STUDIES ON DIVERSITY OF MAJOR INSECT-PEST OF SUGARCANE ALONG WITH EFFICACY OF SOME NOVEL INSECTICIDES AGAINST TERMITES IN FIELD AND HOUSEHOLD ECOSYSTEM

Thesis

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By

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Pantnagar
November, 2014

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON DIVERSITY OF MAJOR INSECT-PEST OF SUGARCANE ALONG WITH EFFICACY OF SOME NOVEL INSECTICIDES AGAINST TERMITES IN FIELD AND HOUSEHOLD ECOSYSTEM"** submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** with major in **Entomology** and minor in **Plant Pathology**, of the college of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Ms. Vijay Laxmi Rai, Id. No. 31981,** under my supervision and no part of the thesis has been submitted for any degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

18/11/2014

(A.K. Karnatak)
Chairman
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November, 2014

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Ms. Vijay Laxmi Rai, Id. No. 31981,** a candidate for the degree of **Doctor of Philosophy** with major in **Entomology**, and minor in **Plant Pathology** agree that the thesis entitled **"STUDIES ON DIVERSITY OF MAJOR INSECT-PEST OF SUGARCANE ALONG WITH EFFICACY OF SOME NOVEL INSECTICIDES AGAINST TERMITES IN FIELD AND HOUSEHOLD ECOSYSTEM"** may be submitted in partial fulfilment of the requirements for the degree.

18/11/2014

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Introduction

Chapter 1 INTRODUCTION

Sugarcane, *Saccharum officinarum* L. is an important industrial and cash crop in India. It is grown in sub-tropical and tropical regions in a wide range of climates from hot dry environment near sea level to cool and moist environment at higher elevations. In India, sugarcane occupies an area of 5.062 million ha with the annual production of 334.54 million tonnes and productivity of 66.08 tonnes per ha (**Anonymous, 2013**). About 45 million sugarcane farmers, their dependents and agricultural laborer are involved in Indian sugar industry **(Dhanraj and Dharne, 2013**). Sugar industry is the second largest agro-based industry comprising of more than 500 sugar mills, next to textiles (**Takale, 2013).** Besides sugar production, sugarcane produces numerous valuable byproducts like, alcohol used by pharmaceutical industry, ethanol used as a fuel, production of electricity power and chip board manufacturing and press mud used as a rich source of organic matter for crop production.

Sugarcane is a long duration crop of 10-18 months and normally crop is followed by one or two ratoon crop, grown over large areas for higher production of sugarcane per unit area and time. This provides a sort of mono-cropping stable agro-ecosystem for multiplication of insect pests **(Mann *et al*., 2006).** Though sugarcane agro-ecosystem is stable one but periodically it is affected by different abiotic and biotic changes in the environment. These changes along with difficulties in application of chemicals in closed canopy and limited control provided by various pest control tactics (*viz.* cultural, mechanical and biological) individually or jointly influence the insect-pest complex over a period of time and ultimately, accentuated the existing pest problems and also change the status of many insects. Sugarcane is liable to attack by insect pest right from planting till harvest. The pest causes enormous losses both in tonnage and recovery of sugar in the mills. Out of 211 species of insect pests reported to infest sugarcane crop in India, 18 have attained major pest status **(David and Nandgopal, 1986)**. These include borers, termites, black bugs, scale insects, mealy bugs, pyrilla, white flies etc. The losses inflicted by pests are influenced by sugarcane genotype, pest severity, nature of crop-plant / ratoon, time of planting, climatic and edaphic factors **(Rai, 1997)**. Among various pests, borers and termites are key factors in causing crop losses in terms of plant stand and number of millable canes that result in huge loss of sugar output **(Sharma *et al.,* 2011).**

Subterranean termites are the major problem which affect the sugarcane crop from its germination through shoot emergence and finally on the quality of canes **(Singh and Singh, 2003)**. Sugarcane is vulnerable to termites at initial and later stages of growth **(Miranda *et al*., 2004)**. At germination stage, the termite losses up to 90-100% have been recorded in sugarcane **(Salihah *et al.,* 1988; Sattar and Salihah, 2001).** Termites fed on inner soft juicy tissue leaving the rind intact. The cavity thus formed is, subsequently, filled with moist soil with galleries in which these insects move freely. The affected canes exhibit yellowing and drying of outer leaves followed by similar withering of inner leaves and ultimately these canes die **(Kushwaha, 1961; Mora *et al.,* 1996)**.

There are various species of termites existing, proves destructive not only to sugarcane crop but also known as notorious pest of other agricultural crops, trees and wooden articles (outdoors as well as indoors) etc. In natural ecosystems, termites feed on organic matter too. They are responsible for reducing soil fertility by removing both plant and animal debris and locking them in their underground nests thus making them unavailable for plant growth. Out of the nearly 3,106 (world termite fauna) living and some fossils species, only 371 (12.4%) have been reported in the literature as destructive **(Krishna *et al.,* 2013)**. On the other hand, Indian region termite fauna shares a very small portion of the global fauna i.e. 352 species distributed over seven families and fifty-nine genera **(Kumar, 2010)** till date. Out of which, about 35 species have been reported as damaging agricultural crops and timber in buildings. According to their diverse feeding and nesting activities, termites are divided into three groups; (1) Subterranean termites, which dwell the subterranean nests or trees and connect to moisture source through mud tubes, (2) Dampwood termites, which lives in rotten logs or highly moist timber in soil, and (3) Dry wood termites, which nests entirely in timber above ground **(Krishna and Weesner, 1970; Pearce, 1997)**. The principle factors that influence the distribution of termites in India are the rainfall pattern, humidity, altitude, vegetation, soil types, natural enemies and other associated organisms (**Kumar, 2010**). The majority of the termite species are soil inhabiting, either as mound builders or as subterranean nest builders. The major mound building species are *Odontotermes obesus, O. redemanni* and *O. wallonensis* while, major subterranean species are *Heterotermes indicola, Coptotermes ceylonicus, C. heimi, Odontotermes horni, Microtermes obese, Trinervitermes biformis* and *Microcerotermes beesoni* (**Rajagopal, 2002**).

Pesticides happen to be the major effective weapon under modern agricultural technology against various insect pests to obtain maximum yield and additional returns. For the control of termites, many measures have been recommended, among which use of insecticides found effective over long time (**Sands, 1977, James *et al.*, 1990; Mill, 1992; Gold *et al.,* 1994**). The insecticides being applied as sett treatments in furrows at the time of sowing of sugarcane gave an increased yield of 46.62 to 55.33 per cent more over untreated, saving considerable amount of loss due to termite attack (**Santharam *et al.,* 2002**). But the excessive, irrational and indiscriminate uses of chemical pesticides have resulted into the problems of resistance and residues which cause several hazards to the human beings as well as to the ecosystem **(Phokela *et al.,* 1990).**

In household ecosystem, subterranean termites are major pest of timber and timber based products and is closely associated with the soil habitat where they excavate a network of tunnels through the soil to reach water and food**.** These are difficult insect to control because they have complex social patterns and form great extent colonies generally made of several thousands individuals with an outstanding ability to develop from one caste to another (**Sheets *et al*., 2000**). Even though the queen dies, secondary reproductive can get that function. Thus, the removal of foragers is usually not enough to eliminate the colony.

There are usually three major strategies in termites control (1) inserting chemical and/or physical barriers to prevent termites from entering to buildings or attacking timbers in contact with the ground, (2) using naturally durable timbers or impregnation of susceptible ones with a wood preservatives that act as a termiticide (3) eliminating the termites colonies using chemicals directly to the nests or indirectly via toxic baits that are eaten and distributed through the colony, leading to their destruction.

Over the last several years, there has been increasing popularity in the use of non-repellent termiticides because foraging termites could not detect the presence of the treated soil with this kind of termiticide, and thus they would continue to forage through the treated soil and would receive amounts of insecticides on their bodies that ultimately causes the death of termites **(Shelton and Grace, 2003)**.

In addition to synthetic chemicals for the management of subterranean termites, a revolutionary method called baiting techniques has been introduced and adopted as one of the options in subterranean termite management programs **(Su, 2003)**. Baiting involves impregnating a cellulose substrate with a slow-acting toxicant, generally an insect growth regulator (IGR) and placing it near a termite colony **(Potter, 2001).** Termite workers feed upon the bait and transfer it by grooming or trophallaxis to other colony members, eventually reducing or eliminating the entire colony populations of several million individuals **(Su, 1994)**.

Among the bait toxins, the chitin synthesis inhibitor, hexaflumuron proved efficient for bait applications in comparison with noviflumuron, diflubenzuron etc. **(Robertson and Su, 1995; Su and Scheffrahn, 1996)**. Hexaflumuron belongs to benzoylphenylurea chemical class which inhibits chitin synthetase enzymes, preventing proper chitin deposition in the cuticle **(Nakagawa *et al.,* 1992)** thus unable to complete the formation of insect exoskeleton. Sufficient quantities of active ingredient must be present within the insect as it molts to cause mortality. It is virtually harmless to vertebrates. Because of its slow lethal effect on mammals (LD_{50} > 5,000 mg/kg) as well as on non-target organisms, it is registered in the least toxic category "caution".

Several studies have evaluated the effectiveness of the chitin synthesis inhibitor, hexaflumuron, applied as a bait to control subterranean termites **(Su *et al.,* 1995; DeMark *et al.,* 1995; Yates and Grace, 2000; Clement *et al.,* 1996; Forschler and Ryder, 1996)**. Field applications of Hexaflumuron succeeded in suppressing foraging activities of the two species of subterranean termites, *Coptotermes formosanus* Shiraki and *Reticulitermes flavipes* (Kollar) in Florida and only a small amount of active ingredient was needed to reduce foraging populations by 80-90% **(Su, 1994).** A successful baiting program can take up to nine months (as 3-9 months **Su, 1994**; 7 months **Tsunoda *et al.,* 1998**; more than 3-7 months **Su *et al.,***

2000), which is much slower control than that provided by other methods (**Evans and Gleeson, 2006**).

Keeping above points in view, present investigation entitled "Studies on diversity of major insect-pest of sugarcane along with efficacy of some novel insecticides against termites in field and household ecosystem" has been proposed with the following objectives:

1. To assess the diversity of major insect species associated with Sugarcane.
2. To identify the major termite species available at Pantnagar Campus.
3. To determine the bio-efficacy of Spinoteram in comparison of Imidacloprid, Chloropyrifos and Fipronil for controlling Sugarcane Termites.
4. To evaluate the toxicity of Spinetoram 12 SC w/v (11.7% w/w) against termite, *Odontotermes brunneus* (Hagen) under laboratory conditions.
5. To determine the effectiveness of Sentricon Colony Elimination System using Hexaflumuron bait on termites in household ecosystem.

Review of Literature

Chapter 2 REVIEW OF LITERATURE

Sugarcane (*Saccharum officinarum* L.) is one of the most important commercial crops of the sub-tropical and tropical countries and is the main source of sugar in the world by contributing nearly 70 per cent to the world's total sugar production. The cane yield is markedly influenced by many factors like soil fertility, climate, variety, and cultural practices, prevalence of pests and diseases and environmental stress. Among them, pests are known to inflict considerable loss in cane yield as well as sugar output.

The available literature on the present investigation and related aspects have been reviewed and presented below under following headings and sub-headings:

2.1 Insect-pest diversity in sugarcane
- 2.1.1a. Sugarcane shoot borer, *Chilo infuscatellus* Snellen
- 2.1.1b Nature and symptoms of damage
- 2.1.1c Seasonal incidence of *C. infuscatellus*
- 2.1.2a Sugarcane top borer, *Scirpophaga nivella* Fabricius
- 2.1.2b Nature and symptoms of damage
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2.2 Review of literature on Termite Species

2.3 Efficacy of insecticides against termite

2.4 Laboratory evaluation of insecticides

2.5 Use of Baiting System against termite
- 2.5.1 Assessment of Sentricon Colony Elimination System

2.1 Diversity of major insect species associated with Sugarcane

Regular surveys were conducted by **Mann *et al.* (2006)** in the 16 sugar mills located in nine districts of Punjab state from 2001 to 2004 to develop survey schedule for recommending control measures and to determine the spatial pattern and intensity of different sugarcane pests. Among the various pests, stalk borer, top borer, pyrilla and black bug can be considered as key pests, while early shoot borer, root borer, white grub and whitefly as localized pests. The third brood of top borer can be controlled on the basis of incidence of second brood. The surveillance can be conducted in the months of April for black bug, pyrilla, thrips and mite, in June for top borer (II brood), shoot borer and termite in September for top borer (III brood), root borer, gurdaspur borer, whitefly, and pyrilla and at the time of harvesting for stalk borer.

According to **Rao *et al.* (2009)** in sugarcane crop, among the various insect and non-insect pests, early shoot borer, internode borer, scale insect and mealy bugs can be considered as key pests, while whitefly, Pyrilla, woolly aphid, red mite, yellow mite, white grub, termites and grasshoppers as localized pests. The incidence of internode borer could be avoided by managing the population density of early shoot borer in the early stages of the crop growth as both the species in Coastal Andhra Pradesh remains same i.e., *Chilo infuscatellus* Snellen. The surveillance can be conducted in the months of March to May for early shoot borer, mealy bugs and red mite; in June to August for grass hopper, internode borer and yellow mite; in June to October for grasshoppers, root grub, scale insect, termites, whitefly and woolly aphid.

Innocent and Merlindayana (2012) studied the insect diversity in the Sugarcane field at Allinagaram village, Periyakulam in Theni District, Tamil Nadu, India. 2660 insects belonging to 44 species and 10 orders were recorded; Diptera recorded a maximum density of 1650 insect with a population percentage of 62% followed by Lepidoptera with 12 species and a population percentage of 10.6%. The diversity index was high in Diptera due to numerical abundance of individuals. Physical factor like rainfall which was high during December increased the density of Diptera, followed by other groups.

2.1.1a Sugarcane Shoot borer, *Chilo infuscatellus* Snellen

Butani (1969) reported that early shoot borer, *Chilo infuscatellus* was one of the common and injurious pests of sugarcane in India and is found in all the growing parts of the country. He also observed that the borer is most active in Punjab, Haryana and Uttar Pradesh in late May and June.

Sugarcane early shoot borer is cosmopolitan in distribution, infesting the crop at the shoot stage both in tropical as well as subtropical India **(Eswaramoorthy, 1986).**

According to **Bhavani (2013)** the moth of sugarcane early shoot borer, *Chilo infuscatellus* Snellen laid eggs on the ventral surface of the leaf, close to the midrib. The fecundity of female ranged from 368 to 384 and the incubation period ranged from 4.0 to 4.1 days. The larva passed through four moults with five instars and the total larval period ranged from 16.0 to 16.3 days. Pupation occurred in the outermost leaf sheath in a silken cocoon and the pupal period varied from 6.3 to 6.6 days. The peak period of activity of the pest was observed from March to May.

2.1.1b Nature and symptoms of damage

According to **Rahman and Singh (1942),** the first sign of the presence of this pest in a field is the appearance of the dead heart which consists of the dried up central whorl. The freshly hatched larvae enter between the first leaf sheaths and stem and eat its way into the interior of the shoot.

