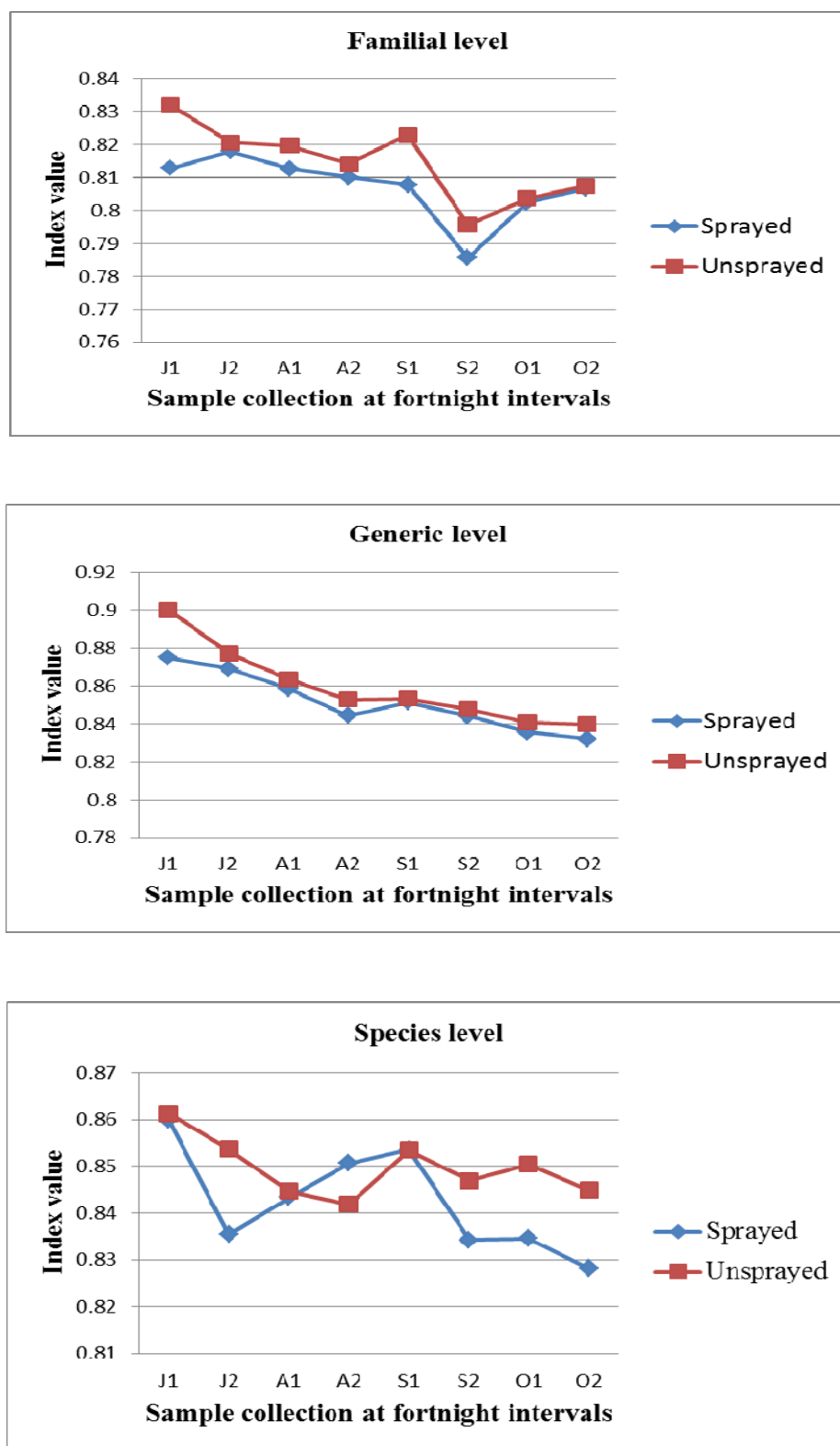


Fig. 43. Arthropod diversity based on McInthosh index in cotton ecosystem

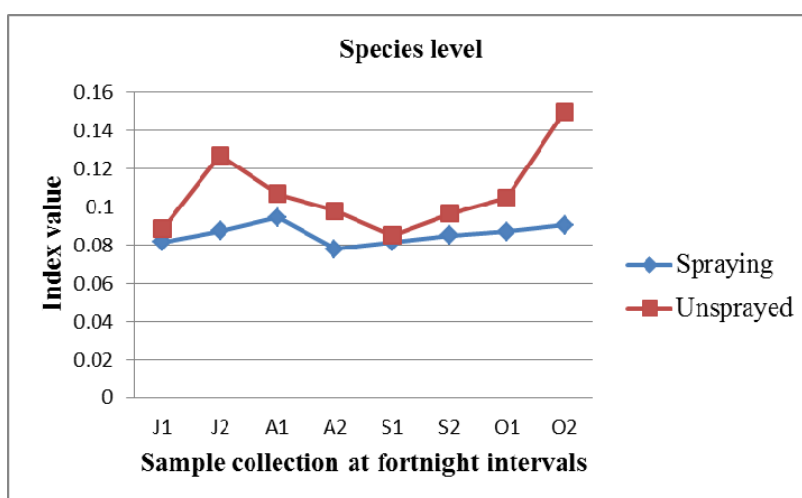
