

**BIOECOLOGY AND MANAGEMENT OF MEALYBUG,  
*Phenacoccus solenopsis* TINSLEY (HEMIPTERA:  
PSEUDOCOCCIDAE) ON Bt COTTON**

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# I. INTRODUCTION

Cotton (*Gossypium* spp) occupies an enviable place amongst the commercial crops of India. Introduction of transgenic Bt cotton for commercial cultivation in India during 2002 has become boon to the cotton growing farmers and have harvested good yields with maximum returns. Bt cotton clearly appears to have been playing a key role in production and productivity. The area under Bt cotton reached 76 lakh ha, accounting nearly 80 per cent of the area under cotton in the country. India has also emerged as a major cotton exporter with 85 lakh bales export in 2008 and 35 lakh bales in 2009. India ranks second in the world in cotton production after China. However, productivity of 560 kg/ha is far less than other cotton growing countries (Anon., 2009).

The development of transgenic cotton has resulted in an immensely increase in the seed-cotton yield and reduction in the insecticidal sprays from 3.10 to 1.17 (Barwale *et al.*, 2004) and from 12.20 sprays on Non Bt to 5.75 sprays on Bt cotton in irrigated ecosystem at Raichur, Karnataka (Patil *et al.*, 2007), which resulted in increase of sucking pests on Bt cotton. Second generation Bt cotton has given solution to the bollworm complex to the larger extent but at the same time they are susceptible to most of the sucking pests *viz.*, thrips, *Thrips tabaci* (Linnman), leaf hoppers, *Amrasca biguttula biguttula* (Ishida) aphids, *Aphis gossypii* (Glover), whitefly, *Bemisia tabaci* (Gennadius) and dusky cotton bug, *Oxycarenus hyalinipennis* (Costa). Recently mirid bug and mealybug have been reported as severe pests on cotton from different parts of the country. In the current decade, the trend of increased build up of various mealybug species in crop plants and in the wild is observed mainly due to certain biotic changes in climate and environment. Mealybug species *viz.*, *Phenacoccus solenopsis* Tinsley, *Phenacoccus solani* Ferris and *Maconellicoccus hirsutus* (Green) have been recorded on cotton in India. Among them *P. solenopsis* is a major and wide spread species in the country (Nagrare *et al.*, 2009).

Mealybug, *P. solenopsis* (Hemiptera: Pseudococcidae) is a pest of ornamental and fruit trees world wide and is known to be cryptic in nature. It was described originally from the U.S. in 1898 and it remained there until 1992. Later it was reported in Central America, the Caribbean and Ecuador (Williams *et al.*, 1992 and Ben-Dov, 2004). Its occurrence in other areas is not surprising because insects that were previously found in a particular area are now occurring in other new geographic areas where they are believed to have been introduced. Its existence was reported for the first time in Brazil on tomato plant (Mark and Penny, 2005). This mealybug has been found previously on a relatively wide variety of host plants including species in economically important families such as Solanaceae, Cucurbitaceae and Fabaceae.

Recently, *P. solenopsis* has emerged as a serious sucking pest of cotton due to decrease in the number of pesticidal applications in cotton agro-ecosystem, and caused serious damage in cotton in Pakistan during 2005 (Abbas *et al.*, 2005). In India cotton mealybug is known to be introduced from Pakistan since the three largest cotton players in Asia are China, India and Pakistan which share common borders that make them vulnerable to insect and disease transfers (Anon., 2006). Later it has spread to cotton crop in some districts of Punjab but in 2007 it has spread throughout major cotton growing districts and caused 30 to 40 per cent loss in cotton yield (Dhawan *et al.*, 2007). Mealybug infestation was also recorded on *Gossypium hirsutum* in all the nine cotton growing states of India *viz.*, Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh and Karantaka (Dharajyoti *et al.*, 2008).

Severe economic damage to *G. hirsutum* was reported in 2007 in four major cotton growing districts of Punjab, two districts of Haryana, and low to moderate damage in parts of Maharashtra, Tamil Nadu and Andhra Pradesh (Dharajyoti *et al.*, 2008 and Dhawan, 2008). Nearly 2000 acres of cotton destroyed by mealybug and over 100 acres of infested cotton was uprooted in Bhatinda and estimated loss ranged from US\$ 400000 to 500000 in North India alone (Goswami, 2007).

In Karnataka, mealybug appeared in isolated patches of cotton growing districts during 2006. Later it was found in the cotton growing districts of Raichur, Bellary, Gulbarga, Haveri, Dharwad and Belgaum during 2007-08. Mealybug incidence was more in the Tungabhadra project (TBP) and Upper Krishna Project (UKP) areas which comprises major irrigated cotton (Hanchinal *et al.*, 2009).

The mealy bugs feed on phloem tissue, removing plant sap and causing leaves to distort yellow and dry. They feed on all parts of a plant, particularly new growth. Yellowing of leaves or leaf drop is the symptom of its infestation. They can be observed particularly on growing tips or on leaves that join stems or along leaf veins. Like the aphids, mealy bugs also excrete the honeydew substance over plant surfaces and sometimes a secondary fungus called black sooty mold that grows on it and reduces the quality of the lint.

The change of pesticide usage with new technological development or by introduction of transgenic insect tolerant plants into farming ecosystem and favourable weather conditions from last five years has resulted this new pest problem. Thus incidence of mealybugs hitherto unknown as pest on cotton has emerged as a key pest and assumed a magnitude of production threat.

Management of mealybug is difficult due to its wide host range, presence of waxy coating on the body and high reproductive potential. But the crawler stage is the most fragile and easily controllable stage in its life history. Recently some organophosphates, insect growth regulators (IGRs) and Bio-pesticides have been recommended for the control of mealybug (Suresh *et al.*, 2010).

Therefore it is necessary to understand the status of this pest in both irrigated and rainfed situation comprising major cotton growing districts of North Karnataka with respect to seasonal fluctuation of mealybug and their primary predatory and parasitoid population. For better management of cotton mealybug, it is necessary to understand its life history, so as to target the pest at its weak stage of life span. Economic threshold level of mealybug and loss caused by them is very much lacking in cotton growing areas. Evaluation of new and safer molecules along with conventional pesticides against mealybug is the need of the hour. Further, there is an immediate need to develop economically feasible and viable integrated pest management approach to combat the insect pests under irrigated situation on Bt cotton. Keeping the above points in view, the detailed investigation against mealy bug on Bt cotton was undertaken with the following objectives:

1. Survey on species diversity and level of mealybug incidence on Bt cotton in North Karnataka.
2. To identify the natural enemies and alternate hosts of mealybug.
3. Population dynamics of mealybug and its natural enemies on Bt cotton.
4. Biology of mealybug, *P. solenopsis* and its predator *Cryptolaemus montrouzieri*.
5. Crop loss estimation due to mealybug damage and economic injury level (EIL) on Bt cotton and
6. Management of mealybug on Bt cotton under irrigated ecosystem.

## II. REVIEW OF LITERATURE

The literature pertaining to the cotton mealybug *Phenacoccus solenopsis* Tinsley is scanty, hence related species of mealybugs which were recorded on cotton has been reviewed and presented here under the following objectives. (i) Survey of mealybug in North Karnataka to determine the species and status of incidence on Bt cotton, (ii) To identify the natural enemies and alternate hosts of mealybug, (iii) Studies on population dynamics of mealybug and its natural enemies on Bt cotton, (iv) Studies on the biology of mealybug on Bt cotton and its predator *Cryptolaemus montrouzieri* Muls. (v) Studies on the crop loss estimation due to mealybug damage and development of ETL on Bt cotton. and (vi) Studies on the management of mealybug on Bt cotton under irrigated ecosystem.

### 2.1 Survey of mealybug in North Karnataka to determine the species diversity and level of incidence on Bt cotton

Mealybug, *Maconellicoccus hirsutus* (Green) incidence was first reported by (Dhawan *et al.*, 1980) on cotton, *Gossypium arborium* (Linn.) in Punjab, India. Fuchs *et al.*(1991) first time recorded mealybug *Phenacoccus solenopsis* as miner pest in cultivated cotton in USA and *M. hirsutus* has been recorded on new world cotton, *Gossypium herbaceum* (Linn.) in Gujarat (Muralidharan and Badaya, 2000).

Three species of mealy bug were recorded on cotton crop *i.e.* *Phenacoccus* sp., *Ferrisa* sp. and *Maconellicoccus* sp. Among them, the dominant species in Punjab was *Phenacoccus* sp (Dhawan, 2007). Further it was also reported that mealybug appeared in some pockets in Ferozepur (Abohar), Muktsar (Malout) and Bathinda (Sangat) districts in Punjab during 2006-07. Damage was comparatively more in Muktsar district followed by Bathinda and Ferozepur. Mealybug was observed in all types of cotton including Bt cotton hybrids, American varieties (*Gossypium hirsutum*) and cultivated cotton hybrids.

Tanwar *et al.* (2007) reported that cotton crop in Punjab, Rajasthan, Maharashtra and Gujarat was seriously infested with mealybug. Sudden appearance of the mealybug pest on cotton in Multan, Sanghar, Mirpurkhas and Tando Allahyar of Pakistan destroyed the entire crop within a few days during 2005.

According to Durgaprasad *et al.* (2008), the infestation of mealybug was seen in an extent of 50 to 75 % fields with damage ranging from 1 to 5 per cent. Dominant species of mealy bugs recorded were *P. solenopsis* Tinsley and *M. hirsutus* Green during 2007- 08 cropping season in Andhra Pradesh.

Acharya *et al.*(2008) conducted rowing survey in Rajasthan and they observed the the incidence of mealy bug on Bt cotton in Sriganganagar and Hanumangarh districts. Infestation of mealy bug was also noticed on desi cotton only due to the fact that farmers were using minimum pesticide in the crop after appearing of first flush of fruiting bodies. The level of incidence ranged from 10 to 50 per cent in cotton fields in both the districts.

Thomas and Ramamurthy (2008) made studies on the mealybugs collected from different parts of India on cotton and other hosts which revealed the abundance of *P. solenopsis*. These studies also revealed confusions in the identification of this species due to synonymy, misidentifications and anomalies due to material preparation, terminology and interpretation of taxonomic characters, in particular, the multilocular disc pores and circulus in the abdominal segments.

A survey was conducted in 47 locations in nine cotton-growing states of India to identify the composition of mealybug species occurring on cotton (Nagrare *et al.*, 2009). Results of the taxonomic study showed that two mealybug species, *P. solenopsis* and the pink hibiscus mealybug, *M. hirsutus* were found to infest cotton plants from all nine cotton growing states of the country. However, *P. solenopsis* was found to be the predominant

mealybug species, comprising 95 per cent of the samples examined. *P. solenopsis*, which was hitherto not reported to occur in India, now appears to be widespread on cotton in almost all cotton-growing states of the country.

Akintola and Ande (2008) reported that mealybugs were found in the southern guinea savanna of Nigeria on Hibiscus plants. Specimens were identified as *P. solenopsis* by Douglas Miller (Systematic Entomology Laboratory, USA) based on the tip of the abdomen which protruded with long setae, various body appendages and the life cycle studies. Comparison between this mealybug and other related species was done and documented for the first time in Nigeria.

The incidence of mealy bug, *P. solenopsis* was recorded from the South-Western districts of Punjab i.e. Mansa, Bathinda, Muktsar, Faridkot and Ferozepur. The highest field infestation recorded was mostly in the 30<sup>th</sup> meteorological week with 14.9, 31.5 and 26.9 per cent in Bathinda, Muktsar and Ferozepur district, respectively. In Faridkot, the highest field infestation of 10.2 per cent was recorded in 34<sup>th</sup> meteorological week (Dhawan *et al.*, 2009).

Saini *et al.* (2009) conducted survey in Haryana on mealy bug, *P. solenopsis* and they reported that it was first recorded in 2006 in Dabwali area of Sirsa District, adjoining Punjab and emerged as a serious pest on cotton in subsequent years. *P. solenopsis* is differentiated from other mealy bug species by the following characters: presence of two black longitudinal stripes having three prominent dorsomedial spots on abdomen; two black spots interiorly with sickle shaped line originating from each spot; wax along mid dorsal line up-raised; 9-segmented plumose antennae, and a well developed ovisac ventrally.

Mealy bug, *P. solenopsis* was the dominant species over large areas of all the three cotton growing regions widely cultivating Bt hybrids across cropping systems in India was reported by Deshmukh *et al.* (2009). Similarly *P. solenopsis* and pink hibiscus mealy bug *Maconellicoccus hirsutus* (Green) occur on rainfed cotton dominated by Bt transgenic hybrids of central India (Pinjarkar *et al.*, 2009).

Bhosle *et al.*(2009) conducted survey during rainy season of 2008 on the incidence of mealybugs in Marathwada region on different transgenic cotton hybrids. Incidence of *P. solenopsis* was maximum in Parbhani with 40.95 per cent leaf infestation and 35.77 per cent of green boll damage. Lowest incidence was recorded in Hingoli district with 11.37% leaf infestation and 10.10% of green boll damage.

Saini *et al.*(2009) conducted survey to investigate the off season survival of the mealybug in cotton growing belt of the Punjab in 2007 and 2008 which revealed that the pest survived on more than 28 species of plants.

## 2.2 To identify the natural enemies and alternate hosts of mealybug

### 2.2.1 Natural enemies

Some of the Hymenopteran parasitoids were common on both *P. solenopsis* and *M. hirsutus*. A total of eleven parasitoids all belonging to order Hymenoptera has been recorded on *M. hirsutus*. Of these parasitoids, *Anagyrus kamali* Moursi parasitised *M. hirsutus* to an extent of 66-100 per cent in Egypt (Moursi,1948).

In India, *Anagyrus* sp. was an important parasitoid causing 19-47 per cent parasitisation in West Bengal (Ghose, 1971b). According to Manjunath (1985), *Anagyrus daotylopii* (How.) was found parasitising *M. hirsutus* on grapes to an extent of 70 per cent in Bangalore.

Twenty nine species of predators belonging to five insect orders have been reported on *M. hirsutus*. Of these predators, *C. montrouzieri* has been introduced and evaluated for the control of *M. hirsutus* in Egypt and India. (Ranga Reddy and Lakshminarayana, 1986).

Several species of *Scymnus* were also recorded as active predators of *M. hirsutus* (Misra, 1919; Hall 1921; Dutt *et al.*, 1951; Rao, 1967 and Manjunath, 1985).

Hymenopteran parasitoid, *Promuscidea unfasciiventris* Girault (Chalcidoidea: Aphelinidae) on mealybug was earlier reported from Andhra Pradesh, Bihar, Delhi, Karnataka and Maharashtra by Sinha *et al.* (1985) and Hayat (1986). Mani (1986) conducted a field experiment to study the population of grape mealybug and its predator, *Cryptolaemus montrozieri* at Kadur. Initial population of mealybug was 53.40/ ten shoots. After releasing predator at five adults per vine reduced the population to 12.25 within 90 days. He also reported six species of parasitoids and seven species of predators on *M. hirsutus*. Among parasitoids, *Anagyrus dactylopii* (How.) recorded maximum parasitisation as compared to others.

Malleshaiah (1995) reported the consumption of citrus mealybug by different instar of predator *Chrysoperla cornea* (Stephens). Individual grub of predator consumed 3583.75, 728.52 and 96.39 eggs, nymphs and adults of citrus mealybug, respectively.

According to Mani and Krishnamoorthy (1997), parasitoids such as *Coccidoxenoides peregrinus* (Timberlake) and *Leptomastix dactylopii* How are potential parasitoids of *P. citri* on sapota. However, they do not appear to regulate *P. citri* throughout the year and are active only during specified months. Among the predators *Scymnus coccivora*, *C. montrozieri*, *Chrysopa sp.* and *spalgius epius* (West.) recorded maximum activity and predation. Above mentioned parasitoids and predators were also reported on citrus mealybug by Malleshaiah *et al.* (1999).

Sureshan and Narendran (2005) reported that hymenopteran parasitoid *Promuscidea unfasciiventris* on coccids, *H. rosasinensis* in Maharashtra. Survey conducted in Pusa campus and nearby areas in Delhi during July and August, 2008 indicated the presence of cocoons of a hymenopterous parasitoid, *Aenasius* sp. (Chalcidoidea: Encyrtidae) on mealy bug, *Phenacoccus solenopsis* infesting *P. hysterothorus*, *Xanthium strumarium* L. and *Achyranthes aspera* L. Its parasitization on these weeds ranged from 20-70 per cent. The parasitoid cocoons appeared brown in colour among the mealy bugs.

Tanwar *et al.* (2008) conducted survey in five Tehsils of Parbhani district (Maharashtra) indicating the presence of cocoons of parasitoid, *P. unfasciiventris* parasitizing *P. solenopsis* on cotton and *P. hysterothorus* in four out of the five Tehsils. This parasitoid is a solitary endoparasitoid causing mealy bugs to swell and change their colour to light brown. The developing larva at the later stage turns the mealy bug into a legless, brown, barrel-shaped mummy with dark brown in colour.

Saini *et al.* (2009) observed a nymphal parasitoid, *Aenasius* sp. during sampling and rearing of mealy bug on cotton which has been recently named as *Aenasius bambawalei* Hayat (Encyrtidae : Hymenoptera), which caused 5-90 per cent parasitization of this pest in different areas. It was also parasitized mealy bugs present on other host plants, indicating its great potential for exploitation in biological control.

A survey conducted on the occurrence of natural enemies of mealy bugs during 2007 and 2008 seasons on cotton led to records of higher diversity and abundance of hymenopteran parasitoids on *M. hirsutus* than *P. solenopsis*. A total of three and nine parasitoids were documented on *P. solenopsis* and *M. hirsutus*, respectively. While *A. bambawalei* (Encyrtidae) was recorded only on *P. solenopsis*, two species viz., *P. unfasciiventris* and *Aprostocetus bangaloricus* Narendran (Eulophidae) were recorded on both *P. solenopsis* and *M. hirsutus* (Pinjarkar *et al.*, 2009).

Gulsarbanu *et al.* (2009) have made survey in order to get information on the role of naturally occurring pathogens in the regulation of mealy bug population. Survey resulted in the recovery and isolation of the following fungi from mealy bug, *Aspergillus clavatus*, *A. oryzae*, *A. terreus*, *Verticillium* sp. and *Lecanicillium lecanii* (Zimm.) Zare & Gams. Among them *L. lecanii* was found to be highly pathogenic to *P. solenopsis* under laboratory condition. At an initial inoculum of  $1 \times 10^4$  conidia mL<sup>-1</sup>, lethal time (LT<sub>50</sub>) was 3.77 and 2.51 days for

nymphs and adults respectively. This was the first report on the natural occurrence of entomopathogenic fungi from mealy bug.

### 2.2.2 Alternate hosts

The pink hibiscus mealybug, *M. hirsutus* was reported as a pest of many plants, trees, and shrubs. It infests hibiscus, citrus, coffee, sugar cane, annonas, plums, guava, mango, okra, sorrel, teak, pigeon pea, peanut, grape vines, maize, asparagus, chrysanthemum, beans, cotton, soybean, cocoa, and many other plants (Mani, 1986). Similarly Tanwar *et al.* (2007) reported that mealybugs are polyphagous, feeding on variety of plants belonging to Malvaceae, Solanaceae and Leguminaceae. The host range of mealybugs includes grape, fig, date palm, apple, avocado, banana, citrus, okra, tomato, brinjal, cotton and few ornamentals. *Hibiscus rosa - sinensis* is a typical host which is frequently attacked by *Maconellicoccus hirsutus*.

Dhawan (2007) reported that, carryover of mealybugs was mainly through the weeds in cotton fields, ants, water channels and wastelands. Polyphagous nature of cotton mealy bug migrated to number of plants after the uprooting of cotton stocks. Besides, this pest can also survive on a number of tree plantations during the off-season. Similarly Acharya *et al.* (2008) observed that, *Parthenium hysterophorus* was the most preferred host and as good as breeding sites for the pest. Mealybugs were survived on this host and then migrated to cotton.

Rathod *et al.* (2008) made survey and found that an unusual severe infestation of mealybug, *M. hirsutus* on sunflower, *Helianthus annuus* which is an important oilseed crop grown in kharif, rabi and summer seasons in Western Vidarbha, Maharashtra. It was also reported in Akola, Buldhana and Amravati districts and emerged as a new pest.

Deshmukh *et al.* (2009) conducted the survey for host range under the rainfed cotton production system which revealed a total record of 91 host plants spread across 24 families. *P.solenopsis* was found multiplying on 30 host plants during the cotton growing season and 61 plants exclusively during off-season. Ten and 27 host plants had the highest severity of Grade 4 during cotton and off seasons, respectively. Plant species from three families' viz., Compositae, Leguminaceae and Malvaceae constituted 50 per cent of the host plants of *P.solenopsis*. Most preferred host plants families of mealybug were in the order of Compositae (10)>Leguminaceae and Malvaceae (eight each) >Amaranthaceae, Euphorbiaceae and Solanaceae (four each) >Graminae (3)>Convolvulaceae and Labiatae (two each). Off season hosts were higher than the growing season indicating the strong carry over between cotton seasons.

Saini *et al.*(2009) reported that cotton mealybug survived on more than 28 species of plants, including okra, egg plant, sesame, guava and some ornamental plants. The most preferred hosts were *Gossypium* spp., *Parthenium hysterophorus* L., *Trianthema portulacastrum* L., *Xanthium strumarium* L., *Tribulus terrestris* L., *Abutilon indicum* L., *Conyza canadensis* L., *Achyranthes aspara* L., *Chenopodium* spp., *Hibiscus rosasinensis* L., *Withmia somnifem* L., etc. From July to December, the pest survived on cotton, *T. partulacastrum*, *P. hysterophorus*, *T. terrestris*, *A. indicum*, *C. canadensis*, *Physalis minima*, *A. aspara*, *Chenopodium* spp., *Helianthus annus*, *Azadirachta indica*, *W. somnifera*, *Datura metel*, *Peristrophe peniculata* and several other unidentified host plants. In January - February, it survived in winter season on stacks of cotton, *C. canadensis*, *A. aspara*, *P. hysterophorus* and *A. indicum*. During March-April, it developed on *W. somnifera*, sprouts from cotton stubbles and *H. rosasinensis*. During May-June, it thrived on early sown cotton, *P. hysterophorus*, *H. rosasinensis*, etc. During winter the pest population declined drastically but it could survive in low numbers on plants growing under trees and shrubs where adverse effect of low temperature on its host plants was less pronounced.

Twenty two host plants were studied for the prevalence of cotton mealy bug, *Phenacoccus solenopsis* from December 2006 to November 2007 in the area around Faisalabad city. Maximum prevalence was observed on China rose (*Hibiscus chinensis*) followed by okra (*Abelmoschus esculentus*) with maximum of 8.11 and 5.41 per cent incidence, respectively. Mealybug remained throughout study period on China rose (Aheer *et*

*al.*, 2009). Where as Nagarare *et al.* (2009) reported that *P.solenopsis* was found on cotton and other crops of 14 families in India.

Further Suresh *et al.* (2010) reported that earlier *P. solenopsis* was predominant in many places of Tamil Nadu and was slowly replaced by *P. marginatus* especially in Coimbatore, Erode and Tiruppur districts. The level of incidence varied from nil to 60 per cent on many crops. He also recorded *P. solenopsis* on sunflower, vegetables (brinjal, tomato, bhendi, cucurbits), pulses and parthenium as alternative hosts.

### 2.3 Population dynamics of mealybug and its natural enemies on Bt cotton

Rishikumar *et al.* (2009) observed the correlation between the mealy bug *P.solenopsis* population with a biotic factors and its vertical and horizontal rate of dispersal on cotton. There was positive correlation among the per cent field infestation, number of infested rows by mealy bug and temperature, whereas negative correlation was observed with relative humidity and rainfall. All the meteorological parameters influenced the incidence of mealy bug on cotton in all the districts studied in Faridkot district where r-value was 0.71 in per cent infestation by mealy bug and 0.76 in rows infested by mealy bug (Dhawan *et al.*, 2009).

Similarly Pinjarkar *et al.*(2009) reported that seasonal mean parasitization of *P. solenopsis* by *A. bambawalei* and *P. unfasciiventris* together was estimated to be 21 per cent with a maximum of 48 per cent during August. The control offered by these hymenopterans on *M.hirsutus* based on the abundance of adult emergence was of the order *Encyrtus aurantii* (Geoffray) > *Promuscidea unfasciiventris* (Girault) > *Prochiloneurus pulchellus* Silvestri > *Chartocerus kerrichi*(Agarwal).

Suresh *et al.* (2010) reported that seasonal incidence of *Phenacoccus solenopsis* population was maximum (35 mealybugs/ 5cm) during June and decreased slowly during September and there was no incidence up to February. Multiple correlation studies with weather parameters and natural enemy activities indicated that there was a significant positive correlation with minimum temperature and significantly negative correlation with relative humidity. For every one unit increase of minimum temperature, there was an increase of 0.77 unit of the pest population and likewise a unit increase in morning relative humidity resulted in decrease in pest population by 0.75 units.

### 2.4 Biology of mealybug, *P. solenopsis* and its predator *Cryptolaemus montrouzieri*

Literature on biology of *P. solenopsis* is limited and hence other mealybug species recorded on cotton are reviewed and presented here under.

Singh and Ghosh (1970) studied life history of *M.hirsutus* on mesta. According to them incubation period occupied 6 to 7 days, nymphal stage occupied 22 days. Pre oviposition period lasted for 3-5 days. Only parthenogenic oviposition was observed. Ghose (1972) reported that *M. hirsutus* was active during winter without hibernation but was most active in March to October. He made detailed investigation of *M. hirsutus* on Roselle. The nymphal development in male and female was completed in 10 to 19 and 11 to 17 days, respectively. Life cycle occupied 23 to 29 days.

Mani (1986) made studies on the biology of *M. hirsutus* and reported incubation period of 5.15 days. The females had three while the males four nymphal instars. The nymphal development in male and female was completed in 24.85 and 26.31 days, respectively when reared on pumpkin fruits in the laboratory. Its fecundity ranged from 386 to 510 eggs.

Tanwar *et al.*(2007) briefly noted that, reproduction in *P.solenopsis* was mostly parthenogenic but some species such as *M.hirsutus* are bi-parental. The female lays eggs in

an egg sac of white wax, usually in clusters on the twigs, branches, or bark of the host plant but sometimes on the plant's leaves and terminal ends. Each egg sac may contain as many as 600 eggs, majority of which are female resulting in explosive outbreak. Eggs are minute, varying from 0.3 to 0.4 mm in length. There are three nymphal instars in female and four in males which lasts for 22-25 days. The last instar of the male was an inactive stage with wing buds within a cocoon of mealy wax

Katke and Balikai (2008) made studies on biology of the grape mealy bug *M. hirsutus* on sprouted potatoes during winter 2005-06 and summer 2006. During winter season, the duration from egg to adult emergence occupied by the female and male was  $29.1 \pm 1.29$  and  $26.5 \pm 1.62$  days, respectively. In summer season, the female and male lives for  $26.4 \pm 1.57$  and  $24.6 \pm 1.53$  days, respectively. The longevity of female ranged from 12-15 days with a mean of  $14.3 \pm 0.85$  days, whereas male lives 3 - 4 days with a mean of  $3.4 \pm 0.46$  days during winter season

According to Mohammad (2008), *P. solenopsis* nymphs feed and develop into adults in approximately 30 days. The female mealy bug produces 10-15 generations per year in colonies of 500-600 eggs. The insect has a life cycle of 24 to 30 days.

Akintola and Ande (2008) determined life history as well as the instar duration in days and documented for each developmental stage. There were three nymphal stages which lasted for six, eight and 10 days in female and the adult stages. The total number of days from egg to adult longevity was 37 days.

Rishikumar *et al.* (2009) studied the life history of *P. solenopsis* in Sirsa. The number of ovisac varied on an average from 2-4 per female. The mealy bug was found as a prolific breeder with mean reproductive potential based on crawler production per female in a range from 289 to 517 on cotton. The numbers of nymphal stages recorded were 3 both in female and male (two nymphal instars and a cocoon). Both 1<sup>st</sup> and 2<sup>nd</sup> instar mealy bug lacked mealy wax secretion. The first instar mealy bug / crawlers lacked permanent feeding site because of high motility. The total nymphal duration in case of male and female was 13-15 days and 14-19 days, respectively. In the last instar female nymph the appearance of mealy wax scale covering entire body was observed but in male secretion of cocoon (puparia) was observed leading to emergence of short lived winged males with two long waxy caudal filaments at the posterior end. The longevity of males and females was 1-1.8 days and 13-16 days, respectively.

Aheer *et al.* (2009) made investigation on biology of *P. solenopsis* on China rose in laboratories of Entomological Research Institute, AARI, Faisalabad (Pakistan) during 2007. There were three nymphal stages in case of female and two in male. The pupal stage in female was absent. Adult male lived for 2 to 3-days and female 45 to 85-days.

#### 2.4.1 Predator, *Cryptolaemus montrouzieri*

##### 2.4.1.1 Biology

Biology of *C. montrouzieri* has been studied earlier by several workers (Hall, 1921; Bishop, 1931; Tirumala Rao and David, 1958; Fisher, 1963; Liotta and Mineo, 1965; Mineo, 1967, Bhat *et al.*, 1981 and Mani, 1986).

The entire life cycle of *C. montrouzieri* was completed in 30 days on *Pseudococcus* sp. Bishop (1931) found that the incubation period occupied 8-10 days while the grub and pupal stage lasted for 20-28 and 14-20 days, respectively in spring.

According to Hall (1921), incubation period was 3-5 days. Grub development took 14-21 days. The pupal stage lasted for 6-9 days on *M. hirsutus*.

Tirumala Rao and David (1958) studied the biology of *C. montrouzieri* on *Dactylopius tomentosus* Lam. The life cycle varied from 24 to 28 days; the egg, grub and pupal stage occupied 3 to 4, 14 to 16 and 7 to 8 days, respectively. According to Fisher (1963), the

development of *C. montrouzieri* was completed in 28 to 29 days, while Liotta and Mineo (1965) found it to occupy 22-36 days on *P. citri*. The study made on the biology of this coccinellid on *P. citri* by Bhat *et al.* (1981) revealed that the incubation period was 5 to 6 days. The duration of the first, second, third and fourth instar grubs were 3 to 4, 4, 4 to 5 and 7 to 8 days, respectively. Prepupal and pupal periods ranged from 3 to 4 and 7 to 8 days, respectively.

The longevity was reported as 52.5 days for male and 80.2 days for female (Tirumala Rao and David, 1958), about 70 days for both (Mineo, 1967) and about 60 days for both (Liotta and Mineo, 1965). According to Fisher (1963) females lived for 50.7 days at 25°C. Bhat *et al.* (1981) reported that males lived for 76.7 days and females for 77.8 days when fed with honey agar plus mealybugs.

Liotta and Mineo (1965) observed the pre-mating period of 1 to 2 days. According to Tirumala Rao and David (1958), pre-mating period was 8-11 days. Bhat *et al.* (1981) reported the mean pre-mating period as 6.2 days. Mineo (1967) found the pre-oviposition period to be 3 to 4 days at temperature of 25°C. According to Bhat *et al.* (1981), the pre-oviposition ranged from 14 to 15 days.

The oviposition lasted for 45 to 68 days (Bhat *et al.*, 1981). According to Mineo (1967), Liotta and Mineo (1965), Fisher (1963), Tirumala Rao and David (1958), Bhat *et al.*, (1981) and Satyanarayanamurthy (1982), the fecundity was 60-120, 90-100, 64-176, 194-729, 207, 229.2 and 89.93 eggs respectively. The sex ratio was 1:1 (Fisher, 1963 and Bhat *et al.*, 1981). Male to female ratio of *C. montrouzieri* when reared on *M. hirsutus* was 1:0.91 (Satyanarayanamurthy, 1982).

Development of *C. montrouzieri* was studied on the eggs, nymphs and adult females of *M. hirsutus*. The life cycle of this coccinellid was prolonged when it was reared on mealybug eggs. Incubation period ranged from 4 to 5 days. The grub took 22.8, 13.85 and 13.45, days when reared on eggs, nymphs and adult female of *M. hirsutus*, respectively. The prepupal and pupal period averaged 2.15 and 8.50 days, respectively. Adult longevity averaged 55.90 days for males and 61.40 days for females. The mean fecundity of a mated female was 210.52. The coccinellid grub consumed a total of 881.30 eggs or 259.00 nymphs or 27.55 adult females of *M. hirsutus* under laboratory conditions (Mani, 1986).

#### 2.4.1.2 Feeding potential

According to Whitcomb (1940), a single grub of *C. montrouzieri* consumed 1325 eggs of *P. citri*. Oncuer and Baylan (1982) reported an individual fourth instar grub consumed an average of 3330 eggs of *P. citri* in Turkey. Satyanarayanamurthy (1982) found a single fourth instar grub eating 188.2 eggs of *M. hirsutus* or 157 eggs of *P. citri*. According to Bhat *et al.* (1981), the average number of mealybugs consumed by 1st, 2nd, 3rd and 4th instar grub was one mealybug in 3 days, one in 2 days, one per day and three mealybugs in 2 days respectively. According to Mani (1986) average number of adult grape mealybugs consumed by 1st, 2nd 3rd and 4th instar grubs of *C. montrouzieri* were 1.65, 3.35, 7.90 and 14.65 mealybugs, respectively.

#### 2.4.1.3 Use of *Cryptolaemus montrouzieri* in the management of mealybugs

Successful utilisation of *C. montrouzieri* in the control of mealybugs on fruit crops has been reviewed and presented here under.

*Cryptolaemus montrouzieri* was native to Australia. In 1892, it was introduced into California for the control of citrus mealybug (Calusen, 1915). Following the success in the control of mealybugs in California, the predatory beetle was introduced into more than 40 countries. The beetle was introduced into India in 1898 by New Port (Puttarudriah *et al.*, 1952 and Mayne, 1953). Later it was recorded from a number of localities in South India as a common predator of mealybugs (Rao *et al.*, 1971). The predator was recovered from Wynaad (Kerala) and Shervaroy Hills (Tamil Nadu) (Chacko *et al.*, 1978 and Chacko, 1979).

According to Smith and Armitage (1920), ten beetles per lemon tree were adequate for the control of the mealybug. The predator gave outstanding control of citrus mealybug in Western Australia (Wilson, 1960). Greathead (1971) reported that *C. montrouzieri* gave complete control of citrus mealybug in South Africa. In Andhra Pradesh (Tenali), a severe infestation of mealybug on citrus was wiped out with the liberation of 10 *Cryptolaemus* per tree (Tirumala Rao and David, 1958). Singh (1978) recommended ten beetles per mandarin plant for the control of citrus mealybug in Coorg.

As early as 1897 an attempt was made with the release of *C. montrouzieri* in Auckland orchards. For sometime good results were not obtained, but in 1901 the mealybugs were under control (Miller, 1924). However, a survey in 1981 revealed the absence of *Cryptolaemus* in the vineyards (Charles, 1981).

Flanders (1940) reported that *C. montrouzieri* was a tree frequenting predator that could not operate effectively against the mealybugs in vineyards. Serious efforts were made in U.S.A. to utilise *C. montrouzieri* for the control of *Pseudococcus maritimus* on vines but did not result in the establishment in vineyards (Barlett, 1977). However, according to Ruiz Castro (1938) this coccinellid was successfully established in Valencia region Of U.S.S.R. against *P. citri* on grapevine. Subsequently Sysoev (1953) reported that *C. montrouzieri* became established in vineyards infested with *P. citri*. In practice, *Cryptolaemus* was most often used against grape mealybug and the rate of release was 3 beetles per plant (Beglyarov and Smetnik, 1977).

In India, attempts were made to evaluate the effectiveness of *C. montrouzieri* in the control of grape mealybug, *M. hirsutus* around Hyderabad. The predator was released during 1979-81. Grubs were observed feeding on the mealybugs in the vineyards where limited sprayings were done in the released plots (Ranga Reddy and Lakshminarayana, 1985).

## 2.5 Crop loss estimation due to mealybug damage and EIL on Bt cotton

The literature pertaining to the crop loss estimation due to mealybug and development of EIL on cotton is lacking and hence related reports are reviewed below.