This species is capable of completely severing the connection between the lower portion of the shoot and the central growing whorl of leaves. The larvae bore into the stalk and kill the growing point in 7-8 days **(Gupta, 1940).** The dead heart is formed in 12-18 days after the entry of larva into the plant, and is made up of the leaf spindle and the first and second leaves and very nearly the third leaf **(Rahman and Singh, 1942).** The dead heart is greyish white in colour and completely severed from the parent plant, can be easily pulled out, thereby leaving behind a well defined cavity. The base of the dead heart which gets completely rotted gives an offensive smell.

It has been calculated that 30-75 per cent shoots are eliminated in the early stage of crop growth in the different growing regions of the country **(Rahman and Singh, 1942; Gupta and Awasthy, 1954; Krishnamurthy Rao, 1954)**.

Shoot borer destroys 26-65 per cent mother shoots and 6.4, 27.1 and 75.0 per cent primary, secondary and tertiary tillers, respectively **(Doss, 1956; Khan and Krishnamurthy Rao, 1956)**.

Usman *et al.* (1957) stated that pupation takes place inside plant. The larva move up within the young plants and cut an emergence hole 4-10 cm above the ground level before pupating in white, thin silken web inside the larval tunnel.

Kalra and Sharma (1963) observed that the activity of *Chilo infuscatellus* continued till October and in such cases, it becomes a cane borer infesting even 70-80 per cent of the cane. 38.7 per cent of shoots were affected as a result of its infestation.

According to **Agarwal and Siddiqui (1964),** the characteristic dead heart resulting in loss of shoots even upto 50 per cent in some part of India while, **David (1977)** recorded 69.7 per cent of infestation in Tamil Nadu.

Avasthy (1968) established a positive correlation between borer incidence and intensity of damage and a negative one between incidence and yield as well as intensity and yield. **Subha Rao (1972)** showed that when incidence of dead hearts did not exceeds 22 per cent; the varieties were able to overcome the infestation, resulting in no apparent reduction in the number of shoots or weight of clumps at harvest provided mother shoots were healthy.

Patil and Hapse (1981) reported losses from 22-23 per cent in yield; 12 per cent in sugar recovery, 2 per cent in CCS and 27 per cent in jaggary due to attack of *Chilo infuscatellus*.

2.1.1.c Seasonal incidence

The shoot borer, *Chilo infuscatellus* is more active during hot periods of the year both in tropical **(Murthy, 1953a; Sulaiman, 1954; Nagaraj Rao and Chandy, 1957; Jagannatha Rao, 1960; Varadharajan *et al.*, 1971)** and subtropical India **(Agarwala and Haque, 1955; Gupta, 1959; Bains and Dev Roy, 1981)**.

The shoot borer is widely distributed in all sugarcane growing areas in India, infesting the crop during shoot stage in spring or eksali planted crop (March through June). In Adsali crop, borer damage occurs during September and October. It also infests millable canes in years of drought or scanty rainfall. The losses suffered by farmers are due to (1) gaps in crop stand, (2) loss in yield due to late formed canes with reduced weight and sucrose content, (3) reduction in weight and deterioration in juice quality, when borer infest millable canes, especially if drought occurs in post monsoon period in the area **(Mukunathan, 1985).**

Pradhan and Bhatia (1956) studied the effect of temperature and relative humidity on the activity of the borer, under North Indian condition. The borer enters into a physiological diapause during winter months and the lower and upper temperature, threshold limits are found to be 12-40^{0}C respectively for the development of egg, larva and pupa.

Nagarajan and Chandy (1957) have shown the positive influence of maximum temperature on the oviposition and ultimately of the borer population in Tamil Nadu. The borer has been observed to multiply well at an average maximum temperature range of 96-106 ^{0}F (35.6-41.1^{0}C) and 40-45 per cent relative humidity. In Maharashtra and Andhra Pradesh, it is more active from September to March at a maximum temperature of 85-95^{0}F (29.4-35^{0}C) and mean relative humidity of 50-75%.

According to **Kalra and Sharma (1963)**, high day temperature with moderate humidity is conducive for its multiplication and its activity continues till October.

Chandy *et al.* (1964) and Butani (1966) has observed that this pest is very active with the onset of monsoon. In Punjab, the peak period of the pest is between May and December.

Varadharajan *et al.* (1971) reported the pest to be very active during March-June when the maximum temperature is high (30.2-35.3 ^{0}C) low humidity (76.8-89%) and scanty rain. The pest is completely inactive in rainy season (October-November), when the maximum temperature is low with high humidity (86.9-90.2%) and heavy rainfall (19.88-31.43 cm). The larvae are very active during April, May and June. The activity declined in July on the onset of South-west monsoon, but continues till harvest. The pupal population also is very high during April and May.

According to **Easwaramoorthy and Jayaraj (1988),** the borer infestation was low in March-April planted crop compared to December-January and special season planted crops owing to high rainfall. The infestation was more on 45 and 60 days old crop compared to 75 and 90 days.

Mehta and Chaudhary (1990) reported that mean generation time of shoot borers varied from 30 to 40 days at 27.5 to 35 ^{0}C temperature.

The population of *Chilo infuscatellus* Snellen appeared during April and infestation increased gradually up to 21.44 per cent in September **(Bhatti *et al.,* 2008).**

Pandey and Kumar (2014) reported that the highest incidence of *C. infuscatellus* during 21st standard week (8.8 per cent) at 43.1ºC maximum temperature, 28.4ºC minimum temperature, 57.0 per cent maximum relative humidity, 21.0 per cent minimum relative humidity and 9.1 sun shine hours. The correlation coefficient showed significant and positive correlation with minimum temperature while it was highly significant and negatively correlated with minimum relative humidity with shoot infestation. The effect of maximum temperature with shoot infestation showed a negative correlation. The maximum relative humidity showed non significant positive correlation where as it was positively correlated with minimum relative humidity and sun shine hours.

2.1.2a Sugarcane top borer, *Scirpophaga nivella* Fabricius

Top shoot borer, *Scirpophaga excerptalis* wlk. (Lepidoptera: Pyralidae) is reported to be a serious pest in northern states as compared to the southern states (**Haque and Agarwala, 1955; Butani, 1983**). The top borer is a major pest in north India, especially in the states of Bihar, Uttar Pradesh, Haryana and Punjab.

Scirpophaga nivella (F.) occur on sugarcane in Burma, Ceylon, China, Formosa, India, Japan, Malayasia, Pakistan, Philippines and Thailand **(Gupta, 1959; Pamberton and Williams, 1969)**.

Eggs are deposited in clusters of 2-5 overlapping rows, on following day of mating, on the under-surface of the leaves near the midrib and are covered by the hairs of the anal tuft (**Haque and Agarwala, 1955**). According to **Lee and Rao (1962)**, the majority or egg masses are on the second to fifth leaves from the top.

The newly hatched caterpillars are greyish brown with black head and thorax with long hairs on the body. They crawl actively on leaves, suspend themselves by silken threads and get dispersed to adjacent plants by wing. After 3-4 hours they bore into the midribs of leaves through the lower epidermis **(Verma and Mathur, 1950; Huque and Agarwala, 1955; Patel, 1963; Kamini and Vyas, 1985)**. The larva prefer the most tender visible midrib, more then one larva bore into the midrib of a leaf and they may tunnel parallel to each other or one behind the other **(Mukunthan, 1985)**.

2.1.2b Nature and symptoms of damage

The cane attacked by *Scirpophaga excerptalis* Wlk. (commonly called as top borer of sugarcane) always showed a dead heart **(Stebbing, 1903)** which consists of the dried central fold of the leaves **(Fletcher, 1919).**

According to **Singh (1978)** up to the fourth instar, the larva feeds above the growing point. Then it cuts across the growing point, causes dead-hearts and enters the top internodes.

In the tillering stage of crop, the attacked shoots die, resulting in the formation of side tillers, while in the grand growth phase, the crop growth is arrested and the growth with the dead-heart completely dries and may be blown off leaving only a stump. In grown up canes, the infestation results in dead-heart formation which induces sprouting of the lateral buds giving a "bunchy top" appearance. Occasionally, top borer infestation induces aerial root formation **(Singh *et al.*, 1980).** While, **Jayanthi (1982)** and **David (1985)** reported a key for identifying the symptoms of top borer damage was parallel rows of shot holes seen on the emerging leaves, midrib mining seen on top leaves and dead hearts cannot be pulled out easily

Mukunthan (1985) reported that each caterpillar makes a separate longitudinal tunnel of its own which extends parallel to one another and of these tunnels, only 56% to 76% reach the base of the leaf. The caterpillar then eats its way through the tunnel which is having its inlet at the lower side of the midrib, runs nearer to the upper surface. The caterpillar reaches the base of the bored leaf and at the point of the junction punctures the inner leaf. As the larva feeds by boring into the narrow central core towards the growing point, the leaf dries up and become atrophied, turns dark brown forming the dead-heart.

According to **Mukunthan and Rakkiyapan (1989),** 'Bunchy top' formation in an 8 months old autumn planted sugarcane crop because of the larva entering the cane in the spindle region near the growing point, which it killed leading to the sprouting of axillary buds and bunchy top formation. Occasionally, top borer infestation induces aerial root formation. The migratory larva attacks the sprouts to cause more than one dead heart in the bunchy top.

Sallam (2006) reported that the top shoot borer (*Scirpophaga excerptalis*) attack the youngest part of the plant top, and usually destroy the growing point. Young stalks die, whereas older stalks often die or produce side shoots and sucrose content is usually adversely affected.

2.1.2c Seasonal incidence

In Uttar Pradesh, the climatic conditions during the monsoon months, with average maximum temperature ranging from 90-95^{0}F (32.2-35 ^{0}C) and mean relative humidity 75-85% are conducive for multiplication **(Gupta, 1954a). Singh *et al.* (1957)** observed that the incidence is directly correlated with the rise in relative humidity and with the increase in maximum temperature. Relative humidity above 50% during the period of third brood appearance favors the incidence of this pest.

According to **Gupta (1959),** the prolific multiplication of *S. excerptalis* is observed to occur in Punjab at an average maximum temperature ranging from 93.2 to 101.3 ^{0}F (34-38.5 ^{0}C) with 62-100 per cent mean relative humidity. But high maximum temperature coupled with low relative humidity is detrimental to its multiplication **(Singh, 1964).** The successful incubation of eggs, survival of the first instar larvae and longevity for the moth is favoured with a temperature range of 90-95^{0}F, relative humidity 80-90% **(Narayanan and Mukherji, 1954)**.

Varadharajan *et al.* (1971) reported top borer infestation in April. Highest mean infestation of 6.7 per cent was felt during July. The larvae are not active during monsoon periods i.e., September to November. Large number of pupae obtained in May and June.

Kalra (1975) reported its severe incidence on sugarcane in June-July in North Indian conditions.

Shah *et al.* (1981) studied the population abundance of the *S. nivella* (F) as affected by weather condition in Gujrat, by night trapping of adult. The largest numbers of insects were caught in January-February, when the maximum average temperature was 30^0C, the minimum average temperature 11^0C.

According to **Butani (1983),** the pest activity starts when the average maximum temperature falls below 38 ^{0}C and relative humidity rises above 60 per cent.

Benerjee *et al.* (1986) reported that night catches of *S. nivella* (F.) in light traps in rice plots (West Bengal), found significant correlation with maximum temperature and minimum relative humidity of the day and minimum relative temperature and wind speed of the night during summer catches (mid March-mid June), while during autumn catches (mid July-mid November), were significantly associated with maximum temperature and minimum relative humidity of the night.

A study on the incidence of sugarcane top borer (*Scirpophaga excerptalis*) and its larval parasitization by natural enemies in the fields in Cuddalore, Tamil Nadu, India, during 1999-2002 was conducted. The results indicated the varying incidence of the pest and its parasitization by natural enemies in the field. The mean incidence of top borer was 15.86, 12.31 and 3.22%, and the mean natural parasitization on the larvae of the top borer was 27.72, 21.56 and 8.72%, during 1999-2000, 2000-01 and 2001-02, respectively (**Rajendran and Giridharan, 2003**).

Bhatti *et al*. (2008) observed that the top borer appeared in the month of March and caused maximum damage of 14.46 per cent in July.

Sharma *et al*. (2009) reported that the sugarcane top borer *Scirpophaga excerptalis* (Walker) causes significant damage to sugarcane (*Saccharum* spp.) crop in India. They evaluated 133 sugarcane genotypes for their reaction against the top borer and its incidence was related with the meteorological parameters. The cumulative incidence ranged from 0.53 (Sel 22-01) to 31.72 (Sel 1046-03). Thirty genotypes showed less than five per cent cumulative top border incidence, which were rated as comparatively resistant genotypes while nineteen genotypes showed more than 15 per cent incidence and these were rated as comparatively less resistant genotypes.

2.1.3.a Sugarcane stalk borer, *Chilo auricilius* Dudgeon

This pest is very well known to cause heavy loss to the sugar industry particularly in Bihar, Uttar Pradesh, Haryana and Punjab **(Chaudhary, 1981).** A number of workers have reported the loss caused by stalk borer in cane yield and sugar recovery. **Gupta and Singh (1951)** reported that at 29 per cent infestation of internodes by stalk borer, the reduction in cane yield was 17-33 per cent and the loss in sugar recovery range from 1.7-3.7 units at Jarwal Road in Uttar Pradesh.

2.1.3.b Nature and Symptoms of damage

Garg and Chaudhary (1979) observed the incidence of *Chilo auricillia* throughout the year. In heavy infested areas, its incidence was as high as 90-100 per cent on stalk basis, and about 30 per cent on internodes basis. It caused damaged to about 33 per cent in yield and about 12 percent in sucrose content. This borer flourished mostly under moderate temperature (28-35 ^{0}C) and high humidity (67-90 per cent), and low temperature only prolonged its life-cycle. Heavy and continuous rains, waterlogged and heavy manuring conditions favored its heavy multiplication.

A positive correlation was observed between intensity of the stalk borer infestation and per cent loss in yield, juice extraction and sugar recovery. The loss was estimated to be equivalent to 0.63 per cent in cane yield, 0.64 per cent in juice extraction and 0.08 units in CCS (commercial cane sugar) for one per cent intensity of borer infestation in Haryana **(Bhardwaj *et al*., 1980).**

2.1.3.c Seasonal incidence

Gupta and Awasthy (1954) observed that stalk borer spread through the un-harvested late shoots to the newly planted sugar crops. They also found that the stalk borer attack in the plant crop began in April-May. The infestation peak reached sometime in June-July when about 2 per cent shoots were destroyed. Infestation started declining with the onset of monsoon and the borer became inactive in the standing crop form September onwards.

The stalk borer, *Chilotraea auricilia* Ddgn. Caused 65-80 per cent incidence **(Gupta, 1958)** and its activity increased from September to October onwards and continued till harvest **(Butani, 1961).**

In '*tarai*' areas of the western U.P., **Atwal (1963)** reported the appearance of the stalk borer *Chilotraea auricilia* Dudgeon for the first time in 1954 and hence known as "*Tarai borer*". In January, 1962 the pest was noticed for the first time in fields near Jagadhri (Punjab) where its incidence of attack was 40 per cent or more.

Kalyanaraman *et al.* (1963) found high positive correlation for prolific multiplication of *Chilotraea* sp. with high day temperature and moderate relative humidity.