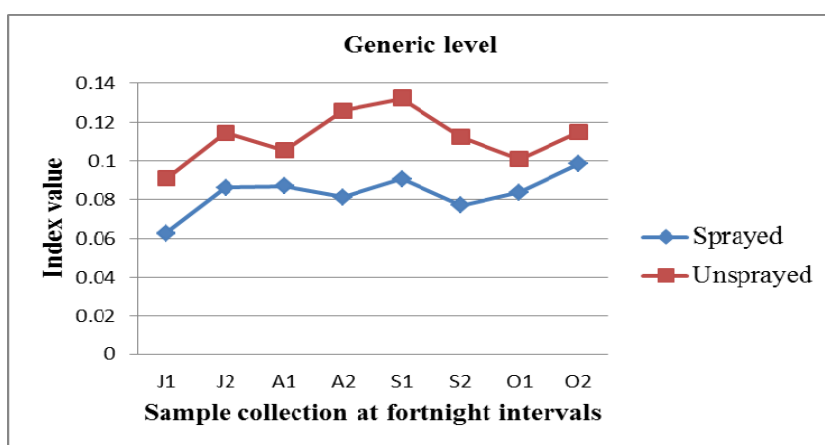
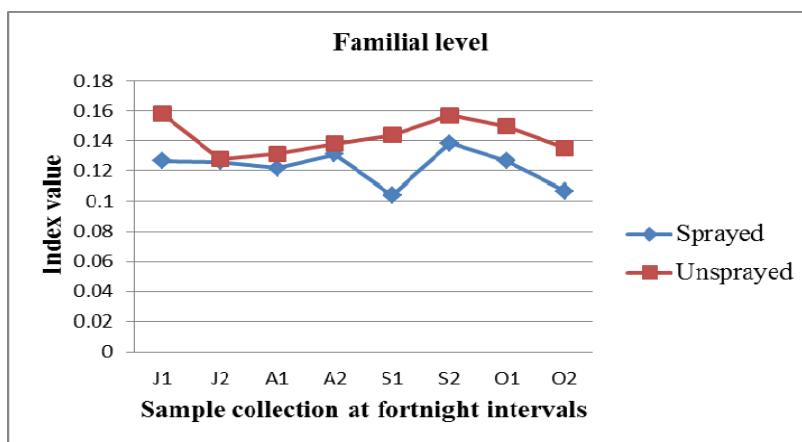


Fig. 44. Arthropod diversity based on Berger parker diversity index in cotton ecosystem