Dhawan (2007) reported that, four thousand and eight hundred hectares of crop in Sirsa district was affected due to mealybug. In Odhan block, 0.9-1.2 per cent, in Badaguda block 0.9 per cent and in other blocks 0.1-0.9 per cent plants were found to be affected by mealy bug. In severely infested plants, the size of the bolls was reduced and resulted in low yield. Cotton lint was found covered with sooty mould.

During 2007 cotton mealybug *P. solenopsis* has spread throughout major cotton growing districts and caused 30 to 40 per cent loss to cotton yield (Dhawan *et al.*, 2007).

Acharya *et al.* (2008) briefly noted the damage symptoms and loss to cotton crop. The affected plants become distorted, stunted, bunchy top symptoms and reduction in boll number, boll size and seed cotton yields. In heavily attacked plants white masses of wax concealing mealybug accrued on leaf axial, twigs and stem. Two to five more numbers of insecticide sprays were given against mealy bug.

Rathod *et al.* (2008) observed increase in infestation of *P. solenopsis* on sunflower resulted in deformed leaves, become rosette, young shoots respond by curling, twisting and finally showing bushy appearance by shortening of stem internodes and stunted plant growth. Hence, plant withers and occasionally dies. The recorded population ranged from 14.4 to 142 adult mealy bugs per plant, resulting in 60 per cent reduction in seed yield than the normal average yield of morden variety. Similarly, Jhala and Bharpoda (2008) reported that, mealy bug *P. solenopsis* infesting cotton has reduced 50 % yield of cotton yield in Gujarat.

## 2.6 Management of mealybug on Bt cotton under irrigated ecosystem

Bedford *et al.* (1996) evaluated the buprofezin against mealybug (*Planococcus citri*) on celery plants. Destructive analysis of all plants revealed that infestation had been significantly reduced and the effects on mealybugs were greater with higher rate of buprofezin applied.

Irulandi *et al.* (2001) reported that, spraying of neem formulations alone at 15 ml or 25 ml/litre resulted in a significant reduction of 86.56 to 88.33 per cent of coffee mealybug (*Planococcus citri*) population as against 83.55% at recommended dose of quinolphos 20 AF. Combination spray of azadirachtin 10 ml + quinolphos 0.75 ml recorded maximum control of 86.82 per cent.

Balikai (2002) reported that, buprofezin 25 SC @ 1000 ml/ha recorded maximum protection of 80.4 per cent of mealybug, *M. hirsutus* population on grape when sprayed along with fish oil rosin soap (Meenark) @ 3125 g/ha. Similarly, Muthukrishnan *et al.* (2005) reported that buprofezin 25 SC @ 1125 and 1500 ml/ha sprayed thrice at 15 days interval reduced the congregation of *M. hirsutus* on grape and increased the yield. Similarly, Balikai (2005) recommended buprofezin 25 SC @ 1125 ml/ha along with fish oil rosin soap (Meenark) at 3125 g /ha for the management of mealy bug, *Maconellicoccus hirsutus* (Green) on grape vines.

According to Muthukrishnan *et al.* (2005) buprofezin as foliar spray at 1125 and 1500 ml/ha reduced the nymphal and adult population and bunch infestation of *M. hirsutus* and increased the fruit yield as compared to untreated check and recommended insecticides. As the efficacy of both the doses was statistically on par with the lower dose of 1125 ml/ha was sufficient to effectively mitigate the mealy bug colonies. There were no phytotoxic symptoms observed on any part of the treated plants due to any of the insecticides

Vaughn (2006) reported that, mating disruption was most effective when the mealybug density was low, suggesting that for best results a combination of buprofezin application and mating disruption may be necessary, at least initially.

Pre-bloom applications of buprofezin produced the longest sustainable mortality rates of mealybugs, *Pseudococcus* spp. in pome fruits, table and wine grapes (Gonzales and Volosky, 2006).

Dhawan (2007) has given brief note on management of mealybug which involves several aspects *viz.*, control of care taking ants that are important for the proper development of mealybugs. Uproot and destroy the alternate host plants of mealy bug growing on field bunds, water channels and wastelands in the area during the off-season of cotton. Do not throw the uprooted infested plants in cotton fields/water channels to check further spread of mealy bugs to far off areas. Follow cultural operations at monthly interval up to end of May. The recommended insecticides are carbamates like carbaryl 50 WP and thiodicarb 75WP and organophosphates like profenophos 50 EC, quinalphos 25 EC, acephate 75 SP, and chlorpyrifos 20 EC.

According to Dhawan *et al.* (2008), the order of toxicity of insecticides was same for both one day old nymph/crawler and adult female. The order of toxicity was spirotetramate > clothianidin > profenophos > thiodicarb > quinalphos > buprofezin > acephate with their relative toxicity values being 5.05, 2.93, 1.00, 0.84, 0.82, 0.29, 0.25  $\mu\text{g mL}^{-1}$  for one day old nymph/crawlers and 5.29, 2.41, 1.00, 0.96, 0.73, 0.35, 0.19  $\mu\text{g mL}^{-1}$  for the adult female, respectively. Profenophos and thiodicarb proved to be the best insecticides for mealy bug control. Acephate was found to be least toxic against both nymph and adult mealy bug.

Further Dhawan *et al.* (2009) made studies on persistence and residual toxicity of profenophos, thiodicarb, buprofezin, quinalphos, chlorantraniliprole, spirotetramate, acephate, carbaryl and chlorpyrifos at recommended concentrations in field on cotton against first instar and adult female of mealybug *Phenacoccus solenopsis*. Based on the index of persistence toxicity, the order of effectiveness for the crawlers of *P. solenopsis* were

profenophos (637.1)>thiodicarb (587.9)> buprofezin (492.3) >quinalphos (407.9) chlorantraniliprole (380.0) > Spirotetremate (371.6) > acephate (345.7) > carbaryl (314.6) > chlorpyrifos (273.4). Similarly, for the adult female this order of effectiveness was profenophos (572.9) > buprofezin (483.1) > thiodicarb (430.0)> > quinalphos (379.9) chlorantraniliprole (371.6)> spirotetremate (361.3) > acephate (296.7) > carbaryl (260.0) >chlorpyrifos (252.3).

Agarwal *et al.* (2009) evaluated nine treatments of spirotetramat and imidacloprid in mixtures and alone at different doses including two checks, thiodicarb (Larvin 75WP) and profenophos (Curacron 50 EC) and compared to test their effectiveness against mealy bug infestation on cotton. Three days after second spray, profenophos 50 EC (check) recorded 93.73 per cent mortality over control and was at par with spirotetramat 12% + imidacloprid 36% 480 SC (36+108 g ai/ha) (85.09% mortality) and thiodicarb 75 WP 750 g ai/ha (84.48% mortality). The mortality of mealy bug due to single molecules at different doses ranged between 53.04 and 62.39 per cent while the checks showed the promising results as compared to other treatments after the first spray.

Out of 12 insecticides tried as curative spray at 2,7 and 14 days, acephate 70 SP, followed by profenophos 50 EC and diclorvos 76 EC was effective in the management of mealybug. The yield of seed cotton was significantly highest in acephate 70 SP (22.2 q/ha) and profenophos 50 EC (22.2 q/ha) which were at par with each other (Bhosle *et al.*, 2009).

Kharbade *et al.* (2009) recorded that, *Metarhizium anisoplae* @ 2000 gm/ha was most effective by recording minimum of 87.46 mealy bugs/ 5 cm shoot tip length/plant resulting in reduction of mealy bugs over untreated control. This treatment was statistically on par with Neem oil 2000 ml/ha and Dashparni @ 10% in which average of 108.73 and 110. 33 mealy bugs/ 5 cm shoot tip length/ plants were noticed, respectively. The higher seed cotton yield of 1521 kg/ha was obtained in treatment with *M. anisopliae* @ 2000 gm/ha. The untreated control recorded maximum of 322.06 mealy bugs/5 cm shoot tip length/plant with lower seed cotton yield of 913 kg/ha.

Many host plants of *P.solenopsis* could delay the outbreaks on any one crop plant the numerous and widespread host plants would facilitate spatial spread of the insect. Since the occurrence of *P.solenopsis* was on large number of weed hosts over agriculturally important crop plants, cultural management practices such as field sanitation, weed removal and disposal during crop and off seasons play a significant role in preventing spread of *P.solenopsis*. Thus the host plant diversity for *P.solenopsis* can be a boon and bane in rainfed Bt cotton production system (Deshmukh *et al.*, 2009).

Pinjarkar *et al.* (2009) recorded parasitoids belonging to the family Encyrtidae and Aphelinidae of Hymenopterans. These parasitoids regulate the population of *P. solenopsis* and *M. hirsutus* effectively under field conditions. They also opined that strategies of mealybug management placing priority for natural control coupled with cultural control before the curative measure of spray of insecticides would go a long way in tackling mealy bugs in cotton fields.

Suresh *et al.* (2010) evaluated efficacy of different insecticides/ entomopathogen against *P. solenopsis*. The insecticides, profenophos and methyl parathion were found to be quite effective and caused cent per cent mortality one day after treatment while imidacloprid, fish oil rosin soap and dimethoate caused cent per cent mortality after two days of the treatment imposition. All the tested insecticides were found to be quite effective upto 10 days of application. *Beauveria* was found to be moderately effective and caused 77 per cent mortality after 10 days of treatment.

According to Patel *et al.* (2010) more than 95 per cent reduction in mealy bug population over control was observed after 3 DAS in buprofezin in all the three doses (250, 312.5 and 625 g ai/ha). The efficacy of buprofezin against early and later instar nymphs of *P. solenopsis* under laboratory condition was also found to be dose dependent and it was more toxic to early instars than later instar nymphs. It was most effective against early as well as later instars nymphs at highest dose (625 g ai/ha). At 2 lower doses (250 g ai/ha and 312.5 g

ai/ha), its effectiveness was comparable to chlorpyrifos 400 g ai/ha and Carbaryl 1000 g ai/ha.

### 2.6.1 Effect of pesticides on natural enemies.

Evans (1966) reported that dicrotophos virtually did not leave residual toxic to the adults of *Anagyrus* sp. Furness (1977) recorded the mortality of *Anagyrus fusciventris* (Grit.) with maldison, methidathion, methomyl and aminocarb. The LD<sub>50</sub> values ranged from 0.003 to 0.02 for *A. fusciventris*. Parasitoids were also emerged from the insecticide treated mealybug mummies.

Adults of *A. pseudococci* were exposed to leaf surface treated with pesticides namely methidathion, carbophenathion, azinphosmethyl, chlorobenzilate, ethion and oil. The residual toxicity of azinphosmethyl and oil combination gave the highest natural enemy mortality over 35 day post treatment, while a chlorobenzilate-oil combination resulted in the lowest mortality (Meyerdirk *et al.*, 1979). In another residual toxicity test conducted by Meyerdirk *et al.* (1982), diazinon resulted in lower residual toxicity to *A. pseudococci* at one day post treatment as compared to other insecticides. Toxic residual activity of dimethoate and diazinon dropped sharply to non-significant levels on the 9<sup>th</sup> day of treatment and thereafter.

Walton and pringle (1999) studied the effect of regularly used table grape insecticides and fungicides on 1 day-old adults of the parasitoid *Coccidoxenoides peregrinus* (Timberlake) of vine mealybug, *Planococcus ficus* (Signoret), were determined in the laboratory. The insecticides chlorpyrifos, endosulphsn and cypermethrin were higly toxic to the parasitoid, while the fungicides penconazole and mancozeb were not. Results suggested that the insecticides may be detrimental to a biological control system using *C. peregrinus*.

### III. MATERIAL AND METHODS

The present investigation covered six major objectives viz., (i) Survey of mealybug in North Karnataka to determine the species and level of incidence on Bt cotton, (ii) To identify the natural enemies and alternate hosts of mealybug, (iii) Studies on population dynamics of mealybug and its natural enemies on Bt cotton, (iv) Studies on the biology of mealybug, *P. solenopsis* and its predator *Cryptolaemus montrouzieri* Muls. (v) Studies on crop loss estimation due to mealybug damage and development of EIL on Bt cotton and (vi) Studies on the management of mealybug on Bt cotton under irrigated ecosystem. The materials used and the methods followed to conduct the above objectives are as under.

#### 3.1 Survey on species diversity and level of mealybug incidence on Bt cotton in North Karnataka

The survey was confined to major cotton growing districts of North Karnataka to determine the mealybug species and level of infestation on cotton, to find out the host range of mealybug and to identify the natural enemies of mealybug.

Roving survey was conducted during 2008-09 and 2009-10 in major cotton growing districts of North Karnataka viz., Raichur, Bellary, Gulbarga, Dharwad, Belgaum and Haveri (Plate.1 to 3). In each district two talukas were selected for recording mealybug incidence. At each spot one acre of cotton plot was selected and divided into four quadrates and in each quadrate 20 plants were randomly selected for observations. Observation on 20 plants in each infested plot and total number of observations in each taluk and in each districts were recorded and average numbers presented in tables. The observations were recorded at monthly intervals on level of infestation, host range and natural enemies. Incidence of mealybug was recorded in the scale of zero to four ranges on cotton as given by (Anon., 2008).

- 0 -- No damage
- 1 -- Scatter appearance of mealybug
- 2 -- Fully infested on any one of the branch of the plant
- 3 -- Infestation on more than one branch or half portion of the plant
- 4 -- Heavy infestation in total plant

Per cent infestation of mealybug was also worked out by counting infested rows to the total number of rows in the cotton field. Predatory population was also counted on randomly selected 20 plants and expressed as numbers per plant. Parasitoid cocoons (mummified mealybugs) (Plate 4 to 6) were counted and expressed in per cent. From each place adult females were collected from infested cotton plants and as well as on alternate host plants. Collected specimens were preserved in 80 per cent alcohol and sent for identification.

#### 3.2 Identification of natural enemies and alternate hosts in North Karnataka

Number of cocoons (mummified mealybugs) were counted per plant on main shoot in 20 plants and expressed as per cent cocoons per plant. The shoots of cotton infested with mealybug from various places were brought and placed in wooden cages (30 cm x 30 cm x 30 cm) (Plate 7) in the laboratory for emergence of parasitoids and expressed as per cent emergence. Parasitoids that emerged in the cages were collected and preserved in 80 per cent alcohol and sent for identification.

During survey the flora grown in and around the cotton field was also examined for the presence of mealybug and to assess the host range. Predators were also recorded on cotton plants infested with mealybugs.



Plate.1. Mealybug infested cotton field at Raichur



Plate.2. Mealybug infested cotton field at Bellary



Plate.3. Mealybug infested cotton field at Gokak



Plate.4. Parasitoid cocoons on mealybug infested cotton plant



Plate.5. *Anasius bambawalei* on mealybug infested cotton flower



Plate.6. *Anasius bambawalei* on mealybug infested cotton twig

Identification of the mealybug was done by the scientist, Dr. Sandhya Kranthi Entomology division, CICR, Nagpur. Parasitoids identification was done by the scientists, Inset identification service, IARI, New Delhi and T.C. Narendran trust Calicut. Alternate hosts of mealybug such as weeds and plant species were identified with the help of scientists from Agronomy and Botany Department of University of Agricultural Sciences, Raichur

### 3.3 Population dynamics of mealybug and its natural enemies on Bt cotton

Cotton plot at Main Agricultural Research Station, Raichur was maintained for population dynamics and its natural enemies. The study was conducted on hybrid Bt cotton NCS-145 Bt (Bunny Bt) which was a local popular hybrid. The crop was sown in the month of August in both the years and all other recommended cultural practices were followed. Irrigation was given four times during the cropping season. The crop was kept free from insecticidal applications during the period of study. Observations were made at weekly interval throughout the cropping season during 2008-09 and 2009-10.

Twenty plants were selected at random and number of mealybugs were recorded on top 10 cm shoot length of main stem of the cotton plant and expressed as number of mealybugs per 10 cm shoot length. Number of cocoons (mummified mealybugs) were counted per plant on the main shoot on 20 plants and expressed as per cent cocoons per plant.

At each observation, the infested shoots from cotton plant were collected and brought to the laboratory. After counting, the infested cotton shoots were placed in wooden cages and plastic boxes (Plate 8 to 9) for the emergence of parasitoids and expressed as per cent emergence. Predators like coccinellids and *Chrysoperla* were also counted on randomly selected 20 plants and expressed as numbers per plant. Two years data on weather parameters viz., minimum temperature, maximum temperature, lower relative humidity, higher relative humidity, number of rainy days and rainfall were recorded during the period of study to work out the relationship between mealybug population and weather factors using correlation analysis.

### 3.4 Biology of mealybug, *P. solenopsis* and its predator *Cryptolaemus montrouzieri*

Biology of *P. solenopsis* was studied on potato sprouts in the laboratory. The technique of using sprouted potato as an insectary host for mealy bug culture was elaborated by Fisher (1963). Matured ovisacs of *P. solenopsis* producing crawlers were placed on potato sprout for 24 hrs (Plate 10). Observations were made on the development of mealybug right from crawler to adult stage. The number of nymphal instars and interval between moultings were recorded. A total of 50 eggs laid on the same day were held individually in glass vials to determine the incubation period.

Sex ratio of mealybugs reared from potato sprout was worked out by counting the number of females and male cocoons. Twenty ovisacs from the mealybugs reared on potato sprout were examined and the mean number of eggs laid per female was determined. Similarly the development of *P. solenopsis* was also studied on cotton stalk and *Hibiscus* stalk and compared with the development on potato sprout. Freshly emerged 50 nymphs were kept separately in plastic vial measuring 30 ml capacity with 80 mesh cap having moisturized sand carrying the host stick of cotton and *Hibiscus* sp. (Plate 11 to 12) at  $25 \pm 2^\circ\text{C}$  and  $70 \pm 5$  per cent RH. Sex ratio of mealybugs, reared from each host was worked out by counting the number of females, and male cocoons. Twenty mealybugs reared on each host were examined and the mean number of eggs laid per female was determined.



Plate.7. Wooden cages used for parasitoids emergence study



Plate.8. Plastic containers used for parasitoids emergence study



Plate.9. Plastic containers used for parasitoids emergence study



Plate.10. Potato sprouts used for biology study of *P. solenopsis*



Plate.11. Hibiscus stalk used for fecundity study



Plate.12. Cotton stalk used for fecundity study

### 3.4.1 Predator – *Cryptolaemus montrouzieri*

The predator was reared on mealybug, *Maconellicoccus hirsutus* infested pumpkins (Plate 13 to 14) in the laboratory. Initially culture of mealybug *P. solenopsis* was tried on pumpkin but could not succeed. Later it developed on sprouted potato (Plate 15) in the laboratory as suggested by Singh (1978) and Chacko *et al.* (1978).

#### 3.4.1.1 Developmental period of immature stages

The developmental period of immature stages of *C. montrouzieri* was determined by feeding the nymphs and adults of *P. solenopsis*.

The newly hatched predatory grubs (20) were fed individually with 10-15 days old mealybug nymphs until pupation. Fresh nymphs were offered to the predators once in three days. Similar observations on the developmental period of different stages of the predator were recorded. Freshly hatched predatory grubs (20) were fed with adult mealybugs individually and mealybugs were supplied to the predator once in three days until pupation. Observations were made on the duration of different developmental stages of the predator.

#### 3.4.1.2 Longevity and oviposition

Newly emerged beetles were collected and kept in pairs separately and fed with 50 per cent honey in glass vials (7.5 cm x 2.5 cm). To record the oviposition, each pair was transferred to fresh vials daily supplied with the cotton mealybugs to facilitate egg laying. Number of eggs laid by the predator was counted using binocular microscope. This procedure was continued till all the adults died. Observation was also made on pre-oviposition, oviposition and post-oviposition periods and on the longevity of adults. The total number of eggs laid per female was computed at the end. The study on the longevity and oviposition was conducted on ten pairs of adult beetles considering each pair as one replicate.

#### 3.4.1.3 Feeding potential

Experiments were conducted to determine the rate of consumption of different stages of the cotton mealybug (nymphs and adults) by the predatory grubs. After hatching, each predatory grub was confined in a glass vial (10 cm x 2.5 cm) and provided with a known number of preys and observation was taken on the number of preys eaten at every 24 hr. Surviving preys were counted and removed. Fresh preys were offered to the predatory grub every day until pupation. Number of preys consumed by the predatory grub in each instar and also the total number consumed in its grub development were later calculated. The feeding potential studies were conducted with 20 predatory grub where each predatory grub was considered as one replicate (Plate 16 and 18).

### 3.5.1 Crop loss estimation due to mealybug damage and EIL on Bt cotton

Crop loss estimation due to *P. solenopsis* damage on Bt cotton was undertaken by following the concept of comparing the yield from healthy plants with that of infested ones. To know the extent of loss caused by mealybug, pot and field experiments were conducted on NCS -145 Bt during cropping season of 2008-09 and 2009-10, respectively.

Totally five treatments *viz.*, 50, 100, 150, 200 and 250 females per plant with four replications were released on potted cotton plants (Plate 19 to 21). Female mealybugs were released at 60, 90, 120 and 150 days after sowing in different caged plants during 2008-09.



Plate.13. *Cryptolaemus* reared on mealybug infested pumpkin



Plate.14. *Cryptolaemus* grubs and adult on mealybug infested pumpkin



Plate.15. *P. solenopsis* culture maintained on potato plants

During 2009-10 cropping season a field experiment was conducted with six damage levels (D<sub>0</sub> to D<sub>5</sub>) /treatments viz., control (D<sub>0</sub>) 50 (D<sub>1</sub>), 100(D<sub>2</sub>), 150(D<sub>3</sub>), 200(D<sub>4</sub>) and 250(D<sub>5</sub>) female mealybugs per plant with four replications. Six plants were caged for each replication before releasing mealybugs (Plate 22 to 24).

Care was taken to remove all the insect pests including mealybugs if any from plants before enclosing in cages. Observations were recorded on population build up i.e. number of mealybugs per 10 cm shoot length, growth parameters like GOB, BOB and seed cotton yield per plant. Quality parameters were also recorded by analyzing the cotton lint by CIRCOT regional office, Dharwad farm, UAS, Dharwad. Oil estimation of cotton seeds was done at Main Agricultural Research Station, Raichur. Correlation studies were made to know the impact of mealybug damage on plant height, yield parameters and lint quality.

### 3.5.1 Economic injury level for *P. solenopsis* on Bt cotton

Economic injury level was worked out using cage method to avoid the invasion of other pests. Cage size of 2.25 x 2.25 x 2.0 m with 45 μ mesh (Plate 25 and 26) was used covering six plants in each cage. Adult mealybugs were released at 60, 90, 120 and 150 days of sowing at different density levels viz., control (0), 50, 100, 150, 200, and 250 mealybugs per plant.

The actual level of population attained at each infestation levels were counted at weekly interval and the yield reduction at each infestation level was compared with zero level infestation to work out the EIL. Further, mealybug population was correlated with yield reduction observed at each infestation level in comparison with control plot and the regression coefficient was worked out. Economic injury level (EIL) was computed with the help of the following formula adopted by Stone and Pedigo (1972) and modified by Ogunlana and Pedigo (1974).

Treatment details:

Sl. No.	Treatments
1.	0 (No mealybugs)
2.	50 mealybugs per plant
3.	100 mealybugs per plant
4.	150 mealybugs per plant
5.	200 mealybugs per plant
6.	250 mealybugs per plant

For calculation of EIL, the cost of mealybug control was recorded from the data generated without cage with spray of selected insecticides. Cost of protection was worked out based on prevailing market value and cost of average seed cotton price was taken from APMC, Raichur. Gain threshold (GT) and loss per treatment were worked out based on yield reduction per mealybug using the following formula.

$$\text{Gain Threshold (GT)} = \frac{\text{Management cost (Rs./ha)}}{\text{Market value of the produce (Rs/q)}}$$

Regression co-efficient (b) was worked out using the formula

$$b = \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}}$$



Plate.16. Cryptolaemus grub feeding on *P. solenopsis* adult



Plate.17. Fourth instar cryptolaemus grub



Plate.18. Adult cryptolaemus feeding on *P. solenopsis*



Plate.19. Crop loss estimation on potted plants during 2008-09



Plate.20 Mealybug, *P. solenopsis* population on caged plant



Plate.21. Wilted cotton plant due to mealybug damage



Plate.22. Crop loss estimation in field conditions during 2009-10



Plate.23. *P. solenopsis* population and honeydew on caged plant



Plate.24. Dried cotton plants due to mealybug damage

Where,

X = Number of mealybugs released per plant

Y = Seed cotton yield (q/ha)

N = Number of observations

GT

Then EIL =  $\frac{GT}{\text{Yield reduction (q/ha) per mealybug adult (b)}}$

### 3.6 Management of mealybug on Bt cotton under irrigated ecosystem

Field experiment was conducted during 2008-09 and 2009-10 to evaluate the efficacy of insecticides and bioagents against *P. solenopsis* on Bt cotton NCS-145 (Bunny) at Main Agricultural Research Station, UAS, Raichur. The experiment was laid out in a randomized block design with twelve treatments during 2008-09 and fourteen treatments during 2009-10. The experiment was replicated thrice in both the years. Plot sizes of 7.20 x 6.00 m with a spacing of 90 x 60 cm between row to row and plant to plant were maintained (Plate 27). In each plot 80 plants were maintained and five plants were randomly selected and tagged for observation. In both the years, agronomic practices were followed as per the recommended package of practices (Anon., 2008).

In both the years two rounds of treatments were imposed and two rounds of common sprays were taken to combat early sucking pests of cotton. Treatments were imposed when sufficient number of mealybug population was observed in the experimental block. Mealybugs were recorded on top apical shoot and presented as number of mealybugs/10 cm shoot length. Observations were recorded a day before spray and one, three, seven and 14 days after spray.

Reduction in the mealybug population in different treatments was calculated and transferred to square root transformation for statistical analysis. Yield parameters like GOB, BOB and seed cotton yield were recorded per plot and computed per hectare.

Effect of pesticides on parasitoids emergence was also recorded a day before spray and three, seven and 14 days after spray. After each spray adult mealybugs were brought to the laboratory along with twigs and kept in cages for emergence of parasitoids and expressed as per cent emergence. The details of the treatments during 2008-09 and 2009-10 seasons are given below.

Treatment details during 2008-09

Sl. No.	Treatments	Commercial formulations Dose g/ml/ha
1.	Thiodicarb 75WP	625 g
2.	Profenophos 50EC	1500 ml
3.	Profenophos 50EC + Soap water	1500 ml + 1%
4.	Quinalphos 25EC	2000 ml
5.	Acephate 75SP	2000 g
6.	Chlorpyriphos 20EC	2500 ml
7.	Buprofezin 25 SC	1000 ml
8.	Neem oil	2000 ml
9.	Neemark1500 ppm	5000 ml
10.	<i>Cryptoleamus</i> grubs	10/plant
11.	Soap water	1%
12.	Untreated Control	--



Plate.25. Field of EIL estimation due to mealybug on cotton



Plate.26. *P. solenopsis* population on cotton shoot



Plate.27. Field view of bioefficacy studies plot

Treatment details during 2009-10

Sl. No.	Treatments	Commercial formulations Dose g/ml/ha
1.	Thiodicarb 75WP	625 g
2.	Profenophos 50EC	1500 ml
3.	Profenophos 50EC	2000 ml
4.	Quinalphos 25EC	2000ml
5.	Acephate 75SP	2000 g
6.	Chlorpyriphos 20EC	2500 ml
7.	Buprofezin 25 SC	1000 ml
8.	Buprofezin 25 SC	1500 ml
9.	Neem oil	2000 ml
10.	Neemark1500 ppm	5000 ml
11.	Fish oil rosin soap	3125 ml
12.	<i>Verticillium lecanii</i>	2000 g
13.	Un treated Control	--

## IV. EXPERIMENTAL RESULTS

The results of the experiments conducted on the following objectives viz., Survey of mealybug in North Karnataka to determine the species and status of incidence on Bt cotton, To identify the natural enemies and alternate hosts of mealybug, Studies on population dynamics of mealybug and its natural enemies on Bt cotton, Studies on the biology of mealybug, , *Phenacoccus solenopsis* Tinsley and its predator *Cryptolaemus montrouzieri* Muls., Studies on the crop loss estimation due to mealybug damage and development of EIL on Bt cotton and Studies on the management of mealybug on Bt cotton under irrigated ecosystem and presented here under.

### 4.1 Survey on species diversity and level of mealybug incidence on Bt cotton in North Karnataka

#### 4.1.1 Mealybug species attacking cotton

It was evident from the survey that the species available in the region on Bt cotton was *P. solenopsis* Tinsley identified using DNA analysis at Central Institute for Cotton Research, Nagpur, India. The species was found common in several areas of cotton growing states of country. Since *P. solenopsis* was the only species commonly found in the cotton fields, the pest status was determined by surveying the major cotton growing areas in North Karnataka. Mealybug was found in all the major cotton growing districts viz., Raichur, Bellary, Parts of Gulbarga, Dharwad, Haveri and Belgaum (Table 1).

#### 4.1.1.2 Pest status of *P. solenopsis*

Mealybug incidence was assessed in the scale of zero to four grades and infestation ranged between zero to 3.62 through out the cotton growing Northern districts. Incidence was initially low during June to November and there after gradually increased at the end of the season. In general mealybug infestation on cotton was high in Thungabhadra Project area (TBP) and Upper Krishna Project area (UKP) which comprises of Bellary, Raichur and Gulbarga districts. Mean mealybug grade was as high as 3.42, 3.15 and 3.34 in Raichur, Gulbarga and Bellary districts, respectively. Mean mealybug population grade of 1.32, 1.04, 1.33, 0.57, 0.71 and 1.03 were recorded at Raichur, Gulbarga, Bellary, Dharwad, Belgaum and Haveri districts, respectively during 2008-09 cropping season (Table1).

Similarly, 2009-10 cropping season survey revealed that, mealybug infestation was low as compared to previous season due to intermittent rains in November and January and presence of parasitoids in Northern Karnataka. Incidence of mealybug appeared in the month of August in most of the cotton growing districts. *Phenacoccus solenopsis* was severe in some parts of Bellary and Raichur districts and the mean infestation grade ranged between zero to 2.78 and zero to 2.58, respectively. Maximum mean infestation grade was recorded in Bellary taluk (1.20) followed by Raichur taluk (1.11) and Siruguppa taluk (1.09). Moderate to low mean population grade of 0.74, 0.59, 0.41 and 0.13 were recorded in Gulbarga, Belgaum, Haveri and Dharwad districts, respectively (Table 2).

Per cent infestation of mealybug presented in table 3 and 4 revealed that *P. solenopsis* was severe in isolated patches of cotton fields in Raichur, Bellary and Gulbarga districts. Field infestation varied from 8.33 to 36.30 per cent in different taluks of North Karnataka. The problem posed by *P. solenopsis* was high in Raichur and Bellary districts wherein maximum cotton fields were infested with mealybug. Extensive damage (20.14 to 36.30%) was observed in four taluks namely Raichur, Deodurg, Bellary and Siruguppa. Mealybug infestation in Raichur taluk was highest and ranged from zero in June to 71.40 per cent in March during 2008-09 season. At Dharwad and Hubli taluks of Dharwad district, several cotton fields were infested moderately with the mealybug and the per cent infestation ranged from zero to 18.5. Infestation in Gokak and Bailhongal taluks of Belgaum district ranged from zero to 24.22 per cent with a mean of 12.56 to 10.64 per cent, respectively.

Table 1. Incidence of *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2008-09 season

Month	Zero to 4 scale *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.08	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.31	0.00	0.16	0.00	0.00	0.00	0.22	0.11	0.17	0.00	0.12	0.06	0.00	0.00	0.00	0.07	0.04	0.06
August	0.52	0.24	0.38	0.22	0.20	0.21	0.28	0.18	0.23	0.12	0.18	0.15	0.04	0.02	0.03	1.08	0.08	0.58
September	0.75	0.32	0.54	0.15	0.31	0.23	0.31	0.22	0.27	0.15	0.23	0.19	0.05	0.08	0.07	1.14	1.13	1.14
October	0.80	0.42	0.61	0.32	0.35	0.34	0.35	0.35	0.35	0.16	0.25	0.21	0.08	0.08	0.08	1.33	1.28	1.31
November	1.10	0.48	0.79	0.82	0.28	0.55	1.28	0.82	1.05	0.18	0.28	0.23	1.02	1.12	1.07	1.24	1.35	1.30
December	2.41	0.62	1.52	1.14	0.32	0.73	2.14	1.35	1.75	0.22	0.32	0.27	1.12	1.20	1.16	1.54	1.88	1.71
January	2.82	2.12	2.47	2.18	2.12	2.15	3.21	2.12	2.67	0.31	1.12	0.72	1.25	2.10	1.68	1.22	1.12	1.17
February	3.51	3.10	3.31	3.04	3.08	3.06	3.45	3.22	3.34	2.15	1.38	1.77	2.18	1.18	1.68	1.84	1.45	1.65
March	3.62	3.22	3.42	3.14	3.15	3.15	3.56	3.12	3.34	1.82	2.40	2.11	1.20	1.35	1.28	0.85	1.88	1.37
Mean	1.58	1.05	1.32	1.10	0.98	1.04	1.50	1.16	1.33	0.51	0.63	0.57	0.69	0.71	0.70	1.03	1.02	1.03

\* Mean of 20 plants

Large area of rainfed cotton fields in Haveri district were infected with mealybug where in incidence in Haveri and Shiggaon taluks ranged from zero to 24.32 per cent with a mean of 16.50 and 11.33 per cent, respectively (Table 3).

During 2009-10 cropping season, mean per cent infestation of mealybug on cotton across North Karnataka ranged from lowest of 2.96 in Dharwad district to highest of 12.47 in Raichur district. Over all infestation was low as compared to 2008-09 cropping season. Similarly *P. solenopsis* infestation was maximum in TBP and UKP areas which ranged from 9.65 to 12.47 per cent. Its appearance started in the month of September (12.11%) and reached maximum (40.40%) during March 2010 in Raichur taluk. The incidence appeared early in the month of July and August in Dharwad, Belgaum and Haveri districts due to early sowing and in some parts on summer grown irrigated cotton crop. It was also noticed on left over cotton fields of previous season in Gokak taluk of Belgaum district which recorded 0.11 per cent in July 2009 (Table 4).

## 4.2 Natural enemies and alternative hosts of mealybug

The natural enemies found attacking *P. solenopsis* in the cotton field are furnished in table 5 to 10.

### 4.2.1 Predator population

Predatory populations like Coccinellids, *Chrysoperla*, spider and dipterans were recorded during the survey in some places but their population was negligible. All the stages of Coccinellids (Plate 28 & 29) and *Chrysoperla* (Plate 30) were encountered feeding on mealybugs. Mean predatory population ranged from 0.02 to 0.14 per plant across North Karnataka. Maximum mean predatory population of 0.14 per plant was recorded in Raichur and Bellary Talukas during 2008-09 season. Mean predatory population of 0.13, 0.08, 0.12, 0.04, 0.05 and 0.02 in Raichur, Gulbarga, Bellary, Dharwad, Belgaum and Haveri districts, respectively. Predatory activity was maximum from October to January which ranged between 0.12 to 0.32 and 0.18 to 0.32 per plant in Raichur and Deodurg taluks of Raichur district. Similar trend was also observed in all the places however, predatory population was low throughout the cropping season. The dipteran predator, *Gitonides perspicax* Knab (Drosophilidae) was found only at Raichur during January to March 2008-09. The maggots were found to prey on the mealybugs mainly in summer months (Table 5).

During 2009-10 cropping season, again predatory population was very low in all the surveyed places. Predatory population varied between 0.02 to 0.29 per plant from August to December in Raichur district. In Gulbarga district it ranged between 0.01 to 0.17 per plant during peak activity of mealybugs on cotton. Similarly in Bellary, Dharwad, Belgaum and Haveri district predatory population varied from 0.01 to 0.29 per plant during August to December months. Lowest mean predatory population of 0.05 per plant was recorded in both Dharwad and Belgaum districts, whereas maximum of 0.12 and 0.10 mean predators per plant were recorded in Raichur and Bellary districts, respectively (Table 6).

### 4.2.2 Parasitoid population

The data on total parasitoids cocoons present on the mealybug infested cotton plants and adults emergence in laboratory from different cotton growing districts are presented in table 7-10.