In October 1963, the *Chilo auricilius* damage reached up to 100 per cent in some softer cane varieties at Golagokarannath, Rosa and Pantnagar in U.P. **(Singh, 1983)**. This pest *Chilo auricilius* Ddgn was quite active during August – February when its population in water shoots and late shoots was mostly below ground level. The incidence of stalk borer increased from July to November, 1971 averaging to 63.8%, as the incidence increased from July to November which was 7.1, 31.1, 44.2, 52.4 and 67.0 per cent in the months of July, August, September, October and November, respectively.

Verma *et al.* (1991) found that the incidence of *Chilo auricilius* to be 61 per cent during December, 1989.

Jena and Patnaik (1997) studied the seasonal activities of *Chilo auricilius,* the pest remained active form fourth week of June till November when the maximum temperature remained between 32.5^{0}C and 36.5 ^{0}C and relative humidity between 71.3 and 79.5 per cent.

Singla and Duhra (1991) reported the incidence level of *C. auricilius* before 1979-80 of about 2 per cent in Punjab. But in 1979-80, its mean incidence in different sugar mills was 7.3 per cent. Its incidence ranged from 4.8 to 9.2 per cent during 1979-80 to 1985-86. In 1986-97, its population builds up rapidly and the incidence level reached up to 22.00 per cent with 15.3 per cent intensity. But in 1990-91, due to congenial weather condition and severe lodging of the crop, its mean incidence in the state was 23.5 per cent with 15.4 per cent intensity. In most of the sugarcane fields its incidence varied from 7-40 per cent but in some fields, it was more than 50 per cent.

Pal and Singh (2001) studied on the incidence and intensity of the stalk borer (*C. auricilius*) in sugarcane (varieties Co.S.767, Co.7717, Co.S.8436, and Co.J.64) in different sugar mill zones (Sonepat, Karnal, Jind and Yamuna Nagar) in Haryana, India during 1997-98. The highest and lowest mean incidence of stalk borer was 36.59, 38.36, 38.38, and 31.13; and 32.47, 32.67, 29.56, and 20.71% from the Karnal, Sonepat, Yamuna Nagar and Jind mill zones, respectively.

Pandey and Kant (2005) studied on the population build-up of *Chilo auricilius* Dudgeon, in autumn and spring planted plant crops and ratoon of autumn planted crop in relation to maximum and minimum temperatures and relative humidity prevailing during the cropping season of 1999-2001. They observed that the pest remained active from the first fortnight of June till the second fortnight of January. Pest attained its peak activity during second fortnight of November in spring and autumn crops and during the second fortnight of October in ratoon crop. For population build up, an average maximum temperature was observed to decline from 39.30 to 30.30 and average minimum temperature from 26.62 to 14.44^{0}C; a relative humidity around 70.00 per cent appeared to be conducive for population build up. A significant and positive correlation (r ranging from 0.465 to 0.541 for the crops) existed between the pest population and the maximum temperature whereas minimum temperature correlated negatively. A highly significant positive correlation with relative humidity (r ranging from 0.71 to 0.84) clearly showed a major role in pest build up.

Singh *et al.* (2007) determined the correlation between physical parameters of different sugarcane genotypes with the incidence and intensity of stalk borer (*Chilo auricilius*) infestation. Maximum girth of 2.63 cm was observed in Co.H 35, with a borer intensity of 21.1%, and incidence of 76.7%; followed by Co.1148 (23.5 and 89.8%, respectively). The lowest girth (1.62 cm) was observed in genotype UP.5 with an intensity of 4.7% and incidence of 15.0%; followed by Co.LK 8002, Co.P84213, Co.H12, Co.H 8312 and Co.H24 with 1.67, 1.75, 1.78, 1.79 and 1.82 cm girth, respectively.

Chatterjee *et al.* (2007) studied the population dynamics of four different lepidopteran borer pests of sugarcane by using sex pheromone traps and lures at the Sugarcane Research Station, Bethuadahari, Nadia, West Bengal, India during October to March 2004-05 and 2005-06. The catch of adult male moths of early shoot borer (*Chilo infuscatellus*), top shoot borer (*Scirpophaga excerptalis*), internode borer

(*Chilo sacchariphagus*) and stalk borer (*Chilo auricilius*) in separate set of traps revealed species-specific population dynamics for the four borer pests. During 2004-05, the peak population of early shoot borer, top shoot borer, internode borer and stalk borer were observed in the months of November (11.53), November (10.07), November (10.93) and February (9.84), respectively. During 2005-06, the peak population of early shoot borer, top shoot borer, internode borer and stalk borer were observed in the months of February (10.56), December (13.44), March (10.61) and February (11.70), respectively.

2.1.4.a Sugarcane root borer, *Emmalocera depressella* Swinehoe

This species was first recorded in 1885 in sugarcane in India **(Hampson, 1896; Cheema, 1947)**, however, it received attention as a key pest only recently **(Sardana, 1993)**. **Banerjee and Butani (1975)** stated that the *Emmalocera depressella* swinhoe is an indigenous pest confined so far to Indian sub-continent. *E. depressella* is currently considered a major pest of sugarcane in some parts of India and Pakistan **(Sardana, 1993; Singh and Madan, 2001)**.

Sardana (1999) studied *E. depressella* life cycle in Haryana, India and recorded incubation period, pupal stage and adult longevity to require 5-12, 7-18 and 15-18 days at 27°C, respectively. Total life cycle was complete within 54-68 days at 27°C and no development occurred when temperature dropped below 15°C.

Laboratory studies also showed that one female can lay more than 200 eggs under 27°C. Other studies in Karnal recorded an average of up to 270.50 eggs per female in the second generation, and recorded 5 larval instars with larval duration ranging of 27.0-39.8 days **(Singh *et al.,* 1996)**.

A recent outbreak of *E. depressella* was recorded during 2005-2006 in the West Nimar Valley of Madhya Pradesh in Central India **(Das and Vida, 2005)**.

2.1.4.b Nature and Symptoms of damage

Distinguishing characteristics for identifying the root borer dead heart from that caused by other species of borers are given by **Rahman and Singh (1942).** The dead heart cannot be pulled out easily and often, in the process the plant gets pulled out, with the larva either hanging out at the broken end of the shoot or remaining partly inside the underground portion and partly protruding outside. The dead-hearts does not emit any offensive smell and often one or two leaves adjacent to the central leaf whorl also dry up. There is only one entry hold at the base of the shoot.

At harvest, a decrease in yield up to 10 per cent and reduction in sucrose in juice by about 0.3 unit had been observed in U.P. **(Gupta and Avasthy, 1952).** As a result of infestation by the larvae of the first brood, 52 per cent of the shoots affected produce no tillers, 30 per cent produce only one tiller and 18 per cent two tillers **(Cheema, 1953; Tandon, 1957)**

Cheema (1953) observed that the root borer larvae of first brood killed all the attacked shoots and stumps of 52 per cent of such shoots produced no tillers, 30 per cent produced only one tiller each, while 18 per cent put forth 2 tillers each.

According to **Agarwala and Prasad (1954),** losses in weight and sucrose amount to 1.3 and 2.9 per cent, respectively in Bihar.

Gupta and Avasthy (1954) reported that *Emmalocera depressella* infested the crop to the extent of 6-8 per cent in Bihar. They also recorded that the larvae of the first brood attacked the crop plant in April-May. The infestation increased during the second and third broods in July, August and September.

Sulaiman (1954) observed in his study that root borer *Emmalocera depressella* started its activities in March and goes on increasing in number until July. From August it started decreasing during the months of September and October is disappeared altogether

Butani (1961) reported that the *Emmalocera depressella* swinhoe preferred dry and hot weather and was tolerant to rains up to certain extent (about 18 inches). After which its population declined. The most active period was from May to September.

Alagesan *et al.* (1991) reported that *Emmalocera depressella* [*Polyocha depressella*] is recorded damaging the roots of sugarcane in Tamil Nadu, India, for the first time. In a ratoon crop observed in December 1989, nearly 30% of clumps were infested, and of the 4-5 tillers/clump only 1 or 2 were millable: the rest dried up. Of 3 varieties studied, infestation occurred mainly on Co. 8021 and Co. 7704; Co. 671 was somewhat less affected. Infestation was most pronounced on light soils in drought-prone areas, and in plots planted and ratooned in March-May.

Hashmi (1994) reported that root borer larvae bore in to stem below the soil surface. The central leave of attacked plant dry up caused “dead-heart” before the cane forming stage. The “dead-heart” is not easily pulled out. It is the major pest of the sugarcane infestation can exceed 10-20 per cent.

Plants infested with *E. depressella* suffer dead hearts and general yellowing of the leaves. Infestation also results in poor tillering in mature plants **(Bhatt *et al.,* 1996)**.

The root borer (*Emmalocera depresella)* disconnects the conducting tissues of the root from the soil due to which the plant die. It also paves way for Ratoon Stunning Disease (RSD).Plants infested with *E. depressella* suffer dead hearts and general yellowing of the leaves and may result in poor tillering in mature plants **(Gul, 2007).**

2.1.4.c Seasonal incidence

Sardana (1997) studied the seasonal patterns of *Emmalocera depressella* [*Polyocha depressella*] in the early sugarcane cultivar 'Co 89003' during 1992-93 in India. Results showed that pyralid incidence was significantly negatively correlated (r=-0.531) with maximum temperature and positively correlated (r=0.580) with relative humidity. The seasonal index based on a time series showed that the maximum temperature ranging from 31 to 34°C and relative humidity (RH) from 48.2 to 78.4% during July/August were congenial for multiplication of the pyralid which was observed to peak during Aug-Oct. Populations of the pest remained low during May-June.

Singh and Madan (2001) conducted an experiment in which Ninety-three sugarcane genotypes were tested against root borer, *Emmalocera depressella [Polyocha depressella],* in Karnal, Haryana, India, during 1997-98 and 2000-01. The highest incidence of root borer was 90.90% (1997-98) in CoS 88230, 40.00% (1998-99) in CoP 94211, 51.86% (1999-2000) in CoS 95222 and 80.00% (2000-01) in CoP 96219. This indicated that the attack of root borer during post monsoon depends upon the climatic conditions during the monsoon/summer months.

Table 2.1: Damage symptoms caused by different sugarcane borers

Name of the borer	Stage(s) of the crop	Crop damage on the basis of which observation of infested plants were taken
Stalk borer		
Chilo auricilius Dudgeon (Lepidoptera: Crambidae)	Shoot stage	Deadhearts of spindle 2^{nd} and 3^{rd} leaves
	Tillering stage	Presence of deadhearts, that can only be pulled with some strength
	Cane stage	More number of nearly rounded holes on internode
Shoot borer		
Chilo infuscatellus Snellen (Lepidoptera: Crambidae)	Shoot stage	Complete drying of germinating shoots
	Tillering stage	Presence of deadhearts; One or many borer holes and/or puncture holes on leaf sheath; old deadhearts were rotten and become fibrous; deadhearts with offensive smell.
Root borer		
Emmalocera depressella Swinehoe (Lepidoptera: Crambidae)	Germination stage	Shoot dries up completely; Generally three borer holes on leaf sheath of underground portion of seedling.
	Tillering stage	Nearly semicircular cut on under ground leaf sheath; deadhearts of spindle alongwith 2^{nd} and 3^{rd} leaves and in some plant 4^{th} leaf dried.
	Grand growth stage,	Deadhearts can be pulled only by applying strength; the broken end of deadhearts showed round shape.
	Shoot, tillering and grand growth stage	Leaves of clump showed yellowing and poor growth performance.
Top borer		
Scirpophaga nivella Fabricius (Lepidoptera: Pyralidae)	Cane stage	Presence of shot holes on leaves; mined midrib and severely damaged leaf whorl; Presence of exit holes. Presence of only apical buds without whorl leaves at grand growth stage.
	Shoot stage	Presence of bunchy top.
	Tillering stage	Deadhearts; plenty of wet frass near the hole immediately above the soil surface.
Pink borer		
Sesamia inferens Walker (Lepidoptera: Noctuidae)	Cane stage	Plenty of wet frass on inner side of leaf sheath; horizontal tunneling of internode area; length of tunnel generally shorter than other borers; yellowing of plant above the bored portion.
Internode borer		
Chilo sacchariphagus Indicus Kapur (Lepidoptera: Crambidae)	Grand growth and Cane stage	Nearly rectangular bore hole; length of tunnel shorter than other borers; Plenty of wet frass on inside of leaf sheath; presence of dried frass innerside of the leaf sheath during January; damaged eye buds at late cane stage.
Gurdaspur borer		
Acigona steniellus Hampson (Lepidoptera: Crambidae)	Grand growth and	Presence of white streaks on leaf whorl; presence of plenty of wet frass on leaf sheath;
	Cane stage	Leaf whorl yellowed; breaking of plant horizontally at injury point. Presence of entrance holes on sheathless internode portion or on eye bud during the gregarious phase of pest; spiral fashioned incisions on internode portion.

Source: Rai, A. K., PhD thesis (1997) submitted to G.B. Pant University of Agriculture and Technology, Pantnagar.

Two light traps fitted with a 20-watt tube rod were installed in one-acre sugarcane area to study the population dynamics of sugarcane root borer in Haryana, India during 1998-2000 **(Sardana, 2001).** The emergence and the activity of root borer adults were observed from April to November with population peak recorded in the second fortnight of April. There were four peaks of adult moth catch showing the four broods of root borer in a year. After a large emergence during April, incidence of root borer remained low during the pre-monsoon period of May to June. For both years, the incidence in the field with installed light traps was consistently lower compared to that in the field without light traps. The incidence peaked in October to November in both fields. The difference in the fields varied from 1.0% (in January and March) to 17.1% (in November) during 1998-99, and from 0.7% (in April) to 12.1% (in November) during 1999-2000.

A field trial was conducted by **Bhatti *et al.* (2008)** to investigate the incidence and intensity of borer complex infestation on different sugarcane genotypes at National Sugar Crops Research Institute, Pakistan during the year 2005-06. They found that the root borer appeared during the month of the April and maximum infestation of 10.21 per cent was caused during August followed by September, June, July, October, May and April with average damage of 8.25, 7.91, 7.74, 6.38, 3.82 and 1.36 per cent, respectively.

2.1.5.a Sugarcane black bug, *Cavelerius sweeti* Slater

Verma (1983) reported that the black bug (*Cavelerius excavatus* Distant) was the major pest of ratoon. Vast area of sugarcane ratoon in central and western U.P., Haryana and Punjab suffered due to black bug infestation.