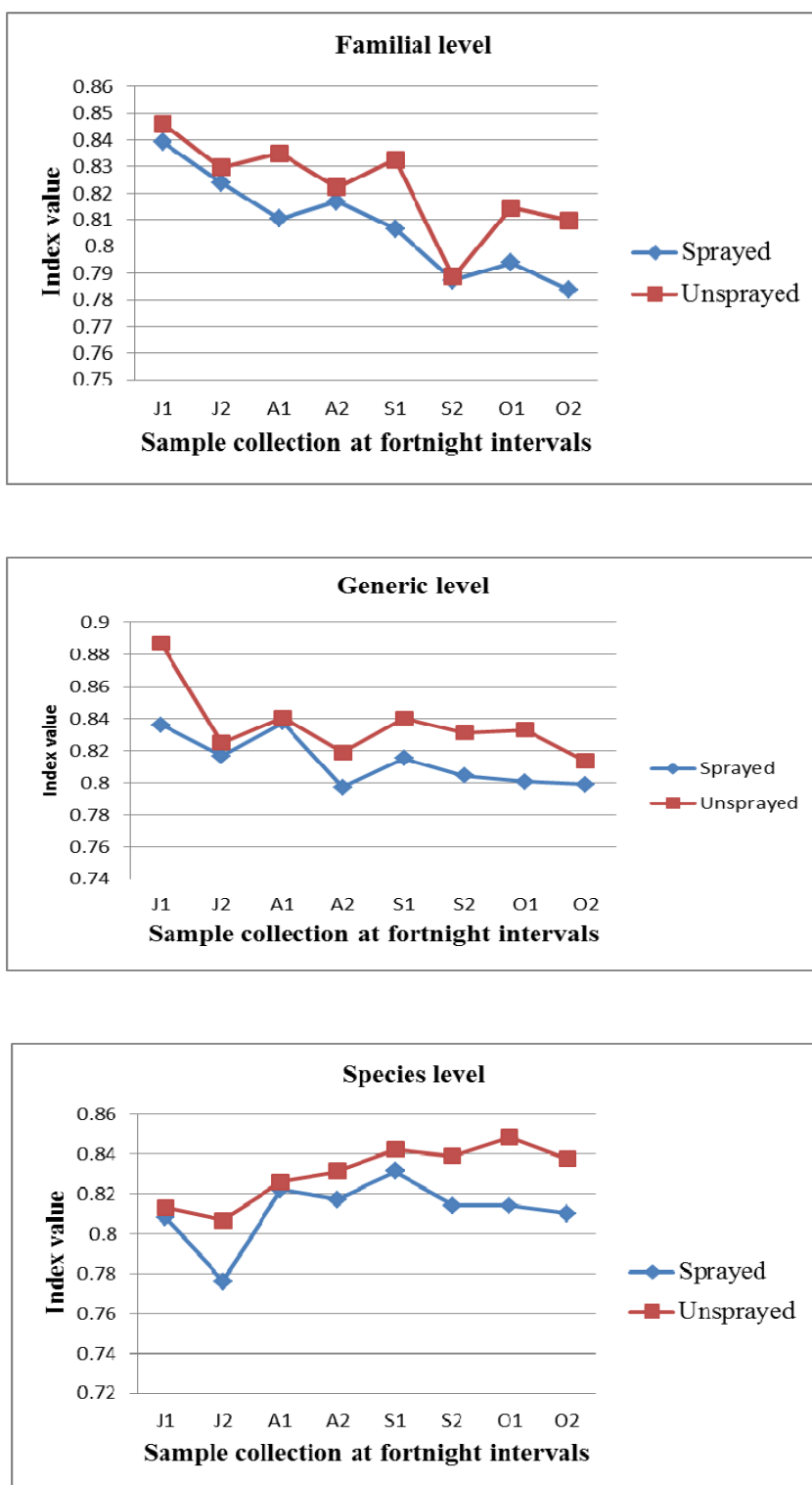


Fig. 45. Arthropod diversity based on Equitability J in cotton ecosystem

Summary

CHAPTER VI

SUMMARY

Studies were conducted to evaluate emamectin benzoate 5 SG for its bioefficacy against bollworms in cotton and fruit borers in okra, its phytotoxicity, persistence, selective toxicity to non target organisms, physical and biological compatibility, residues, assessment of levels of resistance, and arthropods diversity in cotton ecosystem. The findings are summarized below.