Parasitoids activity was found in all the areas of cotton growing districts in both the years (2008-09 and 2009-10). Totally there were five parasitoids recorded belonging to the order Hymenoptera viz., *Aenasius bambawalei* Hayat, *Hamolotylus eytelweinii* (Ratzeburg), *Prochiloneurus pulchellus* Silvestri and *Anagyrus dactylopii* (Howard), from family Encyrtidae whereas *Promuscidea unfacliventris* Girault belonging to Aphelinidae family. Among all these parasitoids, *A. bambawalei* was the dominant species and its activity was found on *P. solenopsis* at all the places surveyed.

Table 2. Incidence of *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2009-10 season

Month	Zero to 4 scale *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.02	0.15	0.09	0.00	0.00	0.00	0.12	0.14	0.13	0.02	0.00	0.01	0.02	0.02	0.02	0.08	0.08	0.08
September	0.85	0.34	0.60	0.12	0.11	0.12	1.34	1.21	1.28	0.16	0.13	0.15	0.04	0.11	0.08	0.78	0.63	0.71
October	0.88	0.24	0.56	0.10	0.24	0.17	1.38	1.35	1.37	0.11	0.14	0.13	0.06	0.18	0.12	0.81	0.38	0.60
November	0.68	0.48	0.58	0.32	0.18	0.25	0.88	0.22	0.55	0.08	0.11	0.10	0.04	1.12	0.58	0.24	0.25	0.25
December	2.15	0.33	1.24	1.14	0.14	0.64	0.84	0.28	0.56	0.12	0.08	0.10	0.06	0.20	0.13	0.18	0.21	0.20
January	2.04	2.44	2.24	2.12	1.32	1.72	2.07	2.34	2.21	0.31	0.32	0.32	1.27	2.11	1.69	0.42	0.55	0.49
February	2.11	2.67	2.39	2.28	2.18	2.23	2.66	2.54	2.60	0.44	0.48	0.46	2.15	2.18	2.17	1.84	1.08	1.46
March	2.34	2.81	2.58	2.45	2.12	2.28	2.72	2.84	2.78	0.00	0.00	0.00	1.38	0.85	1.12	0.36	0.40	0.38
Mean	1.11	0.95	1.03	0.85	0.63	0.74	1.20	1.09	1.15	0.12	0.13	0.13	0.50	0.68	0.59	0.47	0.36	0.41

\* Mean of 20 plants

Table 3. Per cent infestation of *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2008-09 season

Month	Zero to 4 scale *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	13.22	9.10	11.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	15.44	0.00	7.72	0.00	0.00	0.00	15.24	12.24	13.74	5.22	4.10	4.66	0.00	0.00	0.00	12.10	8.12	10.11
August	18.22	16.10	17.16	10.10	10.10	10.10	18.20	18.10	18.15	4.50	5.24	4.87	9.44	8.40	8.92	14.20	9.25	11.73
September	20.25	17.12	18.69	12.22	12.21	12.22	22.46	15.24	18.85	8.45	8.12	8.29	11.24	10.24	10.74	14.56	9.20	11.88
October	35.50	18.12	26.81	15.40	15.40	15.40	24.23	18.30	21.27	9.50	9.56	9.53	13.25	11.45	12.35	15.20	10.24	12.72
November	40.10	18.10	29.10	18.10	18.34	18.22	28.20	18.24	23.22	10.22	9.20	9.71	15.60	12.20	13.90	16.66	10.60	13.63
December	42.42	23.20	32.81	20.23	22.12	21.18	33.45	23.45	28.45	12.50	10.22	11.36	18.22	13.32	15.77	17.65	13.25	15.45
January	51.22	28.40	39.81	28.40	28.50	28.45	38.30	24.30	31.30	14.25	11.24	12.75	13.46	15.24	14.35	22.10	15.30	18.70
February	68.40	38.15	53.28	32.14	36.44	34.29	40.12	35.42	37.77	18.66	12.10	15.38	20.12	17.25	18.69	28.20	18.55	23.38
March	71.40	42.20	56.80	38.30	38.20	38.25	43.20	41.20	42.20	18.50	13.50	16.00	24.22	18.30	21.26	24.32	18.74	21.53
Mean	36.30	20.14	28.22	17.49	18.13	17.81	27.66	21.56	24.61	10.18	8.33	9.25	12.56	10.64	11.60	16.50	11.33	13.91

\* Mean of 20 plants

Table 4. Per cent infestation of *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2009-10 season

Month	Zero to 4 scale *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.06	0.12	2.10	1.11
August	0.00	0.00	0.00	0.00	0.00	0.00	4.22	8.13	6.18	0.00	0.00	0.00	2.13	2.41	2.27	1.16	2.21	1.69
September	12.11	10.14	11.13	12.34	12.24	12.29	13.54	14.15	13.85	4.16	3.12	3.64	6.20	5.18	5.69	4.52	3.62	4.07
October	10.05	8.88	9.47	11.44	5.48	8.46	15.22	9.11	12.17	5.23	6.53	5.88	4.43	4.68	4.56	4.14	4.18	4.16
November	7.45	8.14	7.80	8.04	7.12	7.58	9.62	7.22	8.42	4.11	5.12	4.62	3.12	5.21	4.17	2.45	3.16	2.81
December	6.48	6.86	6.67	7.22	5.24	6.23	8.12	6.34	7.23	3.22	3.17	3.20	2.45	4.32	3.39	2.64	3.24	2.94
January	16.45	20.41	18.43	18.40	16.33	17.37	11.23	22.31	16.77	6.25	5.12	5.69	4.37	6.24	5.31	5.18	4.68	4.93
February	38.41	28.16	33.29	22.15	18.44	20.30	26.11	25.45	25.78	6.84	6.33	6.59	7.14	6.92	7.03	8.61	8.54	8.58
March	40.40	35.44	37.92	28.31	20.25	24.28	32.12	26.28	29.20	0.04	0.00	0.02	10.21	8.44	9.33	6.48	8.12	7.30
Mean	13.14	11.80	12.47	10.79	8.51	9.65	12.28	11.90	11.96	2.99	2.70	2.96	4.02	4.34	4.18	3.53	3.99	3.76

\* Mean of 20 plants

Table 5. Population of predators on cotton mealybug in different locations of North Karnataka during 2008-09 season

Month	Number of predators per plant *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.04	0.08	0.06	0.02	0.00	0.01	0.08	0.03	0.06	0.02	0.01	0.02	0.00	0.04	0.02	0.00	0.02	0.01
September	0.06	0.09	0.08	0.04	0.04	0.04	0.12	0.04	0.08	0.04	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
October	0.12	0.18	0.15	0.08	0.02	0.05	0.14	0.08	0.11	0.02	0.04	0.03	0.03	0.06	0.05	0.04	0.04	0.04
November	0.25	0.23	0.24	0.22	0.08	0.15	0.28	0.22	0.25	0.04	0.08	0.06	0.06	0.08	0.07	0.08	0.08	0.08
December	0.28	0.32	0.30	0.26	0.11	0.19	0.32	0.32	0.32	0.12	0.11	0.12	0.08	0.13	0.11	0.12	0.04	0.08
January	0.32	0.21	0.27	0.20	0.15	0.18	0.24	0.18	0.21	0.14	0.12	0.13	0.12	0.18	0.15	0.02	0.00	0.01
February	0.30	0.15	0.23	0.18	0.08	0.13	0.14	0.08	0.11	0.08	0.00	0.04	0.08	0.00	0.04	0.00	0.00	0.00
March	0.04	0.02	0.03	0.08	0.04	0.06	0.08	0.02	0.05	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.14	0.13	0.13	0.11	0.05	0.08	0.14	0.10	0.12	0.05	0.04	0.04	0.04	0.05	0.05	0.03	0.02	0.02

\* Mean of 20 plants

Table 6. Population of predators on cotton mealybug in different locations of North Karnataka during 2009-10 season

Month	Number of predators per plant *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.01	0.02	0.02	0.02	0.00	0.01	0.01	0.00	0.01	0.03	0.00	0.02	0.00	0.02	0.01	0.04	0.02	0.03
September	0.02	0.04	0.03	0.03	0.03	0.03	0.13	0.01	0.07	0.04	0.02	0.03	0.02	0.04	0.03	0.12	0.04	0.08
October	0.10	0.12	0.11	0.06	0.02	0.04	0.16	0.04	0.10	0.06	0.05	0.06	0.03	0.12	0.08	0.14	0.11	0.13
November	0.21	0.30	0.26	0.24	0.06	0.15	0.22	0.20	0.21	0.05	0.11	0.08	0.11	0.11	0.11	0.08	0.12	0.10
December	0.22	0.35	0.29	0.22	0.12	0.17	0.34	0.24	0.29	0.14	0.13	0.14	0.12	0.14	0.13	0.14	0.14	0.14
January	0.28	0.20	0.24	0.21	0.13	0.17	0.21	0.14	0.18	0.16	0.14	0.15	0.11	0.18	0.15	0.18	0.04	0.11
February	0.31	0.11	0.21	0.13	0.06	0.10	0.16	0.12	0.14	0.02	0.00	0.01	0.04	0.02	0.03	0.02	0.02	0.02
March	0.04	0.02	0.03	0.05	0.02	0.04	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.12	0.12	0.12	0.10	0.04	0.07	0.13	0.08	0.10	0.05	0.05	0.05	0.04	0.06	0.05	0.07	0.05	0.06

\* Mean of 20 plants



Plate.28. Coccinellid grub feeding on cotton mealybug



Plate.29. Adult predator scymnus coccivora



Plate.30. Chrysoperla grub feeding on mealybug

Parasitoid cocoons (mummified mealybugs) which were brown in colour found on mealybug infested cotton shoots. Mean parasitoid cocoons per plant varied from 2.41 to 10.42 per cent in North Karnataka. Parasitoids activity started in the month of October (3.2%) and gradually increased as the mealybug population reached peak during January (18.9 %) per plant at Raichur taluk. Mean parasitoid cocoons were highest in Bellary district (10.42 %) followed by Raichur district (8.32 %). In Gulbarga district it ranged between lowest of 2.72 in Jevargi taluk during August to a maximum of 19.24 per cent in Shahapur taluk during January. Highest mean parasitoid cocoons of 20.49 per cent were found in the month of January in Bellary district. Parasitoid activity was low in the districts of Dharwad, Belgaum and Haveri and mean cocoons ranged between 2.41 to 4.52 per cent during 2008-09 (Table 7).

The peak activity of the parasitoids was observed mainly from January to March and the parasitism reached up to 34.15 per cent during March 2009-10 in Raichur taluk. These parasitoids were also found to occur in Gulbarga and Bellary districts. The mean parasitism ranged from 5.59 to 6.74 per cent in these areas. The same species was also found in Dharwad, Belgaum and Haveri district where mean parasitism varied from 2.16 to 2.56 per cent. It was lowest in Dharwad and Haveri districts which varied from 2.16 to 2.18. Parasitoid activity was generally low in these districts because of lower mealybug incidence on rainfed cotton which was also terminated early during February (Table 8).

Parasitoids emerged in the laboratory from different locations are furnished in table 9 and 10. During 2008-09 cropping season, mealybugs collected from different locations for the presence of parasitoids revealed that, *A. bambawalei* was a dominant solitary endo parasitoid of nymphs and adults of *P. solenopsis*. It was reared from the mealybug samples collected from all the cotton growing districts in North Karnataka. *Anagyryus dactylopii* was the next major parasitoid and others were of least importance. Mean per cent emergence of parasitoids from all the districts varied from 1.29 to 7.33. Emergence of parasitoids in laboratory started in the month of October which recorded 2.52 per cent and it gradually increased up to 18.45 per cent in January which coincided with peak increasing activity of mealybugs on cotton in Raichur taluk. Similar trend was observed with respect to parasitoid emergence in all the places. Maximum mean parasitoids emergence (7.83%) was recorded from mealybugs of Bellary taluk followed by Deodurg taluk (7.38%) of Raichur district and Siruguppa taluk (6.83 %) of Bellary district. Mean per cent emergence of parasitoids were in the order of Bellary (7.33 %) > Raichur (6.58 %) > Gulbarga (3.20 %) > Haveri (2.39 %) and Belgaum (1.29 %). Mean parasitoid emergence was lowest (0.79%) in Gokak taluk of Belgaum district (Table 9).

During 2009-10 cropping season, parasitoids emergence in laboratory was maximum as compared to previous season. Mean parasitoids emergence from mealybugs collected at various places were highest in the districts of TBP and UKP areas which varied from 5.36 to 9.52 per cent. In other districts mean parasitoids emergence ranged between 2.13 to 3.46 per cent. Parasitoids emergence was maximum with 36.12 and 28.44 per cent in the month of March from Raichur and Deodurg, respectively. Mean emergence of parasitoids from different districts were in the order of Bellary (9.52 %) > Raichur (7.82 %) > Gulbarga (5.36 %) > Belgaum (3.46 %) > and Haveri (2.21 %). Lowest mean parasitoid emergence of 2.13 per cent was recorded from Dharwad district (Table 10).

#### 4.2.3 Host range of mealybug

Alternative hosts of cotton mealybug, *P. solenopsis* were also recorded and details are furnished in the table 11. The survey for host range under rainfed as well as irrigated cotton production system revealed a total of more than 15 hosts spread across eight families in cotton growing districts of North Karnataka. The results on the host range are as follows.

- i) Country mallow, *Abutilon indicum* L. (Malvaceae) (Plate 31 & 32)

It was the dominant weed host along the cotton field bunds in Raichur and Bellary districts. *Abutilon indicum* plants were severely infested by *P. solenopsis* at Raichur. The mealybug infestation had resulted in stunted plant growth, honeydew secretion on leaves with sooty mold development. Mealybugs were first noticed on this weed along the border and

Table 7. Population of parasitoids on cotton mealybug in different locations of North Karnataka during 2008-09 season

Month	Per cent parasitoid cocoons *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.0	0.0	0.00	0.00	0.00	0.00	5.12	3.4	4.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.0	8.1	4.06	0.00	2.72	1.36	6.32	5.2	5.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.0	9.2	4.62	0.00	5.12	2.56	10.12	6.1	8.12	1.12	4.52	2.82	0.00	4.02	2.01	0.00	3.55	1.78
October	3.2	10.3	6.73	3.42	6.25	4.84	12.44	8.4	10.43	3.25	8.62	5.94	0.00	6.12	3.06	2.12	5.25	3.69
November	5.5	15.2	10.33	12.12	7.18	9.65	15.54	12.1	13.83	4.36	8.52	6.44	3.42	7.08	5.25	3.24	4.52	3.88
December	7.3	18.3	12.75	14.15	7.24	10.70	21.84	15.5	18.65	5.34	9.12	7.23	5.12	7.25	6.19	4.54	6.56	5.55
January	18.9	15.3	17.10	19.24	8.52	13.88	18.52	22.5	20.49	5.12	10.11	7.62	6.24	6.13	6.19	5.56	5.54	5.55
February	18.5	12.1	15.29	10.12	7.41	8.77	10.54	18.3	14.40	4.32	4.32	4.32	4.32	2.08	3.20	4.12	3.12	3.62
March	14.3	10.5	12.35	3.45	4.12	3.79	5.22	11.3	8.24	2.40	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00
Mean	6.76	9.89	8.32	6.25	4.86	5.55	10.57	10.27	10.42	2.59	4.52	3.56	1.91	3.27	2.59	1.96	2.85	2.41

\* Mean of 20 plants

Table 8. Population of parasitoids on cotton mealy bug in different locations of North Karnataka during 2009-10 season

Month	Per cent parasitoid cocoons *																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	1.32	1.24	1.28	0.00	0.00	0.00	0.12	0.24	0.18	0.44	0.24	0.34
September	0.12	0.22	0.17	0.00	3.12	1.56	4.16	6.11	5.14	0.22	0.52	0.37	1.14	2.27	1.71	0.58	3.55	2.07
October	3.21	1.18	2.20	3.11	6.28	4.70	5.44	8.46	6.95	0.54	1.62	1.08	2.22	4.14	3.18	2.14	5.10	3.62
November	2.15	4.21	3.18	5.42	7.65	6.54	6.58	10.14	8.36	4.36	5.82	5.09	3.42	6.18	4.80	3.48	5.52	4.50
December	2.38	5.32	3.85	6.15	6.24	6.20	7.12	6.54	6.83	5.34	6.32	5.83	5.46	4.25	4.86	5.54	4.54	5.04
January	6.48	12.31	9.40	8.24	8.45	8.35	18.52	8.51	13.52	6.12	5.12	5.62	6.33	6.13	6.23	4.28	4.57	4.43
February	28.51	25.46	26.99	10.12	10.41	10.27	10.54	11.32	10.93	3.32	4.32	3.82	2.15	2.08	2.12	2.12	1.12	1.62
March	34.15	32.54	33.35	22.45	14.12	18.28	15.22	13.48	14.35	0.00	0.00	0.00	2.08	3.00	2.54	0.00	0.00	0.00
Mean	7.70	8.12	7.91	5.55	5.63	5.59	6.89	6.58	6.74	1.99	2.37	2.18	2.29	2.83	2.56	1.86	2.46	2.16

\* Mean of 20 plants

Table 9. Population of parasitoids on cotton mealybug in different locations of North Karnataka during 2008-09 season

Month	Per cent emergence of parasitoids in laboratory																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	4.08	0.45	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	5.12	2.22	3.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	9.22	4.61	0.00	4.22	2.11	8.44	3.22	5.83	0.00	1.12	0.56	0.00	2.16	1.08	2.12	4.58	3.35
October	2.52	12.16	7.34	1.25	4.58	2.92	9.04	6.52	7.78	0.25	7.12	3.69	0.00	3.24	1.62	3.25	5.44	4.35
November	4.26	16.22	10.24	4.22	6.22	5.22	10.12	8.45	9.29	3.15	5.16	4.16	1.25	4.15	2.70	3.56	6.44	5.00
December	7.02	14.56	10.79	8.44	6.08	7.26	15.45	12.22	13.84	3.52	7.24	5.38	2.12	5.20	3.66	5.44	5.48	5.46
January	18.45	10.34	14.40	7.15	6.44	6.80	13.14	18.32	15.73	3.68	8.04	5.86	3.25	3.24	3.25	4.54	4.56	4.55
February	15.46	8.12	11.79	4.28	5.28	4.78	9.42	12.26	10.84	2.12	0.00	1.06	1.26	0.00	0.63	2.33	0.00	1.17
March	10.12	3.15	6.64	2.62	3.16	2.89	3.52	4.63	4.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	5.78	7.38	6.58	2.80	3.60	3.20	7.83	6.83	7.33	1.27	2.87	2.07	0.79	1.80	1.29	2.12	2.65	2.39

Table 10. Population of parasitoids on cotton mealybug in different locations of North Karnataka during 2009-10 season

Month	Per cent emergence of parasitoids in laboratory																	
	Raichur			Gulbarga			Bellary			Dharwad			Belgaum			Haveri		
	Raichur	Deodurg	Mean	Shahapur	Jevargi	Mean	Bellary	Siruguppa	Mean	Dharwad	Hubli	Mean	Gokak	Bailhongal	Mean	Haveri	Shiggaon	Mean
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	1.14	1.46	1.30	0.00	0.00	0.00	0.08	0.12	0.10	0.08	0.04	0.06
September	1.06	1.24	1.15	0.28	0.00	0.14	6.42	3.02	4.72	0.45	0.46	0.46	0.14	2.16	1.15	1.12	1.58	1.35
October	1.42	6.48	3.95	1.24	1.33	1.29	7.04	6.44	6.74	0.88	2.12	1.50	1.28	3.24	2.26	4.24	3.41	3.83
November	3.22	8.45	5.84	4.23	5.20	4.72	6.16	8.41	7.29	3.15	5.44	4.30	2.26	4.15	3.21	3.58	4.42	4.00
December	4.08	5.44	4.76	8.05	4.04	6.05	5.45	6.24	5.85	3.52	4.28	3.90	3.16	5.20	4.18	3.54	3.48	3.51
January	12.66	11.24	11.95	8.16	6.44	7.30	8.14	11.32	9.73	4.64	8.46	6.55	6.25	6.24	6.25	7.78	6.56	7.17
February	15.46	18.12	16.79	9.28	7.26	8.27	14.42	16.24	15.33	6.12	8.15	7.14	8.26	7.00	7.63	2.31	2.08	2.20
March	22.12	18.44	20.28	12.60	9.16	10.88	18.46	20.04	19.25	0.00	0.00	0.00	9.00	8.21	8.61	0.00	0.00	0.00
Mean	6.00	6.94	6.47	4.38	3.34	3.86	6.72	7.32	7.02	1.88	2.89	2.38	3.04	3.63	3.34	2.27	2.16	2.21

Table 11. Alternate hosts of cotton mealybug in different locations of North Karnataka during 2008-09 and 2009-10 seasons

Sl. No	Raichur	Gulbarga	Bellary	Dharwad	Belgaum	Haveri
1.	<i>Abutilon indicum</i> L.	<i>Abutilon indicum</i> L.	<i>Abutilon indicum</i> L.	<i>Abutilon indicum</i> L.	<i>Abutilon indicum</i> L.	<i>Abutilon indicum</i> L.
2.	<i>Parthenium. hysterophorus</i> L.	<i>Parthenium. hysterophorus</i> L.	<i>Parthenium. hysterophorus</i> L.	<i>Parthenium. hysterophorus</i> L.	<i>Parthenium. hysterophorus</i> L.	<i>Parthenium. hysterophorus</i> L.
3.	<i>Helianthus annus</i> L.	<i>Helianthus annus</i> L.	<i>Helianthus annus</i> L.		<i>Lycopersicon esculentum</i> L.	
4.	<i>Lycopersicon esculentum</i> L.	<i>Lycopersicon esculentum</i> L.	<i>Hybiscus cannabina</i>	<i>Hibiscus rosa-sinensis</i> L.	<i>Abelmoschus esculentus</i>	<i>Hibiscus rosa-sinensis</i> L.
5.	<i>Amaranthus spp</i>	<i>Hibiscus rosasinensis</i> L.	<i>Hibiscus rosasinensis</i> L.	<i>Tectona grandis</i>	<i>Hibiscus rosa-sinensis</i> L.	<i>Helianthus annus</i> L.
6.	<i>Vigna mungo</i>	<i>Achyranthes aspera</i> L.	<i>Abelmoschus esculentus</i> L.	<i>Abelmoschus esculentus</i> L.	<i>Morus alba</i> L.	<i>Abelmoschus esculentus</i> L.
7.	<i>Ziziphus spp</i>	<i>Morus alba</i> L.				
8.	<i>Physalis minima</i>	<i>Abelmoschus esculentus</i>				
9.	<i>Abelmoschus esculentus</i> L.					
10.	<i>Leucos spp</i>					
11.	<i>Achyranthes aspera</i> L.					
12.	<i>Hibiscus rosasinensis</i> L.					
13.	<i>Annona squamosa</i> L.					
14.	<i>Solanum melongena</i>					

then spread in to the adjacent cotton plants in the fields. This weed was also found infected by mealybugs throughout the season in Dharwad, Belgaum, Haveri and Gulbarga districts.

ii) *Parthenium hysterophorus* L. (Asteraceae): Congress weed (Plate 33)

This weed was the next major host of this mealybug in all the districts. Mealybugs were congregated on main apical shoot. In severely infected plants, growth was stunted and leaves shriveled. Mealybugs were found on this weed in entire North Karnataka from July to January during cropping season. Mealybugs were found on this weed all along the road side and bunds of cotton fields.

iii) Sunflower, *Helianthus annuus* L. (Asteraceae) (Plate 34)

Mealybugs were found congregated on the heads of sunflower and young plants were stunted and shriveled due to heavy infestation at Raichur. This was also found in Gulbarga and Bellary districts.

iv) Tomato, *Lycopersicon esculentum* L. (Solanaceae) (Plate 35)

*Phenacoccus solenopsis* was found on tomato in Raichur and Gulbarga districts. Adults and nymphs were congregated on tip of the shoots.

v) *Amaranthus* spp. (Amaranthaceae)

Mealybugs were found feeding on this weed which was grown along with cotton at Raichur.

vi) Okra, *Abelmoschus esculentus* L. (Malvaceae) (Plate 36)

The mealybugs were seen on the tender shoots, leaves and fruits at Raichur, Dharwad, Belgaum, Gulbarga, Haveri and Bellary. Severe infestation resulted in the death of plants in some areas.

vii) Chafe flower, *Achyranthes aspera* L. (Amaranthaceae)

Mealybugs were congregated along the main shoot on this weed in Raichur and Bellary districts.

viii) *Hibiscus rosasinensis* L. (Malvaceae) (Plate 37 & 38)

Mealybug was found to infest the shoots of these plants at Raichur, Dharwad, Belgaum, Gulbarga, Haveri and Bellary districts. Apical portion of the plant was infested due to congregation and feeding, infested leaves got crumpled and thus their growth retarded in February, 2010 at Raichur.

ix) *Hibiscus cannabina* L. (Malvaceae) (Plate 39)

Mealybug was found to infest the shoots of these plants at Bellary district. Apical portion of the plant was infested due to congregation and feeding, infested plant growth was retarded.

x) Mulberry, *Morus alba* L. (Moraceae)

Mulberry plants were affected by *P. solenopsis* at Gulbarga and Belgaum districts. The mealybug infestation had resulted in malformed shoots.

xi) Custard apple, *Annona squamosa* L. (Annonaceae)

The mealybugs were found to occur between eyes of custard apple fruit. The



Plate.31. Alternate host, *Abutilon indicum*



Plate.32. Severe incidence of mealybug on *Abutilon indicum*



Plate.33. Alternate host, *parthenium hysterophorus*



Plate.34. Alternate host, *Helianthus annuus*



Plate.35. Alternate, *Lycopersicon esculentum*



Plate.36. Alternate host, *Abelmoschus esculentus*

infestation was noticed between August - October at Raichur.

Other miner hosts viz., Greengram (*Vigna mungo*), Ber (*Zizipus spp.*), Ground cheery (*Physalis minima*), Teak (*Tectona grandis*), Brinjal (*Solanum melongena*) and *Leucos spp.* were infested by *P. solenopsis* at different places.

### 4.3 Population dynamics of mealybug and its natural enemies on Bt cotton

The study conducted at main agricultural research station (MARS), UAS, Raichur indicated that the mealybug, *P. solenopsis* occurred on cotton from September to till harvest of the crop in March-April. During September, the mealybugs first moved to the top apical shoot and later spread to squares, flowers, bolls and along the main stem. The yellowish crawlers moved out of the egg sacs and settled in groups on the growing points of axillary and terminal buds besides under surface of leaves on cotton plant.

Mealybug population was considerably high from January to March, and attained peak population before harvesting of cotton during March (Table 12 and 13). At MARS, Raichur, mealybug population started appearing on cotton during third week of September which gradually increased as the crop stage advanced. Steep increase in the population was observed after January and it was 154.62 mealybugs/10 cm shoot length in the last week of January. A maximum population of 180.42 mealybugs/10 cm shoot length (Plate 40) was recorded during 6<sup>th</sup> standard week in February, 2009. Further, mealybug population gradually decreased and it was 116.64/10cm shoot length in the last week of March. Mean population of 54.54/10cm shoot length was recorded during 2008-09 cropping season (Table 12).

During 2009-10 season, population ranged from 0.14 in October first week to 184.32 in second week of March. In the rainy and winter seasons (August to December), the population was low. Steep increase in mealybug population was noticed after January and peak growth of mealybug population was recorded from January to March. Mean mealybug population was low (33.84 /10 cm apical shoot length) as compared to previous season because of rains in November 2009 and January, 2010.

Predators population was negligible in the entire season and mean population of coccinellids, *Chrysoperla* and spiders were 0.02, 0.01 and 0.02 per plant, respectively in 2008-09 and 0.05, 0.07 and 0.14 per plant, respectively in 2009-10. A drosophilid predator, *Gitonides perspicax* Knab (Plate 41 & 42) appeared during February and March 2008-09 season. This predator was found in isolated patches on mealybug infested cotton. The maggot of the predator was found feeding in the ovisac. The ovisacs were flat in shape and hard with puparia of the predator inside. More than one maggot and puparia was seen in the single ovisacs. The adults are flies with red eyes that are characteristic of Drosophilidae.

Parasitoids activity was noticed from October to till harvest of the crop in March which ranged from 0.52 to 34.62 per cent. Initially parasitoid population was low and peak activity started in the first week of January (9.82%) and gradually increased up to 34.62 per cent in last week of March 2009. Similarly during 2009-10 season, its activity varied from 0.02 to 34.64 per cent. Parasitoids activity was peak from January last week (12.45 %) to third week of March (34.64 %). Parasitoids activity increased as there was increase in mealybug population towards the end of the season in March in both the years (Table 12 and 13).

#### 4.3.1 Parasitoids emergence in the laboratory

The mealybugs collected during weekly observations were reared in the laboratory for the emergence of natural enemies and the details are furnished in tables 14 and 15.

Taxonomic identities of the parasitoids were established on the adult specimens sent to Insect Identification Service centre at Division of Entomology, Indian Agricultural Research Institute, New Delhi as well as to T.C. Narendran Trust, Calicut, Kerala.



Plate.37. Alternate host, *Hibiscus rosasinensis*



Plate.38. Ants as carriers of mealybug and parasitoid cocoon



Plate.39. Alternate host, *Hibiscus cannabina*

Totally five Hymenopteran parasitoids were identified by both the institutes and species were similar. Out of five parasitoids four belonged to Encyrtidae and one belonged to Aphelinidae.

*Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae) (Plate 43 & 44)

*Hamolotylus eytelweinii* (Ratzeburg)(Hymenoptera: Encyrtidae) (Plate 45)

*Prochiloneurus pulchellus* Silvestri (Hymenoptera: Encyrtidae) (Plate 46)

*Anagyrus dactylopii* (Howard) (Hymenoptera: Encyrtidae) (Plate 47)

*Promuscidea unfaciativentris* Girault (Hymenoptera: Aphelinidae) (Plate 48)

Parasitoids emergence started from the 39<sup>th</sup> standard week during September 2008-09 wherein *Aenasius bambawalei* was the dominant species which ranged from lowest of 0.93 per cent in September to maximum of 24.26 per cent in March. Adults peak activity was observed from February till harvest of the crop in March last week. It was also reflected in adult emergence in laboratory (6.30 to 24.26%) during 2008-09. *Aenasius bambawalei* population increased significantly during 2009-10 and its population varied from 1.33 to 34.66 per cent with a peak emergence during January last week to March last week (8.66 to 34.66%). Mean parasitoid emergence of *A. bambawalei* was 4.17 and 6.70 per cent during 2008-09 and 2009-10, respectively. *Anagyrus dactylopii* was the next major parasitoid and its emergence in the laboratory was observed from September to March in both the seasons. Its population varied from 0.70 to 4.43 per cent during 2008-09 and 1.00 to 6.33 per cent in 2009-10. *Anagyrus dactylopii* activity was peak between 5<sup>th</sup> standard week in January to 14<sup>th</sup> standard week in March during both the seasons. Mean emergence of 1.73 and 2.73 per cent was recorded during 2008-09 and 2009-10, respectively (Table 14 and 15).

Another parasitoid, *P. unfaciativentris* emergence was recorded from September to March in both the cropping seasons which ranged from 0.70 to 4.43 per cent and 1.00 to 6.33 per cent, respectively during 2008-09 and 2009-10. The mean population of 1.38 and 2.22 per cent was recorded in 2008-09 and 2009-10, respectively. Emergence of *H. eytelweinii* was also recorded during the same period which varied from 0.70 to 3.96 per cent and 1.00 to 5.66 with a mean population of 1.25 and 2.02 per cent during 2008-09 and 2009-10 respectively. *Prochiloneurus pulchellus* parasitoid emergence ranged from 0.23 to 3.26 per cent and 0.33 to 4.66 per cent with a mean population of 1.02 and 1.64 per cent during 2008-09 and 2009-10 seasons respectively (Table 14 and 15).

The relationship between mealybug population and its natural enemies with the weather parameters like maximum temperature, minimum temperature, relative humidity, rainy days and rainfall were studied using correlation coefficients and data is furnished in Table 16.

The impact of weather parameters has revealed that maximum temperature showed a positive and significant correlation with the mealybug population (0.821), while others showed significantly negative correlation. Presence of predators with respect to weather parameters were non significant. Minimum temperature and number of rainy days showed significantly negative correlation (-0.537 and -0.419) with coccinellids and relative humidity was positively correlated (0.377) with chrysoperla predators. However, presence of parasitoid cocoons on mealybug infested cotton plants showed significantly positive correlation (0.734) with maximum temperature while other parameters showed significantly negative correlation (Table 16).

The relationship of mealybug population and its natural enemies like coccinellids, *Chrysoperla*, spiders, parasitoid cocoons and parasitoid emergence was studied using correlation coefficients. Presence of predators were non significant, however positive correlation was observed with coccinellids (0.184) while *Chrysoperla* (-0.244) and spiders (-0.129) were negatively correlated. Mealybug population was significantly influenced by the parasitoids and their emergence in laboratory. Parasitoids cocoons (0.973) were highly



Plate.40. Severe incidence of mealybug and its parasitoid cocoons on cotton plant in population dynamics plot



Plate.41. Cocoons of dipteran predator *Gitonides perspicax* on mealybug infested cotton plant



Plate.42. Adult dipetran predator, *Gitonides perspicax*

Table 12. Population dynamics of mealybugs, predators and parasitoids on cotton (NCS-145 Bt) under irrigated ecosystem during 2008-09 season

Months	ISW Week	Number of mealybugs per 10 cm apical shoot length	Number of predators per plant*			% Parasitoid cocoons
			Coccinellids	<i>Chrysoperla</i>	Spiders	
July 28-3	31	0.00*	0.00	0.00	0.00	0.00
Aug 4-10	32	0.00	0.00	0.00	0.00	0.00
Aug 11-17	33	0.00	0.00	0.00	0.00	0.00
Aug 18-24	34	0.00	0.00	0.00	0.02	0.00
Aug 25-31	35	0.00	0.00	0.00	0.04	0.00
Sep 1-7	36	0.00	0.02	0.00	0.04	0.00
Sep 8-14	37	0.00	0.00	0.04	0.00	0.00
Sep 15-21	38	0.50	0.02	0.02	0.00	0.00
Sep 22-28	39	0.52	0.00	0.00	0.02	0.00
Sep 29-5	40	0.61	0.02	0.00	0.02	0.00
Oct 6-12	41	0.65	0.04	0.00	0.02	0.00
Oct 13-19	42	0.72	0.06	0.00	0.04	0.00
Oct 20-26	43	0.84	0.02	0.00	0.06	0.00
Oct 27-2	44	0.86	0.00	0.00	0.02	0.52
Nov 3-9	45	2.16	0.02	0.04	0.04	1.28
Nov 10-16	46	6.24	0.00	0.00	0.00	1.32
Nov 17-23	47	6.58	0.00	0.02	0.00	2.12
Nov 24-30	48	8.24	0.00	0.00	0.16	3.62
Dec 1-7	49	10.64	0.04	0.12	0.04	4.54
Dec 8-14	50	13.21	0.02	0.13	0.02	6.24
Dec 15-21	51	16.58	0.08	0.04	0.08	7.60
Dec 22-28	52	22.42	0.02	0.00	0.04	9.21
Dec 29-4	1	36.52	0.00	0.00	0.00	9.44
Jan 5 -11	2	66.28	0.12	0.00	0.04	9.82
Jan 12-18	3	85.34	0.14	0.02	0.00	10.25
Jan 19-25	4	115.42	0.00	0.00	0.02	12.62
Jan 26 -1	5	154.62	0.10	0.00	0.00	13.45
Feb 2 -8	6	142.16	0.00	0.00	0.02	15.62
Feb 9 -15	7	180.42	0.08	0.00	0.00	20.65
Feb 16 -22	8	158.44	0.00	0.00	0.04	22.12
Feb 23 -1	9	156.24	0.02	0.00	0.00	20.02
Mar 2 - 8	10	154.50	0.00	0.00	0.02	26.42
Mar 9-15	11	152.26	0.00	0.00	0.00	28.64
Mar 16-22	12	150.65	0.00	0.00	0.02	30.20
Mar 23-29	13	148.64	0.00	0.00	0.00	34.62
Mar 30-5	14	116.64	0.00	0.00	0.00	33.26
Mean		54.54	0.02	0.01	0.02	8.99
S.D.		67.18	0.04	0.03	0.03	11.01

S.D = standard deviation

\* Mean of 20 plants

Table 13. Population dynamics of mealybugs, predators and parasitoids on cotton (NCS-145 Bt) under irrigated ecosystem during 2009-10 season

Months	ISW Week	Number of mealybugs per 10 cm apical shoot length	Number of predators per plant*			% parasitoid cocoons
			Coccinellids	<i>Chrysoperla</i>	Spiders	
Aug 20-26	34	0.00	0.00	0.00	0.00	0.00
Aug 27-2	35	0.00	0.00	0.00	0.02	0.00
Sep 3-9	36	0.00	0.00	0.02	0.07	0.00
Sep 10-16	37	0.00	0.00	0.02	0.05	0.00
Sep 17-23	38	0.00	0.00	0.04	0.02	0.00
Sep 24-30	39	0.00	0.00	0.02	0.15	0.00
Oct 1-7	40	0.14	0.00	0.12	0.02	0.08
Oct 8-14	41	0.33	0.02	0.05	0.30	0.12
Oct 15-21	42	0.41	0.03	0.12	0.02	0.18
Oct 22-28	43	0.52	0.04	0.06	0.25	0.21
Oct 29-4	44	2.53	0.02	0.02	0.06	0.23
Nov 5-11	45	0.22	0.03	0.14	0.32	0.08
Nov 12-18	46	0.45	0.01	0.30	0.04	0.06
Nov 19-25	47	0.62	0.01	0.12	0.25	0.36
Nov 26-2	48	0.66	0.08	0.02	0.00	0.92
Dec 3-9	49	1.22	0.12	0.04	0.16	1.15
Dec 10-16	50	1.64	0.07	0.12	0.04	3.55
Dec 17-23	51	3.27	0.05	0.25	0.12	4.23
Dec 24-31	52	6.24	0.06	0.27	0.28	5.11
Jan 1-7	1	12.32	0.02	0.02	0.24	7.25
Jan 8-14	2	16.42	0.04	0.04	0.27	8.44
Jan 15-21	3	28.25	0.14	0.07	0.15	8.82
Jan 22-28	4	35.37	0.12	0.02	0.24	9.27
Jan 29-4	5	45.42	0.15	0.05	0.25	12.45
Feb 5-11	6	64.68	0.22	0.02	0.32	13.84
Feb 12-18	7	82.13	0.30	0.12	0.22	15.08
Feb 19-25	8	88.55	0.04	0.27	0.30	15.66
Feb 26-4	9	108.13	0.02	0.00	0.04	18.12
Mar 5-11	10	122.21	0.04	0.00	0.12	22.42
Mar 12-18	11	184.32	0.05	0.00	0.02	26.56
Mar 19-25	12	154.20	0.03	0.00	0.00	34.64
Mar 26-1	13	122.64	0.00	0.00	0.00	32.20
Mean		33.84	0.05	0.07	0.14	7.54
S.D.		52.71	0.07	0.09	0.12	10.04

S.D = standard deviation

\* Mean of 20 plants.