Cavelerius sweeti was considered as a minor pest till it appeared in an epidemic form in Punjab during 1930. The ratoon crops of hybrid canes had considerably increased the incidence of this pest **(Agarwal and Siddiqi, 1964).**

During summer eggs are laid in clusters on the inner surface of leaf sheath bases which are arranged in linear fashion in groups of 60-70. Individual egg of black bug is small, about 1.25 mm long, cigar shaped, creamy white or brownish when freshly laid but turns reddish 3-4 days after their deposition. The number of eggs laid by a female varies from 55-475 in Punjab **(Khan and Nath, 1939)**, 28-108 during summer in Bihar **(Pandey, 1975)** and 166 eggs at 33ºC **(Atwal and Singh, 1971).**

Amongst sucking insect pests, four species of black bugs, namely, *Cavelerious sweeti* Slater and Mogomoto, *Cavelerius excavatus* (Distant) and *Dimorphopterus gibbus* (Fabricius) are supposed to be associated with sugarcane crop in India but only one of them *viz., C. sweeti* has been studied in greater details as these are commonly found in different cane growing tracts of India **(Chaudhary, 2008).**

As per a survey report of Haryana and Punjab, black bug is not a pest of ratoon crops only but it causes severe damage to the all types of crops *viz*., planted as well as ratoon crops **(Pandey and Chhabra, 2012)**

2.1.5.b Nature and Symptoms of damage

Khan and Nath (1939) observed that the damage of the pest occurs in the early stage of the crop growth, it is difficult to estimate the actual losses caused by it. However, in the severely infested crops, the quality of gur is adversely affected. Depending upon the degree of infestation and crop conditions, the fall in yield due to black bug attack varies from 1-5 tones per hectare **(Pandey, 1975).**

The nymphs and adults were found in the leaf whorls and under the leaf sheath. **Gupta and Avasthy (1954)** observed that both nymphs and adults suck the sap resulting in stunting of ratoon crops.

Yadav (2003) reported that the number of nymphs and adults varying from few to 200 per stool suck the leaf sap, due to which growth of plant is considerably retarded. The leaves of the infested plants become pale and individual leaves show deep brown spots. The tips and the margins of the leaves started drying-up gradually. In severe cases the whole plant withers. The plant finally gives scorched appearance which can be spotted from a long distance.

According to **Zada *et al.* (2013)** both adults and Nymphs of black bug cause damage by sucking cell sap from the plants. The leaves of the affected plants turn yellow with brown patches. The growth of the plant and quality of the juice is adversely affected. Adult black bugs are highly mobile and heavy populations may quickly invade the sugarcane fields. Attack of seedling plants reduced plant growth significantly after one or more days of feeding. Damage was characterized by desiccation of leaves and plant death. Sugarcane black bug attack newly emerged plants and significantly retarded growth by sucking cell sap from the stem and leaves.

2.1.5.c Seasonal incidence

Singh and Sharma (1967) reported that among other pests of sugarcane, the black bug attacked the ratoon crop during the hot weather season i.e. April to June. The incidence declined with the onset of rains. The pest was found throughout the states so far it was serious in the western districts of U.P. only. An outbreak of this pest had been reported in Punjab **(Bains and Dhaliwal, 1983)**.

Singh (1983) reported that the black bugs of sugarcane, chiefly affected the ratoon crop particularly during summer at 100-110 F with relative humidity 30-40 per cent. During monsoon, the population came down considerably.

Mathur and Prakash (1989) made an attempt to find out relationship between the incidence of Lygaeid bug and varietal characteristics of sugarcane. They found that one of the most prominent morphological characteristics was the sheathing leaf bases. The varieties having broad sheathing leaf bases and loose leaf sheaths were most preferred varieties as it provide better hiding place for the bugs. They also studied the behavior of Lygaeid bug. The bugs during day time remained in groups below the loose basal leaf sheaths of the mature canes up to the height of 2-3 feet and in loose leaf sheaths of new shoots but at night they migrated to the upper tender shoots for feeding. The highest population of the bugs in field was observed during May when conditions were hot and dry. Heavy rains from late June to August resulted in an abrupt decline in its population which might be due to drowning.

Karnatak *et al.* (2000) studied the population dynamics of sugarcane black bug, *Cavelerius sweeti* on sugarcane (cv CoPant 90223) during 2000 at Pantnagar, Uttar Pradesh, India. The nymphal population was found from March and reached its peak in July-August. Both nymphal and adult stage was found in July-August, which causes more damage. After mid-August, the population started declining. Hence, its management practice should be adopted before it reaches its peak period. As it sucks the sap from the under surface of leaves and remains from dusk to dawn hidden in the leaf whorl, the management must be planned accordingly.

2.2 Termite (Insecta: Isoptera) species composition

The earliest recorded scientific observations were made by **Konig (1779)** who described a termite species from Thanjavur of South India. This termite species was referred to as *Termes jatalis* but later it was named *Odontotetmes redemanni* by **Wasmann (1893)**. Until the end of the 19th century only 16 species of termites were known from the Indian region. A comprehensive review of various termite species was presented by **Chhotani (1977)** who identified three episodes. Each of a quarter of a century during which termite classification was undertaken:

1) 96 species belonging to 28genera were described during the first quarter (1901-1925).
2) 46 species belonging to 16genera in the second quarter (1926-1950),
3) 134 species belonging to 15genera in the third quarter (1951- 1975).

Roonwal (1970) reported that six subfamilies, Coptotermtttnae. Heterotermitinae, Psammotermitinae, Termitogetontnae, Stylotermitinae and Rhinoterminitinae are found in the Indian region. Out of two genera viz., *Heterotermes* and *Reticulitermes* of the Heterotermitinae, the former occurs in all the tropical and subtropical regions. *H. indicola* is primarily tropical in its distribution, but also found very commonly in temperate areas of the sub-Himalayan regions, up to elevations of 1980m.

Chhotani (1980) reported that families or subfamilies other than the Termitidae such as Kalotermitidae. Rhinotermitidae and Stylotermitinae contain species of importance to agriculture and forestry in India.

Termites are distributed throughout the tropical and subtropical regions of India, although the tropical regions harbor more species than the subtropical parts of the country. **Rajagopal (1983)** studied the habitats and distribution of 26 species from different agroclimatic regions of Karnataka.

Ninety-five termite species belonging to 33 genera under 5 families were recorded by **Bose (1984).** Of these 18 species belong to the Kalotermttidae, one species each to the Hodotermitidae and Stylotermitinae, 5 species to the Rhinotermitidae and 70 species to the Termitidae. The family Termitidae includes nearly 75% of the known species of Indian termites.

Among all the eusocial insects which live in complex societies, few occupy such an important position and yet remain as poorly studied as the termites **(Crozier and Pamilo 1996; Thorne *et al.,* 1999)**.Termites are perhaps the insects most closely associated with humans over the longest period, mainly because they attack agricultural crops, forest trees and wooden structures. In India the annual loss due to termites for agricultural crops alone amounts to several millions of rupees. About 10-25 per cent loss is estimated in most field and forest crops. Severe loss in different regions of India has been recorded on highly susceptible crops such as wheat and sugarcane in northern India, maize, groundnuts, sunflower and sugarcane in southern India, tea in north eastern India and cotton in western India. Apart from field crop termites are known to damage forest plantation trees such as *Eucalyptus,* Silver oak, *Casuarina* and all kinds of timber in buildings. In addition they feed on a variety of organic matter such as dung, manure, leaf litter and root stubble. Termites also play an important role in depleting soil fertility.

Rajagopal (2002) stated that out of 300 species of termites known so far from India, about 35 species have been reported as damaging agricultural crops and timber in buildings. The majority of the pest species are soil inhabiting, either as mound builders or as subterranean nest builders. The major mound building species are *Odontotermes obesus, O. redemanni* and *O. wallonensis.* The major subterranean species are *Heterotermes indicola, Coptotermes ceylonicus, C. heimi; Odontotermes homi, Microtermes obesi, Trinervitermes biformis* and *Microcerotermes beesoni.*

Thakur *et al.* (2009) reported fifteen species of termites belonging to four families (Termopsidae, Kalotermitidae, Stylotermitidae and Termitidae) and 9 genera (*Archotermopsis*, *Neotermes*, *Glypotermes*, *Bifiditermes*, *Stylotermes*, *Eremotermes*, *Microcerotermes*, *Angulitermes* and *Odontotermes*) from Kumaon Hills. Four species are reported first time from Kumaon, Uttarakhand as new distributional records: *Eremotermes paradoxalis* Holmgren; *Microcerotermes tenuignathus* Holmgren; *Angulitermes akhorisainesis* Chatterjee and Thakur and *Odontotermes wallonensis* (Wasmann).

Rajagopal (2002) reported that *Odontotermes* represents the most dominant genus of Indian termites with over 40 species. The species of *Odontotermes* have been reported as economically important in India (table 2.2).

Table 2.2: Economically important *Odontotermes* species in India

Termite Species	State where termite species prevalent
O. assmuthi Holmg	Punjab, Bihar, Maharashtra, Tamil Nadu, Kamataka
O. brunneus (Hagen)	Tamil Nadu, Kamataka, Andhra Pradesh
O. brunneus brunneus Hagen	West Bengal, Maharashtra, Tamil Nadu
O. brunneus kushwahai Roonwal & Bose	Rajasthan, Gujarat and Tamil Nadu
O. ceylonicus Wasmann	Karnataka
O. feae (Wasmann)	West Bengal
O. tormosanus (Shiraki)	East India
O. hoi Wasmann	Tamil Nadu, Kamataka
O. microdentatus Roonwal & Sen-Sarma	Uttar Pradesh, Bihar
O. obesus (Rambur)	All parts of India except temperate region
O. parcidens Holmg. and Holmg.	Assam, Maharashtra
O. redemanni (Wasmann)	Bihar, West Bengal, Kamataka, Andhra Pradesh, Maharashtra, Rajasthan, Kerala, Tamil Nadu
O. wallonensis (Wasmann)	Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra

2.3 Bio-efficacy of insecticides

Thompson *et al.* (1995) reported that Spinosyns and Spinosads are inherently broad spectrum, showing activity against insects in the orders Coleoptera, Diptera, Homoptera, Hymenoptera, Isoptera, Orthoptera, Lepidoptera, Siphonaptera and Thysanoptera, as well as mites.

Spinosyns and Spinosoides have some broad spectrum activity and their efficacy has been reported against some other insects in the orders of Coleoptera, Diptera, Homoptera, Hymenoptera, Isoptera, Orthoptera, Siphonaptera, as well as mites (**Salgado, 1998**).

Efficacy of Chlorpyriphos 10 G as soil treatment @ 0.50, 0.75 and 1.00 g a.i./ha and Chlorpyriphos 20 EC as seed dressing @12.5 ml/kg of groundnut seed were tested against termites along with Phorate 10 G @ 1.00 kg a.i./ha, also applied to the soil in the furrows at sowing during the kharif seasons of 1996-97 at Mahispat. The results revealed that the per cent plant damage was significantly less with Chlorpyriphos 20EC seed dressing and Phorate l0G soil applications. The per cent pod infestation at harvest was significantly lowest with Chlorpyriphos 20EC seed dressing and Chlorpyriphos 10 G soil applications @ 1.00 kg a.i./ha. But the pod yield was significantly higher with Chlorpyriphos 10 G @ 1.00 kg a.i./ha, Chlorpyriphos 20EC as seed dressing and Phorate 10G @ 1.00 kg a.i./ha since seed dressing with Chlorpyriphos 20EC @ 12.5ml/kg of seed had the lowest plant damage, per cent pod infestation and highest pod yield, it was adjudged as the best treatment. Nevertheless, soil applications of Chlorpyriphos 10 G and Phorate 10 G were at par with Chlorpyriphos seed dressing in termite control and pod yield **(Mishra, 1999).**

Singh and Singh (2001) conducted field experiments at three different locations of district Shahjahanpur, UP, India during 1995-96 and 1996-97 to determine the effects of insecticide treatments (applied for termite control) on yield contributing characters of sugarcane. It was evident from the results that sett treatment with 0.20% solution of Gaucho 70 WS, soil treatment with Phorate 10G @ 2.50 kg ai/ha, Chlorpyrifos 15G @ 2.50 kg ai/ha and Chlorpyrifos 20 EC @ 1.00 kg ai/ha were the best in controlling the termite infestation and hence promoting the sugarcane yield contribution characters *viz.*, number of shoots, millable canes, stalk height and diameter.

Imidacloprid 70 WS and Imidacloprid 200 SL were evaluated for their efficacy against termites in sugarcane as sett dip and spray over setts in furrows in two field experiments. Setts dip of Imidacloprid 70 WS at 0.1 and 0.15 per cent and spray over setts of Imidacloprid 200 SL at 250 and 375 ml/ha resulted in increased germination of setts. These treatments protected the crop from termite damage and were equal to Chlorpyrifos 20 EC at 5 lit./ ha in the efficacy. They also resulted in increased cane yield. There was no effect on the quality of juice and the residue was at below detectable limit in juice at harvest in these treatments **(Santharam *et al.*, 2002).**

Singh *et al.* (2006) conducted an experiment at the farm of Sugarcane Research Institute, Shahjahanpur during 2001 to 2003 to find out effective and economical dose of Fipronil 0.3% G (Regent 0.3 G) and Imidacioprid 17.8% SL (Confidor 200 SL) for the control of termites in sugarcane. The results revealed that soil application of Fipronil 0.3% G (Regent 0.3 G) @ 20.0 kg/ha and Imidacioprid 17.8% SL (Confidor 200 SL) @ 400 ml/ha diluted hi 1875 lit of water were found at par with each other. These treatments were also found at par to treated control (soil application of Sevidol 4 G @ 25.0 kg/ha and Lindane 6 G @ 20.0 kg/ha) and significantly superior to ($P = >0.05$) to the untreated control in reducing the termite infestation to cane setts, sett ends and sett buds and enhancing the cane yield.

Ahmed *et al.* (2006) reported that Chlorpyrifos gave control of the termites' population after 15, 45, 60, 75 days of application on setts and significantly reduced the termites as compared to Imidacloprid and Monomehypo. Results were non-significant and had no effect of any treatment after 30 days. Similarly the termites' population on the sett was also very low in the plots treated with Chlorpyrifos as compared to Imidacloprid and Monomehypo. Sugarcane eyes damaged were non-significant, whereas the effect was significant, among the treatments, on seedlings damaged by termites in the sugarcane field.

Singh *et al.* (2010) conducted an experiment to find out the bio-efficacy of chemical insecticides and bio-pesticides for effective management of termites. All the treatments with chemical insecticide i.e., Fipronil 0.3% G @ 25 kg/ha was found best with minimum bud damage of 0.00 & 1.25, cut ends damage of 4.44 & 3.68 and cane setts damage of 4.45 & 3.15 per cent and maximum germination of 45.50 and 46.45 per cent during kharif 2006 and kharif 2007 respectively. This treatment was also recorded best with maximum yield of 78.25 and 76.62 q/ha during kharif 2006 and kharif 2007, respectively.

Iqbal and Saeed (2013) evaluated the toxicities of six new chemical insecticides to determine the lethal concentration (LC_{50}) against *M. mycophagus* collected from four locations (tree plantation, untreated building, treated building, agriculture area) of Multan, Pakistan. The population collected from agricultural area was more tolerant to all insecticides compared to those of other three locations. The order of average toxicity of insecticides from highest to lowest was: Chlorfenapyr > Spinosad > Thiamethoxam > Fipronil > Indoxacarb > Imidacloprid.

2.4 Laboratory evaluation of insecticide

Su *et al.* (1987) described a method to examine time trends in mortality of the formosan subterranean termite, *Coptotermes formosanus* Shiraki, exposed to insecticides. Slow-acting toxicants required a longer time to kill termites at low concentrations than at high concentrations. The level of mortality and the speed of death were dependent on concentration. With acute toxicants, the time required to kill termites was similar at high or low concentrations, while the mortality levels were concentration-dependent.