- * Field experiments on cotton variety viz., Rasi 2000 and Surabhi distinctly revealed that emamectin benzoate 5 SG at 11 g a.i. ha⁻¹ was effective in checking the larval population of bollworms. The same dose (11 g a.i. ha⁻¹) resulted in 80.06 and 80.24 per cent reduction of per cent boll damage over untreated check at the end of observation in the first and second field experiments, respectively. The efficacy increased as the concentration increased to 15 g a.i. ha⁻¹, while higher doses of 22 and 44 g a.i. ha⁻¹ did not cause any phytotoxicity symptoms.
- * In all the emamectin benzoate 5 SG treated plots the yield ranged from 18.82 to 20.53 q ha⁻¹ and 16.78 to 19.96 q ha⁻¹ in experiment I (Madhampatti) and II (Narasimanayakkan palayam), respectively.
- * Foliar application of emamectin benzoate SG at 8.5 g a.i. ha⁻¹ in okra with F₁ hybrid Mahyco in both seasons significantly reduced the larval population of *Helicoverpa armigera* (Hubner) (81.53 and 81.64 %) and *Earias vittella* (Fabricius) (81.64 and 81.37 %) and their fruit damage. Higher doses (17 and 34 g a.i. ha⁻¹) did not show any phytotoxicity symptoms.
- * In all the emamectin benzoate 5 SG treated plots, the yield ranged from 6050 to 8100 kg ha⁻¹ and 5948 to 8090 kg ha⁻¹ in experiment I (Madhampatti) and II (Narasimanayakkan palayam), respectively.
- * All the emamectin benzoate 5 SG doses were comparatively less toxic to the predatory spiders and coccinellids. The standard insecticide spinosad 45 SC at 75 g a.i. ha⁻¹ was found to be highly toxic to predatory spiders and coccinellids in cotton and okra ecosystem.

- * Emamectin benzoate 5 SG was highly physically and biologically compatible with other agrochemicals like, lambda cyhalothrin (25 g a.i.ha⁻¹), carbendazim (0.1%) and mancozeb 75 WP (0.2%).
- * Biological compatibility of emamectin benzoate 5 SG at 11 and 8.5 g a.i. ha⁻¹ with lambda cyhalothrin (25 g a.i.ha⁻¹), carbendazim (0.1%) and mancozeb 75 WP (0.2%). as foliar application on cotton (variety - Surabhi) and okra (variety - Mahyco 10) showed that none of the combination treatments caused any phytotoxic symptoms such as injury to leaf tip and leaf surface, wilting, vein clearing, necrosis, epinasty and hyponasty in cotton and okra
- * In cotton, plots treated with all the emamectin benzoate 5 SG combination treatments recorded more than eighty per cent reduction of larval population and the mean boll damage in the range of 6.01- 7.12 per cent. Whereas, buprofezin 25SC, Mancozeb and carbendazim 50 WP alone recorded higher per cent damage than combination (19.95, 20.53 and 20.64 per cent respectively).
- * In okra, all the emamectin benzoate 5 SG combination treatments recorded 1.02 - 1.31 mean larvae per five plants, respectively. The highest larval population was observed in the plots treated with buprofezin (8.75 larvae/ five plants), carbendazim (18.50 larvae/ five plants) and mancozeb (5.97 larvae/ five plants) alone. Fruit damage in all emamectin benzoate 5 SG combination treatments recorded 82.47 to 84.43 per cent reduction from untreated check.
- * The persistence of emamectin benzoate 5 SG revealed that there was a reduction in the mortality of *E.vittella* larvae as the time increased and the toxicity persisted for 11 days in spinosad 45 SC at 75g a.i. ha⁻¹, it was 15 days for emamectin benzoate 5 SG at 8.5, 6.7 g a.i. ha⁻¹ and Proclaim[®], it was 17 days in the case of emamectin benzoate 5 SG at 15 g a.i. ha⁻¹.
- * More than 50 per cent mortality of larvae of *H. armigera* was observed in emamectin benzoate 5 SG at 9, 11 and Proclaim[®] 11 g a.i. ha⁻¹ up to 9 Day After Treatment (DAT), while it was up to 7 DAT for spinosad 45 SC at 75 g a.i. ha⁻¹ and emamectin benzoate at 7 g a.i. ha⁻¹. There was a reduction in the mortality of *H. armigera* larvae as the time increased and there was no mortality after 17 DAT.