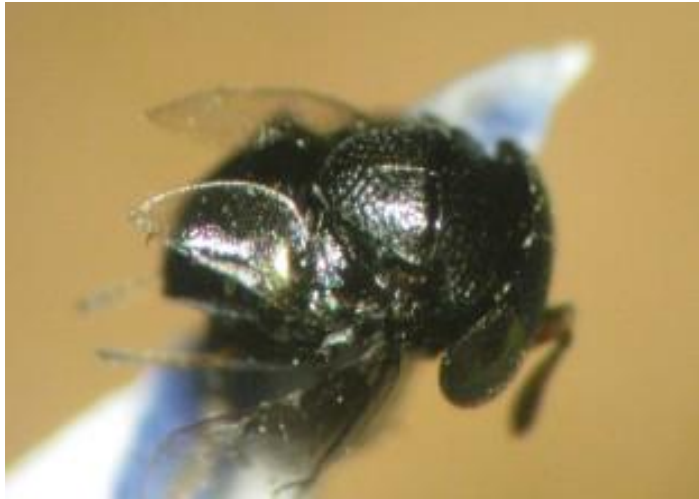


Plate.43. Adult parasitoid, *Aenasius bambawalei*



Plate.44. Adult male and female *Aenasius bambawalei*



Plate.45. Adult parasitoid, *Homolotylus eytelweinii*



Plate.46. Adult parasitoid, *Prochiloneurus pulchellus*



Plate.47. Adult parasitoid, *Anagrus dactylopii*



Plate.48. Adult Parasitoid, *Promuscidea unfaciativentris*

Table 14. Per cent emergence of mealybug parasitoids in the laboratory during 2008-09 season

Months	ISW Week	<i>Aenasius bambawalei</i>	<i>Promuscidea unfasciatiiventris</i>	<i>Hamalotylus eytelweini</i>	<i>Prochiloneurus pulchellus</i>	<i>Anagyrus dactylopii</i>
July 28-3	31	0.00	0.00	0.00	0.00	0.00
Aug 4-10	32	0.00	0.00	0.00	0.00	0.00
Aug 11-17	33	0.00	0.00	0.00	0.00	0.00
Aug 18-24	34	0.00	0.00	0.00	0.00	0.00
Aug 25-31	35	0.00	0.00	0.00	0.00	0.00
Sep 1-7	36	0.00	0.00	0.00	0.00	0.00
Sep 8-14	37	0.00	0.00	0.00	0.00	0.00
Sep 15-21	38	0.00	0.00	0.00	0.00	0.00
Sep 22-28	39	0.93	0.70	0.00	0.23	0.70
Sep 29-5	40	0.93	0.91	0.70	0.91	1.40
Oct 6-12	41	1.16	0.00	0.70	1.40	2.80
Oct 13-19	42	1.40	0.70	1.40	0.70	2.80
Oct 20-26	43	1.63	0.00	0.70	0.70	1.40
Oct 27-2	44	1.86	0.70	0.70	0.00	0.70
Nov 3-9	45	1.86	0.70	0.70	0.00	0.70
Nov 10-16	46	2.33	0.91	0.84	0.00	1.40
Nov 17-23	47	2.56	0.91	0.91	0.91	0.70
Nov 24-30	48	2.33	0.00	0.98	0.70	0.91
Dec 1-7	49	1.86	0.70	0.93	1.63	1.16
Dec 8-14	50	2.33	1.86	0.93	0.46	1.16
Dec 15-21	51	2.56	1.86	1.16	0.93	0.46
Dec 22-28	52	3.03	2.33	0.46	0.93	1.86
Dec 29-4	1	3.26	1.86	1.40	1.16	2.10
Jan 5 -11	2	3.50	1.40	0.70	0.70	2.10
Jan 12-18	3	3.73	1.40	0.93	1.16	1.86
Jan 19-25	4	4.66	1.86	1.16	0.70	2.10
Jan 26 -1	5	6.06	2.10	2.56	1.86	3.03
Feb 2 -8	6	6.30	2.33	1.86	1.16	2.10
Feb 9 -15	7	6.06	1.86	2.56	1.86	3.26
Feb 16 -22	8	6.76	2.56	2.80	2.10	3.73
Feb 23 -1	9	7.23	3.73	3.26	2.56	3.73
Mar 2 - 8	10	7.00	3.26	2.80	2.56	3.26
Mar 9-15	11	8.63	4.20	3.73	2.80	3.03
Mar 16-22	12	17.26	4.43	3.96	2.80	4.43
Mar 23-29	13	18.66	3.96	3.50	3.26	3.73
March 30-5	14	24.26	2.56	2.80	2.56	4.43
Mean		4.17	1.38	1.25	1.02	1.70
S.D.		5.49	1.34	1.21	0.99	1.40

S.D = standard deviation

Table 15. Per cent emergence of mealybug parasitoids in the laboratory during 2009-10 season

Months	ISD Week	<i>Aenasius bambawalei</i>	<i>Promuscidea unfasciatiiventris</i>	<i>Hamalotylus eytelweinii</i>	<i>Prochiloneurus pulchellus</i>	<i>Anagyrus dactylopii</i>
Aug 20-26	34	0.00	0.00	0.00	0.00	0.00
Aug 27-2	35	0.00	0.00	0.00	0.00	0.00
Sep 3-9	36	0.00	0.00	0.00	0.00	0.00
Sep 10-16	37	0.00	0.00	0.00	0.00	0.00
Sep 17-23	38	1.33	1.00	0.00	0.33	1.00
Sep 24-30	39	1.33	1.30	1.00	1.30	2.00
Oct 1-7	40	1.66	0.00	1.00	2.00	4.00
Oct 8-14	41	2.00	1.00	2.00	1.00	4.00
Oct 15-21	42	2.33	0.00	1.00	1.00	2.00
Oct 22-28	43	2.66	1.00	1.00	0.00	1.00
Oct 29-4	44	2.66	1.00	1.00	0.00	1.00
Nov 5-11	45	3.33	1.30	1.20	0.00	2.00
Nov 12-18	46	3.66	1.30	1.30	1.30	1.00
Nov 19-25	47	3.33	0.00	1.40	1.00	1.30
Nov 26-2	48	2.66	1.00	1.33	2.33	1.66
Dec 3-9	49	3.33	2.66	1.33	0.66	1.66
Dec 10-16	50	3.66	2.66	1.66	1.33	0.66
Dec 17-23	51	4.33	3.33	0.66	1.33	2.66
Dec 24-31	52	4.66	2.66	2.00	1.66	3.00
Jan 1-7	1	5.00	2.00	1.00	1.00	3.00
Jan 8-14	2	5.33	2.00	1.33	1.66	2.66
Jan 15-21	3	6.66	2.66	1.66	1.00	3.00
Jan 22-28	4	8.66	3.00	3.66	2.66	4.33
Jan 29-4	5	9.00	3.33	2.66	1.66	3.00
Feb 5-11	6	8.66	2.66	3.66	2.66	4.66
Feb 12-18	7	9.66	3.66	4.00	3.00	5.33
Feb 19-25	8	10.33	5.33	4.66	3.66	5.33
Feb 26-4	9	10.00	4.66	4.00	3.66	4.66
Mar 5-11	10	12.33	6.00	5.33	4.00	4.33
Mar 12-18	11	24.66	6.33	5.66	4.00	6.33
Mar 19-25	12	26.66	5.66	5.00	4.66	5.33
Mar 26-1	13	34.66	3.66	4.00	3.66	6.33
Mean		6.70	2.22	2.02	1.64	2.73
S.D.		8.03	1.90	1.70	1.40	1.92

S.D = standard deviation

significant and showed positive correlation. Correlation of *P. solenopsis* population with parasitoid emergence in the laboratory was significant and positively correlated with all the five parasitoids (Table 17).

The partial regression co-efficient of the mealybugs, parasitoid cocoons on plants and parasitoids emergence in laboratory were found to be highly significant. However, the partial regression coefficients of weather factors on predators population was non significant.

Regression equations calculated for maximum temperature were  $Y = -455.83 + 15.07X_1$ ,  $Y = -68.48 + 2.32X_2$  and  $Y = -21.23 + 0.74X_3$  with  $R^2$  value of 0.79, 0.71 and 0.76 for mealybugs, parasitoid cocoons and parasitoid emergence, respectively. It indicated that about 79.30, 71.10 and 76.90 per cent of population fluctuation depends on weather parameters (Table 18).

The multiple regression equation fitted with *A. bambawalei* and weather parameter to predict the mealybug population (Y) was:

$Y = -164.055X_1 + 6.853X_2 - 2.615X_3 + 0.047X_4 + 1.489X_5 - 0.198X_6 - 0.302X_7 + 3.895X_8$  with a  $R^2$  value of 0.865 at main agricultural research station, Raichur. Where  $X_1, X_2, X_3, X_4, X_5, X_6, X_7$  and  $X_8$  denote maximum temperature, minimum temperature, rainfall, rainy days, relative humidity I, relative humidity II and parasitoid, respectively.

#### 4.4 Biology of mealybug, *P. solenopsis* and its predator *Cryptolaemus montrouzieri*

Biology of *P. solenopsis*, fecundity on different host plants, biology and feeding potential of *C. Montrouzieri* were studied under laboratory conditions during 2008-09.

##### 4.4.1 Biology of mealybug, *P. solenopsis*

The biology of *P. solenopsis* was studied in the laboratory on potato sprout, cotton plant and hibiscus plant at room temperature ranging from 24 to 28°C with a relative humidity varying from 65 to 70 per cent.

The eggs were laid in mass in a loose cottony ovisac. They were closely held with each other within the white ovisac. Freshly laid eggs were orange in colour, smooth and oval in shape with slightly tapering ends. The egg was 0.45 mm to 0.48 mm in length (Plate 49) and the width ranged from 0.18 mm to 0.20 mm. Incubation period occupied 35 to 52 minutes with a mean of 48 minutes.

Newly hatched mealybugs (crawlers) were quite mobile (Plate 49). They settled on the potato sprout and started developing. Male and female nymphs, were indistinguishable in the first instar but by the end of the second instar, it was possible to differentiate the sexes. Three nymphal instars were observed in the development of female. Development of first, second and third (Plate 50) nymphal instars took 7.51, 3.60 and 7.24 days respectively. Full grown female nymph measured 2.2 mm long and 1.76 mm broad, and it was light yellowish in colour (Plate 51). The total developmental period of female nymphs ranged from 15 to 22 days with a mean of 18.35 days.

Male mealybug had two nymphal instars with a mean duration of 5.22 and 6.45 days respectively for first and second instar crawlers. At the end of second nymphal instar, males produced cocoon (puparia) over their bodies. The third moulting took place within the cocoon. Fourth instar, also known as pupa, was characterised by well developed wing pads attached to mesothorax. Male development was completed in 18 to 24 days with a mean of 20.33 days. Males had a pair of wings, and two long waxy caudal filaments at the posterior end of the abdomen (Plate 51). Adult female measured 3.8 mm

in length and 2.11 mm in width (Plate 51). Female was wingless, oval in shape and light green to brownish in colour covered with thick layer of white waxy powder (Table 19).

Table16. Correlation co-efficient between weather parameters and seasonal fluctuation of mealybugs, predators and parasitoids on cotton

Parameters	Mealybugs	Coccinellids	<i>Chrysoperla</i>	Spiders	Per cent parasitoid cocoons
Maximum Temperature (° C)	0.821**	-0.021	-0.280	-0.280	0.734**
Minimum Temperature (° C)	0.147	-0.537**	-0.07	-0.393*	0.017
Rainfall (mm)	-0.237	-0.261	0.058	-0.247	-0.277
No. of Rainy days	-0.402*	-0.419*	-0.047	-0.311	-0.465**
Relative Humidity-I	-0.736**	0.235	0.377*	0.331	-0.686**
Relative Humidity-II	-0.688**	-0.064	0.088	0.109	-0.677**

\* Differs significantly (P = 0.05)

\*\*Differs significantly (P = 0.01)

Table17. Correlation co-efficient between seasonal fluctuation of mealybugs, predators and parasitoids

Parameters	Mealybugs
Coccinellid predators	0.184
<i>Chrysoperla</i> predators	- 0.244
Spiders	- 0.129
Per cent parasitoid cocoons	0.973 **
Per cent parasitoid emergence in laboratory	
<i>Aenasius bambawalei</i>	0.923**
<i>Promuscidea unfasciativentris</i>	0.840**
<i>Homalotylus eytelweinii</i>	0.899**
<i>Prochiloneurus pulchellus</i>	0.882**
<i>Anagyrus dactylopii</i>	0.820**

\* Differs significantly (P = 0.05)

\*\* Differs significantly (P = 0.01)

Table18. Regression equations between weather parameters and seasonal fluctuation of mealybugs, predators and parasitoids on cotton

Mealybugs/10 cm apical shoot		Coccinellids/plant		Chrysoperla/plant	
$Y_1 = -455.83 + 15.070X_1$		$Y_1 = 0.070 - 0.0005 X_1$		$Y_1 = 0.358 - 0.008 X_1$	
$Y_1 = -18.418 + 2.787 X_2$		$Y_1 = 0.307 - 0.014 X_2$		$Y_1 = 0.117 - 0.0024 X_2$	
$Y_1 = 37.985 - 0.185 X_3$		$Y_1 = 0.060 - 0.0003 X_3$		$Y_1 = 0.071 + 7.745 X_3$	
$Y_1 = 46.368 - 14.983 X_4$		$Y_1 = 0.072 - 0.021 X_4$		$Y_1 = 0.076 - 0.0029 X_4$	
$Y_1 = 373.289 - 4.022 X_5$		$Y_1 = -0.093 + 0.002 X_5$		$Y_1 = -0.224 + 0.004 X_5$	
$Y_1 = 153.067 - 2.190 X_6$		$Y_1 = 0.038 + 0.0003 X_6$		$Y_1 = 0.047 + 0.0004 X_6$	
$R^2$	0.793		0.469		0.344
F	16.054		3.693		2.187
spiders/plant		% parasitoid cocoons		% parasitoid emergence in laboratory	
$Y_1 = 0.511 - 0.011X_1$		$Y_1 = -68.482 + 2.324 X_1$		$Y_1 = -21.23 + 0.748 X_1$	
$Y_1 = 0.446 - 0.016 X_2$		$Y_1 = 5.999 + 0.053 X_2$		$Y_1 = 2.467 + 0.032 X_2$	
$Y_1 = 0.146 - 0.004 X_3$		$Y_1 = 7.904 - 0.037 X_3$		$Y_1 = 3.304 - 0.010 X_3$	
$Y_1 = 0.158 - 0.026X_4$		$Y_1 = 9.617 - 2.986 X_4$		$Y_1 = 3.953 - 1.017 X_4$	
$Y_1 = -0.208 + 0.004 X_5$		$Y_1 = 61.609 - 0.647 X_5$		$Y_1 = 20.994 - 0.212 X_5$	
$Y_1 = 0.092 + 0.0007 X_6$		$Y_1 = 27.290 - 0.371 X_6$		$Y_1 = 9.209 - 0.112 X_6$	
$R^2$	0.345		0.711		0.769
F	2.200		10.254		13.867

$X_1$  - Max. Temp. ( $^{\circ}$  C)  
 $X_4$  - No. of Rainy days

$X_2$  - Min. Temp. ( $^{\circ}$  C)  
 $X_5$  - Relative Humidity -I

$X_3$  - Rainfall (mm)  
 $X_6$  - Relative Humidity-II



Plate.49. Egg and first instar crawlers of *P. solenopsis*



Plate.50. Different instars of *P. solenopsis* with adult female



Plate.51. Adult female and male of *P. solenopsis*

Development from egg to adult of male and female mealybug was also studied on cotton plant and hibiscus plant in addition to potato sprout. The duration of development of male mealybug was 20.33, 21.36 and 21.85 days on potato sprout, cotton plant and hibiscus plant, respectively. Total development of the female took 38.47, 39.45 and 39.22 days on potato sprout, cotton plant and hibiscus plant, respectively (Table 20).

The population of male mealybug was very low as compared to females, irrespective of the host used for the development. Male to female ratio was 1:13.79, 1:13.00 and 1:19.49, when reared on potato sprout, cotton plant and hibiscus plant, respectively. Both the sexual and parthenogenetic reproduction were observed in this mealybug. Females held in isolation from the third instar also laid eggs without mating. Mating was also observed when both male and female were held together.

Oviposition lasted usually for 9-12 days. After the completion of egg laying, the female mealybug shrank considerably and ultimately died. The number of eggs laid by a female varied greatly with the host on which it was reared. A mean of 226.12 (188 to 312) eggs was laid by a single female when reared on potato sprout. The average number of eggs per female on cotton plant and hibiscus plant was 284.45 (246 to 372) and 296.34 (242 to 408), respectively.

#### 4.4.2 Predator, *Cryptolaemus montrouzieri*

##### 4.4.2.1 Biology

Biology of *C. montrouzieri* was made on the nymphs and adult females of *P. solenopsis* in the laboratory. The temperature and relative humidity ranged from 24 to 28°C and 58 to 64 per cent, respectively during the study period.

The freshly laid egg was pale yellowish white in colour, smooth and cylindrical in shape. Incubation period ranged from 4 to 5 days. The newly hatched grub was smooth and pale grayish in colour. There were four larval instars and developmental period of each instar was influenced by the stage of prey used. The duration of the first instar was 3.82 and 2.86 days when fed on nymph and adult mealybugs, respectively. The second instar grub took 2.32 and 2.45 days when reared on nymphs and adults, respectively. The third instar grub lasted for 4.58 and 3.58 days on nymph and adult diet, respectively. Duration of fourth instar grub on nymph and adult diet was 5.86 and 4.24 days, respectively. The total developmental period of grub varied when reared on different stages of mealybugs. The grub took 16.58 and 13.13 days when it was reared on nymphs and adult female mealybugs. The prepupal period varied from 3.12 to 2.34 days and pupal period ranged from 9.12 to 9.24 days. Life cycle of predator from egg to adult stage was significantly influenced when it was reared on different stages of the mealybug. The predator took 28.82 and 24.71 days when reared on the mealybug nymphs and adult female, respectively (Table 21).

The mean pre-mating period was 6.12 and the mean pre-oviposition period was 6.84 days. Oviposition lasted for 44.35 days and mean post oviposition period was 7.12 days. Mean longevity of the male and female was 56.45 and 62.56 days, respectively (Table 22).

##### 4.4.2.2 Feeding potential

Grub of *Cryptolaemus* was found feeding on all the stages of mealybugs. A grub consumed an average of 3.65, 12.5, 74.35 and 148.60 mealybug nymphs during the development of first, second, third and fourth instar, respectively. On an average a total of 159.10 mealybug nymphs were consumed by a grub in its development. Mean number of adult female mealybugs consumed by first, second, third and fourth instar grub was 1.25, 4.35, 8.20 and 16.45, respectively. The grub consumed a total of 30.25 adult female mealybugs during its development (Table 23).

Table 19. Duration of different stages of *Phenacoccus solenopsis* on potato sprout under laboratory conditions

Sl. No.	Stages	Female		Male	
		Duration (Days) (Mean $\pm$ S.D.)	Size (mm)	Duration (Days) (Mean $\pm$ S.D.)	Size (mm)
1.	Egg	0.48 $\pm$ 0.12 (h)		0.45 X 0.21 (mm)	
2.	Nymph				
	I instar	7.51 $\pm$ 1.52	0.51 X 0.24	5.22 $\pm$ 1.21	0.51 X 0.24
	II instar	3.60 $\pm$ 1.46	0.76 X 0.32	6.45 $\pm$ 2.22	0.75 X 0.34
	III instar	7.24 $\pm$ 0.54	2.2 X 1.76	--	--
3.	Pupa	--	--	6.84 $\pm$ 2.64	1.9 X 0.6
4.	Total nymphal stage	18.35 $\pm$ 3.52	--	--	--
5.	Total nymphal stage + pupal stage	--	--	18.51 $\pm$ 6.07	--
6.	Adult	28.12 $\pm$ 15.50	3.8 X 2.11	1.82 $\pm$ 1.20	1.20 X 0.22
7.	Total life span	38.47 $\pm$ 19.02	--	20.33 $\pm$ 7.27	--

S.D = standard deviation

## 4.5 Crop loss estimation due to mealybug damage and EIL on Bt cotton

To quantify the crop loss caused by *P. solenopsis*, experiments were carried out during 2008-09 season on potted cotton plants and under field conditions during 2009-10 season. The data were recorded on reduction of plant height, GOB, BOB and seed cotton yield with respect to different levels of damage. Correlations between mealybug population and yield parameters were worked out. Totally six damage levels viz., control ( $D_0$ ), 50 ( $D_1$ ), 100 ( $D_2$ ), 150 ( $D_3$ ), 200 ( $D_4$ ) and 250 ( $D_5$ ) mealybugs were released under caged conditions at 60, 90, 120 and 150 days after sowing.

### 4.5.1 Crop loss estimation (2008-09 season)

The crop loss estimation studies revealed that the mealybug population ranged from 122.52 to 188.25 per 10 cm shoot length in the damage levels  $D_1$  to  $D_5$  at 60 DAS. The plant height ranged from 78.42 cm to 112.42 cm and was maximum at damage level  $D_0$  (112.42 cm) which was superior and highly significant to  $D_1$  (91.51 cm). Plant height significantly reduced in  $D_2$  to  $D_5$ . Because of high density of mealybugs and severe damage, plants withered and yield was nil in  $D_1$  to  $D_5$  levels. However, control ( $D_0$ ) level recorded cotton yield of 122.10 g/plant.

Similarly at 90 DAS, maximum plant height of 115.16 cm was recorded in the control plant ( $D_0$ ) while at  $D_5$  it was 88.25 cm which significantly differed from damage level  $D_1$  to  $D_5$ . Maximum seed cotton yield of 141.16 g/plant was recorded in  $D_0$  level which was significantly

Table 20. Development of *Phenacoccus solenopsis* on potato sprout, cotton and hibiscus plants

Sl. No.	Hosts	Total developmental period (days)		Sex ratio		Fecundity (Mean $\pm$ S.D.)
		Female (Mean $\pm$ S.D.)	Male (Mean $\pm$ S.D.)	Female (%)	Male (%)	
1.	Potato sprout	38.47 $\pm$ 19.02	20.33 $\pm$ 7.27	93.24	6.76	226.12 $\pm$ 25.24
2.	Cotton plant	39.45 $\pm$ 20.50	21.36 $\pm$ 7.65	92.86	7.14	284.45 $\pm$ 34.62
3.	Hibiscus plant	39.22 $\pm$ 17.56	21.85 $\pm$ 7.47	95.12	4.88	296.34 $\pm$ 22.46

S.D = standard deviation

Table 21. Duration of development of the predator, *Cryptolaemus montrouzieri* on *Phenacoccus solenopsis*

Sl. No.	Stage of predator	Developmental period in days when reared on	
		Mealybug nymphs (Mean $\pm$ S.D.)	Mealybug adults (Mean $\pm$ S.D.)
1.	Egg	4.47 $\pm$ 0.62	3.33 $\pm$ 0.24
2.	Grub		
	I instar	3.82 $\pm$ 0.42	2.86 $\pm$ 0.52
	II instar	2.32 $\pm$ 0.45	2.45 $\pm$ 0.45
	III instar	4.58 $\pm$ 0.44	3.58 $\pm$ 0.37
	IV instar	5.86 $\pm$ 0.62	4.24 $\pm$ 0.50
	Total	16.58 $\pm$ 1.91	13.13 $\pm$ 1.84
3.	Prepupa	3.12 $\pm$ 0.36	2.34 $\pm$ 0.46
4	Pupa	9.12 $\pm$ 0.21	9.24 $\pm$ 0.12
5	Total developmental period	28.82 $\pm$ 2.48	24.71 $\pm$ 2.42

S.D = standard deviation

Table 22. Longevity and oviposition of the predator, *Cryptolaemus montrouzieri* on *Phenacoccus solenopsis*

Particulars	Duration in days (Mean $\pm$ S.D.)
Pre-mating period	6.12 $\pm$ 0.44
Pre-oviposition period	6.84 $\pm$ 0.78
Oviposition period	44.35 $\pm$ 5.33
Post-oviposition period	7.12 $\pm$ 1.62
Longevity of male	56.45 $\pm$ 5.26
Longevity of female	62.56 $\pm$ 6.68

S.D = standard deviation

Table 23. Consumption of different stages of *Phenacoccus solenopsis* by different instars of predator, *Cryptolaemus montrouzieri*

Larval instars of predator	Mean number of mealybugs consumed by predator	
	Mealybug nymphs (Mean $\pm$ S.D.)	Mealybug adults (Mean $\pm$ S.D.)
I Instar	3.65 $\pm$ 0.68	1.25 $\pm$ 0.20
II Instar	12.5 $\pm$ 0.92	4.35 $\pm$ 0.42
III Instar	74.35 $\pm$ 8.45	8.20 $\pm$ 2.0
IV Instar	148.60 $\pm$ 15.22	16.45 $\pm$ 3.55
Total consumption	159.10 $\pm$ 25.27	30.25 $\pm$ 5.97

S.D = standard deviation

superior over other levels. However, at lower damage level D<sub>1</sub> recorded 21.14 g/plant which was on par with D<sub>2</sub>, D<sub>3</sub> and D<sub>4</sub> levels of damage (Table 24).

At 120 DAS, minimum population of 132.53 mealybugs/10 cm apical shoot was recorded in D<sub>1</sub> which was significantly lower than other levels of damage. In D<sub>2</sub> to D<sub>5</sub> mealybug population ranged between 158.15 to 194.24 /10 cm apical shoot which were on par with each other. Plant height significantly differed from damage levels D<sub>0</sub> (128.28 cm) to D<sub>5</sub> (118.44) indicating impact of mealybug population on growth of the plant.

The highest seed cotton yield of 128.22 g/plant was recorded in control plant (D<sub>0</sub>) while at the highest damage level (D<sub>5</sub>), minimum cotton yield (30.28 g/plant) was recorded. Per cent reduction of seed cotton yield ranged from 45.06 (D<sub>1</sub>) to 76.38 (D<sub>5</sub>). Similarly at 150 DAS, maximum seed cotton yield of 160.24 g per plant was recorded in the control plant (D<sub>0</sub>) and minimum seed cotton yield of 66.22 g per plant was recorded in highest damage level (D<sub>5</sub>) and per cent reduction of cotton yield ranged from 42.17 (D<sub>1</sub>) to 58.67 (D<sub>5</sub>) per plant (Table 25).

Crop loss estimation (2009-10 season):

At 60 DAS, cotton plants did not survive at all the damage levels of mealybug population. Plants dried due to heavy population of mealybug and honeydew secretion and sooty mold was observed on plant. At 90 DAS, mealybug population was uniform and non significant among different levels at the time of harvest. Significant difference was observed among plant height, GOB and BOB per plant in different damage levels. Significantly higher yield of 26.52 q/ha was recorded in control (D<sub>0</sub>) which ranged from lowest of 3.52 q/ha (D<sub>5</sub>) to highest of 7.68 q/ha (D<sub>1</sub>) and was significantly different at each level of infestation. Per cent reduction in yield ranged from 71.04 (D<sub>1</sub>) to 86.73 (D<sub>5</sub>) (Table 26).

At 120 DAS, not much influence of mealybug damage on plant height at different levels was recorded and it ranged between 104.34 cm (D<sub>5</sub>) to 111.22 cm (D<sub>1</sub>). Maximum cotton yield reduction was recorded in damage level D<sub>5</sub> (57.68%) which was significantly higher than damage levels D<sub>3</sub> (46.91%) and D<sub>4</sub> (48.29 %).

On an average, seed cotton yield reduction ranged from 14.84 per cent (D<sub>1</sub>) to 36.59 per cent (D<sub>4</sub>) at 150 DAS. Influence of different damage levels of mealybug on yield was less as compared to yield levels at 120 DAS. Seed cotton yield of 18.13, 17.46 and 17.26 q/ha recorded in damage levels D<sub>3</sub>, D<sub>4</sub> and D<sub>5</sub>, respectively and were on par with each other. Yield in control was (D<sub>0</sub>) maximum with 27.22 q/ha cotton (Table 27).

The correlation coefficient indicated positive and significant linear relationship and per cent reduction of seed cotton yield was 0.99 and 0.87 at 120 and 150 DAS, respectively (Table 28).

#### 4.5.2 Quality parameters of cotton lint

Quality parameters of cotton lint due to mealybug damage at different days after sowing is furnished in the Table 29 to 30.

Quality analysis of cotton lint at 90 DAS indicated that 100 g seed weight varied from 6.48 to 7.65 g, oil percentage varied from 10.3 to 11 and staple length varied from 30.9 to 32.4 mm in different damage levels. At 120 and 150 DAS, there was no much variation in the 100 seed weight, oil percentage, staple length, tenacity and elongation percentage. However micronaire value was affected at 120 and 150 DAS which varied from 2.4 to 3.1 and 3.1 to 3.5, respectively. This indicates that fiber quality was affected at all the levels of damage from D<sub>0</sub> to D<sub>5</sub> (Table 29).

The correlation coefficient indicated negative relationship with all the quality parameters *viz.*, 100 seed weight, oil percentage, staple length, micronaire, uniformity ratio,

Table 24. Impact of mealybug population during early stages of crop growth on yield parameters and seed cotton yield during 2008-09 season

No. of Mealybugs released/ Plant	On 60 DAS					On 90 DAS				
	Mealybugs per 10 cm apical shoot	Plant height (cm)	GOB/ Plant	BOB/ Plant	Yield (g/ plant)	Mealybugs Per 10 cm apical shoot	Plant height (cm)	GOB/ Plant	BOB/ Plant	Yield (g/ plant)
Control (D <sub>0</sub> )	0.00 (0.71) <sup>a</sup>	112.42 (10.62) <sup>a</sup>	25.42 (5.09) <sup>a</sup>	4.15 (2.15) <sup>b</sup>	122.10 <sup>a</sup>	0.00 (0.71) <sup>a</sup>	115.16 (10.74) <sup>a</sup>	27.32 (5.27) <sup>a</sup>	3.25 (1.93) <sup>a</sup>	141.16 <sup>a</sup>
50 (D <sub>1</sub> )	122.52 (11.08) <sup>b</sup>	91.51 (9.59) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>a</sup>	0.00 <sup>b</sup>	118.22 (10.89) <sup>b</sup>	98.22 (9.93) <sup>b</sup>	4.33 (2.20) <sup>b</sup>	3.73 (2.06) <sup>b</sup>	21.14 <sup>b</sup>
100 (D <sub>2</sub> )	172.52 (13.15) <sup>c</sup>	85.25 (9.25) <sup>c</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>a</sup>	0.00 <sup>b</sup>	130.16 (11.42) <sup>b</sup>	92.56 (9.64) <sup>c</sup>	4.09 (2.14) <sup>b</sup>	4.27 (2.18) <sup>bc</sup>	19.57 <sup>b</sup>
150 (D <sub>3</sub> )	184.22 (13.58) <sup>c</sup>	84.22 (9.20) <sup>c</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>a</sup>	0.00 <sup>b</sup>	152.25 (12.35) <sup>c</sup>	92.20 (9.62) <sup>c</sup>	3.34 (1.96) <sup>bc</sup>	4.64 (2.27) <sup>c</sup>	16.76 <sup>bc</sup>
200 (D <sub>4</sub> )	188.25 (13.74) <sup>c</sup>	80.15 (8.98) <sup>c</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>a</sup>	0.00 <sup>b</sup>	164.24 (12.83) <sup>cd</sup>	90.18 (9.52) <sup>c</sup>	3.10 (1.90) <sup>c</sup>	4.93 (2.33) <sup>c</sup>	15.37 <sup>c</sup>
250 (D <sub>5</sub> )	178.25 (13.36) <sup>c</sup>	78.42 (8.88) <sup>c</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>a</sup>	0.00 <sup>b</sup>	170.42 (13.06) <sup>d</sup>	88.25 (9.41) <sup>d</sup>	1.87 (1.54) <sup>d</sup>	6.73 (2.69) <sup>d</sup>	9.08 <sup>d</sup>
S.Em ±	0.21	0.21	0.05	0.02	1.69	0.20	0.05	0.06	0.04	1.24
CD (P= 0.05)	0.65	0.63	0.16	0.06	5.08	0.61	0.15	0.20	0.12	3.72

DAS : Days after sowing, GOB: Good opened bolls, BOB: Bad opened bolls

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.  
 Figures in the parentheses are  $\sqrt{(x+1)}$  values

Table 25. Impact of mealybug population during early season of crop growth on yield parameters and seed cotton yield during 2008-09 season

No. of mealybugs released/Plant	On 120 DAS						On 150 DAS					
	Mealybugs/10 cm apical shoot	Plant height (cm)	GOB/Plant	BOB/Plant	Yield (g/ plant)	Per cent * reduction over control	Mealybugs/10 cm apical shoot	Plant height (cm)	GOB/Plant	BOB/Plant	Yield (g/plant)	Per cent * reduction over control
Control (D <sub>0</sub> )	0.00 (0.71) <sup>a</sup>	128.28 (11.34) <sup>a</sup>	26.31 (5.17) <sup>a</sup>	4.22 (2.17) <sup>a</sup>	128.22 <sup>a</sup>	0.00 (0.00) <sup>a</sup>	0.00 (0.71) <sup>a</sup>	130.44 (11.43) <sup>a</sup>	28.44 (5.37) <sup>a</sup>	5.22 (2.39) <sup>a</sup>	160.24 <sup>a</sup>	0.00 (0.00) <sup>a</sup>
50 (D <sub>1</sub> )	132.53 (8.96) <sup>b</sup>	122.52 (8.65) <sup>b</sup>	14.44 (3.86) <sup>b</sup>	12.42 (3.59) <sup>b</sup>	70.45 <sup>b</sup>	45.06 (42.16) <sup>b</sup>	75.22 (8.70) <sup>b</sup>	104.22 (10.23) <sup>b</sup>	18.45 (4.35) <sup>b</sup>	9.12 (3.10) <sup>b</sup>	92.66 <sup>b</sup>	42.17 (40.49) <sup>b*</sup>
100 (D <sub>2</sub> )	158.15 (12.59) <sup>c</sup>	121.22 (11.03) <sup>c</sup>	13.62 (3.76) <sup>b</sup>	14.22 (3.83) <sup>c</sup>	65.24 <sup>c</sup>	49.12 (44.49) <sup>b</sup>	115.45 (10.76) <sup>c</sup>	107.10 (10.37) <sup>b</sup>	17.27 (4.21) <sup>b</sup>	9.23 (3.12) <sup>b</sup>	90.04 <sup>b</sup>	43.81 (41.44) <sup>b</sup>
150 (D <sub>3</sub> )	162.25 (12.75) <sup>c</sup>	120.43 (10.99) <sup>c</sup>	11.12 (3.41) <sup>c</sup>	15.45 (3.99) <sup>cd</sup>	55.88 <sup>d</sup>	56.42 (48.70) <sup>c</sup>	164.12 (12.82) <sup>d</sup>	98.22 (9.93) <sup>b</sup>	17.12 (4.20) <sup>b</sup>	10.24 (3.28) <sup>b</sup>	88.11 <sup>b</sup>	45.01 (42.13) <sup>b</sup>
200 (D <sub>4</sub> )	168.25 (12.99) <sup>c</sup>	118.56 (10.91) <sup>c</sup>	10.32 (3.29) <sup>c</sup>	16.42 (4.11) <sup>d</sup>	51.24 <sup>d</sup>	60.04 (50.80) <sup>c</sup>	172.24 (13.14) <sup>d</sup>	95.62 (9.80) <sup>b</sup>	15.42 (3.99) <sup>bc</sup>	10.26 (3.28) <sup>b</sup>	72.45 <sup>c</sup>	54.79 (47.75) <sup>c</sup>
250 (D <sub>5</sub> )	194.24 (13.95) <sup>c</sup>	118.44 (10.90) <sup>c</sup>	6.24 (2.59) <sup>d</sup>	22.44 (4.79) <sup>e</sup>	30.28 <sup>e</sup>	76.38 (61.08) <sup>d</sup>	186.45 (13.66) <sup>e</sup>	95.10 (9.77) <sup>b</sup>	15.20 (3.96) <sup>c</sup>	12.45 (3.60) <sup>c</sup>	66.22 <sup>d</sup>	58.67 (50.01) <sup>c</sup>
S.Em ±	0.79	0.06	0.08	0.07	1.67	1.22	0.19	0.22	0.07	0.06	1.89	0.95
CD (P= 0.05)	2.39	0.18	0.25	0.22	5.01	3.69	0.59	0.68	0.21	0.18	5.67	2.86

DAS : Days after sowing, GOB: Good opened bolls, BOB: Bad opened bolls

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.