Premlatha *et al.* (2008) conducted a mortality test under laboratory condition to know the efficacy of some of the insecticides against *Odontotermes wallonensis* (Wasmann). The insecticides used were Chlorpyriphos, Imidacloprid, Endosulfan, Lindane, Lambdacyhalothrin and Profenofos. The results showed that the LC_{50} value was minimum (1.48 ppm) in Lambdacyhalothrin followed by Imidacloprid (2.79 ppm). The maximum LC_{50} value was observed in Endosulfan (7.84 ppm).

Using both topical application and substrate (sand) treatments the toxicities of seven new generation soil termiticides were evaluated to determine the LD50 and LC50 against two economically important subterranean termite species, eastern subterranean termite, *Reticulitermes flavipes* (Kollar), and Formosan subterranean termite, *Coptotermes formosanus* Shiraki. The lethal dose toxicity (LD50) rankings for *R. flavipes* from highest to lowest were: Fipronil > Bifenthrin > Chlorantraniliprole > Cyantraniliprole > Imidacloprid > Chlorfenapyr > Indoxacarb; the rankings for *C. formosanus* were Fipronil > Imidacloprid > Chlorantraniliprole >

Cyanthraniliprole> Bifenthrin > Chlorfenapyr > Indoxacarb. The respective lethal concentration toxicity (LC_{50}) rankings were Fipronil > Bifenthrin > Chlorfenapyr > Indoxacarb > Cyantraniliprole > Chlorantraniliprole > Imidacloprid for *R. flavipes*; and Fipronil > Chlorfenapyr > Bifenthrin > Imidacloprid > Cyantraniliprole > Chlorantraniliprole > Indoxacarb for *C. formosanus*. The study provided an opportunity to directly compare toxicity, action speed, and bioavailability among the group of newer generation soil termiticides **(Mao *et al.,* 2011).**

Manzoor *et al.* (2012) evaluated four Insecticides Imidacloprid, Chlorfenapyr, Bifenthrin, and Fipronil at concentrations 1.56, 3.125, 6.25, 12.50, 25, 50, 100 ppm and Cadusafos at concentrations 0.098, 0.195, 0.391, 0.781, 1.562, 3.125 and 6.25 ppm were used to explore the feasibility of controlling the *H. indicola,* the toxicities and repellencies of these chemicals to the workers termites in laboratory. The LC50 values for *H. indicola* were 346.75, 75.86, 14.45, 1.05 and 0.46 for Imidacloprid, Chlorfenapyr, Fipronil, Bifenthrin, and Cadusafos, respectively after 8 hrs exposure and corresponding values after one month exposure the values were 1230.27, 190.5, 28.18, 10.47 and 2.51, respectively. Results revealed that Chlorfenapyr was non-repellent and Fipronil was repellent only above 25ppm and Bifenthrin was repellent at all tested concentrations.

Rashid *et al.* (2012) evaluated the toxicity of five insecticides including Agenda EC 25 (Fipronil), Consult EC 100 (Hexaflumuron), Admiral EC 100 (Pyriproxyfen), Confidor SC 350 (Imidacloprid), Reldan EC 400 (Chlorpyrifos methyl) against *A. vilis*. To determine LC_{50} of the insecticides, bioassay was carried out on worker termites of *A. vilis*. The LC_{50} values for Fipronil, Pyriproxyfen, Hexaflumuron, Imidacloprid and Chlorpyrifos methyl were 3.48, 9.56, 32.02, 2.02 and 0.09 ppm, respectively. The LT_{50} value of Pyriproxyfen was shorter than Hexaflumuron. The results showed that Fipronil and Imidacloprid were respectively the most effective insecticides for a short term control of the termite.

2.5 Use of Baiting System against termite

Su *et al.* (1995) reported baiting systems, the first of which was marketed for termite control, contain a slow-acting toxicant incorporated into a cellulose matrix. Commercial prototype monitoring or baiting stations were used to detect, bait, and eliminate field populations of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), near structures. Because of the durable plastic housing, the station can be used by pest control professionals for on-going monitoring and baiting programs to provide continuous protection of structures from subterranean termites.

Soil insecticide barriers have been the single most important tool for subterranean termite control in the last half century, but limitations with current soil termiticides have provided the impetus to look for alternatives in recent years. One such alternative is the monitoring-baiting programme. Monitoring stations to detect termites are paced in the soil surrounding a structure. Once termites are found in the stations, monitoring devices are replaced with slow-acting baits such as chitin synthesis inhibitor, Hexaflumuron **(Su and Scheffrahn, 1998).** However, in order for baiting to work successfully, termites must find and consume the bait matrix and for the toxicant contained therein to be transferred back to the nest **(Evans and Gleeson, 2006).**

Grace and Su (2001) reported that the development of baits using chitin synthesis inhibitors has transformed control practices, although large quantities of liquid termiticides are still used in urban pest management **(Su and Scheffrahn, 1998; Su, 2005).** Considering the environmental impact of such practices, there is a need to evaluate non-chemical methods of termite control as an alternative for structural protection **(Milner and Staples, 1996; Grace, 1997; Culliney and Grace 2000; Verma *et al*., 2009).**

Eger *et al.* (2010) conducted one hundred trials (trial sites) in 2007-2009 under a protocol approved by the Termiticide Scientific Review Panel. The protocol was designed to evaluate the performance of Recruit High Density (HD) durable bait for control of subterranean termites.

Monitoring stations were installed at test structures according to label directions for Recruit IV termite bait. A similar number of additional stations were installed between the monitoring stations. Recruit HD bait, containing 0.5% Noviflumuron and weighing about 150 grams, was installed into each of these additional stations. Although stations were monitored quarterly in this study for data collection purposes, Recruit HD baits were only replenished after one year of baiting and if the bait was depleted by more than one third. Recruit HD baits hit by termites are expected to be monitored and replenished as necessary at intervals up to about 1 year enabling an annual service and monitoring concept for commercial use. Termites were eliminated at all of these structures. Elimination of structural infestation or termite activity within 1 yr or less was achieved in 94.0% of these structures. The percentage of installed baits that were consumed by termites prior to elimination was 33.3% or less in all cases, leaving 66.7% or more of the total bait installed.

2.5.1 Assessment of Sentricon Colony Elimination System

Su (1994) reported a baiting procedure that incorporated a matrix containing a chitin synthesis inhibitor, Hexaflumuron, that was evaluated against field colonies of the eastern subterranean termite, *Reticulitermes fiavipes* (Kollar), and the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. Wooden stakes were first driven into the soil to detect the presence of termites. Bait tubes were placed in soil where termites were detected. A *self-recruiting* procedure, in which termites collected from wooden stakes were forced to tunnel through the matrix in the bait tubes, significantly increased bait intake by termites. Approximately 4-1,500 mg of Hexaflumuron was needed for 90-100% reduction of field populations containing 0.17-2.8 million foragers per colony.

Getty *et al.* (2000) conducted an experiment in which colonies of *Reticulitermes* spp. were baited with prototype and commercial Sentricon stations (Dow AgroSciences LLC, Indianapolis, IN) to test the efficacy of Hexaflumuron in different concentrations and bait matrices and to document reinvasion of the foraging territories vacated by eliminated colonies. The monitoring stations of a colony were devoid of termites 406 d after baiting with one Sentricon station, but became reoccupied with the same species of termites 6month after baiting. A colony at the residential site was baited with 0.5% Hexaflumuron in the Recurit II bait matrix; 60 days later termites were absent from all monitoring stations. These monitoring stations remained unoccupied for more than18 months. Foraging *Reticulitermes* spp. appeared in three of the seven monitoring stations 18, 24, and 36 month after baiting, respectively. Using cuticular hydrocarbon analyses and agonistic behavior studies, it was determined that the *Reticulitermes* spp. occupying these monitoring stations were from three different colonies; none were members of the original colony destroyed by baiting. Another colony at the residential site was baited using a noncommercial, experimental bait; 52 d later termites were absent from all monitoring stations. The monitoring stations remained unoccupied for more than 9 months.

Prabhakaran (2001) conducted an experiment in which five eastern subterranean termite colonies (*Reticulitermes flavipes* (Kollar)) were characterized using a triple mark recapture procedure around five structures at the University of Iowa, Iowa City, IA. The estimated foraging populations ranged from 720,000 to 2,162,000 individuals occupying an estimated foraging territory of between 91.04m^2 to 891. 90m^2. *Sentricon Termite Colony Elimination System* stations (In-ground, Dow AgroSciences LLC, Indianapolis, IN)were installed within the foraging area of 4 sites and the populations were baited with Recruit II (Dow AgroSciences LLC, Indianapolis, IN) termite bait containing 0.5% Hexaflumuron. These termite colonies were eliminated after consumption of 112.6g to 571.2g of bait matrix over a period of 3 to 11 months. Continuous monitoring and follow up baiting in the spring was needed to eliminate larger termite populations. At the remaining site, a single colony was eliminated using above ground bait placement alone. This population consumed 348.7g of bait matrix and required 15 months to eliminate all termite activity. The results demonstrate successful colony elimination if monitoring-baiting-monitoring procedures are followed carefully.

Lee (2002) reported that *Coptotennes travians* (Haviland) is one of the most important subterranean termite pest species attacking urban buildings and structures in Malaysia. Two colonies of C. *travians* infesting residential premises (Colony A & B), and another one in a natural habitat (Colony C) were characterized for experiment. Foraging territories ranged between 125 - 384 m^2, with maximum foraging distances of 17 - 32 m per colony. At pre-baiting, mean wood consumption were recorded at 526.4 g per month 478.2 g per month and 643.7 g per month for colony A, B and C, respectively. Colony size ranged between 3.2 x 10^5 to 1.3 X 10^6 workers. Baiting against colony A and B was done using both in-ground and above-ground Hexaflumuron baits, while only in-ground baiting was executed against colony C. The baits caused a substantial reduction in wood consumption rate in independent monitoring stations within 34 - 44 days post-baiting. At this stage, more soldiers were observed with a small number of workers. No termite activity was visible in the independent monitoring stations, as well as the bait stations at 49, 55 and 62 days post-baiting for colony C, A and B, respectively.

In 2003, **Jones** stated that a major challenge to termite baiting in soil habitats is the prolonged time that it may take for subterranean termites (Isoptera: Rhinotermitidae) to infest stations. He studied to determine whether the location of food sources (Sentricon in-ground monitoring stations and wooden monitors) influences the likelihood of infestation by termites. In field trials conducted at 15 structures in central Ohio, standard placement of stations at 3-4.5 m intervals was compared with targeted placements based on evidence of termite activity indoors and outdoors as well as conducive moisture conditions. Termites infested significantly more targeted placements (70/374) than standard placements (35/372) around structures. At the targeted placement sites, termites infested more wooden monitors than Sentricon stations, but this was not statistically significant. This implies that placement, rather than cellulose composition, was the more important factor. Termites first infested stations/monitors an average of 38 days sooner at targeted sites than standard placement sites. This research indicates that evidence of termite activity indoors and outdoors should be a prime consideration when placing in-ground stations.

Sajap *et al.* (2002) evaluated an above-ground baiting system using bait matrix containing 0.5% Hexaflumuron (Recruit™ AG) for its effectiveness for controlling colonies of *Coptotermes travians* infesting buildings and houses in Selangor, Peninsular Malaysia. Six sites with actively foraging termites were selected for the study. The stations were installed over active infestations of the termite and examined biweekly. Foraging activities of the termite were assessed by monitoring the consumption of the bait matrices in the stations. The result shows that C. *travians* did not detect the presence of toxicant in the baits. They continued to feed on the baits regardless the content of the matrix and eventually ceased feeding 35 - 62 days after baiting had commenced. These colonies consumed 30.5 - 217 g of bait matrix or 152.5 to 1085.0 mg of Hexaflumuron.

In 2009, eight colonies of *Coptotermes gestroi* detected, six were estimated for population size using dyed blank bait before treatment. Then, the colonies were treated with Hexaflurnuron-PTC (Preferred Textured Cellulose) baits. Bait consumption and days to colony elimination were estimated. All of the eight colonies were eliminated between 42-77 days (mean = 60 days) with estimated bait consumption of 22.93-167.00 g (mean = 60.17 g) which is equivalent to 114-835 mg of hexaflumuron. A *Schedorhinotermes* sp. colony appeared in one of the sites within two months after the elimination of C. *gestroi.* The *Schedorhinotermes* colony was baited with Hexaflumuron- PTC bait and eliminated after 59 days with an estimated 48.85 g of bait consumed while, the effect of PTC bait on *Coptotermes* sp. showed no difference from that of Laminated Textured Cellulose (LTC) matrices, the PTC matrices showed increased palatability to other termite species such as *Schedorhinotermes* and *Microtermes pakistanicus* **(Sajap *et al*., 2009).**

Materials and Methods

The experimental methods used and procedures followed during the course of investigation are being described below under the following heads and subheads:

3.1 Experimental Site

The experiments were conducted at the Norman E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar (Uttarakhand) India, during the period 2013-14 while the experiment on household ecosystem were conducted at selected structures within University Campus during 2013-14. Geographically, this place is situated at 29^0 North latitude and 79.3^0 East longitudes and at an altitude of 243.8 meters above the mean sea level in the "*Tarai*" region of the foot hills of "Shivalik" range of the Himalayas in the state of Uttarakhand in Northern India.

3.2 General meteorological information

Pantnagar fall in the sub-humid and sub-tropical climate zone. The meteorological data indicate that the humid climate here is characterized by hot dry summer and cold winter with adequate rainfall. The temperature rises up to 40^0C in summer, while it falls to 2-10^0C in winter. The May is usually the hottest and January is the coolest of all months. The south-west monsoon normally brings rain from third week of June and continues up to September. Approximately, 1400 mm mean rainfall has been recorded and relative humidity fluctuates around 90±5 per cent during rainy season.

Mean monthly weather parameters prevailing in the course of investigation were recorded from the Meteorological Observatory of Pantnagar and are presented in Appendix I and II.

3.3 Details of the field experiment

Sugarcane crop was raised as per recommended agronomic practices. Similar cultural practices were followed in all the experimental plots except specific treatment applied to experimental plot. The field Experimentation was carried out as per following details:

Crop	:	Sugarcane
Variety	:	CoPant 97222
Design	:	Randomized block design
Treatments	:	6
Replications	:	4
Plot size	:	8 ×5 m^2
Total No. of Plots	:	18
Number of rows per plot	:	6
Row to row distance	:	90 cm
Planting material	:	3 budded setts, 4 setts/meter
Date of sowing	:	20 March, 2013
Date of harvesting	:	15 March, 2014

3.3.1 Agronomic Practices

3.3.1.1 Land preparation

The crop field was ploughed at the depth of 50-60 cm with tractor drawn disc plough followed by harrowing. Thereafter, levelling is done to ensure uniform irrigation and proper drainage in the third week of March.

3.3.1.2 Fertilizer Schedule

At the time of sowing, basal dose of N_2 and P_2O_5 was applied in furrows as DAP (Diammonium Phosphate) at the rate of 100 kg/ha.

3.3.1.3 Sowing

The healthy canes, variety CoPant 97222 of 10 to 11 months old with 4-5 setts per cane were selected. Detrashing of the cane is done with hand at the time of sett preparation. Three-budded setts were prepared and planting is done in furrows.

3.3.1.4 Intercultural operation

Two hand weeding at 45 and 60 days after planting were sufficient to keep the field weed free.