- * Emamectin benzoate 5 SG did not cause any adverse effects on the adult of *Trichogramma chilonis* Ishii. The recommended dose of emamectin benzoate 5 SG at 11g a.i. ha⁻¹ recorded 87.60 and 87.50 per cent parasitization and adult emergence, respectively.
- * The lower dose of emamectin benzoate at 7, 9 and 11 g a.i. ha⁻¹ caused 13.33, 16.33 and 23.33 per cent mortality respectively, to *Chelonus blackburni* Cameron at 6 Hour After Treatment (HAT). All the emamectin benzoate 5 SG doses were less toxic to *C. blackburni* adults compared to standard insecticides.
- * In all the insecticidal treatments, hatchability of *Chrysoperla carnea* Stephens eggs ranged between 80.00 and 96.67 per cent. Among them, the toxic effect was the least for emamectin benzoate 5 SG treatments. In the dry film method, emamectin benzoate 5 SG at 7 g a.i. ha⁻¹ recorded very high pupation of 96.29 per cent and higher dose of emamectin benzoate 5 SG (15g a.i. ha⁻¹) recorded a pupation of 82.35 per cent.
- * Emamectin benzoate 5 SG was relatively safer to honey bees Indian bees viz., *Apis cerana indica* F., little bees, *Apis florea* F. and Italian bees, *Apis mellifera* Linn. than spinosad. There was no significant different between the mortality of three species.
- * The LC₅₀ value of emamectin benzoate 5 SG to earthworm, *Eudrilus eugeniae* (Kinberg) was 17.22 ppm in soil and 16.47 ppm in cowdung at 2 DAT.
- * The harvest time residues of emamectin benzoate 5 SG applied at 11 and 22 g a.i. ha⁻¹ left residues at below detectable levels (BDL) in cotton lint, seed, oil and soil at first and third harvest.
- * In okra, the initial deposit of emamectin benzoate 5 SG @ 8.5 and 17.00g a.i ha⁻¹ was 0.1521 and 0.2626 µg g⁻¹ respectively which dissipated to below detectable level on five days after spraying. Since the emamectin benzoate 5 SG residues were found at below detectable levels on 5th day after application and five days may be suggested as waiting period. The residues in the soil at both the doses were at below detectable levels at both the doses. The half-life worked out was 1.0 day for the recommended dose and the double the recommended dose respectively.

- * Based on the LD₅₀ and LD₉₅ values, population of *Pectinophora gossypiella* (Saund.) from Coimbatore was found to be susceptible. LD₅₀ values from F₁ to F₉ generations declined from 0.4282 to 0.1802 ppm and LD₉₅ range from 3.3760 to 1.1564ppm, respectively.
- * The susceptibility index to emamectin benzoate 5 SG based on LD₅₀ was 2.37 and 3.03 based on LD₉₅. Rate of resistance decline (R) when selection pressure was stopped was -0.0417. With regard to number of generations required for 10-fold decrease in LD₅₀, was calculated as 27.77.
- * Considering the F₉ *P. gossypiella* population as the most susceptible, the tentative discriminating dose arrived at was 1.1µg larvae⁻¹ for emamectin benzoate 5 SG.
- * The per cent resistance of *H.armigera* in five districts ranged from 3.33 to 10.00. The highest per cent resistance (10) was recorded in Coimbatore district. The survivability of fruit and shoot borer varied from 6.66 to 15.00 per cent for emamectin benzoate. Erode population was found to be highly susceptible which was evident from 0.00 per cent survival during monitoring.
- * The per cent survival pink bollworm varied from 3.33 to 6.66 per cent for emamectin benzoate 5 SG at 1.1µg larvae⁻¹. All five districts population showed the lowest level of resistance.
- * A total of 4232 individuals belonging to 51 families and 14 orders in both sprayed and unsprayed cotton field were recorded. Among the cotton fields, unsprayed cotton showed little higher species richness, abundance and distribution at ordinal, familial, generic and species level followed by sprayed cotton field. Totally, 10 families of araneae were collected with the majority of individuals grouped under the family lycosidae, salticidae, oxyopidae and araneidae.
- * In the present study, totally three families of orthoptera were collected from both sprayed and unsprayed cotton fields. More individuals were collected in the non-sprayed area than the sprayed area.
- * In the order hemiptera, totally nine families were collected. The abundance of *Oxycarenus hyalinipennis* (Costa), *Dysdercus cingulatus* (Fabricius) and *Geocoris* sp.

was higher in unsprayed field than in sprayed cotton field. In heteroptera, the family lygaeidae was more abundant in the sprayed area during the first month of sampling, and then more were recorded in the non-sprayed area than in sprayed area in the succeeding sampling periods.

- * Totally six families of coleopterans were collected from both sprayed and unsprayed fields. Coccinellidae was abundant in unsprayed cotton field than sprayed field.
- * Among the hemiptera families, lygaeidae, pyrrhocoridae, pentatomidae, cicadellidae, aphididae, aleyrodidae and pseudococcidae, yielded the maximum no of individuals.
- * Simpson's index, McIntosh index and Berger Parker index, expressed higher arthropods diversity in unsprayed cotton field and lower was observed in sprayed field.
- * The maximum diversity of arthropods occurred in the month of July.

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* Originals not seen