Figures in the parentheses are  $\sqrt{(x+1)}$  values

\* Figures in the parentheses are arc sine transformed values

Table 26. Impact of mealybug population during early stages of crop growth on yield parameters and seed cotton yield during 2009-10 season

No. of mealybugs released/Plant	On 60 DAS					On 90 DAS					
	Mealybugs/10 cm apical shoot	Plant height (cm)	GOB/Plant	BOB/Plant	Yield (q/ ha)	Mealybugs/10 cm apical shoot	Plant Height (cm)	GOB/Plant	BOB/Plant	Yield (q/ ha)	Per cent * reduction over control
Control (D <sub>0</sub> )	0.00 (0.71) <sup>a</sup>	120.24 (10.98) <sup>a</sup>	37.24 (6.14) <sup>a</sup>	4.36 (2.26) <sup>a</sup>	26.14 <sup>a</sup>	0.00 (0.71) <sup>a</sup>	120.48 (10.99) <sup>a</sup>	38.64 (6.25) <sup>a</sup>	4.25 (2.18) <sup>a</sup>	26.52 <sup>a</sup>	0.00 (0.00) <sup>a</sup>
50 (D <sub>1</sub> )	160.53 (12.68) <sup>b</sup>	78.48 (8.88) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 <sup>b</sup>	178.14 (13.36) <sup>b</sup>	96.25 (9.83) <sup>b</sup>	6.89 (2.72) <sup>b</sup>	4.78 (2.30) <sup>ab</sup>	7.68 <sup>b</sup>	71.04 (57.53) <sup>b</sup>
100 (D <sub>2</sub> )	168.24 (12.98) <sup>b</sup>	76.27 (8.76) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 <sup>b</sup>	180.34 (13.44) <sup>b</sup>	95.18 (9.78) <sup>c</sup>	5.72 (2.49) <sup>cd</sup>	5.28 (2.40) <sup>b</sup>	6.48 <sup>c</sup>	75.57 (60.52) <sup>c</sup>
150 (D <sub>3</sub> )	170.68 (13.08) <sup>b</sup>	75.14 (8.69) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 <sup>b</sup>	186.21 (13.66) <sup>b</sup>	91.46 (9.59) <sup>bc</sup>	5.39 (2.43) <sup>c</sup>	5.66 (2.48) <sup>c</sup>	5.21 <sup>d</sup>	80.35 (63.84) <sup>d</sup>
200 (D <sub>4</sub> )	180.26 (13.44) <sup>c</sup>	70.28 (8.41) <sup>c</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 <sup>b</sup>	188.28 (13.74) <sup>b</sup>	88.62 (9.44) <sup>cd</sup>	4.89 (2.32) <sup>c</sup>	7.55 (2.84) <sup>c</sup>	4.74 <sup>e</sup>	82.13 (65.06) <sup>d</sup>
250 (D <sub>5</sub> )	185.22 (13.62) <sup>c</sup>	66.42 (8.17) <sup>d</sup>	0.00 (0.71) <sup>b</sup>	0.00 (0.71) <sup>b</sup>	0.00 <sup>b</sup>	194.46 (13.95) <sup>b</sup>	86.24 (9.31) <sup>d</sup>	3.60 (2.02) <sup>d</sup>	8.93 (3.07) <sup>d</sup>	3.52 <sup>f</sup>	86.73 (69.28) <sup>e</sup>
S.Em $\pm$	0.22	0.07	0.06	0.02	0.77	0.23	0.07	0.08	0.04	0.08	0.98
CD (P= 0.05)	0.67	0.21	0.19	0.06	2.34	0.70	0.21	0.24	0.14	0.24	2.94

DAS : Days after sowing

GOB : Good opened bolls

BOB: Bad opened bolls

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.

Figures in the parentheses are  $\sqrt{(x+1)}$  values

\* Figures in the parentheses are arc sine transformed values

Table 27. Impact of mealybug population during later stages of crop growth on yield parameters and seed cotton yield during 2009-10 season

DAS : Days after sowing

GOB: Good opened bolls

BOB: Bad opened bolls

No. of mealybugs released/ Plant	On 120 DAS						On 150 DAS					
	Mealybugs/ 10 cm apical shoot	Plant height (cm)	GOB/ Plant	BOB/ Plant	Yield (q/ ha)	Per cent* reduction over control	Mealybugs/ 10 cm apical shoot	Plant height (cm)	GOB/ Plant	BOB/ Plant	Yield (q/ ha)	Per cent* reduction over control
Control (D <sub>0</sub> )	0.00 (0.71) <sup>a</sup>	122.14 (11.06) <sup>a</sup>	38.66 (6.25) <sup>a</sup>	4.12 (2.15) <sup>a</sup>	26.84 <sup>a</sup>	0.00 (0.00) <sup>a</sup>	0.00 (0.71) <sup>b</sup>	122.11 (11.06) <sup>a</sup>	38.42 (6.23) <sup>a</sup>	4.20 (2.17) <sup>a</sup>	27.22 <sup>a</sup>	0.00 (0.00) <sup>a</sup>
50 (D <sub>1</sub> )	184.33 (13.59) <sup>bc</sup>	111.22 (10.56) <sup>b</sup>	15.16 (3.95) <sup>b</sup>	6.17 (2.58) <sup>b</sup>	16.37 <sup>b</sup>	39.01 (38.64) <sup>b</sup>	154.28 (12.43) <sup>b</sup>	120.33 (10.99) <sup>a</sup>	24.45 (4.99) <sup>b</sup>	5.18 (2.38) <sup>b</sup>	23.18 <sup>b</sup>	14.84 (22.64) <sup>b</sup>
100 (D <sub>2</sub> )	188.16 (13.73) <sup>bc</sup>	110.35 (10.52) <sup>b</sup>	14.22 (3.83) <sup>bc</sup>	6.55 (2.65) <sup>b</sup>	15.45 <sup>c</sup>	42.44 (40.64) <sup>c</sup>	158.46 (12.60) <sup>b</sup>	119.36 (10.94) <sup>a</sup>	22.27 (4.77) <sup>b</sup>	5.24 (2.39) <sup>b</sup>	21.11 <sup>b</sup>	22.45 (28.26) <sup>c</sup>
150 (D <sub>3</sub> )	194.68 (13.96) <sup>bc</sup>	107.32 (10.38) <sup>b</sup>	14.11 (3.82) <sup>bc</sup>	7.72 (2.87) <sup>c</sup>	14.25 <sup>d</sup>	46.91 (43.22) <sup>d</sup>	164.65 (12.84) <sup>ab</sup>	118.12 (10.89) <sup>ab</sup>	19.12 (4.43) <sup>c</sup>	6.21 (2.59) <sup>c</sup>	18.13 <sup>c</sup>	33.39 (35.29) <sup>d</sup>
200 (D <sub>4</sub> )	196.26 (14.02) <sup>bc</sup>	105.64 (10.30) <sup>bc</sup>	12.94 (3.67) <sup>cd</sup>	8.55 (3.01) <sup>d</sup>	13.88 <sup>d</sup>	48.29 (44.02) <sup>d</sup>	178.44 (13.37) <sup>a</sup>	116.32 (10.81) <sup>b</sup>	18.42 (4.35) <sup>c</sup>	6.44 (2.63) <sup>c</sup>	17.46 <sup>c</sup>	35.86 (36.78) <sup>d</sup>
250 (D <sub>5</sub> )	208.32 (14.44) <sup>c</sup>	104.34 (10.23) <sup>c</sup>	11.78 (3.50) <sup>d</sup>	9.38 (3.14) <sup>d</sup>	11.36 <sup>e</sup>	57.68 (49.44) <sup>e</sup>	180.68 (13.45) <sup>a</sup>	105.12 (10.27) <sup>c</sup>	18.20 (4.32) <sup>c</sup>	7.45 (2.82) <sup>d</sup>	17.26 <sup>c</sup>	36.59 (37.20) <sup>d</sup>
S.Em ±	0.23	0.09	0.08	0.05	0.23	0.35	0.22	0.04	0.11	0.04	0.98	1.60
CD (P= 0.05)	0.72	0.27	0.24	0.16	0.69	1.05	0.66	0.12	0.33	0.14	2.96	4.80

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.

Figures in the parentheses are  $\sqrt{(x+1)}$  values

\* Figures in the parentheses are arc sine transformed values

Table 28. Correlation between mealybug incidence and yield parameters on cotton

Levels	120 DAS						150 DAS					
	Mealybugs Per 10 cm apical shoot	Plant height (cm)	GOB/ plant	BOB/ plant	Yield (g/plant)	Per cent reduction in yield	Mealybugs Per 10 cm apical shoot	Plant height (cm)	GOB/ plant	BOB/ plant	Yield (g/plant)	Per cent Reduction in yield
Mealybugs / 10 cm apical shoot	1	-0.946**	-0.996**	0.829*	-0.996**	0.996**	1	-0.525	-0.980**	0.774	-0.878*	0.878*
Plant height (cm)		1	0.966**	-0.963**	0.966**	-0.966**		1	0.586	-0.893*	0.688	-0.688
GOB/ plant			1	-0.864*	0.999**	-0.999**			1	-0.849*	0.952**	-0.952**
BOB/ plant				1	-0.864*	0.864*				1	-0.930**	0.929**
Yield (g/plant)					1	-0.999**					1	-0.999**
Per cent reduction in yield						1						1

\* Differs significantly (P = 0.05)  
 GOB: good opened bolls  
 DAS : Days after sowing

\*\*Differs significantly (P = 0.01)  
 BOB: bad opened bolls

Table 29. Quality parameters of cotton lint due to mealybug damage at different days after sowing

Days after sowing	Number of mealybugs released/ plant	100 seed wt (g)	Oil (%)	2. 5 SL (mm)	Uniformity ratio (%)	Micronaire value	Maturity ratio	Tenacity (g/t)	Elongation (%)
90 DAS	Control (D <sub>0</sub> )	9.30	12.5	34.3	46	3.5	0.92	25.6	6.0
	50 (D <sub>1</sub> )	7.65	11.0	32.4	41	1.8	0.58	20.6	5.8
	100 (D <sub>2</sub> )	7.48	11.0	32.3	41	1.9	0.61	20.8	5.8
	150 (D <sub>3</sub> )	7.38	10.8	31.9	42	1.9	0.62	21.5	5.8
	200 (D <sub>4</sub> )	7.33	10.6	30.9	42	2.3	0.62	22.4	5.8
	250 (D <sub>5</sub> )	6.48	10.3	30.9	42	2.4	0.63	22.5	5.8
120 DAS	50 (D <sub>1</sub> )	8.18	11.5	33.1	43	3.1	0.63	22.5	5.9
	100 (D <sub>2</sub> )	8.14	11.5	32.9	43	3.0	0.63	22.8	5.9
	150 (D <sub>3</sub> )	8.14	11.4	32.8	44	3.0	0.64	22.9	5.9
	200 (D <sub>4</sub> )	8.12	11.4	32.6	44	2.5	0.64	23.3	5.9
	250 (D <sub>5</sub> )	8.08	11.2	32.5	44	2.4	0.64	23.6	6.0
150 DAS	50 (D <sub>1</sub> )	8.67	11.8	33.8	44	3.5	0.64	24.5	6.0
	100 (D <sub>2</sub> )	8.66	11.8	33.7	44	3.2	0.64	24.6	6.0
	150 (D <sub>3</sub> )	8.66	11.7	33.5	45	3.2	0.66	25.4	6.0
	200 (D <sub>4</sub> )	8.58	11.6	33.2	45	3.2	0.66	25.5	6.0
	250 (D <sub>5</sub> )	8.48	11.6	33.1	45	3.1	0.67	25.6	6.0

Table 30. Correlation between mealybug population and quality parameters of cotton lint

	Number of mealybugs released/ plant	100 seed wt (g)	Oil (%)	2.5 SL (mm)	Uniformity ratio (%)	Micronaire value	Maturity ratio	Tenacity (g/t)	Elongation (%)
Number of mealybugs released /plant	1	-0.876*	-0.865*	-0.932**	-0.459	-0.336	-0.556	-0.275	-0.655
100 seed wt (g)		1	0.983**	0.936*	0.797*	0.693	0.847*	0.666	0.898*
Oil (%)			1	0.968**	0.832*	0.744	0.894**	0.706	0.938**
2.5 SL (mm)				1	0.707	0.594	0.790*	0.545	0.852*
Uniformity ratio (%)					1	0.963**	0.985**	0.972**	0.965**
Micronaire value						1	0.955**	0.990**	0.925**
Maturity ratio							1	0.942**	0.991**
Tenacity(g/t)								1	0.903**
Elongation (%)									1

\* Differs significantly (P = 0.05)

\*\* Differs significantly (P = 0.01)

DAS : Days after sowing

maturity ratio, tenacity and elongation (Table 30).

### 4.5.3 Development of EIL

The results of the experiments conducted in field under caged condition during 2009-10 season to establish economic injury level (EIL) due to *P. solenopsis* damage on cotton are presented in Tables 31 to 34.

At 60 days after sowing (DAS) cotton plants did not survive in all the levels of releases. However seed cotton yield in control plot was 27.24 q/ha. Cent per cent yield reduction was recorded in mealybug released plots. The calculated regression coefficient (b) was 0.078 and 20 mealybugs per plant was found to be economic threshold at 60 DAS on irrigated Bt cotton (Table 31).

The average reduction in seed cotton yield due to varying mealybug population ranged from 3.52 to 26.52 q/ha at 90 DAS. The gain threshold was 1.89 and regression coefficient (b) was 0.071. The estimated economic threshold at 90 DAS in irrigated Bt cotton was 27 mealybugs per plant (Table 32). Similarly at 120 DAS, seed cotton yield in different levels of mealybug population varied from 11.36 to 26.84 q/ha. The gain threshold was 2.18 and regression coefficient was 0.049. The results indicated that 44 mealybugs per plant was found to be sufficient to cause economic loss in cotton under irrigated ecosystem (Table 33). Different levels of mealybugs released at 150 DAS caused less variation in seed cotton yield and it was between 17.26 to 27.22 q/ha. The calculated gain threshold and regression coefficients were 2.04 and 0.039, respectively. The economic threshold level was 51 mealybugs per plant which indicates that at 150 DAS crop was at harvesting stage and plants can sustain higher mealybug population (Table 34).

## 4.6 Management of mealybug on Bt cotton under irrigated ecosystem

### 4.6.1 Efficacy of insecticides on mealybugs

The effect of insecticides on the mealybug population in the field experiment conducted on irrigated Bt cotton are presented in tables 35 and 36. Observations on mealybug population were made on a day before, three, seven and fourteen days after each spray on 10 cm apical shoot. The data was subjected to statistical analysis.

2008-09 season (first spray) :

The pretreatment population of the mealybug ranged from 148.25 to 174.65 per 10 cm apical shoot. Difference in the mealybug population among the plots was not statistically significant on a day before the treatment (Table 35).

One day after spray recorded lowest mealybug population of 46.12 mealybugs/ 10 cm apical shoot in profenophos 50 EC @ 1500 ml/ha + soap water (1%) which was significantly superior over rest of the treatments. This was followed by profenophos 50 EC @ 1500ml/ha alone which recorded 60.45 mealybugs/10cm apical shoot. Similar trend was observed on three days after treatment where profenophos 50 EC @ 1500 ml/ha + soap water (1%) was significantly superior over rest of the treatment. Profenophos 50 EC @ 1500 ml/ha + soap water (1%) was significantly effective and superior over rest of the treatment up to seven days after spray which recorded lowest population of 14.12 mealybugs/10 apical shoot. Profenophos 50 EC @ 1500 ml/ha alone was the next best treatment which recorded 20.12 mealybugs/10cm apical shoot. Acephate 75 SP @ 2000 g/ha recorded 24.66 mealybugs /10 cm apical shoot which was on par with thiodicarb 75 WP@ 625 g/ha and these two treatments were significantly superior over control which recorded maximum of 135.36 mealybugs/10 cm apical shoot. Buprofezin 25 SC @ 1000 ml/ha recorded significantly lowest population of 21.24 mealybugs/10 cm apical shoot on 14 DAS. Population slightly increased in profenophos 50 EC @ 1500 ml/ha + soap water (1%) which recorded 26.21 mealybugs/10 cm apical shoot and was on par with thiodicarb @ 625 g/ha and acephate 75 SP@ 2000

Table 31. Economic injury level (EIL) for mealybug on Bt cotton at 60 DAS

Number of mealybugs released per plant (X)	Seed cotton yield (q/ha) (Y)	X <sup>2</sup>	XY
50	0.00	2500	0
100	0.00	10000	0
150	0.00	22500	0
200	0.00	40000	0
250	0.00	62500	0
0.00	27.24	0.00	0
Σ 750	Σ 27.24	Σ 137500	Σ 0

$$\text{Gain Threshold} = \frac{\text{Management cost (Rs. / ha)}}{\text{Market value of the produce (Rs./q)}}$$

$$\begin{aligned} \text{Management cost} &= \text{Cost of plant protection} + \text{Cost of Bt seeds} \\ &= \text{Rs. 2450} + \text{Rs. 1900} \\ &= \text{Rs. 4350 / ha} \end{aligned}$$

$$\text{Market value of the produce} = \text{Rs. 2800/q}$$

$$\text{Gain Threshold} = \frac{4350}{2800} = 1.55$$

$$\begin{aligned} \text{Regression co-efficient (b)} &= \\ b &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} = 0.07783 \end{aligned}$$

$$\text{EIL} = \frac{\text{Gain Threshold}}{b} = \frac{1.55}{0.07783} = 19.96$$

EIL for mealybug at 60 DAS on Bt cotton = 20 mealybugs/plant

Table 32. Economic injury level (EIL) for mealybug on Bt cotton at 90 DAS

Number of mealybugs released per plant (X)	Seed cotton yield (q/ha) (Y)	X <sup>2</sup>	XY
50	7.68	2500	384.00
100	6.48	10000	648.00
150	5.21	22500	781.50
200	4.74	40000	948.00
250	3.52	62500	880.00
0.00	26.52	0.00	0.00
∑ 750	∑ 54.15	∑ 137500	∑ 3641.5

$$\text{Gain Threshold} = \frac{\text{Management cost (Rs. / ha)}}{\text{Market value of the produce (Rs./q)}}$$

$$\begin{aligned} \text{Management cost} &= \text{Cost of plant protection} + \text{Cost of Bt seeds} \\ &= \text{Rs. 3400} + \text{Rs. 1900} \\ &= \text{Rs. 5300 / ha} \end{aligned}$$

$$\text{Market value of the produce} = \text{Rs. 2800/q}$$

$$\text{Gain Threshold} = \frac{5300}{2800} = 1.89$$

$$\begin{aligned} \text{Regression co-efficient (b)} &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} \\ b &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} = 0.07148 \end{aligned}$$

$$\text{EIL} = \frac{\text{Gain Threshold}}{b} = \frac{1.89}{0.07148} = 26.48$$

EIL for mealybug at 90 DAS on Bt cotton = 27 mealybugs/plant

Table 33. Economic injury level (EIL) for mealybug on Bt cotton at 120 DAS

Number of mealybugs released per plant (X)	Seed cotton yield (q/ha) (Y)	X <sup>2</sup>	XY
50	16.37	2500	818.50
100	15.45	10000	1545.00
150	14.25	22500	2137.50
200	13.88	40000	2776.00
250	11.36	62500	2840.00
0.00	26.84	0.00	0.00
∑ 750	∑ 98.15	∑ 137500	∑ 10117

$$\text{Gain Threshold} = \frac{\text{Management cost (Rs. / ha)}}{\text{Market value of the produce (Rs./q)}}$$

$$\begin{aligned} \text{Management cost} &= \text{Cost of plant protection} + \text{Cost of Bt seeds} \\ &= \text{Rs. 4200} + \text{Rs. 1900} \\ &= \text{Rs. 6100 / ha} \end{aligned}$$

$$\text{Market value of the produce} = \text{Rs. 2800/q}$$

$$\text{Gain Threshold} = \frac{4800}{2800} = 2.18$$

$$\begin{aligned} \text{Regression co-efficient (b)} &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} \\ b &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} = 0.04918 \end{aligned}$$

$$\text{EIL} = \frac{\text{Gain Threshold}}{b} = \frac{2.18}{0.04918} = 44.30$$

EIL for mealybug at 120 DAS on Bt cotton = 44 mealybugs/plant

Table 34. Economic injury level (EIL) for mealybug on Bt cotton at 150 DAS

Number of mealybugs released per plant (X)	Seed cotton yield (q/ha) (Y)	X <sup>2</sup>	XY
50	23.18	2500	1159.00
100	21.11	10000	2111.00
150	18.13	22500	2719.50
200	17.46	40000	3492.00
250	17.26	62500	4315.00
0	27.22	0.00	0.00
∑ 750	∑ 124.36	∑ 137500	∑ 13796.5

$$\text{Gain Threshold} = \frac{\text{Management cost (Rs. / ha)}}{\text{Market value of the produce (Rs./q)}}$$

$$\begin{aligned} \text{Management cost} &= \text{Cost of plant protection} + \text{Cost of Bt seeds} \\ &= \text{Rs. 3800} + \text{Rs. 1900} \\ &= \text{Rs. 5700 / ha} \end{aligned}$$

$$\text{Market value of the produce} = \text{Rs. 2800/q}$$

$$\text{Gain Threshold} = \frac{4800}{2800} = 2.04$$

$$\begin{aligned} \text{Regression co-efficient (b)} &= \\ b &= \frac{\sum xy - \frac{\sum X \cdot \sum Y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} = 0.03997 \end{aligned}$$

$$\text{EIL} = \frac{\text{GainThreshold}}{b} = \frac{2.04}{0.03997} = 50.94$$

EIL for mealybug at 150 DAS on Bt cotton = 51 mealybugs/plan

g/ha. All the above treatments were significantly superior over rest of the treatments and control.

Second spray:

One and three days after second spray, profenophos 50 EC @ 1500 ml/ha + soap water (1%) was found to be superior in reducing the mealybugs and recorded significantly lowest population of 13.22 and 2.24 mealybugs/10 cm apical shoot, respectively. On seven days after spray, profenophos 50 EC @ 1500 ml/ha + soap water (1%) recorded lowest population of 1.05 mealybugs/10cm apical shoot which was on par with profenophos 50 EC @ 1500 ml/ha alone. This was followed by buprofezin 25 SC @ 1000 ml/ha which was on par with thiodicarb 75 WP @ 625 g/ha and these two treatments recorded 6.04 and 7.25 mealybugs/10cm apical shoot, respectively. Buprofezin 25 SC @ 1000 ml/ha was found to be effective at later days. It significantly reduced the mealybug to 0.56/10 cm apical shoot on 14<sup>th</sup> day after spray. Mealybug population increased in all other treatments and it was maximum in *Cryptolaemus* released plot @10/plant and soap water (1%) spray which recorded 48.42 and 46.48 mealybugs/10 cm apical shoot and were on par with each other. Untreated control recorded highest population of 112.45 mealybugs/10 cm apical shoot (Table 35).

2009-10 season (First spray):

During 2009-10, fish oil rosin soap and *Verticillium lecanii* were tested in addition to 2008-09 treatments. Higher doses of Buprofezin @ 1500 ml/ha and Profenophos @ 2000 ml/ha were also tested because of their performance in 2008-09 season. Sticker was commonly added to all the treatments and the results are presented in table 36.

Mealybug population was uniform in all the treatments and was non significant on a day before spray. Profenophos 50 EC @ 2000 ml/ha recorded lowest mealybug population of 55.34/ 10 cm apical shoot which was significantly superior over rest of the treatments and was followed by its lower dosage @ 1500 ml which recorded 72.54 mealybugs/10cm apical shoot. Next best treatment was Fish oil rosin soap @ 3125 ml/ha which recorded 83.24 mealybugs/10cm apical shoot and was on par with thiodicarb 75 WP @625 g/ha and chlorpyriphos 20 EC @ 2500 ml/ha. Similar trend was observed on three days after spray (Table 36).

On seventh day after spray, profenophos 50 EC @ 2000 ml/ha recorded lowest mealybugs of 6.94/10 cm apical shoot and was significantly superior over rest of the treatment. On 14<sup>th</sup> day after spray, lowest mealybug population of 20.58 was recorded in buprofezin 25 SC @ 1500 ml/ha which was on par with its lower dosage @ 1000 ml/ha and both the treatments were significantly superior over rest of the treatments. This was followed by profenophos 50 EC @ 2000 ml/ha which recorded 31.45 mealybugs/10 cm apical shoot and was on par with its lower dosage @ 1500 ml/ha. There was considerable increase in the population of mealybug on 14<sup>th</sup> day in all the treatments except buprofezin 25 SC at both the dosages (Table 36).

Second spray:

Profenophos 50 EC @ 2000 ml/ha recorded significantly lowest mealybug population of 15.86 and 2.69/10 cm apical shoot on one and three days after spray, respectively. On seventh day after spray, minimum of 1.26 mealybugs/10 cm apical shoot was recorded in profenophos 50 EC @ 2000 ml/ha which was significantly superior over rest of the treatments. This was followed by its lower dosage treatment @ 1500 ml/ha which recorded 5.06 mealybugs/10 cm apical shoot and was on par with buprofezin 25 SC at both the dosages. Maximum population of 160.96 mealybugs/10 cm apical shoot was recorded in *Verticillium lecanii* @ 2000 g/ha which was significantly superior over control (174.95 mealybugs/10 cm shoot length).

Buprofezin 25 SC @ 1500 ml/ha proved to be superior on 14<sup>th</sup> day after spray which recorded minimum of 3.45 mealybugs/10 cm apical shoot and it was on par with its lower dosage which recorded 3.92 mealybugs/10cm apical shoot. These two treatments were

Table 35. Efficacy of different treatments on mealybug population under irrigated ecosystem during 2008-09 season

Sl No	Treatments	Dosage ml/g/ha	Population of mealybugs /10 cm apical shoot								
			First spray				Second spray				
			1 DBS	1 DAS	3 DAS	7 DAS	14 DAS	1 DAS	3 DAS	7 DAS	14 DAS
1.	Thiodicarb 75WP	625 g	158.44 (12.60)	70.22 (8.40) <sup>c</sup>	42.12 (6.51) <sup>bc</sup>	25.58 (5.07) <sup>c</sup>	29.26 (5.43) <sup>bc</sup>	17.24 (4.15) <sup>ab</sup>	10.08 (3.10) <sup>bc</sup>	7.25 (2.76) <sup>b</sup>	18.69 (4.38) <sup>cd</sup>
2.	Profenophos 50EC	1500 ml	162.44 (12.76)	60.45 (7.80) <sup>b</sup>	35.36 (5.97) <sup>b</sup>	20.12 (4.49) <sup>b</sup>	34.32 (5.88) <sup>c</sup>	19.34 (4.40) <sup>b</sup>	6.25 (2.54) <sup>b</sup>	4.22 (2.07) <sup>ab</sup>	8.22 (2.92) <sup>b</sup>
3.	Profenophos 50EC + Soap water	1500 ml + 1%	165.48 (12.88)	46.12 (6.76) <sup>a</sup>	22.48 (4.58) <sup>a</sup>	14.12 (3.78) <sup>a</sup>	26.21 (5.15) <sup>b</sup>	13.22 (3.66) <sup>a</sup>	2.24 (1.62) <sup>a</sup>	1.05 (1.24) <sup>a</sup>	5.24 (2.40) <sup>b</sup>
4.	Quinalphos 25EC	2000 ml	172.58 (13.15)	94.48 (9.74) <sup>d</sup>	65.44 (8.11) <sup>de</sup>	36.36 (6.05) <sup>de</sup>	42.22 (6.52) <sup>d</sup>	30.82 (5.57) <sup>c</sup>	18.08 (4.25) <sup>e</sup>	14.12 (3.74) <sup>cd</sup>	26.58 (5.17) <sup>ef</sup>
5.	Acephate 75SP	2000 g	182.25 (13.52)	106.65 (10.34) <sup>e</sup>	57.64 (7.60) <sup>d</sup>	24.66 (4.93) <sup>c</sup>	30.44 (5.50) <sup>bc</sup>	20.24 (4.43) <sup>b</sup>	16.34 (3.92) <sup>de</sup>	11.32 (2.99) <sup>bc</sup>	16.54 (3.95) <sup>c</sup>
6.	Chlorpyrifos 20EC	2500 ml	168.58 (13.00)	88.44 (9.42) <sup>d</sup>	61.22 (7.84) <sup>de</sup>	40.34 (6.37) <sup>ef</sup>	48.65 (6.99) <sup>de</sup>	30.45 (5.53) <sup>c</sup>	23.72 (4.87) <sup>f</sup>	21.22 (4.60) <sup>de</sup>	32.70 (5.73) <sup>fg</sup>
7.	Buprofezin 25 SC	1000 ml	174.65 (13.23)	130.82 (11.45) <sup>g</sup>	70.12 (8.38) <sup>e</sup>	45.32 (6.72) <sup>f</sup>	21.24 (4.50) <sup>a</sup>	18.38 (4.13) <sup>ab</sup>	11.22 (3.38) <sup>cd</sup>	6.04 (2.45) <sup>b</sup>	0.56 (1.03) <sup>a</sup>
8.	Neem oil	2000 ml	168.44 (13.00)	125.45 (11.22) <sup>gf</sup>	45.22 (6.75) <sup>c</sup>	32.14 (5.69) <sup>d</sup>	54.68 (7.42) <sup>ef</sup>	46.24 (6.82) <sup>d</sup>	24.13 (4.93) <sup>f</sup>	15.63 (3.94) <sup>d</sup>	22.24 (4.73) <sup>de</sup>
9.	Neemark1500 ppm	5000 ml	158.52 (12.61)	118.62 (10.91) <sup>f</sup>	58.23 (7.65) <sup>d</sup>	40.28 (6.36) <sup>ef</sup>	58.64 (7.67) <sup>f</sup>	42.56 (6.54) <sup>d</sup>	35.36 (5.95) <sup>g</sup>	26.33 (5.13) <sup>ef</sup>	35.44 (5.96) <sup>g</sup>
10.	<i>Cryptoleamus</i> grubs	10/plant	174.63 (13.23)	125.48 (11.22) <sup>gf</sup>	94.46 (9.74) <sup>f</sup>	67.24 (8.23) <sup>g</sup>	52.22 (7.26) <sup>ef</sup>	48.34 (6.99) <sup>d</sup>	56.48 (7.55) <sup>h</sup>	62.44 (7.93) <sup>g</sup>	48.42 (6.99) <sup>h</sup>
11.	Soap water	1%	168.44 (13.00)	122.54 (11.09) <sup>gf</sup>	88.45 (9.42) <sup>f</sup>	64.22 (8.03) <sup>g</sup>	88.48 (9.42) <sup>g</sup>	51.22 (7.17) <sup>d</sup>	36.25 (6.02) <sup>g</sup>	30.56 (5.52) <sup>f</sup>	46.48 (6.83) <sup>h</sup>
12.	Untreated control	--	148.25 (12.19)	154.44 (12.44) <sup>h</sup>	152.52 (12.36) <sup>g</sup>	135.36 (11.65) <sup>h</sup>	124.25 (11.16) <sup>h</sup>	98.22 (9.92) <sup>e</sup>	120.22 (10.98) <sup>i</sup>	134.58 (11.61) <sup>h</sup>	112.45 (10.62) <sup>i</sup>
SEm $\pm$			0.47	0.13	0.21	0.14	0.19	0.21	0.19	0.29	0.21
CD (P= 0.05)			NS	0.40	0.63	0.40	0.55	0.62	0.57	0.85	0.62

DBS – Day before spraying

DAS – Days after spraying

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.

\* Figures in the parentheses are  $\sqrt{(x+1)}$  values

significantly superior over rest of the treatments. Mealybug population increased in all the treatments on 14<sup>th</sup> day and it was maximum in *Verticillium lecanii* @ 2000 g/ha which recorded 134.49 mealybugs/10 cm shoot length. However, mealybug population was significantly highest (146.19/10 cm apical shoot) in control (Table 36).

#### 4.6.2 Influence of different treatments on seed cotton yield

Data on yield parameters like good opened bolls (GOB), bad opened bolls (BOB) and seed cotton yield were recorded and results are presented in table 37.

Profenophos 50 EC @ 1500 ml/ha + soap water (1%) recorded maximum good opened bolls (GOB) of 58.34 per plant with significantly highest cotton yield of 31.41 q/ha. It was on par with profenophos 50 EC @ 1500 ml/ha alone and buprofezin 25 SC @ 1000 ml/ha which recorded seed cotton yield of 30.98 and 29.98 q/ha, respectively and all the above mentioned treatments were significantly superior over rest of the treatments. Minimum seed cotton yield of 20.88 q/ha was recorded in soap water (1%) treatment which was on par with *Cryptolaemus* released treatment (21.47 q/ha) and neemark 1500 ppm @ 5000 ml/ha (22.66 q/ha) treatment but significantly superior over control which recorded lowest seed cotton yield of 18.49 q/ha during 2008-09 season (Table 37).