3.4 Survey and surveillance of major insect species associated with Sugarcane during 2013-14

Systematic survey was taken to assess the diversity of major insect pest population of Sugarcane at C. R. C. Pantnagar. The observations were made at weekly intervals, starting from the first week of May, 2013 onwards till harvest of the crop (March, 2014). The incidence of insect pests was recorded on the basis of nature of damage caused by each pest and the symptoms expressed by the plants in response to the pest attack. The damage was recorded in terms of per cent incidence for tissue borers and in terms of number of nymphs / adults / puparia for sucking pests.

3.4.1 Early shoot borer, *Chilo infuscatellus* Snellen

According to **Ramkrishna Ayyar and Margabandhu (1935),** the shoot borer infestation can be measured in terms of percentage of canes attacked.

Shoot borer often kills the shoots, the first noticeable sign of damage being the characteristic 'Dead-heart' which can be pulled out easily and gives foul odour. The shoot borer infestation can be estimated by recording the number of 'dead-hearts' in the field **(Fletcher and Ghosh, 1920).**

Per cent shoot borer infestation

Fifty canes per replication were selected randomly and presence of characteristic 'dead-heart' and exit hole were recorded to calculate the per cent shoot borer infestation.

3.4.2 Top borer, *Scirpophaga nivella* Fabricius

Top borers attack the youngest part of the cane penetrating the stalk by way of the leaf spindle **(Fletcher and Ghosh, 1920; Gupta, 1959a)**. Older stalk often survive by developing side shoots from the top buds forming 'Bunchy top' (**Rahman and Singh, 1944).**

Per cent top borer infestation

Fifty plants per replication were selected randomly and per cent incidence of top borer was calculated on the basis of red streak on the leaf, shot holes and presence of 'bunchy tops'.

3.4.3 Stalk borer, *Chilo auricilius*

Stalk borers often make more numbers of bored holes below the leaf sheath on the internodal portion. After boring in the internodal portion, borers make a tunnel extending up to more than one internode.

Per cent stalk borer infestation

Fifty plants per replication were selected randomly to calculate the per cent incidence of stalk borer on the basis of exit holes in canes.

3.4.4 Root borer, *Emmalocera depresella* Swinhoe

Root borer causes complete drying of germinating shoot and damage the growing primordia. As a result of feeding of the central leaf sheath, plants shows 'dead-heart' symptom that is not pulled out easily and sometimes whole plant come out along with whitish borer larvae.

Per cent root borer infestation

Per cent incidence of root borer was calculated on the basis of infested plants per row length.

3.4.5 Black bug, *Cavelerius sweeti* Slater

The nymphs and adults were found in the leaf whorls and under the leaf sheath. **Gupta and Avasthy (1954)** observed that both nymphs and adults suck the sap resulting in stunting of ratoon crops.

Per cent incidence of black bug

Twenty five plants per replication from five spots were selected randomly to record population of nymphs and adults per plant. Outer leaves of each plant were removed and insects in leaf sheaths were collected on the white paper sheet and counted.

The populations of insect were correlated with average maximum, minimum temperature (°C), relative humidity (%) at 0700 hrs and 1400 hrs, total rainfall (mm) and sunshine hours to observe the influence of abiotic factors on pest population.

The meteorological data during crop season were recorded from Meteorological Observatory of GBPUA&T Pantnagar.

3.5 Treatments and their allocation

Six treatments including control were allocated randomly to different plots in each of the three blocks. The details of treatments given in Table 3.5 and the layout of the experiment showing the treatments allocation is given in Fig.3.5.1.

Table 3.5: Details of insecticides used in the experiment

Treatments	g a.i./ha	Product (ml/ha)	Trade Name	Company
T_1 : Spinetoram 11.7 SC	90	750	Not revealed till now	Dow AgroSciences Pvt. India Ltd.
T_2 : Spinetoram 11.7 SC	180	1500		
T_3 : Imidacloprid 17.8 SL	70	350	Maharaja	Gharda Chemicals Ltd.
T_4 : Fipronil 0.3 G	60	20 kg/ha	Regent	Bayer Crop Science
T_5 : Chloropyrifos 20 EC	1000	5000	Dursban	Dow AgroSciences Pvt. India Ltd.
T_6 : Untreated check				

3.5.1 Insecticidal application

The treatments were applied on cane setts at the time of planting in furrows. The insecticides (except Fipronil) of required concentration were prepared in water and sprayed over setts while Fipronil 0.3G was applied with hand over cane setts in furrows.

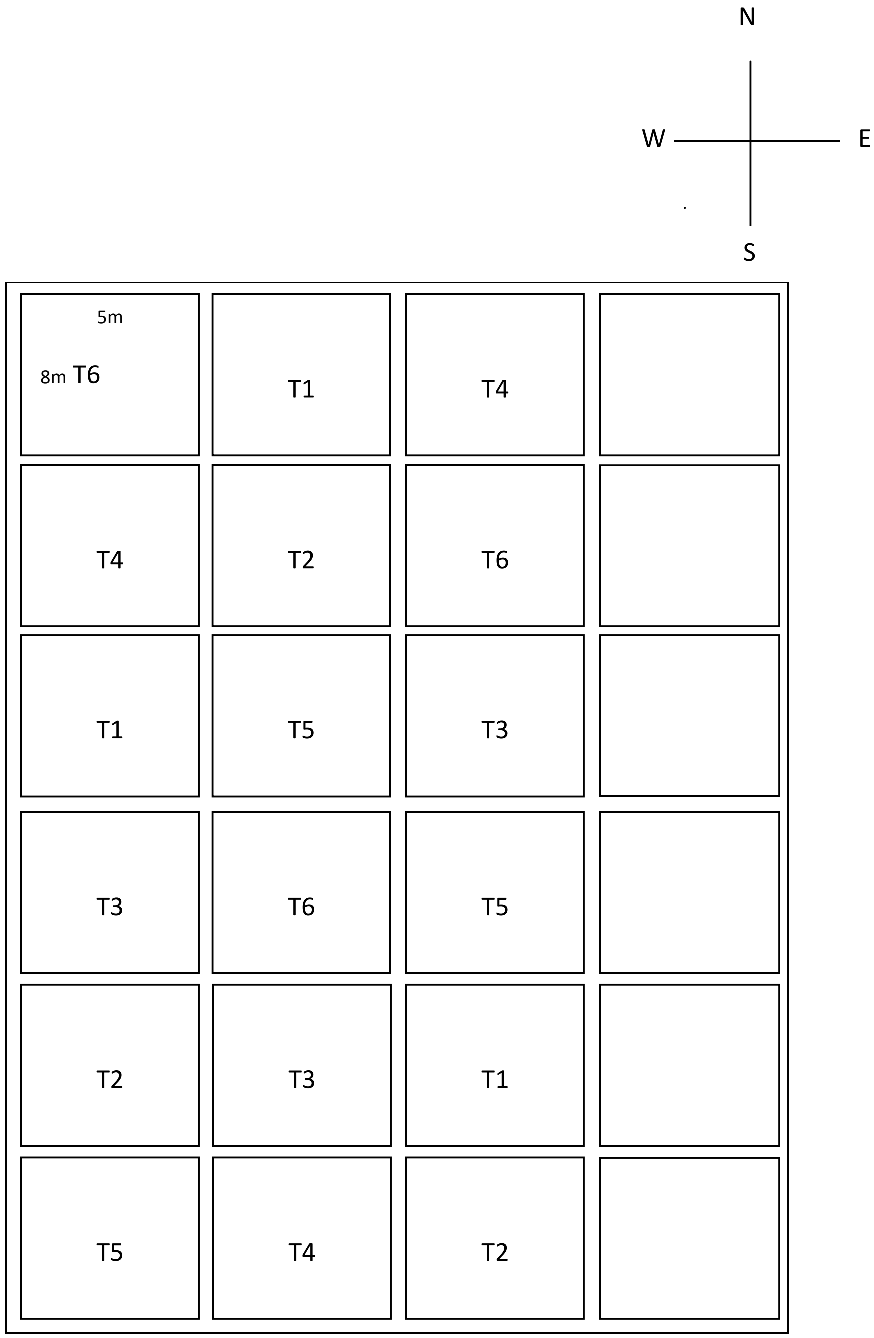


Fig. 3.5.1: The layout of the experiment showing the treatments allocation

3.5.2 Observational procedure

3.5.2.1 Germination Percentage

The germination was recorded after 45 days of planting using following formula:

$$\text{Per cent Germination of buds} = \frac{\text{Number of emerging shoots}}{\text{Total number of buds planted}} \times 100$$

3.5.2.2 Termites

a) Bud damage assessment

Ten spots at random from each plot were dug out to assess the bud damage due to termites after 30 days of planting using following formula:

$$\text{Per cent bud damage} = \frac{\text{Damaged buds}}{\text{Total buds observed}} \times 100$$

b) Plant damage assessment

Ten plants at random from each plot were observed to record the plant damage due to termites at 6, 8 and 10 weeks after planting using following formula:

$$\text{Per cent plant damage} = \frac{\text{Damaged plants}}{\text{Total number of plants observed}} \times 100$$

c) Cane damage assessment

Ten mature canes at random from each plot were observed to record the cane damage due to termites at harvesting time using following formula:

$$\text{Per cent mature cane damage} = \frac{\text{Damaged canes}}{\text{Total number of canes observed}} \times 100$$

d) Yield estimation

All the canes from net plots were cut close to the ground level. The tops and trash were removed and cane yield per plot was recorded and computed to hectare basis.

3.5.2.3 Statistical analysis

The data were subjected to analysis of variance (ANOVA) as prescribed for randomized block design. Data recorded on per cent bud damage and plant damage was subjected to square root transformation.

3.6 Termite Sample collection and identification

One hundred five termite samples collected from different habitats (*viz.* from agricultural crops, dead tree stumps, living trees, grass heaps, termite mounds, kitchen garden and structural woods (indoors as well as outdoors), in Pantnagar University campus and its nearby areas during 2012-13 and 2013-14.

The specimens were preserved in 80% ethyl-alcohol, with proper label containing details of the locality, date of collection and host habitat etc. For identification purpose, a valuable monograph, *"Measurements of termites (Isoptera) for taxonomic purpose"* published by **Roonwal (1970)** was followed.

3.7 Details of laboratory Experiment

3.7.1 Insecticides

The insecticides tested for the bioassay were Spinetoram and Imidacloprid while Chlorantraniliprole and Chlorpyrifos were standard check against *Odontotermes brunneus.* The formulations and active ingredient percentage of insecticides are given in Table 3.7a.

Table 3.7a: Different formulations of insecticides, chemical group and their concentrations used against *O. brunneus* under laboratory condition

S. No.	Chemical name	Trade name	Formulation	Chemical group	Company
1.	Spinetoram	Not revealed till now	11.7%SC	Spinosad	DOW AgroSciences India Pvt. Ltd.
2.	Imidacloprid	Maharaja	17.8%SL	Neo-nicotinoid	Gharda Chemicals Limited
3.	Chlorantraniliprole	Coragen	18.5% SC	Anthranilic Diamides	E. I. DuPont Co.
4.	Chlorpyrifos	Dursban	20 EC	Organophosphates	DOW AgroSciences India Pvt. Ltd.

3.7.2 Collection of test insect termite, *Odontotermes brunneus* (Hagen)

Foraging workers were collected from termitarium present near Practical crop production, campus of GBPUA&T, Pantnagar. The termite individuals were transferred separately in three glass jars (dia. 20 cm, height 15 cm) having an inner lining of moist filter paper. These jars with termite individuals were kept in laboratory at room temperature (25^0C and 80 ± 5% Relative Humidity) in dark conditions. The top of the jar was covered with slightly moist muslin cloth. All termites were tested within three days of collection and only active and healthy termites were used for the experiments.

3.7.3 Determination of lethal concentrations (LC values) of insecticides against termite workers

All the laboratory experiments were conducted in X-Ray laboratory to provide controlled conditions. The efficacy of insecticidal toxicity was studied against termite workers older than third instar. Based on literature the concentrations for preliminary screening of insecticides were decided. The experiments were carried out in two phases, preliminary screening and final testing alternatively, to study the lethal concentration of insecticides. The details of treatments are given in Table 3.7b.

3.7.4 Preliminary screening

Seven concentration of each of the insecticides *viz,* Spinetoram (60, 120, 180, 240, 300, 360, 420 ppm) and Imidacloprid (20, 60, 100, 130, 170, 200 and 240 ppm) were tested against termite workers. The observation recorded at 6, 12, 24, 48 and 72 hours after exposure led to the selection of dosage range for the final testing.

3.7.5 Final Testing

The final dosage regime of the two insecticides selected for the study was: - Spinetoram (360, 300, 240, 180, 120, 60ppm) and Imidacloprid (178, 124, 99.6, 58.7, 19.5 ppm) with Chlorantraniliprole (200 ppm) and Chlorpyriphos (1000 ppm) as standard check. The observations were recorded at 6, 12, 24, 48 and 72 hours after exposure.

3.7.6 Bioassay method

Test concentrations were prepared by serial dilution method in distilled water for each of the four insecticides. The food material, Whatman filter paper No 1 was moistened with distilled water and shade dried for one hour. Then the food materials were thoroughly mixed/ immersed in the different concentrations of test insecticides. Chlorantraniliprole 18.5 SC @ 200 ppm and Chlorpyriphos 20 EC @ 1000 ppm were the standard check. The treated food materials were placed on the bottom of a Plastic trough (18 cm diameter and 6 cm high). Filter paper moistened with distilled water was served as control. Each concentration was replicated three times with 30 numbers of termites introduced by a soft fine brush per replication and thus 90 termite individuals were exposed per concentration. The observation was recorded on mortality at 6, 18, 24 and 48 hours after contact and feeding exposure of insecticides. Workers were considered dead when they showed no movement upon probing with a fine brush.

Table 3.7b: Details of Treatments applied to determine LC_{50} values of different insecticides against termite workers, *O. brunneus*

S. No.	Treatments	Dose (g ai/ha)	Product (ml/ha)	Product (ml/l)	Concentration (ppm)
1.	Spinetoram 12 % SC	30	250	0.5 ml	0.006% (60 ppm)
2.	Spinetoram 12 % SC	60	500	1.0 ml	0.012% (120 ppm)
3.	Spinetoram 12 % SC	90	750	1.5 ml	0.018% (180 ppm)
4.	Spinetoram 12 % SC	120	1000	2.0 ml	0.024% (240 ppm)
5.	Spinetoram 12 % SC	150	1250	2.5 ml	0.03% (300 ppm)
6.	Spinetoram 12 % SC	180	1500	3.0 ml	0.036% (360 ppm)
7.	Imidacloprid17.8%SL	10	56.1	0.11ml	0.001% (19.5 ppm)
8.	Imidacloprid17.8%SL	30	168.5	0.33ml	0.005% (58.7 ppm)
9.	Imidacloprid17.8%SL	50	280.8	0.56 ml	0.009% (99.6 ppm)
10.	Imidacloprid17.8%SL	70	393.2	0.7 ml	0.012% (124 ppm)
11.	Imidacloprid17.8%SL	90	505.6	1.0 ml	0.017% (178 ppm)
12.	Chlorantraniliprole 18.5%SC	100	540.5	1.0 ml	0.02% (200 ppm)
13.	Chlorpyriphos 20 EC	500	2500	5.0 ml	0.1% (1000 ppm)
14.	Untreated check	–	–	–	–

3.7.7 Statistical analysis

The data thus obtained was subjected to Abbott's formula for the determination of corrected mortality (Abbott, 1925) given below while Lethal concentration (LC) values were determined by using probit analysis (Finney, 1971).

$$\textbf{Abbott's corrected mortality } (\%) = \frac{T-C}{100-C} \times 100$$

Where T= Mortality per cent in treatment

C= Mortality per cent in control

The relative toxicity (RT) of insecticides was calculated based on LC 30, 50 and 90 values by using the following formula **(Ramangauda and Srivastava, 2009; Basera, 2009).**

$$\textbf{Relative toxicity (RT)} = \frac{\text{LC value of least toxic insecticide}}{\text{LC value of candidate insecticide}}$$

3.8 Sentricon Colony Elimination System

Sentricon Termite Colony Elimination System with Hexaflumuron 0.5% w/w incorporated in High Density Cellulose Matrix Formulation placed In-Ground (IG) and Above-Ground (AG) Stations for control of subterranean termites (Plate 1). Dow AgroSciences has explored the potential for subterranean termite control using a durable bait approach.