During 2009-10 season profenophos 50 EC @ 2000 ml/ha recorded maximum GOB of 53.09 per plant with significantly highest seed cotton yield of 28.58 q/ha. It was on par with its lower dosage at 1500 ml/ha, buprofezin 25 SC @ 1500 ml/ha and 1000 ml/ha which recorded seed cotton yield of 27.28 and 28.19 and 27.25 q/ha, respectively and all the above mentioned treatments were significantly superior over rest of the treatments. Minimum seed cotton yield of 16.83 q/ha was recorded in *Verticillium lecanii* treatment which was significantly superior over control which recorded lowest seed cotton yield of 11.72 q/ha (Table 37).

#### 4.6.3 Influence of insecticides on parasitoids emergence

Data on the population of parasitoids emergence in the laboratory was recorded on a day before spray, three, seven and 14 days after spray.

One day before spray, emergence of parasitoids were uniform and non significant among the different treatments. On third day after spray, maximum parasitoid emergence (20.22%) was recorded in control which was on par with *Cryptolaemus* grubs released treatment with 18.68 per cent emergence. Parasitoids emergence was nil in the treatments thiodicarb 75wp, profenophos 50EC, quinalphos 25EC, acephate 75 SP, chlorpyrifos 20 EC. However buprofezin 25 SC, neem oil 2000 ml and Neemark 1500 ppm @ 5000 ml per hectare recorded minimum of 6.56, 5.84 and 5.48 per cent, respectively and were on par with each other. Similar trend was observed on seventh day after second spray. On 14<sup>th</sup> day after spray, parasitoid emergence was maximum (23.64%) in control which was on par with cryptolaemus released treatment (20.88%). Neem oil @ 2000 ml/ha and neemark 1500 ppm @ 5000 ml/ha recorded 4.84 and 12.48 per cent emergence, respectively during 2008-09 season (Table 38).

During 2009-10 season emergence of parasitoids ranged from 35.67 to 40.33 per cent and were statistically non significant among the different treatments on a day before spray. On third days after spray, maximum parasitoid emergence (38.33%) was recorded in control which was significantly superior over rest of the treatments. This was followed by *Verticillium lecanii* @ 2000 g/ha which recorded 10.33 per cent parasitoid emergence. Similar trend was observed on seven days after second spray. On 14<sup>th</sup> day after spray, parasitoid emergence was maximum (43.67%) in control which was significantly superior over rest of the treatments. The emergence of parasitoids were in the following order, control (43.67%)>neem oil 2000 ml/ha (13.67%)>*Verticillium lecanii* 2000 g/ha (10.67%)>neemark 1500 ppm @ 5000 ml/ha(8.33%)>buprofezin 25 SC @ 1000 ml and 1500 l/ha (7.67%)>fish oil rosin soap @ 3125 ml/ha (5.33%) acephate 75 SP @ 2000 g/ha(1.33%)>chlorpyrifos 20 EC @ 2500 ml/ha (0.67 %) (Table 38).

Table 36. Efficacy of different treatments on mealybug population under irrigated ecosystem during 2009-10 season

Sl No	Treatments	Dosage ml/g/ha	Population of mealybugs /10 cm apical shoot								
			First spray				Second spray				
			1 DBS	1 DAS	3 DAS	7 DAS	14 DAS	1 DAS	3 DAS	7 DAS	14 DAS
1	Thiodicarb 75WP	625 g	190.13 (13.81)	84.26 (9.20) <sup>c</sup>	50.52 (7.81) <sup>c</sup>	49.85 (7.09) <sup>h</sup>	41.18 (6.45) <sup>c</sup>	20.69 <sup>c</sup> (4.59)	12.10 (3.54) <sup>c</sup>	11.89 (3.52) <sup>e</sup>	22.43 (4.78) <sup>e</sup>
2	Profenophos 50EC	1500 ml	194.93 (13.97)	72.54 (8.54) <sup>b</sup>	42.43 (6.55) <sup>b</sup>	14.14 (3.82) <sup>b</sup>	35.11 (5.96) <sup>b</sup>	17.81 <sup>b</sup> (4.27)	7.50 (2.81) <sup>b</sup>	5.06 (2.35) <sup>b</sup>	9.86 (3.20) <sup>c</sup>
3	Profenophos 50EC	2000 ml	190.58 (14.11)	55.34 (7.47) <sup>a</sup>	26.98 (5.23) <sup>a</sup>	6.94 (2.72) <sup>a</sup>	31.45 (5.65) <sup>b</sup>	15.86 <sup>a</sup> (4.03)	2.69 (1.67) <sup>a</sup>	1.26 (1.27) <sup>a</sup>	6.29 (2.58) <sup>b</sup>
4	Quinalphos 25EC	2000 ml	189.84 (13.80)	103.93 (10.22) <sup>d</sup>	71.98 (8.51) <sup>h</sup>	46.39 (6.84) <sup>g</sup>	64.44 (8.05) <sup>e</sup>	33.90 <sup>e</sup> (5.86)	19.89 (4.51) <sup>e</sup>	15.53 (4.00) <sup>f</sup>	29.24 (5.45) <sup>f</sup>
5	Acephate 75SP	2000 g	191.36 (13.86)	111.98 (10.60) <sup>e</sup>	50.54 (7.14) <sup>c</sup>	43.92 (6.66) <sup>f</sup>	51.96 (7.24) <sup>d</sup>	21.25 <sup>c</sup> (4.66)	10.87 (3.36) <sup>c</sup>	8.70 (3.03) <sup>d</sup>	17.37 (4.22) <sup>d</sup>
6	Chlorpyriphos 20EC	2500 ml	193.87 (13.91)	84.24 (10.11) <sup>c</sup>	54.26 (7.40) <sup>d</sup>	40.00 (6.36) <sup>e</sup>	55.95 (7.51) <sup>d</sup>	20.22 <sup>c</sup> (4.54)	12.34 (3.57) <sup>c</sup>	14.40 (3.86) <sup>f</sup>	37.61 (6.17) <sup>g</sup>
7	Buprofezin 25 SC	1000 ml	192.12 (13.83)	143.90 (12.08) <sup>h</sup>	77.13 (8.81) <sup>i</sup>	30.70 (5.58) <sup>d</sup>	23.36 (4.88) <sup>a</sup>	35.02 <sup>e</sup> (5.96)	27.28 (5.27) <sup>f</sup>	6.64 (2.67) <sup>c</sup>	3.92 (2.04) <sup>a</sup>
8	Buprofezin 25 SC	1500 ml	192.02 (13.88)	126.76 (11.28) <sup>f</sup>	67.95 (8.27) <sup>g</sup>	25.89 (5.13) <sup>c</sup>	20.58 (4.58) <sup>a</sup>	23.21 <sup>d</sup> (4.86)	17.16 (4.20) <sup>d</sup>	5.85 (2.51) <sup>bc</sup>	3.45 (1.92) <sup>a</sup>
9	Neem oil	2000 ml	190.22 (13.81)	150.54 (12.29) <sup>i</sup>	70.40 <sup>j</sup> (8.42) <sup>h</sup>	38.57 (6.25) <sup>e</sup>	65.62 (8.13) <sup>e</sup>	55.49 <sup>d</sup> (7.48)	28.96 (5.42) <sup>f</sup>	18.76 (4.39) <sup>g</sup>	26.69 (5.21) <sup>f</sup>
10	Neemark1500 ppm	5000 ml	193.84 (13.94)	131.67 (11.50) <sup>g</sup>	64.64 (8.07) <sup>f</sup>	44.71 (6.72) <sup>g</sup>	65.09 (8.10) <sup>e</sup>	47.24 (6.91)	39.25 (6.30) <sup>g</sup>	29.23 (5.45) <sup>h</sup>	39.34 (6.31) <sup>g</sup>
11	Fish oil rosin soap	3125 ml	198.84 (13.12)	83.24 (9.15) <sup>c</sup>	55.53 (7.48) <sup>d</sup>	39.36 (6.31) <sup>e</sup>	65.56 (8.12) <sup>e</sup>	35.32 <sup>e</sup> (5.98)	19.15 (4.43) <sup>d</sup>	13.00 (3.67) <sup>ef</sup>	50.20 (7.12) <sup>h</sup>
12	<i>Verticillium lecanii</i>	2000 g	189.12 (13.77)	184.71 (13.61) <sup>j</sup>	182.41 (13.52) <sup>j</sup>	161.89 (12.74) <sup>i</sup>	148.60 (12.21) <sup>f</sup>	117.47 <sup>g</sup> (10.86)	143.7 (12.01) <sup>h</sup>	160.96 (12.71) <sup>i</sup>	134.49 (11.62) <sup>j</sup>
13	Untreated Control	--	192.73 (13.90)	200.77 (14.19) <sup>k</sup>	198.28 (14.10) <sup>k</sup>	175.97 (13.28) <sup>j</sup>	161.53 (12.73) <sup>g</sup>	127.69 <sup>h</sup> (11.32)	156.29 (12.52) <sup>i</sup>	174.95 (13.25) <sup>j</sup>	146.19 (12.11) <sup>j</sup>
SEm ±			1.98	0.06	0.04	0.05	0.11	0.05	0.10	0.07	0.10
CD (P= 0.05)			NS	0.18	0.12	0.14	0.33	0.14	0.29	0.19	0.30

DBS – Day before spraying

DAS – Days after spraying

In vertical columns means followed by similar letters are not different significantly (P = 0.05) by DMRT.

\* Figures in the parentheses are  $\sqrt{(x+1)}$  values

Table 37. Effect of different treatments on seed cotton yield under irrigated ecosystem during 2008-09 season and 2009-10 season

Sl. No	Treatments	Dosage ml/g/ha	2008-09 season			2009-10 season		
			GOB /Plant	BOB /Plant	Seed cotton Yield (q /ha)	GOB /Plant	BOB /Plant	Seed cotton Yield (q /ha)
1	Thiodicarb 75WP	625 g	45.21 <sup>c</sup>	8.32 <sup>bc</sup>	26.87 <sup>b</sup>	41.14 <sup>b</sup>	7.57 <sup>d</sup>	21.81 <sup>c</sup>
2	Profenophos 50EC	1500 ml	55.12 <sup>b</sup>	6.12 <sup>ab</sup>	30.98 <sup>a</sup>	50.16 <sup>a</sup>	5.57 <sup>abc</sup>	27.28 <sup>a</sup>
3	Profenophos 50EC + Soap water	1500 ml + 1%	58.34 <sup>a</sup>	5.47 <sup>a</sup>	31.41 <sup>a</sup>	--	--	--
4	Profenophos 50EC	2000 ml	--	--	--	53.09 <sup>a</sup>	4.98 <sup>ab</sup>	28.58 <sup>a</sup>
5	Quinalphos 25EC	2000 ml	41.23 <sup>d</sup>	8.44 <sup>c</sup>	25.10 <sup>bc</sup>	37.52 <sup>bc</sup>	7.68 <sup>d</sup>	22.84 <sup>bc</sup>
6	Acephate 75SP	2000 g	40.56 <sup>d</sup>	7.36 <sup>abc</sup>	26.49 <sup>b</sup>	36.91 <sup>bc</sup>	6.70 <sup>bcd</sup>	24.11 <sup>b</sup>
7	Chlorpyriphos 20EC	2500 ml	40.64 <sup>d</sup>	8.68 <sup>c</sup>	24.16 <sup>cd</sup>	36.98 <sup>bc</sup>	7.90 <sup>d</sup>	21.99 <sup>cd</sup>
8	Buprofezin 25 SC	1000 ml	52.44 <sup>b</sup>	6.11 <sup>ab</sup>	29.98 <sup>a</sup>	47.72 <sup>a</sup>	5.56 <sup>abc</sup>	27.25 <sup>a</sup>
9	Buprofezin 25 SC	1500 ml	--	--	--	36.69 <sup>bc</sup>	4.14 <sup>bcd</sup>	28.19 <sup>a</sup>
10	Neem oil	2000 ml	40.32 <sup>d</sup>	6.88 <sup>abc</sup>	23.97 <sup>cd</sup>	34.69 <sup>bc</sup>	6.69 <sup>bcd</sup>	20.62 <sup>c</sup>
11	Neemark 1500 ppm	5000 ml	38.12 <sup>de</sup>	7.35 <sup>abc</sup>	22.66 <sup>de</sup>	32.87 <sup>c</sup>	6.90 <sup>cd</sup>	19.54 <sup>cd</sup>
12	<i>Cryptoleamus</i> grubs	10/plant	36.12 <sup>e</sup>	7.58 <sup>abc</sup>	21.47 <sup>e</sup>	--	--	--
13	Fish oil rosin soap	3125 ml	--	--	--	19.72 <sup>d</sup>	6.26 <sup>ab</sup>	19.00 <sup>cd</sup>
14	<i>Verticillium lecanii</i>	2000 g	--	--	--	31.96 <sup>c</sup>	6.93 <sup>cd</sup>	16.83 <sup>d</sup>
15	Un treated Control	--	28.11 <sup>f</sup>	15.48 <sup>d</sup>	18.49 <sup>f</sup>	25.58 <sup>d</sup>	14.0 <sup>e</sup>	11.72 <sup>e</sup>
S.Em ±			1.07	0.67	0.86	2.06	0.53	1.22
CD (P= 0.05)			3.15	1.96	2.58	6.01	1.62	3.55

GOB- Good opened bolls

BOB- Bad opened bolls

In vertical columns means followed by similar letters do not differ significantly (P = 0.05) by DMRT.

Figures in the parentheses are arc sine transformed values

Table 38. Impact of different treatments on parasitoid emergence in the laboratory during 2008-09 season and 2009-10 season

Sl. No.	Treatments	Dosage ml/gm/ha	% parasitoid emergence (2008-09 season)				% parasitoid emergence (2009-10 season)			
			1 DBS	3 DAS	7 DAS	14 DAS	1 DBS	3 DAS	7 DAS	14 DAS
1	Thiodicarb 75WP	625 g	12.44	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>e</sup>	35.67	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	0.00 (0.71) <sup>h</sup>
2	Profenophos 50EC	1500 ml	10.22	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>e</sup>	36.00	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	0.00 (0.71) <sup>h</sup>
3	Profenophos 50EC + Soap water	1500 ml + 1%	19.25	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>e</sup>	--	--	--	--
4	Profenophos 50EC	2000 ml	--	--	--	--	37.67	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	0.00 (0.71) <sup>h</sup>
5	Quinalphos 25EC	2000 ml	11.25	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>e</sup>	37.00	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	0.00 (0.71) <sup>h</sup>
6	Acephate 75SP	2000 g	12.24	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.52 (0.81) <sup>e</sup>	35.67	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	1.33 (1.34) <sup>f</sup>
7	Chlorpyriphos 20EC	2500ml	15.25	0.00 (0.71) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	0.48 (0.80) <sup>e</sup>	36.67	0.00 (0.71) <sup>e</sup>	0.00 (0.71) <sup>f</sup>	0.67 (1.05) <sup>g</sup>
8	Buprofezin 25 SC	1000 ml	13.35	6.56 (2.63) <sup>c</sup>	0.00 (2.49) <sup>d</sup>	0.00 (0.71) <sup>e</sup>	39.33	7.33 (2.80) <sup>cd</sup>	7.00 (2.73) <sup>d</sup>	7.67 (2.86) <sup>d</sup>
9	Buprofezin 25 SC	1500 ml	--	--	--	--	39.00	8.67 (3.03) <sup>c</sup>	8.33 <sup>c</sup> (2.96)	7.67 (2.85) <sup>d</sup>
10	Neem oil	2000ml	16.25	5.84 (2.49) <sup>c</sup>	5.85 (3.01) <sup>c</sup>	4.84 (2.27) <sup>d</sup>	37.33	6.67 (2.68) <sup>d</sup>	9.33 (3.13) <sup>c</sup>	13.67 (3.76) <sup>b</sup>
11	Neemark 1500 ppm	5000 ml	16.62	5.48 (2.41) <sup>c</sup>	8.66 (2.78) <sup>cd</sup>	12.48 (3.59) <sup>b</sup>	40.33	8.67 (3.03) <sup>c</sup>	8.33 (2.97) <sup>c</sup>	8.33 (2.96) <sup>d</sup>
12	<i>Cryptoleamus</i> grubs	10/plant	12.24	18.68 (3.00) <sup>a</sup>	17.36 (2.80) <sup>a</sup>	20.88 (2.50) <sup>a</sup>	--	--	--	--
13	Fish oil rosin soap	3125 ml	--	--	--	--	39.67	6.33 (2.58) <sup>d</sup>	5.67 (2.48) <sup>e</sup>	5.33 (2.41) <sup>e</sup>
14	<i>Verticillium lecanii</i>	2000 g	--	--	--	--	38.67	10.33 (3.29) <sup>b</sup>	11.67 (3.49) <sup>b</sup>	10.67 (3.34) <sup>c</sup>
15	Un treated Control	--	15.54	20.22 (4.55) <sup>a</sup>	18.63 (4.37) <sup>a</sup>	23.64 (4.91) <sup>a</sup>	38.33	38.33 (6.23) <sup>a</sup>	39.33 (6.31) <sup>a</sup>	43.67 (6.65) <sup>a</sup>
S.Em ±			2.14	0.12	0.11	0.12	1.75	0.09	0.07	0.09
CD (P= 0.05)			NS	0.36	0.33	0.37	NS	0.25	0.213	0.27

DBS – Day Before Spraying , DAS – Days After Spraying, GOB- Good opened bolls, BOB- Bad opened bolls  
 In vertical columns means followed by similar letters do not differ significantly (P = 0.05) by DMRT.  
 Figures in the parentheses are arc sine transformed values

#### 4.6.4 Economics of mealybug management in cotton

During 2008-09, a maximum gross income of Rs. 81,666 per ha was recorded in profenophos 50 EC @ 1500 ml/ha + soap water (1%) followed by profenophos 50 EC @ 1500 ml/ha alone and buprofezin 25 SC @ 1000 ml/ha which recorded Rs. 80,548 and Rs. 77,948, respectively. Similarly, the highest net profit of Rs 62,287 per ha was noticed in profenophos 50 EC @ 1500 ml/ha + soap water (1%) followed by profenophos 50 EC @ 1500 ml/ha alone and buprofezin 25 SC @ 1000 ml/ha which recorded Rs. 60,569 and Rs. 57,519, respectively. Profenophos 50 EC @ 1500 ml/ha + soap water (1%), profenophos 50 EC @ 1500 ml/ha alone and buprofezin 25 SC @ 1000 ml/ha recorded an additional net returns of Rs 30,727, Rs 29,009 and Rs 25,959 with C:B ratio of 3.21, 3.03 and 2.82, respectively (Table 39).

During 2009-10 season, maximum gross income of Rs 85,740 was recorded in profenophos 50 EC @ 2000 ml/ha followed by buprofezin 25 SC @ 1500 ml/ha and profenophos 50 EC @ 1500 ml/ha which recorded Rs 84,570 and Rs 81,840, respectively. Net returns of Rs 62,960 was highest in profenophos 50 EC @ 2000 ml/ha followed by buprofezin 25 SC @ 1500 ml/ha and profenophos 50 EC @ 1500 ml/ha which recorded Rs 60,890 and Rs 59,510, respectively. Lowest net returns was in control which recorded Rs 16,995. An additional net returns over control was maximum in profenophos 50 EC @ 2000 ml/ha (Rs 45,965) was followed by buprofezin 25 SC @ 1500 ml/ha and profenophos 50 EC @ 1500 ml/ha which registered Rs. 43,895 and Rs 42,515, respectively. Profenophos 50 EC @ 2000 ml/ha recorded highest C:B ratio of 2.76 which was followed by its lower dosage @ 1500 ml/ha (2.67), buprofezin 25 SC @ 1000 ml/ha(2.59) and buprofezin 25 SC @ 1500 ml/ha(2.57) (Table 40).

Table 39. Economics of different treatments for the management of cotton mealybug under irrigated ecosystem during 2008- 09 season

Sl. No.	Treatments	Total quantity of chemical used (ml/g./ha)	Total cost of chemical used (Rs./ha)	Labour cost for spray (Rs./ha)	Cost of common spray (Rs./ha)	Total cost of spray (Rs./ha)	Cost of agronomic practices (Rs./ha)	Total Expenditure (Rs./ha)	Yield (q/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	Additional net returns over control (Rs./ha)	C:B ratio
1	Thiodicarb 75WP	625 g	3750	360	1755	5865	16514	22379	26.87	69862	47483	15923	2.12
2	Profenophos 50EC	1500 ml	1350	360	1755	3465	16514	19979	30.98	80548	60569	29009	3.03
3	Profenophos 50EC + Soap water	1500 ml + 1%	750	360	1755	2865	16514	19379	31.41	81666	62287	30727	3.21
4	Quinalphos 25EC	2000 ml	900	360	1755	3015	16514	19529	25.10	65260	45731	14171	2.34
5	Acephate 75SP	2000 g	2400	360	1755	4515	16514	21029	26.49	68874	47845	16285	2.28
6	Chlorpyrifos 20EC	2500 ml	1250	360	1755	3365	16514	19879	24.16	62816	42937	11377	2.16
7	Buprofezin 25 SC	1000 ml	1800	360	1755	3915	16514	20429	29.98	77948	57519	25959	2.82
8	Neem oil	2000 ml	2400	360	1755	4515	16514	21029	23.97	62322	41293	9733	1.96
9	Neemark 1500 ppm	5000 ml	2000	360	1755	4115	16514	20629	22.66	58916	38287	6727	1.86
10	Cryptoleamus grubs	10/plant	1388	360	1755	3504	16514	20018	21.47	55822	35804	4244	1.79
11	Soap water	1%	200	360	1755	2315	16514	18829	20.88	54288	35459	3899	1.88
12	Control	--	00	00	00	00	16514	16514	18.49	48074	31560	--	1.91

Cotton price Rs 2600 per quintal

Table 40. Economics of different treatments for the management of cotton mealybug under irrigated ecosystem during 2009-10 season

Sl. No	Treatments	Total quantity of chemical used (ml/gm./ha)	Total cost of chemical used (Rs./ha)	Labour cost for spray (Rs./ha)	Cost of common spray (Rs./ha)	Total cost of spray (Rs./ha)	Cost of agronomic practices (Rs./ha)	Total Expenditure (Rs./ha)	Yield (q/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	Additional net returns over control (Rs./ha)	C:B ratio
1	Thiodicarb 75WP	625 g	3750	410	2405	6565	18165	24730	21.81	65430	40700	23705	1.65
2	Profenophos 50EC	1500 ml	1350	410	2405	4165	18165	22330	27.28	81840	59510	42515	2.67
3	Profenophos 50EC	2000 ml	1800	410	2405	4615	18165	22780	28.58	85740	62960	45965	2.76
4	Quinalphos 25EC	2000 ml	900	410	2405	3715	18165	21880	22.84	68520	46640	29645	2.13
5	Acephate 75SP	2000 g	2400	410	2405	5215	18165	23380	24.11	72330	48950	31955	2.09
6	Chlorpyrifos 20EC	2500 ml	1250	410	2405	4065	18165	22230	21.99	65970	43740	26745	1.97
7	Buprofezin 25 SC	1000 ml	1800	410	2405	4615	18165	22780	27.25	81750	58970	41975	2.59
8	Buprofezin 25 SC	1500 ml	2700	410	2405	5515	18165	23680	28.19	84570	60890	43895	2.57
9	Neem oil	2000 ml	2400	410	2405	5215	18165	23380	20.62	61860	38480	21485	1.65
10	Neemark 1500 ppm	5000 ml	2000	410	2405	4815	18165	22980	19.54	58620	35640	18645	1.55
11	Fish oil rosin soap	3125 ml	2500	410	2405	5315	18165	23480	19.00	57000	33520	16525	1.43
12	<i>Verticillium lecanii</i>	1%	1250	410	2405	4065	18165	22230	16.83	50490	28260	11265	1.27
13	Control	--	0	0	0	0	18165	18165	11.72	35160	16995	0	0.94

Cotton price Rs 3000 per quintal

## V. DISCUSSION

India is the only country where all the four cultivated species of cotton are even now grown on fairly commercial scale in a total coverage of ten million ha. Qualitative and quantitative transformation has taken place in cotton production scenario in India. Area-wise, India ranks first in global scenario (about 33% of the world cotton area) but with regard to production, it ranked second, next to China. The production increased from meager 2.79 million bales in 1947-48 to 17.6 million bales in 1996-97 and all time record of 31.5 million bales during 2007-08 (Anon., 2008).

Many sucking insect pests have attained the serious status after transgenic Bt cotton introduction in India. Among the various insects attacking the Bt cotton, sucking pests like thrips, leaf hoppers, aphids, whiteflies and mirid bugs have been recognised as serious pests whereas, the mealybugs have not yet assumed the pest status until 2005. Historically mealybugs were never considered as major pests of economic significance on cotton in India (Anon., 2006). Of late, mealybugs were found causing severe damage to the Bt cotton (Jhala and Bharpoda, 2008). Three species of mealybugs viz, *Phenacoccus solenopsis* Tinsley, *Phenacoccus solani* Ferris and *Maconellicoccus hirsutus* (Green) were found on cotton in our country, among them *Phenacoccus solenopsis* was the main species, comprising 95 per cent of the samples examined from 47 locations representing nine cotton growing states of India (Anon., 2010). Mealybugs attained the major status due to their polyphagous nature coupled with high reproductive capacity in the form of parthenogenesis and ovisacs with short life cycle. Its ability to withstand extremes of temperatures from 0°C to 45°C during the crop free periods and availability of equally attractive alternate hosts almost round the year, is all set to be even more dreaded than the bollworm, *Helicoverpa armigera* (Hubner).

In view of the absence of an effective and rational control programme, farmers are in the habit of applying various insecticides out of their anxiety, often resulting in complicating pest problems. Hence, it is imperative that an effective management programme should be developed for the cotton mealybug. A sound knowledge on the population dynamics of the mealybug along with its natural enemies is essential for developing such a programme. Keeping this in view, various experiments were conducted so as to know some basic aspects as well as to evolve an effective method of managing the cotton mealybug.

The results of various investigations on the cotton mealybug as envisaged in the introductory chapter are discussed here under.

### 5.1 Survey on species diversity and level of mealybug incidence on Bt cotton in northern Karnataka

#### 5.1.1 Mealybug species attacking cotton

In the present investigations, identification by experts indicated only one species of mealybug, *P. solenopsis* on cotton crop was noticed in North Karnataka. Information on this pest were made by many scientists and it was for the first time recorded as a minor pest in cultivated cotton in USA (Fuchs *et al.*, 1991). *Maconellicoccus hirsutus* (Green) was reported to occur on cotton, *Gossypium arborium* (Linn.) in Punjab (Dhawan *et al.*, 1980) and recorded on new world cotton, *Gossypium herbaceum* (Linn.) in Gujarat by Muralidharan and Badaya (2000). *P. solenopsis* was the dominant species over large areas of all the cotton growing regions in India (Deshmukh *et al.*, 2009). This mealybug species is apparently a new record as a pest of cotton in Karnataka as reported by Hanchinal *et al.* (2009) and only *P. solenopsis* causing extensive damage to the cotton fields in Tungabhadra Project (TBP) and Upper Krishna project (UKP) areas.

#### 5.1.2 Pest status of *P. solenopsis*

In the present study, moderate to severe damage by *P. solenopsis* was observed

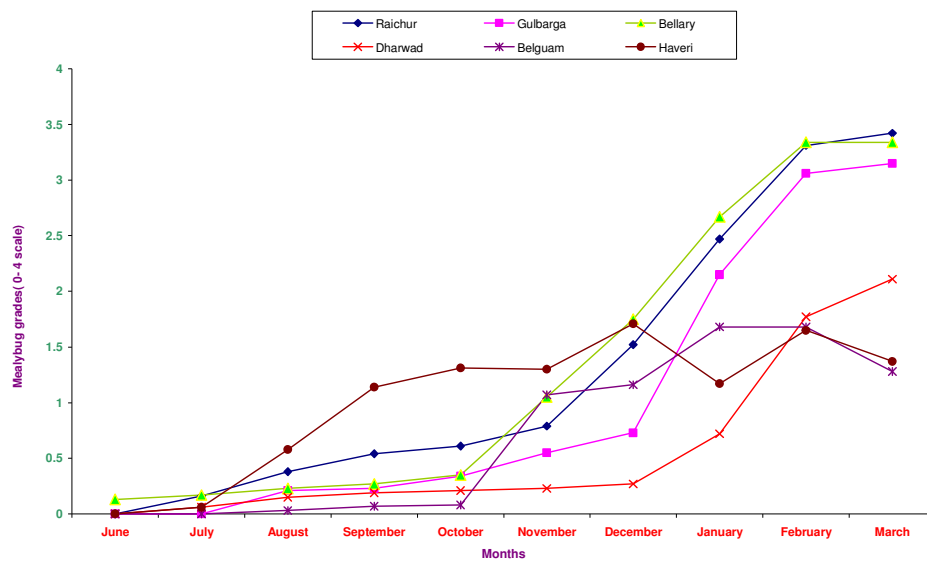


Fig. 1. Incidence of Phenacoccus solenopsis on cotton in different locations of North Karnataka during 2008-09 season

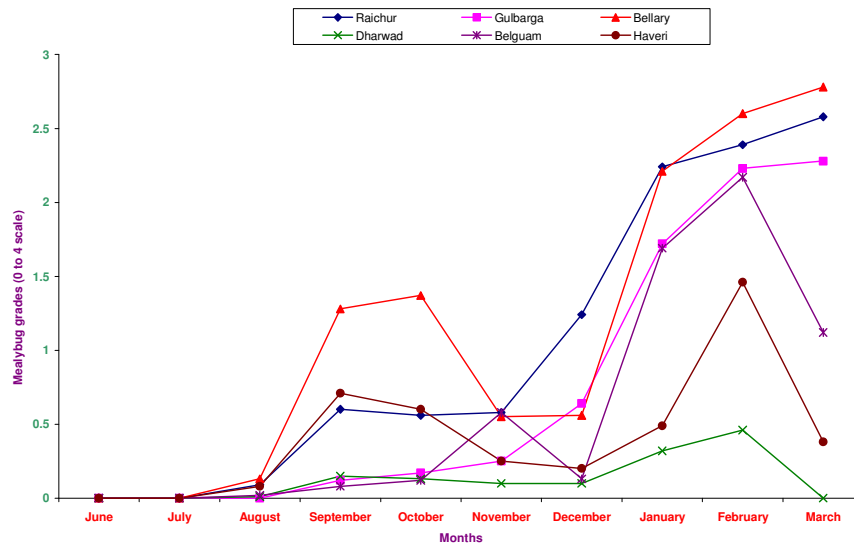


Fig. 2. Incidence of Phenacoccus solenopsis on cotton in different locations of North Karnataka during 2009-10 season

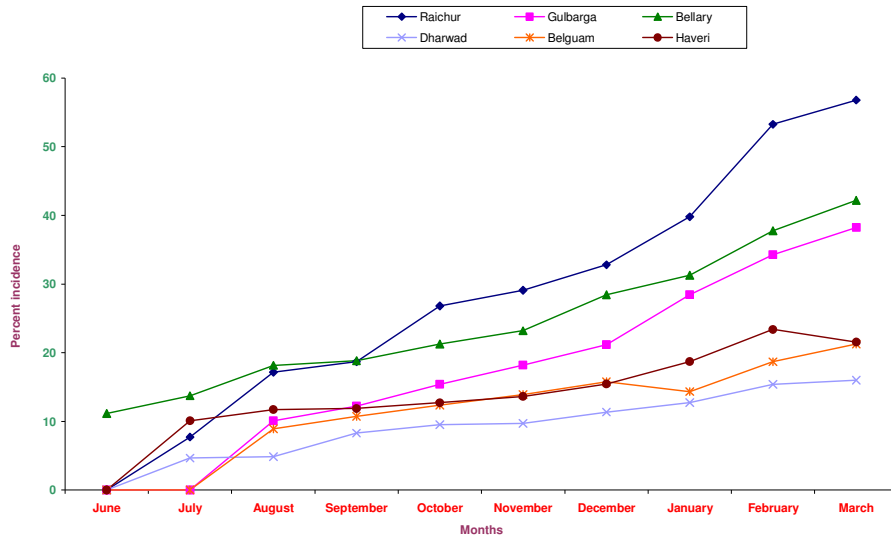


Fig. 3. Per cent infestation of mealybug, *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2008-09 season

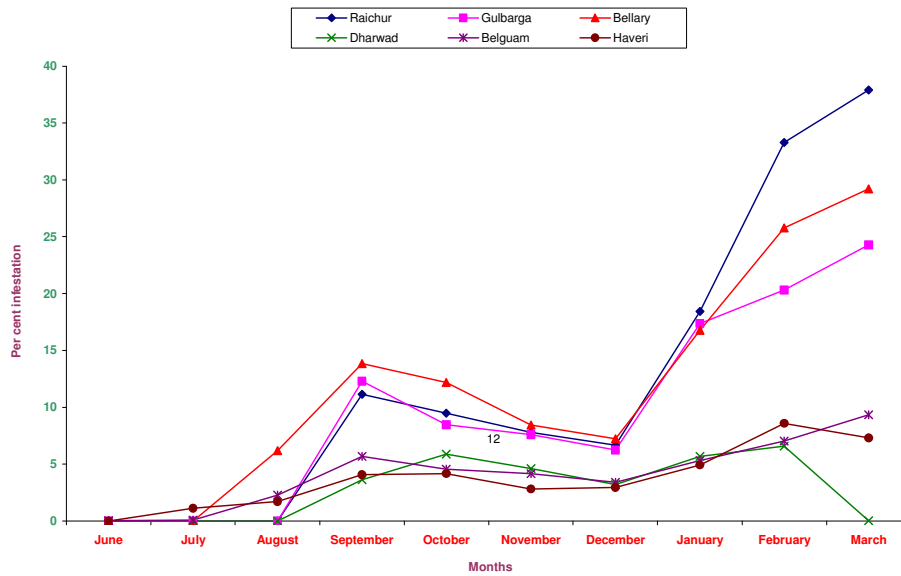


Fig. 4. Per cent infestation of mealybug, *Phenacoccus solenopsis* on cotton in different locations of North Karnataka during 2009-10 season

during the survey in the major cotton growing districts of North Karnataka viz., Raichur, Bellary, Gulbarga, Dharwad, Belgaum and Haveri. Infestation varied from zero to 3.62 grade in major cotton growing districts. Peak increase in mealybug population was noticed from January and it ranged between 2.15 to 3.34 grade in Raichur, Gulbarga and Bellary districts. Incidence was low and ranged between 0.72 to 2.11 grade in Dharwad, Belgaum and Haveri districts during 2008-09 season (Fig1). During 2009-10 season peak incidence was observed from January to March (Fig 2). Infestation of *P. solenopsis* was maximum in TBP and UKP areas and ranged from 38.25 to 56.80 per cent in March 2008-09 (Fig 3) and similarly, during 2009-10 season the incidence was maximum in Raichur, Gulbarga and Bellary districts but it was low as compared to 2008-09 season due to presence of biotic (Increased parasitoids activity) and abiotic (Rainfall in winter) factors in North Karnataka (Fig. 4).

Similar infestation of the cotton mealybugs, *Phenacoccus* sp., *Ferrisa* sp. and *Maconellicoccus* sp. was reported in many districts of Punjab by Dhawan (2007). *P. solenopsis* was also reported on cotton in Punjab, Rajasthan, Maharashtra and Gujarat by Tanwar *et al.*(2007). Mealybugs, *P. solenopsis* and *M. hirsutus* were found in 50 to 75 per cent fields with damage varying from 1 to 5 per cent in Andhra Pradesh (Durgaprasad *et al.*, 2008). Bhosle *et al.* (2009) reported that infestation of *P. solenopsis* on Bt cotton was maximum in Parbhani with 40.95 per cent leaf infestations and 35.77 per cent of green boll damage. Saini *et al.* (2009) observed *P. solenopsis* incidence in major cotton growing areas of Haryana.

The variation in the mealybug incidence in the present study may be due to area under cotton was less, isolated cotton fields, biotic and abiotic factors prevailed during the study period and negligence of the farmers or unable to notice as pest of cotton in this area. In contrary cotton crop in North India was maximum and mono cropping is followed in some area which resulted in higher percent incidence and outbreak of the pest.