3.8.1 Selection of Structures

The structures selected for experiment were taken within campus of GBPUA&T, Pantnagar.

a) The study done on structures that are infested at the time of bait installation (remedial measures); Above-ground(AG) bait were installed

b) The study done on structures that are not infested at the time of durable bait installation but do have active colonies, in the vicinity of the structure (preventative measures); In-ground(IG) monitoring as well as Hexaflumuron bait stations were installed.

3.8.2 Structural Inspections

The complete structural inspections of selected structures were done two times:

a) Prior to installation of the durable bait tubes, and

b) At 3-6 months following elimination of the structural infestation.

3.8.3 General guidelines for structural inspections

Visual inspections were done for all the exterior and interior rooms, including closets before installation of bait stations. Particular attentions were paid to accessible baseboards, doorframes, window frames, built-in cabinets, and ceilings.

3.8.4 Sentricon Monitoring Station Installation and Placement

Sentricon stations containing wood monitors were installed around each structure (preventative and remedial) and numbered consecutively (1, 2, 3, …..). Sentricon stations were installed as per the directions in the Sentricon Technical Manual 2008 as follows:

a) Around each building, Sentricon stations were placed at intervals that do not exceed 3 meters (10 ft) where soil access is not restricted. This was slightly less or more if the 3 meter (10 ft) area is not favourable for termite connection (dry path for instance).

b) Sentricon stations were placed at least 300 mm (1 ft) from structural foundations

c) No termiticide was used in selected structure previously.

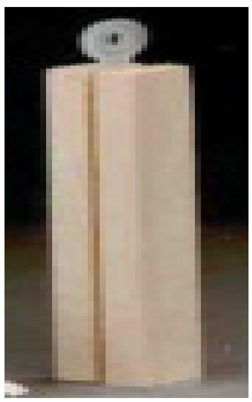
3.8.5 Hexaflumuron 0.5% w/w AG Station Installation and Placement

AG stations containing Hexaflumuron 0.5% w/w were placed on points of termite activity or over mud leads. When placed over a mud lead, the lead were opened inside AG station, and then covered with bait. The station was mounted with screws and a water based sealant to ensure that the station is air tight and light proof.

3.8.6 Sentricon Monitoring Station Inspection Intervals

Termite activity in all Sentricon monitoring stations was checked bi-weekly. During inspections, all Sentricon monitoring stations were opened and checked. Monitors that are consumed or failing due to decay were replaced at bi-weekly inspections.

IN-GROUND STATION



Dummy bait

Hexaflumuron bait

ABOVE-GROUND STATION

Plate 1: Details of materials used in experiment on assessment of Sentricon Colony Elimination System

3.8.7 Installation of Durable Bait Stations

At structures, durable Hexaflumuron bait stations were installed around a structure after termite activity is documented in the Sentricon monitoring stations. As active termite feeding occurred on the wood monitors within a station, Hexaflumuron bait tube introduced in infested area.

3.8.8 Methodology

a) Total number of In-Ground stations installed: 19 In-ground bait stations and 17 Above-ground bait stations

b) AG stations containing Hexaflumuron 0.5% w/w were placed on points of termite activity or over mud leads.

c) All bait tubes were weighed before installing in the stations.

d) Bait stations were manually inspected by opening and checking every station and bait consumption (in grams) were recorded with the help of electronic weighing machine.

e) All stations inspected bi-weekly. Infested units were replaced with new sets of baits.

f) The remaining baits were taken to the laboratory, cleaned by removing soils and debris and weighed. After cessation of feeding activity, monitoring continued up to 25th September, 2014.

g) For identification of termite species: Termite samples were collected from bait stations and preserved in vials containing 90% ethyl alcohol for later identification.

3.8.9 Data Collection –Inspections

The following data were recorded: Date of installation, Station number and station action, estimated number of termites present (in Above-ground bait station), termite species and estimated amount of the bait consumed (g).

Results and Discussion

Chapter 4 RESULTS AND DISCUSSION

The data obtained during the course of present investigation has been analyzed statistically, duly supported by tables and graphs. The results have been presented experiment wise, along with discussion.

4.1 Diversity of insect-pests fauna associated with sugarcane

Regular surveys were conducted at weekly interval in the sugarcane crop at C.R.C. Pantnagar from April, 2013 to March, 2014 to study the diversity of major insect-pests. The diversity of insect-pests fauna associated with sugarcane crop has been enlisted in the Table 4.1a and Plate 2.

A total of thirteen insect-pests were observed attacking the buds, leaves, stalk, and roots of sugarcane plant irrespective to different pests along with various spider species were observed. Among which five insect species belonged to the order Lepidoptera that comprised of borer complex of sugarcane, four to Hemiptera, one to Coleoptera, one to Isoptera, and one to Orthoptera, one to Dermaptera and spider species belonged to Araneae (Arachnida). The peak activity period was observed on the basis of their incidence and the extent of damage caused by them.

4.1.1 Sugarcane Shoot borer, *Chilo infuscatellus* Snellen

The borer enters the young shoot by making fine holes, in to the tender shoot/ stalk and tunnel downwards. The germinating shoots completely dried up due to biting and chewing of the central leaf sheath thus the cut-off portion of central leaf sheath formed dead-heart. The larvae entered into the plant laterally by making one, two or more holes in the shoots. The larvae bore downwards and then upwards in the central leaf sheath thereby the dead-hearts were formed.

The damaged central leaf sheath had diagonally damaged appearance. In the older dead-hearts of the damaged rotten portion showed fibrous symptoms. It was observed that some time borer larvae may come out along with the pulled dead-hearts. In about ten days after the borer entry in to the plants, the central leaf sheath withered and turned yellow. The plant infested by shoot borer gradually dried-up. In this way the borer destroyed a large proportion of the young shoots in the early stage of the plant growth.

Table 4.1a: Diversity of insect-pest fauna associated with sugarcane crop at C R C Pantnagar during 2013-14

S. No.	Common name	Scientific name	Order	Family	Peak activity period
Borers					
1.	Sugarcane Shoot borer	*Chilo infuscatellus* Snellen	Lepidoptera	Crambidae	May-June
2.	Sugarcane Top borer	*Scirpophaga nivella* Fabricius	Lepidoptera	Pyralidae	May-June
3.	Sugarcane Stalk borer	*Chilo auricilius* Dudgeon	Lepidoptera	Crambidae	October
4.	Sugarcane Internode borer	*Chilo sacchariphagus indicus* Kapur	Lepidoptera	Crambidae	July, October
5.	Sugarcane Root borer	*Emmalocera depressella* Swinhoe	Lepidoptera	Pyralidae	May
Sucking pest					
6.	Sugarcane Leaf hopper	*Pyrilla perpusilla* Walker	Hemiptera	Lophodidae	September-October
7.	Sugarcane Black bug	*Cavelerius sweeti* Slater	Hemiptera	Lygaeidae	June-July
8.	Sugarcane Scale	*Melanaspis glomerata* Green	Hemiptera	Diaspididae	September-October
9.	Sugarcane Mealy bug	*Saccharicoccus sacchari*	Hemiptera	Pseudococcidae	September-October
Others					
10.	Termites	*Odontotermes* sp.	Isoptera	Termitidae	May-June
11.	Grasshoppers	*Hieroglyphus banian*	Orthoptera	Acrididae	July-September
12.	Coccinella	*Coccinella septempunctata*	Coleoptera	Coccinellidae	October-November
13.	Earwig	-	Dermaptera	-	November
Other than insects					
14.	Spiders	-	-	-	


Scirpophaga nivella


Chilo infuscatellus


Chilo auricilius

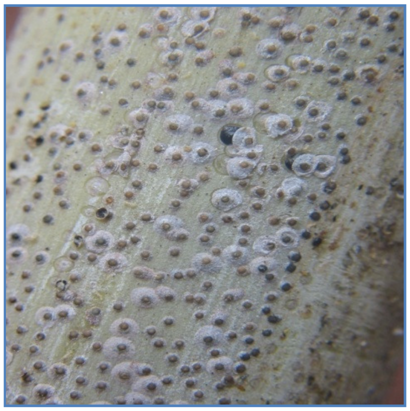

Chilo sacchariphagus indicus


Emmalocera depressella


Termites


Cavelerius sp.


Pyrilla sp.



Sugarcane scale

Sugarcane mealy bug

Sugarcane ants

Spider

Earwig

Coccinella sp.

Plate 2: Diversity of insect-pest fauna associated with sugarcane crop at CRC Pantnagar, during 2013-14

The observations are supported by findings of **Rehman and Singh (1942)**, who reported that the first sign of the presence of this pest in a field is the appearance of the dead heart which consists of the dried up central whorl. The freshly hatched larvae enter between the first leaf sheaths and stem and eat its way into the interior of the shoot.

4.1.1.1 Seasonal incidence of *C. infuscatellus* during 2013-14

The infestation of *C. infuscatellus* was recorded in sugarcane variety CoP97222 from first week of May (18^{th} standard week) to second week of July (27^{th} standard week) are presented in Table 4.1b and Figure 4.1.1 Perusal of data revealed that the per cent infestation by shoot borer varied from 1.78 to 23.70 per cent during the course of investigation. The maximum infestation of shoot borer was observed in the month of May, however the peak activity recorded in the fourth week of May (23.70 per cent) when the maximum and minimum temperature ranged from 38.4 to 39.2°C and 19.1 to 29.1°C, respectively, with RH at 0700 hrs and 1400 hrs ranged from 56.7 to 70 per cent and 23 to 44.4 per cent, respectively with negligible rainfall.

Thereafter, the pest population started gradually declining in the month of June with the infestation percentage ranging from 3.25 to 16.25 per cent. Later on, the infestation decreased with increase in relative humidity (90.6 per cent) and rainfall (154.8 mm) till second week of July with minimum infestation percentage of 1.78 per cent.

The findings are in accordance with **Varadharajan *et al*. (1971)** who reported that the pest to be very active during March-June when the maximum temperature is high (30.2-35.3 ^{0}C) low humidity (76.8-89%) and scanty rain. The pest is completely inactive in October-November, when the maximum temperature is low with high humidity (86.9-90.2%) and heavy rainfall (198.8-314.3 mm). The larvae are very active during April, May and June while the activity declined in July on the onset of South-west monsoon.

The incidence of early shoot borer started from the time of germination and continued up to the month of July **(Pandey *et al.,* 1996). Pandey and Kumar (2014)** also reported that the highest incidence of *C. infuscatellus* was recorded during 21st standard week (8.8 per cent) at 43.1ºC maximum temperature, 28.4ºC minimum temperature, 57.0 per cent maximum relative humidity, 21.0 per cent minimum relative humidity and 9.1 sun shine hours.

Table 4.1b: Seasonal incidence of Sugarcane Shoot borer, *Chilo infuscatellus* Snellen during crop season from March 2013 to March 2014

Months/week	Standard week	Mean per cent infestation (%)	Weather parameters					
			Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
			Max.	Min.	0700am	1400pm		
May	18	08.32 (3.05)	38.9	19.1	60	23	10.1	000.0
May	19	13.25 (3.77)	38.7	19.7	56.7	26	07.9	001.2
May	20	15.75 (4.09)	38.4	23.8	60.4	31.6	08.8	000.0
May	21	23.70 (4.96)	39.2	29.1	70	44.4	04.3	000.0
May-Jun	22	16.25 (4.15)	37.9	25.8	67	41	07.8	000.0
Jun	23	09.25 (3.20)	35.2	27.0	75	56	04.2	023.6
Jun	24	06.10 (2.66)	33.6	25.2	80	66	03.9	119.8
Jun	25	03.25 (2.06)	31.3	25.2	87	70	03.0	173.0
Jun-Jul	26	02.92 (1.97)	31.1	25.2	91.6	71.6	02.4	287.0
Jul	27	01.78 (1.66)	32.3	25.3	90.6	73.1	02.5	154.8
CD at 5%		0.65(0.078)						
Sem±		0.22(0.026)						

Values in parentheses are Square root transformation (x+1) values

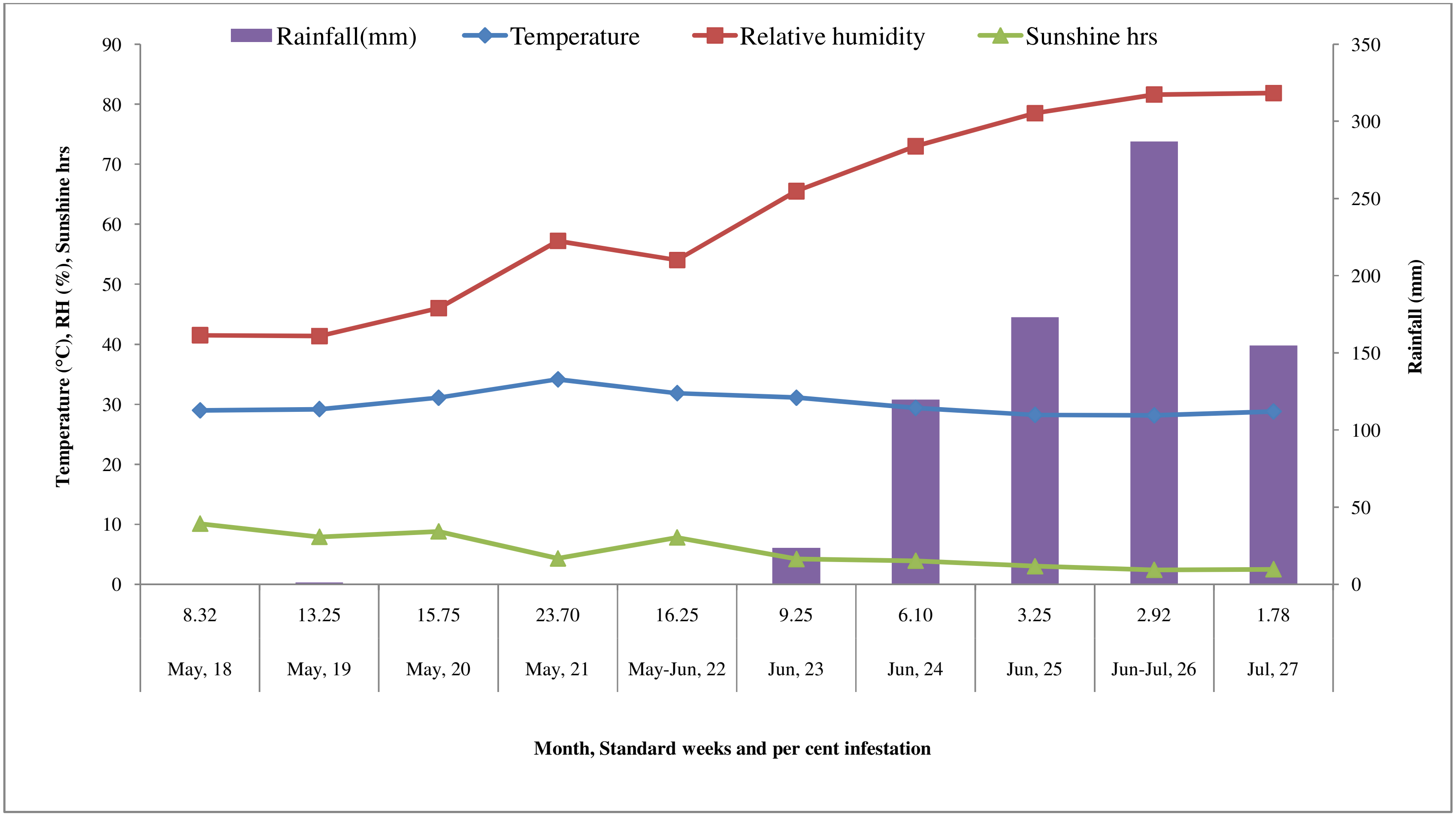


Fig. 4.1.1: Effect of weather parameters on seasonal incidence of Sugarcane Shoot Borer, *C. infuscatellus* during 2013-14