## 5.2 Identification of natural enemies and alternative hosts of mealybug

### 5.2.1 Predatory population

During the present survey, general predators like coccinellids, *Chrysoperla* and spiders were recorded on *P. solenopsis* infested cotton but their population was negligible. Peak activity of predators was observed from October to February in all the districts during both the years.

Mean predatory population ranged from 0.02 to 0.14 per plant across the North Karnataka during 2008-09 cropping season. In general predatory population was more in the TBP and UKP areas where mealybug incidence was also more during the season. Maximum mean predator population of 0.14 per plant was recorded in both Raichur and Bellary talukas. A dipteran predator, *Gitonides perspicax* Knab (Drosophilidae) was found only at Raichur during January to March 2008-09. The maggots were found to prey the mealybugs mainly in summer months. During 2009-10, lowest mean predatory population of 0.05 per plant was recorded in both Dharwad and Belgaum districts as compared to a maximum of 0.12 and 0.10 mean predators per plant in Raichur and Bellary districts, respectively.

Similar observations were made in the past (Misra, 1919; Hall, 1921; Dutt *et al.*, 1951; Rao, 1967 and Manjunath, 1985) and reported that several species of *Scymnus* were found as active predators of *M. hirsutus* on grape vines. Twenty nine species of predators belonging to five insect orders have been reported on *M. hirsutus* in India by Ranga Reddy and Lakshminarayana (1986). Activity of *Cryptolaemus montrouzieri* on *M. hirsutus* in Karnataka was reported by Mani (1986). Among the predators, *Scymnus coccivorus*, *Cryptolaemus montrouzieri*, *Chrysopa* sp. and *Spalgius epius* (West.) were recorded with maximum activity on citrus mealybug (Malleshaiah *et al.*, 1999).

## 5.2.2 Parasitoids population

In the present investigations, five parasitoids were recorded on cotton mealybug, *P. solenopsis*. Among them *Aenasius bambawalei* Hayat was the dominant parasitoid in several fields. Parasitoid cocoons per plant varied from 2.41 to 10.42 per cent in major cotton growing districts of North Karnataka. Highest mean parasitisation was recorded in Bellary district (10.42 %) followed by Raichur district (8.32 %) with cocoons of 20.49 per cent in the month of January in Bellary district. Parasitoid activity was low in the districts of Dharwad, Belgaum and Haveri and mean per cent cocoons ranged between 2.41 to 4.52 during 2008-09 (Fig. 5) with peak activity of the parasitoids from January to March. Parasitism reached up to 34.15 per cent in March in Raichur taluk during 2009-10 season (Fig. 6). Parasitoid activity was generally low in the districts of Dharwad, Haveri and Belgaum because of lower mealybug incidence on cotton which was terminated early during February. On the contrary, parasitoids activity was maximum during February and March in TBP and UKP areas which coincided with higher population of mealybug. In these areas majority of the cotton crop was under irrigation and final cotton picking was done at the end of March.

Parasitoids emergence from all the districts revealed that lowest of 1.29 per cent emergence was in Belgaum district with highest emergence of 7.33 in Bellary district with a peak activity from January to March in all the locations during 2008-09 (Fig. 7). Similarly, during 2009-10 cropping season parasitoids emergence in the laboratory was maximum as compared to previous season. Mean parasitoids emergence from mealybugs collected at various places were highest in TBP and UKP areas which varied from 5.36 to 9.52 per cent. In other districts mean parasitoids emergence ranged between 2.13 to 3.46 per cent (Fig. 8).

These results of present investigations are in conformity with Ghose (1971) and Manjunath (1985) who reported that *Anagyrus* sp. causing 19 to 47 per cent parasitisation on *M. hirsutus* in West Bengal and *Anagyrus dactylopii* was found parasitizing *M. hirsutus* on grapes to an extent of 70 per cent in Bangalore, respectively. Similarly another parasitoid, *Promuscidea unfasciiventris* Girault (Chalcidoidea: Aphelinidae) on mealybug was earlier reported from Andhra Pradesh, Bihar, Delhi, Karnataka and Maharashtra by Sinha *et al.* (1985) and Hayat (1986). Mani (1986) reported six species of parasitoids on *M. hirsutus*, among them *Anagyrus dactylopii* recorded maximum parasitisation compared to others. Similar studies were made by Mani and Krishnamoorthy (1997), who found that *Coccidoxenoides peregrinus* (Timberlake) and *Leptomastix dactylopii* are potential parasitoids of *Planococcus citri* on sapota. However, they do not appear to regulate *P. citri* throughout the year and are active only during specified months. The difference in the parasitism may be attributed to the difference in the host observed and change of location.

## 5.2.3 Host range of mealybug

Examination of plants grown in and around mealybug infested cotton fields revealed the presence of *P. solenopsis* on more than 15 host plants spread across eight families in cotton growing districts of North Karnataka. Among them, *Abutilon indicum* L. (Malvaceae) and *Parthenium hysterophorus* L. (Asteraceae) were the major weed hosts found across the North Karnataka. Initially mealybug population was found on these hosts in the cotton field bunds and along the road side water canals. Mealybugs were found on these two weed hosts even in off season which carried over to next season.

*Abutilon indicum* was the dominant weed host along the cotton field bunds in Raichur and Bellary districts. *Abutilon indicum* plants were severely affected by *P. solenopsis* at Raichur. Mealybugs were first noticed on this weed along the border and later spread to the cotton fields. This weed was also found infested by mealybugs throughout the season in Dharwad, Belgaum, Haveri and Gulbarga districts. *P. solenopsis* was also found on many hosts *viz.*, *Lycopersicon esculentum*, *Amaranthus* sp., *Abelmoschus esculentus*, *Achyranthes aspera*, *Hibiscus rosasinensis*, *Morus alba*, *Annona squamosa*, *Helianthus annuus*, *Vigna mungo*, *Zizipus* spp., *Physalis minima*, *Tectona grandis* and *Leucos* spp. These hosts were found either in the mealybug infested cotton or near by cotton fields.

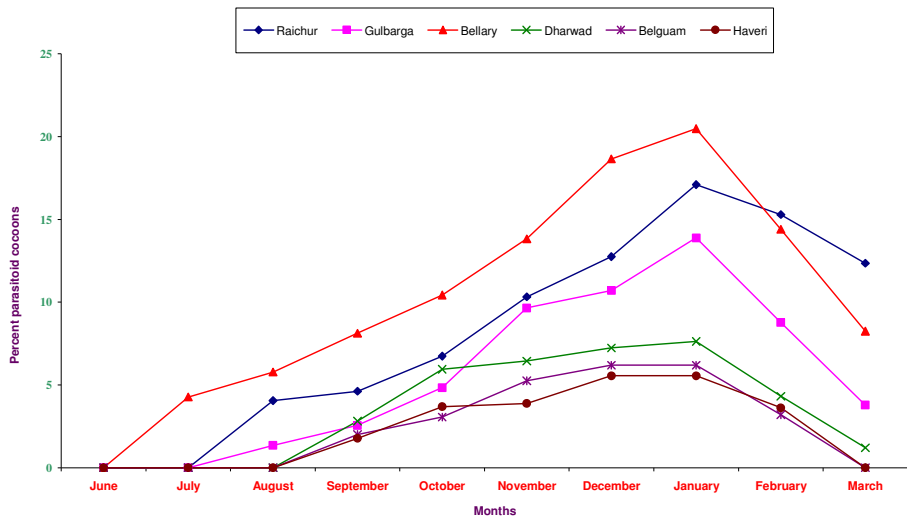


Fig. 5. Per cent parasitoids cocoons on mealybug infested cotton in different locations of North Karnataka during 2008-09

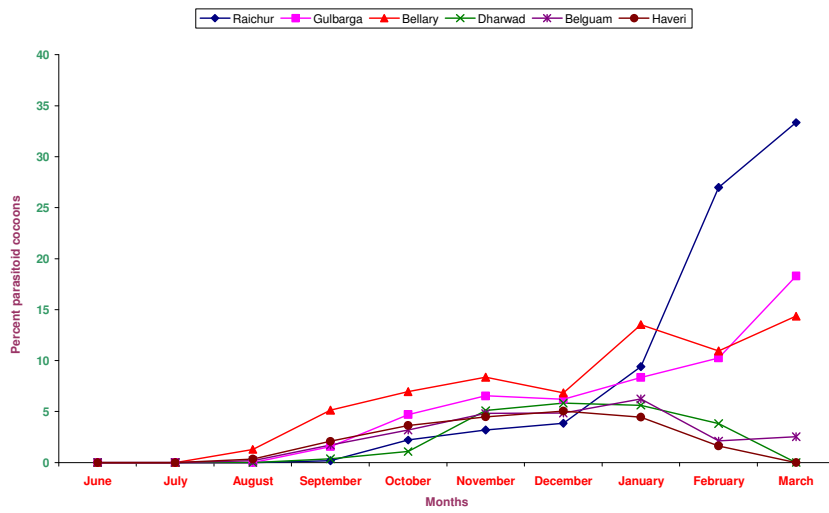


Fig. 6. Per cent parasitoids cocoons on mealybug infested cotton in different locations of North Karnataka during 2009-10

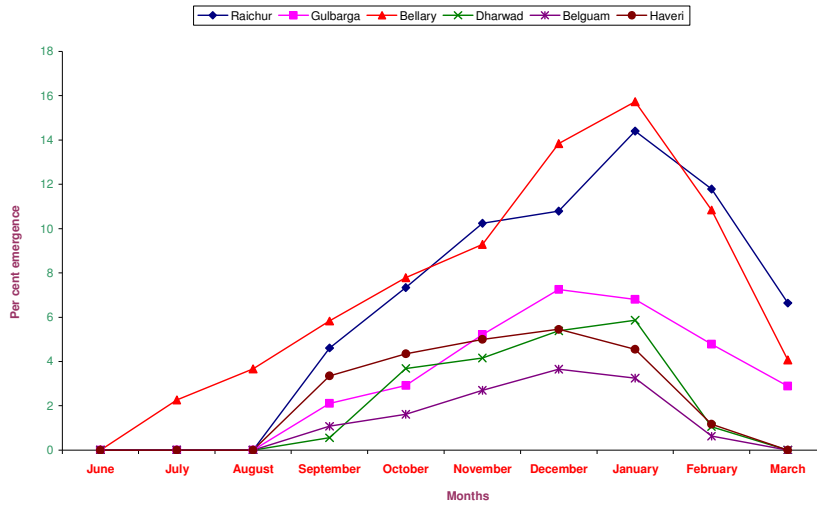


Fig. 7. Parasitoids population on cotton mealybugs in different locations of North Karnataka during 2008-09 season

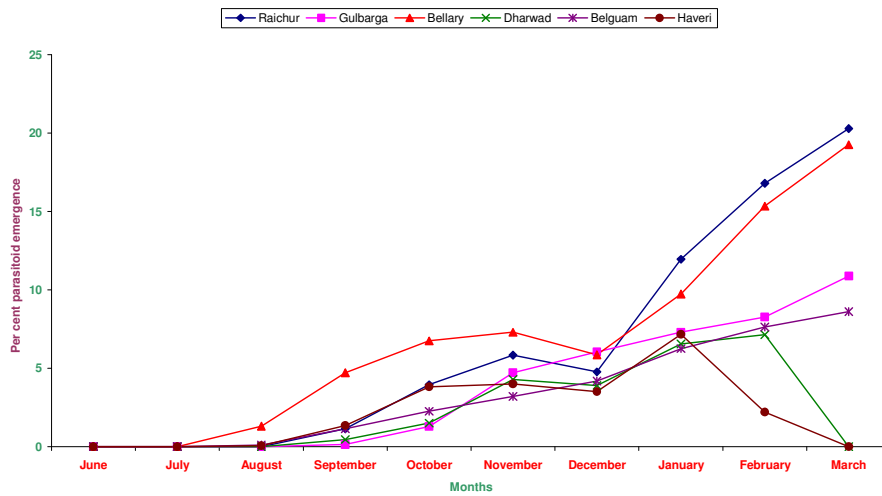


Fig. 8. Parasitoids population on cotton mealybugs in different locations of North Karnataka during 2009-10 season

Present investigation are in conformation with the studies of Mani (1986) and Tanwar *et al.* (2007), who reported that, mealybugs are polyphagous, feeding on variety of plants belonging to Malvaceae, Solanaceae and Leguminaceae families. The host range of mealybugs includes grape, fig, date palm, apple, avocado, banana, citrus, okra, tomato, brinjal, cotton and few ornamentals. *Hibiscus rosa sinensis* is a typical host which was frequently attacked by *Maconellicoccus hirsutus*. Besides, this mealybug survived on a number of tree plantations during the off-season as observed by Dhawan (2007). Present findings are also in line with Acharya *et al.* (2008), who observed that *Parthenium hysterophorus* was the most preferred host and as good as breeding sites for the *P. solenopsis* on canal banks and then migrated to cotton. Similarly, Deshmukh *et al.*(2009) reported a total record of 91 host plants spread across 24 families and *P. solenopsis* was found to multiply on 30 host plants during the cotton growing season and 61 plants exclusively during off-season.

Saini *et al.*(2009) observed that *P.solenopsis* survived on more than 28 species of plants, including okra, egg plant, sesame, guava and some ornamental plants. He further noted that *Parthenium hysterophorus*, *Trianthema portulacastrum*, *Xanthium strumarium*, *Tribulus terrestris* and *Abutilon indicum*, were the most preferred hosts. Prevalence of *P.solenopsis* on *Hibiscus chinensis* and *Abelmoschus esculentus* was reported by Aheer *et al.* (2009). Presence of *P. solenopsis* on sunflower, vegetables (brinjal, tomato, bhendi, cucurbits), pulses and parthenium as alternative hosts was also observed by Suresh *et al.* (2010).

### 5.3 Population dynamics of mealybug and its natural enemies on Bt cotton

The present investigation indicated that the cotton mealybug, *P. solenopsis* was found as early as on 60 days after sowing and remained on cotton till harvest of the cotton in March. Mealybug population started appearing on cotton during third week of September which gradually increased as the crop stage advanced. Steep increase in the population was observed after January and it was 154.62 mealybugs/10 cm shoot length during the last week of January. Maximum population of 180.42 mealybugs/10 cm shoot length was recorded in 6<sup>th</sup> standard week in February. Mean population of 54.54/10 cm shoot length was recorded during 2008-09 cropping season. Predators population was negligible in the entire season and mean population of coccinellids, *Chrysoperla* and spiders were 0.02, 0.01 and 0.02 per plant, respectively in 2008-09 (Fig. 9).

During 2009-10 season, population ranged from 0.14 in October first week to 184.32 per 10 cm shoot length in second week of March. Mean mealybug population was low (33.84 /10 cm apical shoot length) as compared to previous season because of rains in November 2009 and January 2010. Mean predatory population of coccinellids, *Chrysoperla* and spiders were 0.05, 0.07 and 0.14 per plant, respectively in 2009-10. (Fig. 10). Higher population of mealybug in February and March was due to higher temperature prevailed during this period which probably helped fast multiplication of the mealybug. Maximum temperature showed positive relationship with the mealybug population in the present study.

The information on population dynamics of *P. solenopsis* is very much lacking, hence results are compared and discussed with other mealybug species which were recorded on cotton and other crops.

The mealybug population in the present investigation remained low in the rainy season and the following winter season from June to December. The low population may be due to low rate of reproduction of the mealybug at low temperature during the above period. These results are in agreement with the reports of Misra (1919) from India and Hall (1921) from Egypt that the developmental time of *M. hirsutus* was extended in cooler months. Charles (1982) reported that the population of *Pseudococcus longispinus* remained very low during winter in the vineyards of New Zealand.

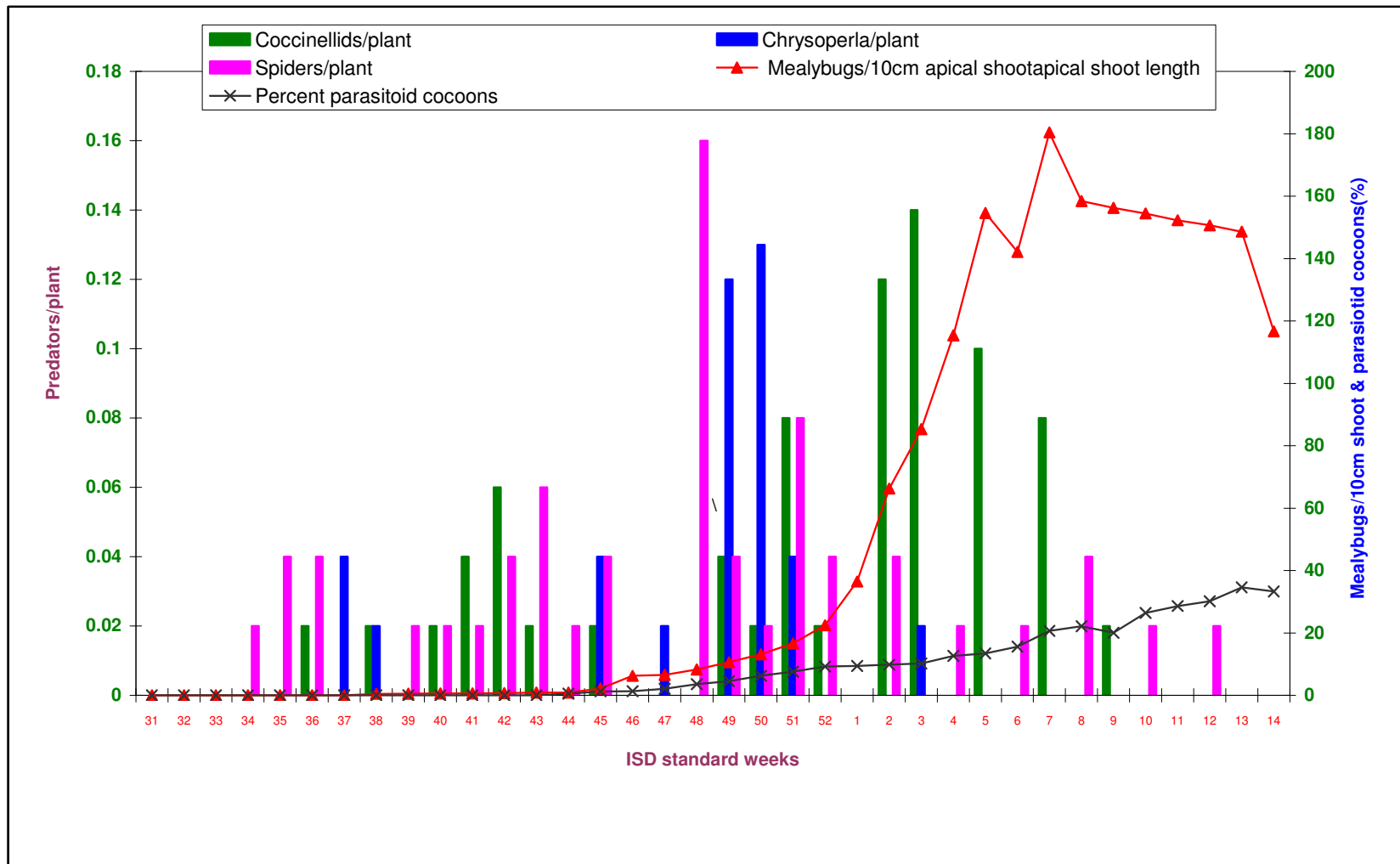


Fig. 9. Population dynamics of mealybugs and its natural enemies on Bt cotton under irrigated ecosystem during 2008-09 season

Similarly, Azam (1983) also reported that active period of *M. hirsutus* population was high from January to May and low from June to December. This was also in conformity with Manjunath (1985), who reported that *M. hirsutus* became active during January and the population increased in March in the vineyards around Bangalore. Maximum temperature showed positive and significant correlation with mealybug population on grape while the relative humidity showed negative correlation as observed by Mani (1986). Similar studies were made by Dhawan *et al.* (2009), who reported positive correlation among the per cent field infestation, number of infested rows by *P. solenopsis* and temperature, whereas negative correlation with relative humidity and rainfall at Faridkot.

In the present study predatory population was negligible in the entire season and mean population of coccinellids, *Chrysoperla* and spiders were 0.02, 0.01 and 0.02 per plant, respectively in 2008-09 and 0.05, 0.07 and 0.14 per plant, respectively in 2009-10. A drosophilid predator, *Gitonides perspicax* Knab appeared in February and March during 2008-09 season. Same species was reported by Vennila *et al.* (2009) on *M. hirsutus* infested cotton in Maharashtra. Another drosophilid, *Cacoxenus perspicax* was recorded earlier by Manjunath (1985) on *M. hirsutus*. However, Ghose (1971) also found the activity of an unidentified drosophilid on *M. hirsutus* during December-January.

Parasitoids activity was noticed from October till harvest of the crop in March which ranged from 0.52 to 34.62 per cent. Initially parasitoid population was low and peak activity started during first week of January (9.82%) and gradually increased up to 34.62 per cent during last week of March 2009. Similarly during 2009-10 season, parasitoids activity was at peak from January last week (12.45%) to third week of March (34.64%). Parasitoids activity increased with increase in mealybug population towards the end of the season in March in both the years (Fig. 9 and 10). However, the seasonal activity of most of these natural enemies coincided with the activity of the mealybugs. Present findings are in line with Suresh *et al.* (2010), who reported that multiple correlation studies with weather parameters and natural enemy activity had significant and positive correlation with minimum temperature and significantly negative correlation with relative humidity. For every one unit increase of minimum temperature, there was an increase of 0.77 unit of the pest population and likewise a unit increase in morning relative humidity resulted in decrease in pest population by 0.75 units.

Among different parasitoids emerged in the laboratory, *A. bambawalei* was the dominant species which ranged from lowest of 0.93 per cent in September to maximum of 24.26 per cent in March. Peak activity of adults was observed from February to till harvest of the crop in last week of March which was also reflected in adult emergence in laboratory (6.30 to 24.26%) during 2008-09. *Aenasius bambawalei* population increased significantly during 2009-10 and its population varied from 1.33 to 34.66 per cent with peak emergence from January last week to March last week (8.66 to 34.66%). Other four parasitoids and its emergence in laboratory was also observed from September to March in both the seasons with low population (Fig. 11 and 12).

Correlation studies indicated that *P. solenopsis* population was significantly influenced by the parasitoids and their emergence in the laboratory. Per cent parasitoid cocoons were highly significant and showed positive correlation (0.849 and 0.973) during both the seasons. Correlation of *P. solenopsis* population with parasitoid emergence in the laboratory resulted in highly significant and positive correlation with all the five parasitoids during 2008-09 and 2009-10 seasons.

The partial regression co-efficient of the mealybugs and weather parameters were analysed in the present study. The  $R^2$  value indicated that the population fluctuation of mealybugs, parasitoid cocoons and parasitoid emergence could be dependent on weather parameters *viz.*, temperature, rainfall, number of rainy days and relative humidity to the extent of 67.50, 82.8 and 80.1 per cent, respectively during 2008-09. Similarly during 2009-10, the  $R^2$  value for mealybugs, parasitoid cocoons and parasitoid emergence were 0.79, 0.71 and 0.76, respectively. It indicated that about 79.30, 71.10 and 76.90 per cent of population fluctuation depended on above weather parameters.

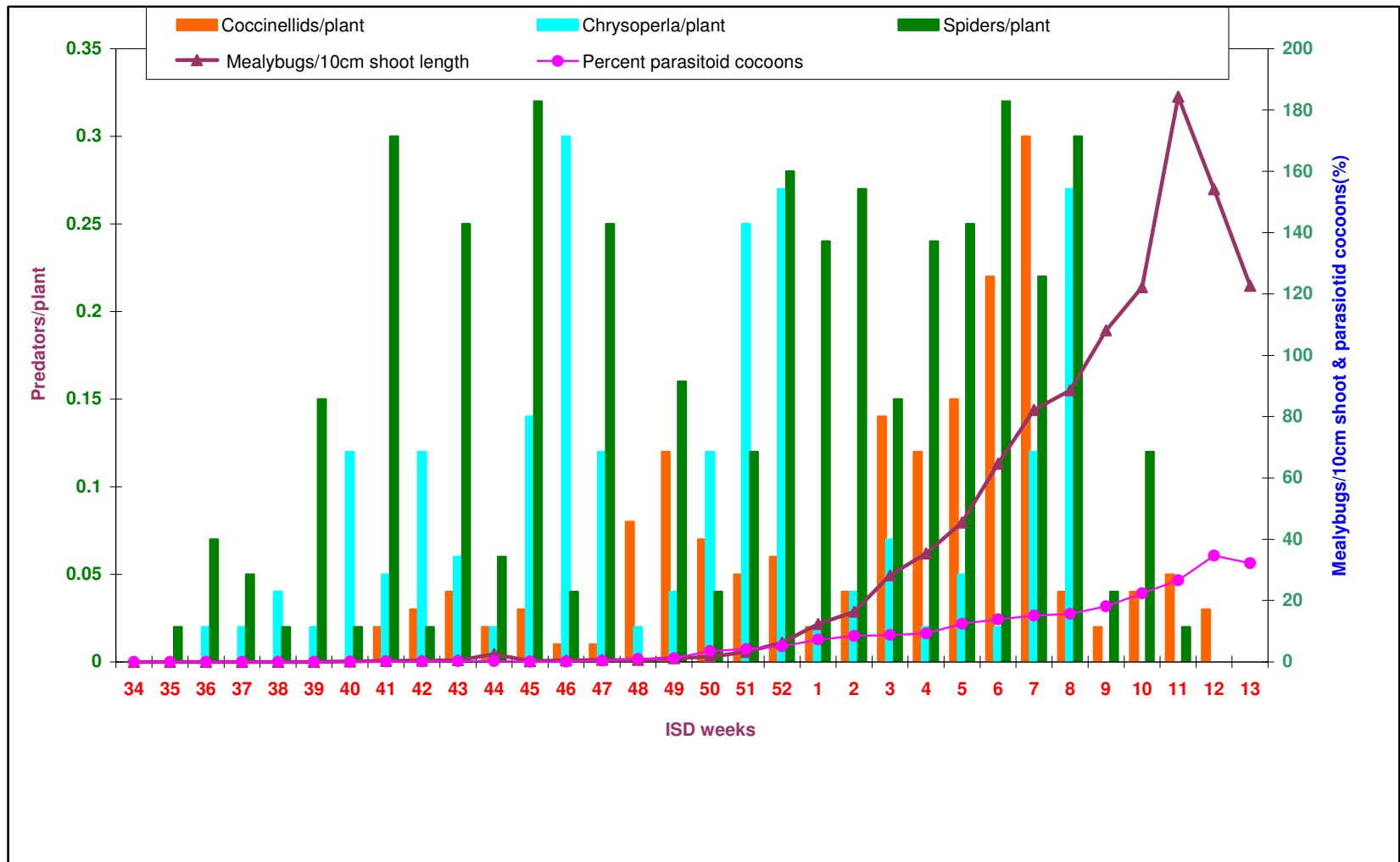


Fig. 10. Population dynamics of mealybugs and its natural enemies on Bt cotton under irrigated ecosystem during 2009-10 season

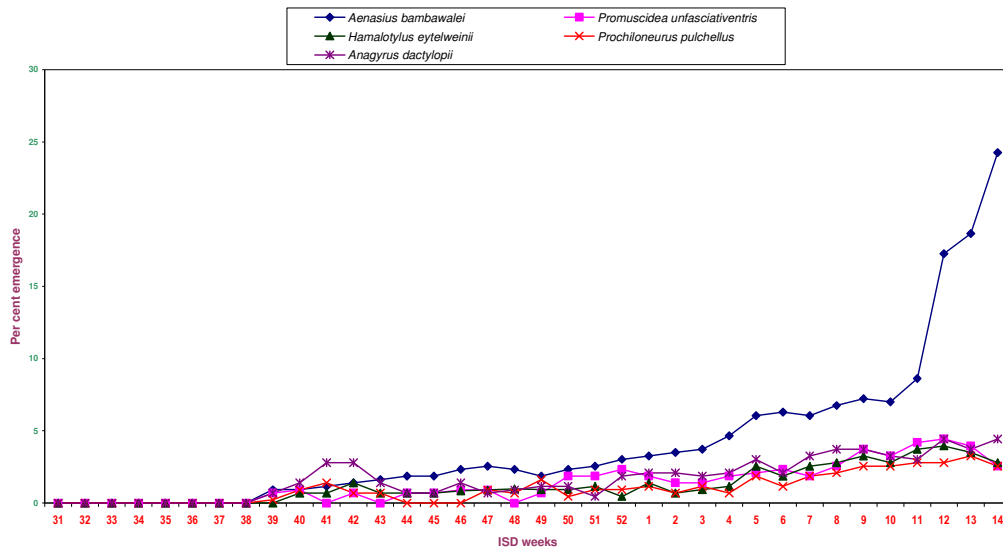


Fig. 11. Per cent emergence of mealybug parasitoids in laboratory during 2008-09 season

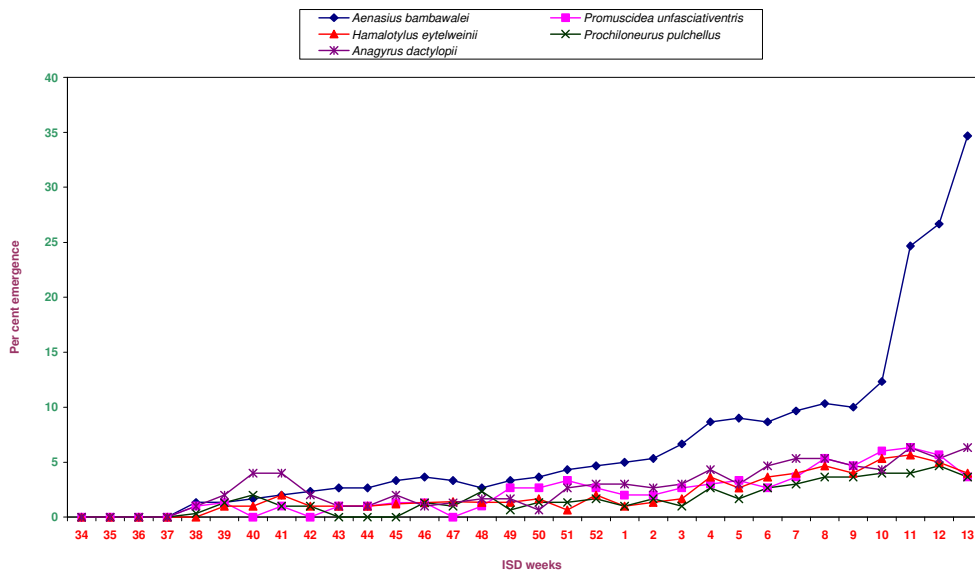


Fig. 12. Per cent emergence of mealybug parasitoids in laboratory during 2009-10 season

By and large, the population of the parasitoids depended on the density of mealybugs and high temperature as shown by correlation analysis carried out in the present study. A similar result of the parasitism by *A. dactylopii* in March-April ranging from 60 to 70 per cent in the vineyards around Bangalore has been reported by Manjunath (1985). Another parasitoid, *Promuscidea unfasciiventris* on Mealybugs in Andhra Pradesh, Bihar, Delhi, Karanataka and Maharashtra was mentioned by Hayat (1986). Tanwar *et al.* (2008) reported that parasitisation of mealybug, *P. solenopsis* on cotton and other hosts by *Anasius* sp. and *Promuscidea unfasciiventris* Girault ranged from 20-70 per cent in Parbhani district of Maharashtra.

Dominant species of parasitoid, *A. bambawalei* on *P. solenopsis* observed in the present study was also reported by Pinjarkar *et al.* (2009), where seasonal mean parasitisation of *P. solenopsis* by *A. bambawalei* and *P. unfasciiventris* together was estimated to be 21 per cent with a maximum of 48 per cent during August in Maharashtra.

## 5.4 Biology of mealybug on Bt cotton and its predator *Cryptolaemus montrouzieri* Muls

### 5.4.1 Biology of mealybug, *P. solenopsis*

Observations made on the biology of *P. solenopsis* reared in the laboratory are discussed below. Further as mentioned earlier the detailed studies on biology of *P. solenopsis* were limited and available results are discussed here under

In the present study, the incubation period of *P. solenopsis* egg was 35 to 52 minutes at 24-28°C and 65-70 per cent relative humidity and development of first, second and third nymphal instars of female took 7.51, 3.60 and 7.24 days respectively. The total developmental period of female nymphs ranged from 15 to 22 days with a mean of 18.35 days. Male mealybug had two nymphal instars. Mean duration of first and second instar was 5.22 and 6.45 days, respectively. At the end of second nymphal instar, males produced cocoon (puparia) over their bodies. The third moulting took place within the cocoon. Fourth instar, also known as pupa, was characterised by well developed wing pads attached to mesothorax. Male development was completed in 18 to 24 days with a mean of 20.33 days. The size of the egg, adult female and male was 0.45 x 0.21 mm, 3.8 x 2.11 and 1.20 x 0.22 mm, respectively.

Similar findings on biology was made by Tanwar *et al.* (2007), who briefly noted that reproduction in *P. solenopsis* was mostly parthenogenetic. Eggs were minute, varying from 0.3 to 0.4 mm in length. There were three nymphal instars in female and four in males which lasts for 22-25 days. The last instar of the male is an inactive stage with wing buds within a cocoon of mealy wax. According to Mohammad (2008) *P. solenopsis* life cycle was 24 to 30 days. Present findings also corroborate with the reports of Akintola and Ande (2008), who documented three nymphal stages which lasted for six, eight and 10 days in female. The total number of days from egg to adult longevity was 37 days. Similarly, Rishikumar *et al.* (2009) observed three nymphal stages in female and male (two nymphal instars and a cocoon) in *P. solenopsis*. The total nymphal duration in case of male and female was 13-15 days and 14-19 days and longevity was 1-1.8 days and 13-16 days, respectively. Similar results were obtained by Aheer *et al.* (2009), who reported that incubation period of egg was 35-45 minutes with three nymphal stages in case of female and two in male with pupal stage. Adult male lived for two to three days and female lived for 45 to 55-days. Slight variation on above biological parameters may be due to variation in climatic conditions of the study period.

The number of eggs laid by a female *P. solenopsis* varied greatly with the host on which it was reared. A mean of 226.12 (188 to 312) eggs was laid by a single female when reared on potato sprout. The average number of eggs per female on cotton plant and hibiscus plant was 284.45 (246 to 372) and 296.34 (242 to 408), respectively. Similarly fecundity recorded by earlier workers was 386 to 510 eggs in *M. hirsutus* (Mani 1986), 500- 600 eggs in *P. solenopsis* (Mohammad, 2008), 289 to 517 eggs in *P. solenopsis* (Rishikumar *et al.* 2009) and 98-239 eggs in *P. solenopsis* (Aheer *et al.*, 2009). Variation in the fecundity may be

attributed due to the difference in climatic conditions in the study period and also the host used for the studies by earlier workers.

## 5.4.2 *Cryptolaemus montrouzieri*

### 5.4.2.1 Biology

Development of *C. montrouzieri* by feeding on nymphs and adult female of mealybug *P. solenopsis* is discussed below.

Impact of feeding on nymphs and adults on the development of the predator revealed that the eggs hatched in 4 to 5 days in the present study. Similar observation was made by Fisher (1963), Liotta and Mineo (1965) and Bhat *et al.* (1981) who found the incubation period ranging from 3 to 6 days. Slight difference in incubation period may be due to climatic conditions that prevailed during the study period. Results on the rearing of grubs on different stages of *P. solenopsis* indicated that the grub period was extended when reared on nymphs compared to rearing on mealybug adults. This difference in the developmental period of grubs reared on different stages of the mealybug may be due to the quantity and quality of the prey offered to the predator. The grub took 15 to 18 days to complete the development on *P. solenopsis*. This is in agreement with Liotta and Mineo (1965) and Fisher (1963) who also observed the grub developmental period ranging from 12 to 17 days. The pre-pupal and pupal period of *Cryptolaemus* ranged from 2 to 3 days and the 8 to 9 days, respectively. Similar observations were made on the pupal development by earlier workers (Tirumala Rao and David, 1958 and Bhat *et al.*, 1981). Males lived for 56.45 days and females for 62.56 days. Similar results on the longevity of male and female were reported earlier by Tirumala Rao and David (1958).

### 5.4.2.2 Feeding potential

In the present study, predatory grub totally consumed an average of 159 mealybug nymphs or 30.25 adult female mealybugs. Number of adult mealybugs required for a grub was less than that of nymphs because of larger body size. During the present study the average number of adult mealybugs of *P. solenopsis* consumed by first, second, third and fourth instar grubs were 1.25, 4.35, 8.20 and 16.45, respectively. Similar study was made on *M. hirsustus* by Bhat *et al.* (1981), who reported that the average number of mealybugs consumed by 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> instar grubs was one mealybug in 3 days, one in 2 days, one per day and three mealybugs in 2 days, respectively. Present findings are also in line with Mani (1986) who observed that average number of adult grape mealybugs consumed by 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> instar grubs of *C. montrouzieri* were 1.65, 3.35, 7.90 and 14.65 mealybugs, respectively.

## 5.5 Crop loss estimation due to mealybug damage and development of EIL on Bt cotton

### 5.5.1 Crop loss estimation

To quantify the crop loss caused by mealybug, *P. solenopsis* the pot and field experiments were conducted during 2008-09 and 2009-10 seasons, respectively and the results are discussed here under.

Cotton plants did not survive at all the damage levels (D<sub>1</sub> to D<sub>5</sub>) at 60 days after sowing in both years in pot and field studies. At 90 days, cotton yield ranged from 9.08 to 21.14 g/plant during 2008-09 and 3.52 to 26.52 q/ha during 2009-10. Seed cotton yield significantly differed in all the damage levels at 120 days after sowing in both the years. Percent reduction in the yield varied from 45.06 to 76.38 and 39.01 to 57.68 in different damage levels during 2008-09 and 2009-10 seasons, respectively. Similarly at 150 days after sowing per cent yield reduction ranged from 42.17 to 58.67 and 14.84 to 36.59 in different level of damage during 2008-09 and 2009-10 seasons, respectively (Fig. 13). Study clearly

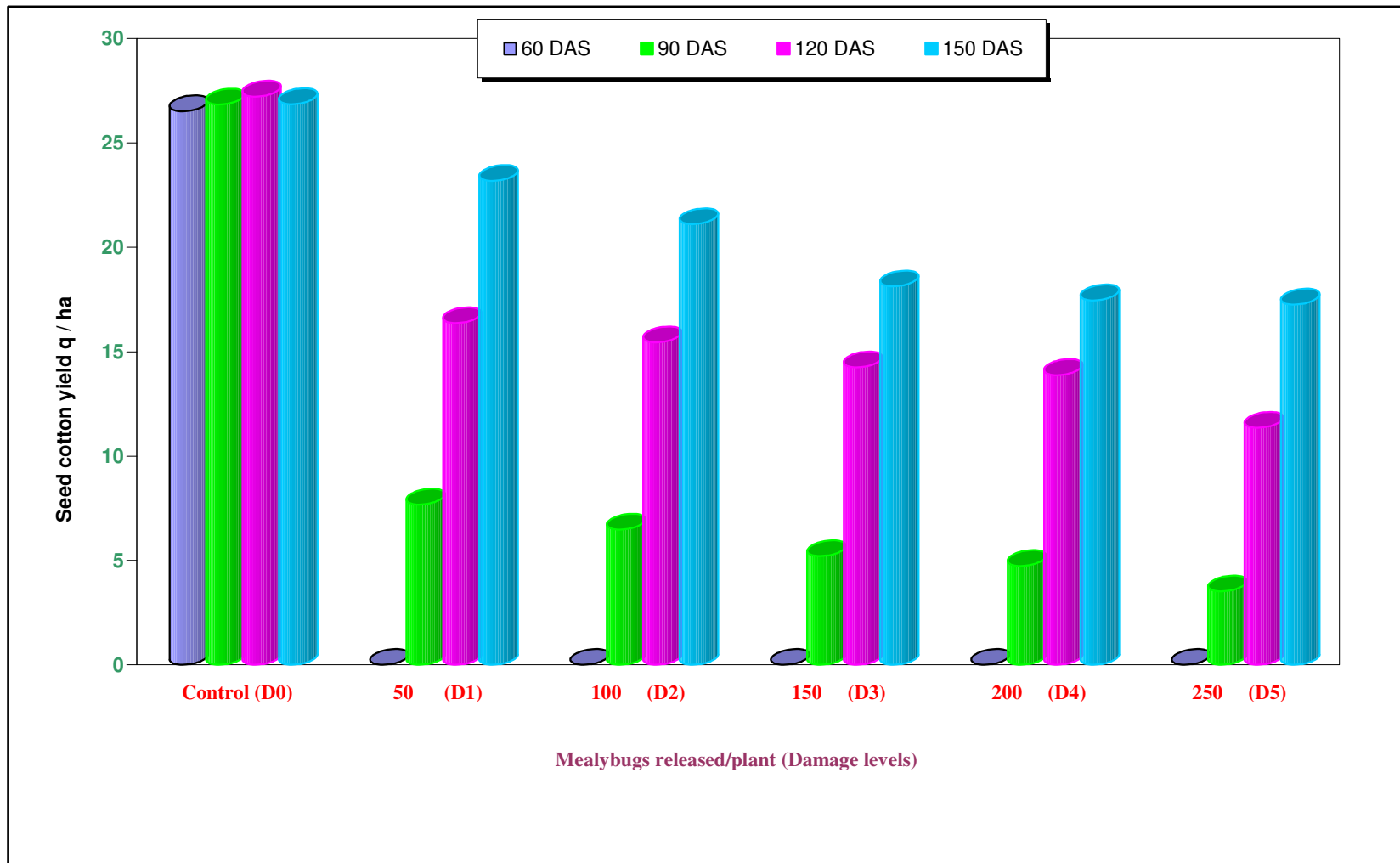


Fig. 13. Influence of different damage levels on seed cotton yield during 2009-10 season

indicated that mealybug damage in the early stage inflicts more loss and as the cotton plant ages (120 to 150 DAS) reduction in yield loss also reduces. Correlation between mealybug population and yield parameters were assessed at different days after sowing. Percent reduction in the yield was highly significant and positively correlated in both the years of study.

As already mentioned that the quantitative estimation of yield loss in cotton due to mealybug damage is very much lacking and hence, could not be compared with earlier reports. However Dhawan (2007) reported that, four thousand and eight hundred hectares of cotton crop in Sirsa district, Punjab was affected due to mealybug and 0.9 to 1.2 per cent plants were found to be affected by mealy bug. In severely infested plants, the size of the bolls was reduced and resulted in low yield. Cotton lint was found covered with sooty mould. Similarly Dhawan *et al.* (2007) also reported that, mealybug caused 30 to 40 per cent loss to cotton yield in Punjab.

Similar report was also made by Acharya *et al.* (2008), who briefly noted that, mealybug affected cotton plants become distorted, stunted, bunched top symptoms and reduction in boll number, boll size and seed cotton yields. In another study, Jhala and Bharpoda (2008) reported that, mealy bug *P. solenopsis* infesting cotton has reduced 50 per cent yield of cotton in Gujarat.

However, cotton yield was severely affected in many farmers fields wherever mealybug incidence noticed in the early stage of the crop growth during 2008-09 cropping season. In general mealybug incidence was low during 2009-10 season except few isolated patches in TBP and UKP areas where infestation was severe. Cotton yield was not much affected due to mealybug damage throughout cotton growing districts in the North Karnataka. If mealybug colonises in the vegetative phase of the crop, certainly yield loss will be more and quality of the lint will be reduced.

### 5.5.2 Quality parameters of cotton lint

Quality parameters of cotton lint due to mealybug damage were assessed at different days after sowing for the first time and results are discussed here under.

Quality parameters like staple length, micronaire value, maturity ratio and tenacity were affected maximum at 90 DAS as compared to 120 and 150 DAS. Release of mealybugs at 90 DAS indicated that 100 g seed weight varied from 6.48 to 7.65 g, oil percentage varied from 10.3 to 11 and staple length varied from 30.9 to 32.4 mm in different damage levels. At 120 and 150 DAS, there was no much variation in the quality parameters. However, micronaire value was affected at 120 and 150 DAS which varied from 2.4 to 3.1 and 3.1 to 3.5, respectively. This indicates that fiber quality was more affected at all the levels of damage from  $D_{(0)}$  to  $D_{(5)}$  at early infestation as compared to later infestation at 120 and 150 DAS. The correlation coefficient indicated negative relationship with all the quality parameters.

Literature on qualitative estimation of cotton lint due to mealybug damage on cotton under irrigated ecosystem is totally lacking. Hence, it could not be compared and discussed with earlier reports and this study is first of its kind in this regard

### 5.5.3 Development of EIL

Estimation of EIL due to mealybug damage on Bt cotton under irrigated ecosystem at different days after sowing was under taken for the first time and results are discussed here under.

At 60 days after sowing (DAS), cotton plants did not survive at all the levels of releases due to damage made by heavy population of mealybug. Initially mealybug population congregated on apical shoot and later covered the entire plant. Cent per cent yield reduction was recorded in all the levels of mealybug released in caged plots. However seed cotton yield

in control plot was 27.24 q/ha. EIL at 60 DAS was 20 mealybugs per plant on irrigated Bt cotton.

The average reduction in seed cotton yield due to varying mealybug population in different treatments ranged from 3.52 to 26.52 q/ha at 90 DAS and the EIL was 27 mealybugs per plant. Similarly at 120 DAS, seed cotton yield in different levels of mealybug population varied from 11.36 to 26.84 q/ha and the EIL was 44 mealybugs per plant. Different levels of mealybugs released at 150 DAS, caused less variation in seed cotton yield and it ranged from 7.26 to 27.22 q/ha. The economic injury level was 51 mealybugs per plant which indicates that at 150 DAS crop was at harvesting stage and mealybugs population did not cause much variation in the yield level (Table 31 to 34).

Literature on quantitative estimation of yield loss and EIL due to mealybug on cotton under irrigated ecosystem is totally lacking. Hence, it could not be compared and discussed with earlier reports and this study is first of its kind in this regard. However, economic threshold level for mealybug in mulberry was 10 per shoot as reported by (Anon., 2010)

## 5.6 Management of mealybug on Bt cotton under irrigated ecosystem

### 5.6.1 Efficacy of insecticides on mealybugs

It is evident from the results that mealybug damage reduced the cotton yield drastically if not managed properly. During 2007-08, the pest caused serious damage in Punjab with approximate yield loss up to 0.2 million bales worth of Rs 1.59 billion (Khadi, 2008). Subsequently this pest was also damaged the cotton crop and reduced the yield considerably in all the cotton growing states of India. Mealybugs can be controlled by cultural methods like destroying the weeds which act as alternate host around the cotton fields, water channels and fallow land. Biological control is also considered as the effective long term solution to the mealybug infestation. However, mealybug outbreaks require the use of insecticides due to their rapid growth as compared to the predators and parasitoids (Wysocki *et al.*, 1981). In this regard, efficacy of insecticides and other bioagents against mealybug was conducted on irrigated Bt cotton under field conditions during 2008-09 and 2009-10 seasons. The results obtained from the study are presented and discussed critically here under.

The results indicated that profenophos 50 EC @ 1500 ml/ha + soap water (1%) and buprofezin 25 SC @ 1000 ml/ha during 2008-09 were effective in managing of mealybug on cotton. These two chemicals recorded least incidence of mealybugs after each spray. During 2009-10, higher doses of profenophos 50 EC @ 2000 ml/ha and buprofezin 25 SC @ 1500 ml/ha were significantly superior over rest of the treatments. However profenophos 50 EC @ both 1500 ml and 2000 ml/ha was effective at one, three and seven days after spray but population gradually increased on 14<sup>th</sup> day after spray. On the contrary, buprofezin 25 SC was effective after seven days and it was significantly superior over rest of the treatments after 14 days of spray. In general, profenophos at higher doses reduced mealybug incidence to the extent of 5.24 and 6.29 mealybugs/10 cm apical shoot after second spray during 2008-09 and 2009-10 seasons, respectively. Whereas, buprofezin 25 SC recorded lowest mealybug population of 0.56 and 3.45/10 cm apical shoot during 2008-09 and 2009-10 season, respectively.

The superiority of profenophos 50 EC and buprofezin 25 SC are in agreement with Bedford *et al.* (1996) who reported that destructive analysis of all plants revealed that infestation had been significantly reduced and the effects on mealybugs were greater with higher rate of buprofezin application. Similarly, Balikai (2002 and 2005) reported that buprofezin 25 SC @ 1000 and 1125 ml/ha recorded maximum protection of 80.4 per cent of mealybug, *M. hirsustus* population on grape when sprayed along with fish oil rosin soap (Meenark) @ 3125 g/ha. Similar results were also obtained by Muthukrishnan *et al.* (2005), who reported that buprofezin 25 SC @ 1125 and 1500 ml/ha sprayed thrice at 15 days interval reduced the congregation of *M. hirsustus* on grape and increased the yield.

The effectiveness of buprofezin 25 SC was also in corroborate with Vaughn (2006), who reported that mating disruption was most effective when the mealybug density was low, suggesting that for best results a combination of buprofezin application and mating disruption may be necessary, at least initially. Pre-bloom applications of buprofezin produced the longest sustainable mortality rates of mealybugs, *Pseudococcus* spp. in pome fruits, table and wine grapes as observed by Gonzales and Volosky (2006). The superiority of profenophos and buprofezin is in conformity with Dhawan *et al.* (2009) who made studies on persistence and residual toxicity of insecticides at recommended concentrations in field on cotton against first instar and adult female mealybug *P. solenopsis*. Based on the index of persistence toxicity, the order of effectiveness for the crawlers of *P. solenopsis* was profenophos (637.1) > thiodicarb (587.9) > buprofezin (492.3) > quinalphos (407.9) chlorantraniliprole (380.0) > Spirotetremate (371.6) > acephate (345.7) > carbaryl (314.6) > chlorpyrifos (273.4). Similarly, for the adult female this order of effectiveness was profenophos (572.9) > buprofezin (483.1) > thiodicarb (430.0) > quinalphos (379.9) chlorantraniliprole (371.6) > spirotetremate (361.3) > acephate (296.7) > carbaryl (260.0) > chlorpyrifos (252.3).

The effectiveness of profenophos 50 EC in the present study is also in conformity with Agarwal *et al.* (2009) who reported that profenophos 50 EC (check) recorded 93.73 per cent mortality over control and was at par with spirotetramat (12%) + Imidacloprid (36%)- 480 SC (85.09% mortality) and thiodicarb 75 WP @ 750 g a.i./ha (84.48% mortality) after three days of second spray. The mortality of mealy bug due to single molecules at different doses ranged between 53.04 and 62.39 per cent while the checks showed the promising results as compared to other treatments after the first spray. Similarly, Patel *et al.* (2010) reported that more than 95 per cent reduction in mealy bug population over control after three DAS in buprofezin at all the three doses (250, 312.5 and 625 g a.i./ha) tested. Superiority of profenophos 50 EC was also confirmed by Suresh *et al.* (2010) who reported that profenophos and methyl parathion were found to be quite effective and caused cent per cent mortality of *P. solenopsis* on one day after treatment while imidacloprid, fish oil rosin soap and dimethoate caused cent per cent mortality after two days of the treatment imposition. All the tested insecticides were found to be quite effective up to 10 days of the application. *Beauveria* was found to be moderately effective and caused 77 per cent mortality after 10 days of treatment.

Insect growth regulators (IGRs) represent the newest of all approaches to operational and commercial insect control. Buprofezin being biorational insecticide offered both effective control of mealybug and selectivity to many of the beneficial insects and have a novel mode of action was effective against all the stages of mealybug and useful in pest resistance management tool. Similarly profenophos was effective against mealybug since it acts as both systemic and contact insecticide. Both the insecticides effect was increased when second spray was given within a week after first spray because it covered the overlapping generations of mealybug effectively. Buprofezin having low impact on beneficial insects, it is ideally suited for mealybug management when population is low and profenophos is effective whenever mealybug outbreaks on cotton or use of both the insecticides in cycle one after the other. These two insecticides can be used judiciously in IPM program of mealybug on cotton.

### 5.6.2 Seed cotton yield

The efficacy of profenophos 50 EC and buprofezin 25 EC was well reflected on seed cotton yield. These two treatments recorded significantly maximum seed cotton yield at all the dosages in both the years. These two chemicals after each spray could effectively control mealybug population, which might have resulted in good growth and yield parameters of the crop. The present findings on higher seed cotton yield are in accordance with Bhosle *et al.* (2009) who evaluated 12 insecticides as curative spray at two, seven and 14 days which indicated that profenophos 50 EC and acephate 70 SP were effective in controlling the mealybug with higher seed cotton yield of 22.2 q/ha in both the treatments which were at par with each other.

### 5.6.3 Influence of insecticides on parasitoids emergence

In the present investigation effect of insecticides on the emergence of parasitoids was recorded and the results are discussed below.

Parasitoids emergence was nil in the treatments thiodicarb 75 WP, profenophos 50 EC, quinalphos 25 EC, acephate 75 SP and chlorpyrifos 20 EC indicating their detrimental effects on them. However, parasitoids emergence was observed in the treatments which received buprofezin 25 SC, neem oil, Neemark 1500 ppm, Fish oil rosin soap and *Verticillium lecanii* because of their less hazard ness to mummified mealybugs.

Similar studies were made by Furness (1977) who recorded the mortality of mealybug parasitoid *Anagyrus fusciventris* (Grit.) exposed to maldison, methidathion, methomyl and aminocarb. Further he also observed that the emergence of *Anagyrus fusciventris* from the treated mealybug mummies was not affected. Earlier workers (Lingappa *et al.*, 1972 and Wilkinson *et al.*, 1975) have also expressed that the larval and pupal stages of the parasitoids were more tolerant than adult stages. The residual toxicity of azinphosmethyl oil combination gave the highest natural enemy mortality over 35 days post treatment, while a chlorobenzilate-oil combination resulted in the lowest mortality of mealybug parasitoid, *Anagyrus pseudococci* as observed by Meyerdirk *et al.*, (1979). Similarly Meyerdirk *et al.* (1982) reported that diazinon resulted in lower residual toxicity to *A. pseudococci* at one day post treatment as compared to other insecticides. Similar study was made by Mani (1992) who reported that mealybug parasitoids like *Aenasius advena* Comp. and *Blepyrus insularis* (Cam.) were exposed to the guava leaves treated with different insecticides. Diazion (0.05%) was found to be non-toxic to *A. advena* and least toxic to *B. insularis*. The other chemicals such as endosulfan (0.07%), phosalone (0.07%) and dichlorvos (0.20%) showed lesser toxic residual effect while chlorpyrifos (0.05%), carbaryl (0.10%) and fenthion (0.10%) recorded significantly higher residual effect to both the parasitoids.

The low toxicity of IGRs like buprofezin 25 SC was confirmed by Raymond and Dickinson (2006) who reported that buprofezin, pyriproxyfen, and flonicamid were not harmful to *Leptomastix dactylopii* when applied at the label rate. Both buprofezin and flonicamid were not toxic to *L. dactylopii* with 100 per cent adult survival after 72 h. dinotefuran was extremely detrimental to the adult parasitoid at the label rate with 100 percent mortality after 24 h. The IGR pyriproxyfen and the insecticide flonicamid were not directly or indirectly harmful to the predator, *C. montrouzieri* and parasitoid, *L. dactylopii*, indicated that insecticides were compatible with both natural enemies when used together for control of citrus mealybug in greenhouses and conservatories. Toxicity of organophosphate and other insecticides on mealybug parasitoids was also confirmed by Walton and Pringle (1999) who reported that, insecticides like chlorpyrifos, endosulphan, cypermethrin were highly toxic to parasitoid of vine mealybug, *Coccidoxenoids peregrinus* (Timberlake) in South Africa.

#### 5.6.4 Economics of mealybug management in cotton

The economic analysis of the usage of chemicals is required for advising the farmers for getting higher net profit. In the present study economic analysis revealed that profenophos and buprofezin were found effective for the management of mealybugs on cotton. Profenophos 50 EC and buprofezin 25 EC recorded additional net return of Rs. 30,727/ ha and Rs. 25,959/ ha, respectively compared to untreated control during 2008-09, while during 2009-10 higher doses of profenophos and buprofezin accrued the net returns of Rs. 45,965 and Rs.43,895, respectively.

##### Future line of work

1. Confirmation of crop loss in cotton due to mealybug damage and life table studies
2. Exploitation of predators and parasitoids for long term management of mealybug
3. Biology and mass multiplication of dominant parasitoids like *A. bambawalei*
4. Large scale field testing of the predator, *Cryptolaemus montrouzieri*
5. Development of IPM for mealybug management on Bt cotton in both rainfed and irrigated ecosystem.

## VI. SUMMARY AND CONCLUSIONS

During the present investigation, survey was conducted to identify the species of mealybugs infesting cotton crop. Efforts were made to study the distribution, life history, seasonal fluctuation of mealybug, natural enemies, crop loss assessment, estimation of EIL and biology of *Phenacoccus solenopsis* Tinsley besides the efficacy of few insecticides including IGR, neem oil, commercial neem formulation, fish oil rosin soap, predators, *Cryptolaemus montrouzieri* Muls. and entomophagous pathogen, *Verticillium lecanii* in the suppression of mealybug. The results of these investigations are summarised here under.

Survey made in different major cotton growing areas of North Karnataka revealed the presence of only one species of mealybug *i.e.*, *P. solenopsis*. It is a moderate to severe pest in Raichur, Bellary, Gulbarga, Dharwad, Haveri and Belguam districts of North Karnataka on Bt cotton. *Phenacoccus solenopsis* was severely infested in isolated patches of Raichur, Deodurga, Bellary, Siruguppa and Shahapur taluks. Similarly many cotton fields in Dharwad, Hubli, Haveri, Siggaon, Bailhongal and Gokak taluks were also infested with the mealybug but the incidence was low.

Mealybug infestation varied from zero to 3.62 grade in major cotton growing districts of North Karnataka. Peak increase of mealybug population was noticed from January to March and population was maximum in Raichur, Gulbarga and Bellary districts as compared to Dharwad, Belguam and Haveri districts where population was low to moderate during 2008-09 and 2009-10. Similarly per cent infestation of *P. solenopsis* on Bt cotton was also maximum in Tungabhadra Project (TBP) and Upper Krishna Project (UKP) areas.

In general, predatory population on mealybug was low in all the surveyed districts. However, predatory population was more in the TBP and UKP areas where mealybug incidence was also maximum during both the years. A dipteran predator, *Gitonides perspicax* Knab (Drosophilidae) was found only at Raichur during January to March 2008-09. Parasitoid cocoons were highest in Bellary and Raichur districts as compared to other cotton growing districts in both the years. The peak activity of the parasitoids was observed mainly from January to March in both the years. Mean per cent parasitoid emergence from mealybugs collected at various places was highest in TBP and UKP areas as compared to other districts in both the years.

There were more than 15 alternate host plants of *P. solenopsis* belonging to eight families found across the cotton growing districts of North Karnataka. Among them, *Abutilon indicum* L. (Malvaceae) and *Parthenium hysterophorus* L. (Asteraceae) were the major weed hosts. *Phenacoccus solenopsis* was also found on many hosts *viz.*, *Lycopersicon esculentum* L., *Amaranthus* spp, *Abelmoschus esculentus* L., *Achyranthes aspera* L., *Hibiscus rosasinensis* L., *Morus alba* L., *Annona squamosa* L., *Helianthus annuus* L., *Vigna mungo* L., *Zizipus* spp. *Physalis minima* L., *Tectona grandis* L. and *Leucos* spp.

Population dynamics of *P. solenopsis* indicated that, mealybug population started appearing on cotton during third week of September which gradually increased as the crop stage advanced in both the years. Steep increase in the population was observed from January and reached peak in March in both the years of study. In general, predatory population was low in both the years.

Parasitoids activity was noticed from October till harvest of the crop in March. Initially parasitoid population was low and peak activity started during first week of January which gradually increased up to 34.62 per cent and 34.64 per cent during the last week of March 2008-09 and 2009-10 seasons, respectively. *Aenasius bambawalei* Hayat was the dominant species among different parasitoids. Adults peak activity was observed from February to till harvest of the crop in March during both the years. Highest emergence of 24.26 per cent and 34.66 per cent was in the month of March 2008-09 and 2009-10 seasons, respectively.

Correlation studies indicated that *P. solenopsis* population was significantly influenced by the parasitoids and their emergence in laboratory. Per cent parasitoid cocoons were highly significant and showed positive correlation (0.849 and 0.973) during both the years. The partial regression co-efficient of the mealybugs and weather parameters indicated that the population fluctuation of mealybugs, parasitoid cocoons and parasitoid emergence was dependent on weather parameters viz., temperature, rainfall, number of rainy days and relative humidity to the extent of more than 70 per cent in both the seasons.

Studies on the biology of *P. solenopsis* indicated that, total developmental period of female nymphs ranged from 15 to 22 days with a mean of 18.35 days. Male mealybug had two nymphal instars and at the end of second instar, males produced cocoon (puparia) over their bodies. Fourth instar, also known as pupa, was characterised by well developed wing pads attached to mesothorax. Male development was completed in 18 to 24 days with a mean of 20.33 days.

Development of *Cryptolaemus montrouzieri* was studied on the nymphs and adult females of *P. solenopsis*. The total developmental period of grub was less when it was reared on adult female mealybugs. The total life cycle was 28.82 and 24.71 days when reared on the mealybug nymphs and adult female, respectively. Feeding potential of *Cryptolaemus* grub revealed that it consumed more than 150 mealybug nymphs and 30 adult females during its developmental period.

Crop loss estimation due to mealybug damage indicated that cotton plants did not survive at all the damage levels at 60 days after sowing in both years. At 90 days cotton yield was severely affected due to different levels of mealybug damage. Seed cotton yield differed significantly in all the damage levels at 120 and 150 days after sowing in both the years and yield reduction was more than 14 to 50 per cent in different levels. Quality parameters like staple length, micronaire value, maturity ratio and tenacity were affected maximum at 90 DAS as compared to 120 and 150 DAS and all the quality parameters were negatively correlated.

Correlation between mealybug population and yield reduction was highly significant and had positively correlated at 120 and 150 days after sowing in both the years of study. Estimation of EIL due to mealybug damage on Bt cotton under irrigated ecosystem resulted in 20, 27, 44 and 51 mealybugs per plant at 60, 90, 120 and 150 days after sowing, respectively.

Efficacy of different insecticides was evaluated against mealybugs under field conditions during 2008-09 and 2009-10 years. Profenophos 50 EC @ 2000 ml/ha and buprofezin 25 SC @ 1500 ml/ha were effective in reducing the mealybug population on cotton. These two treatments recorded significantly maximum seed cotton yield with higher net returns in both the seasons of study.

Impact of insecticides on parasitoids was evaluated and results indicated that parasitoids emergence was nil in thiodicarb 75 WP, profenophos 50 EC, quinalphos 25 EC, acephate 75 SP and chlorpyrifos 20 EC indicating their detrimental effects on them. However, parasitoids emergence was observed in buprofezin 25 SC, neem oil, Neemark 1500 ppm, Fish oil rosin soap and *Verticillium lecanii*.

## Conclusions

- The present study clearly indicated that mealybug, *P. solenopsis* has spread across the cotton growing districts in northern part of Karnataka with varying damage levels.
- Simultaneously hymenopteran parasitoids population also increased to the extent of more than 40 per cent wherever mealybug population is in abundance.
- Incubation period is very short and both sexual and parthenogenetic reproduction was observed.
- Total life cycle of *P. solenopsis* was 38 to 45 days, male was having a pair of wings and

short lived

- More than 16 alternate hosts were recorded and among them *Abutilon indicum* and *Parthenium hysterophorus* were the major weed hosts.
- Mealybug population increased drastically from January onwards and same time parasitoids activity was also peak.
- Mealybug causes heavy loss if it occurs during vegetative stage of the crop and fairly less reduction in the yield if incidence occurs after 120 days after sowing. Quality parameters were affected maximum at 90 DAS as compared to 120 and 150 DAS and all the quality parameters were negatively correlated.
- Buprofezin having novel mode of action and less hazardous to the natural enemies can be used whenever mealybug population crosses ETL during early stage of the crop growth.
- Profenophos can be used as an alternative to buprofezin whenever outbreak of mealybug is noticed. These two insecticides can be used judiciously looking to natural enemies population and to avoid development of resistance in mealybug population.
- Use of profenophos and buprofezin for the management of mealybug on cotton increased the seed cotton yield significantly and accrued higher returns.

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\* Original not seen

## APPENDIX

Weather parameters prevailed during 2008-09

Period	ISW	Temperature (°C)		Rainfall (mm)	Rainy Day	Relative humidity (%)	
		Max.	Min.			Morning	Evening
Jul 30-5	31	32.6	22.3	6.2	1	87	58
Aug 6-12	32	29.9	22.0	34.8	3	85	67
Aug 13-19	33	31.4	22.0	54.5	3	87	62
Aug 20-26	34	32.3	22.9	11.0	1	78	59
Aug 27-2	35	33.3	22.1	56.6	3	88	61
Sep 3-9	36	32.0	21.8	10.8	1	91	69
Sep 10-16	37	31.2	21.4	18.0	2	89	62
Sep 17-23	38	33.5	21.3	5.4	1	88	57
Sep 24-30	39	32.4	20.0	3.6	1	88	54
Oct 1-7	40	34.3	21.5	15.8	3	86	55
Oct 8-14	41	32.7	20.2	37.4	1	88	53
Oct 15-21	42	32.8	21.0	23.2	2	83	54
Oct 22-28	43	31.6	18.0	40.8	2	84	50
Oct 29-4	44	32.8	15.1	0.0	0	84	37
Nov 5-11	45	32.1	15.7	0.0	0	91	48
Nov 12-18	46	30.1	17.8	14.8	1	90	56
Nov 19-25	47	32.0	19.9	20.6	2	91	49
Nov 26-2	48	29.7	20.7	3.2	1	92	69
Dec 3-9	49	31.4	16.2	0.0	0	95	47
Dec 10-16	50	31.6	16.9	0.0	0	84	46
Dec 17-23	51	30.6	14.7	0.0	0	92	35
Dec 24-31	52	31.4	12.9	0.0	0	74	32
Jan 1-7	1	30.1	16.4	0.0	0	88	37
Jan 8-14	2	30.4	17.3	0.0	0	89	37
Jan 15-21	3	30.4	15.1	0.0	0	89	41
Jan 22-28	4	32.5	14.1	0.0	0	87	41
Jan 29-4	5	34.9	16.1	0.0	0	87	51
Feb 5-11	6	34.1	17.5	0.0	0	90	45
Feb 12-18	7	34.2	17.7	0.0	0	87	35
Feb 19-25	8	35.5	17.1	0.0	0	85	52
Feb 26-4	9	33.8	16.0	0.0	0	75	44
Mar 5-11	10	38.7	18.3	0.0	0	51	16
Mar 12-18	11	38.3	20.2	0.0	0	56	22
Mar 19-25	12	38.3	20.5	0.0	0	56	22
Mar 26-1	13	38.4	21.3	0.0	0	53	20

APPENDIX – II

Weather parameters prevailed during 2009-10

Period	ISW	Temperature (°C)		Rainfall (mm)	Rainy Day	Relative humidity (%)	
		Max.	Min.			Morning	Evening
Jul 30-5	31	35.5	22.6	0.0	0	79	39
Aug 6-12	32	35.7	22.3	5.6	1	76	37
Aug 13-19	33	34.5	23.0	37.2	2	80	49
Aug 20-26	34	31.5	21.8	55.4	3	90	74
Aug 27-2	35	31.5	20.7	70.9	4	88	69
Sep 3-9	36	29.8	21.4	36.4	4	88	63
Sep 10-16	37	32.5	21.9	7.6	2	88	61
Sep 17-23	38	33.7	21.8	28.0	1	86	55
Sep 24-30	39	32.5	21.4	92.4	4	90	71
Oct 1-7	40	29.2	20.7	362.6	3	90	76
Oct 8-14	41	32.0	21.4	0.0	0	86	67
Oct 15-21	42	33.1	19.6	0.0	0	80	42
Oct 22-28	43	32.4	16.9	0.0	0	75	33
Oct 29-4	44	32.3	18.0	0.0	0	83	40
Nov 5-11	45	30.5	20.1	8.2	1	88	66
Nov 12-18	46	31.2	21.1	41.9	3	92	74
Nov 19-25	47	30.3	18.9	32.0	1	90	69
Nov 26-2	48	33.1	14.6	0.0	0	92	76
Dec 3-9	49	31.5	15.0	0.0	0	93	73
Dec 10-16	50	30.3	15.7	0.0	0	91	48
Dec 17-23	51	30.0	16.9	0.0	0	88	49
Dec 24-31	52	28.8	15.7	0.0	0	84	47
Jan 1-7	1	30.6	14.2	0.0	0	87	44
Jan 8-14	2	30.8	18.6	18.6	1	90	63
Jan 15-21	3	30.3	16.1	18.0	1	88	55
Jan 22-28	4	29.8	13.4	0.0	0	82	64
Jan 29-4	5	31.3	15.8	0.0	0	90	69
Feb 5-11	6	32.4	15.5	0.0	0	87	54
Feb 12-18	7	34.4	18.5	0.0	0	94	57
Feb 19-25	8	36.6	19.3	0.0	0	93	38
Feb 26-4	9	32.3	16.4	0.0	0	69	35
Mar 5-11	10	38.6	20.8	0.0	0	76	27
Mar 12-18	11	38.0	20.8	0.0	0	64	33
Mar 19-25	12	38.3	20.5	0.0	0	62	30
Mar 26-1	13	38.5	20.3	0.0	0	60	28

# BIOECOLOGY AND MANAGEMENT OF MEALYBUG, *Phenacoccus solenopsis* TINSLEY (HEMIPTERA: PSEUDOCOCCIDAE) ON Bt COTTON

SHIVANAND G. HANCHINAL 2010

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## ABSTRACT

Investigations were carried out on survey, seasonal fluctuation of mealybug, *Phenacoccus solenopsis* Tinsley and its natural enemies, crop loss assessment, estimation of EIL, biology of mealybug, biology of the predator *Cryptolaemus montrouzieri* Muls. and efficacy of insecticides including biological agents against mealybugs were undertaken during 2008-09 and 2009-10 at MARS, Raichur and Department of Entomology, College of Agriculture, Dharwad.

Mealybug incidence was moderate to severe in Raichur, Bellary and Gulbarga districts while its incidence was low in Dharwad, Haveri and Belgaum districts of North Karnataka on Bt cotton. The peak activity of the parasitoids was observed mainly from January to March in both the years. Mean per cent parasitoid emergence from mealybugs collected at various places was highest in TBP and UKP areas as compared to other districts in both the years. There were more than 15 alternate host plants of *P. solenopsis* belonging to eight families found across the cotton growing districts of North Karnataka. Among them, *Abutilon indicum* L. (Malvaceae) and *Parthenium hysterophorus* L. (Asteraceae) were the major weed hosts.

Steep increase in the mealybug population was observed from January and reached peak in March in both the years of study. Initially parasitoid population was low and peak activity started during first week of January which gradually increased up to 34.62 per cent and 34.64 per cent during the last week of March 2008-09 and 2009-10 seasons, respectively. Among different parasitoids, *Aenasius bambawalei* Hayat was the dominant species. Total life cycle of *P. solenopsis* female and male was 38.47 and 20.33 days, respectively. The total life cycle of *Cryptolaemus montrouzieri* was 28.82 and 24.71 days when reared on the mealybug nymphs and adult female, respectively.

Crop loss estimation due to mealybug damage indicated that cotton plants did not survive at all the damage levels at 60 days after sowing in both the years. Cotton yield was severely affected due to different levels of mealybug damage at 90 days after sowing. Estimation of EIL due to mealybug damage on Bt cotton under irrigated ecosystem resulted in 20, 27, 44 and 51 mealybugs per plant at 60, 90, 120 and 150 days after sowing, respectively. Profenophos 50 EC @ 2000 ml/ha and buprofezin 25 SC @ 1500 ml/ha were effective in reducing the mealybug population on cotton. These two treatments recorded significantly maximum seed cotton yield with higher net returns in both the seasons of study.