4.1.2 Sugarcane Top borer, *Scirpophaga nivella* Fabricius

The larval period of the pest was the active stage during which damage to the sugarcane is done. The affected shoots were killed in young stage. Their growth stops resulting in the development of side buds as 'Bunchy top' on the cane. The top borer larvae damage the growing point as a result of which further growth of the shoot was arrested. In the initial stages of the crop growth when the cane formation had not yet started, the attacked shoots dried after sometime. The young larva bored into the mid-rib from the under surface of the first opened leaf on the top. It tunnels down through the mid-rib till it reaches the point from where the leaf sheath starts.

It comes out from the mid-rib and pierces its way through the central whorl of unopened leaves, bores down into the spindle towards the growing point. The damaged central leaf later appeared in the form of dead-heart. Characteristics shot holes were formed from where the larvae pierce in the unopened leaves. Similar observations were made by **Kalra and Sindhu (1965).**

4.1.2.1 Seasonal incidence of *S. nivella* during 2013-14

The weekly data were collected on per cent infestation of sugarcane top borer along with weather parameters, like maximum temperature, minimum temperature, relative humidity at 7.00 AM, relative humidity at 2.00 PM and rainfall, during the course of study (April 2013-March 2014). It was observed that the infestation of *S. nivella* occur in sugarcane variety CoP97222 from third week of May (20^{th} Standard week) to third week of October (42^{nd} Standard week). The recorded data have been presented in Table 4.1c and Figure 4.1.2. Results indicated that top borer incidence varied from 0.48 to 5.52 per cent during the 20^{th} Standard week to 42^{nd} Standard week.

From the third week of May onwards, the borer incidence started increasing with a peak activity during third week of June (5.52 per cent) when the maximum and minimum temperature ranged from 33.6 to 39.2°C and 25.2 to 29.1°C, respectively, with RH at 0700 hrs and 1400 hrs ranged from 60.4 to 80 per cent and 31.6 to 66 per cent, respectively and rainfall was recorded 119.8 mm. Thereafter, the pest population started gradually declining with low incidence during third week of July (1.24 per cent).

Table 4.1c: Seasonal incidence of Sugarcane Top borer, *Scirpophaga nivella* Fabricius during crop season from March 2013 to March 2014

Months/week	Standard week	Mean per cent infestation (%)	Weather parameters					
			Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
			Max.	Min.	0700am	1400pm		
May	20	1.43 (1.55)	38.4	23.8	60.4	31.6	08.8	000.0
May	21	2.83 (1.95)	39.2	29.1	70	44.4	04.3	000.0
May-Jun	22	3.63 (2.14)	37.9	25.8	67	41	07.8	000.0
Jun	23	4.56 (2.35)	35.2	27.0	75	56	04.2	023.6
Jun	24	5.52 (2.55)	33.6	25.2	80	66	03.9	119.8
Jun	25	3.55 (2.13)	31.3	25.2	87	70	03.0	173.0
Jun-Jul	26	1.52(1.58)	31.1	25.2	91.6	71.6	02.4	287.0
Jul	27	1.36 (1.53)	32.3	25.3	90.6	73.1	02.5	154.8
Jul	28	1.24 (1.49)	32.4	26.3	87	70.7	06.2	037.2
Jul	29	2.50 (1.86)	31.3	25.5	90.7	77	02.6	097.8
Jul	30	2.06 (1.74)	32.4	25.6	85.4	68.6	04.5	095.8
Jul-Aug	31	1.55 (1.58)	33.0	26.0	87	68	06.1	044.0
Aug	32	1.17 (1.46)	32.1	25.3	91	74	05.2	175.6
Aug	33	0.67 (1.28)	31.5	24.5	88	73	04.9	187.8
Aug	34	0.48 (1.20)	33.6	25.9	87	65	07.3	012.4
Aug-Sep	35	1.76 (1.65)	31.2	25.2	93	73	02.4	043.8
Sep	36	2.86 (1.96)	32.1	23.6	91	69	06.4	005.2
Sep	37	2.44 (1.85)	33.4	23.6	85	62	07.9	034.0
Sep	38	3.42 (2.09)	32.8	23.8	81	65	08.7	005.4
Sep	39	2.29 (1.81)	33.0	24.1	89	62	06.6	033.2
Oct	40	1.74 (1.64)	30.3	23.1	82	67	04.2	006.8
Oct	41	1.35 (1.52)	31.2	22.1	90	61	06.7	079.6
Oct	42	1.10 (1.44)	30.4	20.1	91	63	05.5	000.0
CD at 5%		0.99(0.28)						
Sem±		0.35(0.09)						

Values in parentheses are Square root transformation (x+1) values

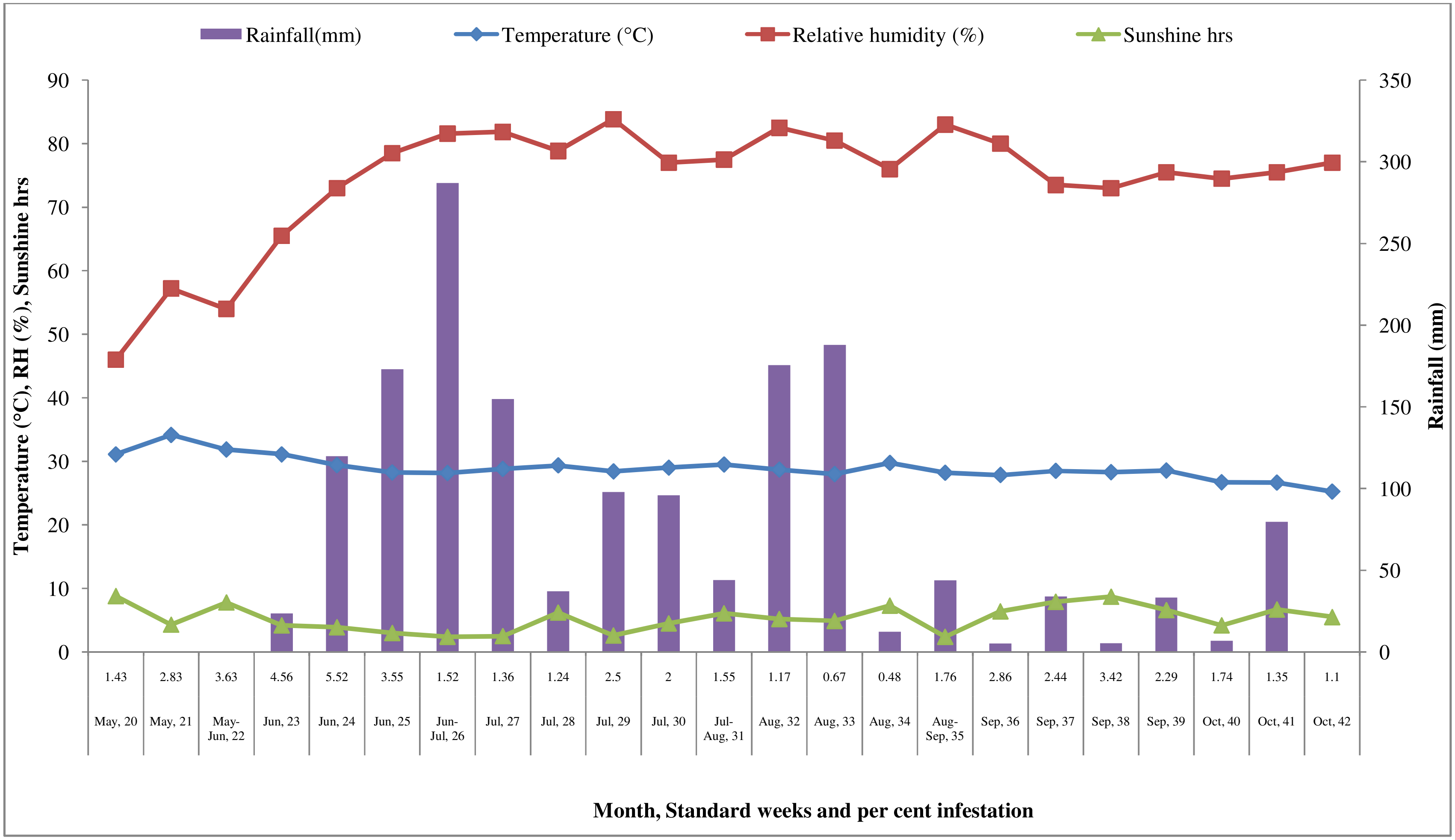


Fig. 4.1.2: Effect of weather parameters on seasonal incidence of Sugarcane Top Borer, *S. nivella* during 2013-14

In the fourth week of July, there was slight increase in the infestation percentage with a value of 2.50 per cent while it again started gradually declining with negligible activity during August month with minimum infestation of 0.48 per cent (fourth week of August).

There was slight increase in the infestation percentage in September month up to fourth week ranging from 1.76 to 3.42 per cent. Further, the infestation decreased with decrease in temperature up to third week of October (1.10 per cent)

These findings are supported by **Mann *et al.* (2006),** who reported that the top borer incidence occur both in second and third brood in May and July. The second brood of this pest appears in mid May and the third in the end of June or early July. **Singh *et al.* (2005**) reported 4.2 per cent incidence of top borer in Punjab in 2003.

4.1.3 Sugarcane Stalk borer, *Chilo auricilius* Dudgeon

The stalk borer moth laid eggs on any portion of foliage on cane stalk. On hatching, the larvae fed in the spindle and leaf sheath before boring in to the main stalk. There were mined marks present in the leaf sheath. The larvae bore in to shoot causing dead-heart of spindle leaf, second and third leaf. In the tillering stage of the plant, the borer larvae formed dead-heart up to fourth leaf. In the cane stage of crop, there were more numbers of bored holes below the leaf sheath on the internodal portion. The holes made by this pest were more or less symmetrical in appearance. After boring in the internodal portion, borer made a tunnel extending up to more than one internode.

4.1.3.1 Seasonal incidence of *C. auricilius* during 2013-14

Incidence of this borer pest was very less. Perusal of data indicated that the pest incidence started from second week of October and continued till first week of March with negligible or no activity during December and January month of crop season 2013-14. The data represented in Table 4.1d and Figure 4.1.3 revealed that the per cent infestation by stalk borer varied from 1.12 to 3.58 per cent from October 2013-March 2014. During the fourth week of October (43rd standard week), the maximum incidence was recorded i.e. 3.58 per cent at 30.2 ºC maximum temperature, 16.8 ºC minimum temperature, 88.0 per cent maximum relative humidity, 55.0 per cent minimum relative humidity, and 7.8 sun shine hours, although the pest did not infested the crop significantly then infestation decreased with decrease in temperature, gradually in the month of November-December with minimum 1.12 per cent while no activity observed in remaining part of the month of December and January. Thereafter it was slightly increased in first week of February (2.81 per cent). Further, the incidence gradually came down up to first week of March with per cent infestation of 1.15 per cent.

The pest started its activity in the month of October which was also in accordance with the finding of **Gupta and Avasthy, 1954; Bhardwaj *et al.,* 1981; Verma *et al*., 1982; Pandya *et al*., 1996; Jena and Patnaik, 1997. Singh (1983)** also reported that this pest *Chilo auricilius* Dudgeon was quite active during August – February when its population in water-shoots and late shoots was mostly below ground level.

4.1.4 Sugarcane Root borer, *Emmalocera depressella* Swinhoe

Root borer caused complete drying of germinating shoot and damaged the growing primordia and then larvae bored upwards into the germinating shoot. In some shoots, the larvae bored upwards up to the soil surface level. Two borer holes were observed in the closed vicinity (near one another) and a third hole was seen a little apart below the two holes. In the tillering stage of plant, the larvae cut the upper leaf sheath in a semicircular fashion and then made a gallery in the root region. As a result of feeding of the central leaf sheath, plants showed dead-heart symptoms comprising of spindle, 2^{nd}, 3^{rd} and 4^{th} leaves. The present observations are in accordance with the similar findings made by **Rehman and Singh (1942).**

The dead-hearts formed were not pulled out easily and some times whole plant came out along with whitish borer larvae. As a result of damage caused by borer larvae, the primordial of the plant was affected. This resulted poor flow of nutrients in the plant. The plant growth as a whole was greatly affected. In the late tillering and grand growth period the plant showed yellowish symptoms.

Table 4.1d: Seasonal incidence of Sugarcane Stalk borer, *Chilo auricilius* Dudgeon during crop season from March 2013 to March 2014

Months/week	Standard week	Mean per cent infestation (%)	Weather parameters					
			Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
			Max.	Min.	0700am	1400pm		
Oct	41	2.25 (1.80)	31.2	22.1	90	61	08.8	079.6
Oct	42	3.27 (2.06)	30.4	20.1	91	63	04.3	000.0
Oct	43	3.58 (2.13)	30.2	16.8	88	55	07.8	000.0
Oct-Nov	44	3.48 (2.13)	30.2	18.8	85	53	04.2	006.8
Nov	45	2.47 (1.85)	27.9	16.2	90	56	03.9	000.0
Nov	46	1.97 (1.72)	27.1	9.0	93	38	03.0	000.0
Nov	47	1.42 (1.55)	26.0	9.9	93	42	02.4	000.0
Nov-Dec	48	1.35 (1.53)	26.4	9.5	92	49	02.5	000.0
Dec	49	1.12 (1.45)	25.7	8.2	94	42	06.2	000.0
Dec	50	0.00 (1.00)	23.2	7.4	93	49	06.6	000.0
Dec	51	0.00 (1.00)	21.6	8.5	92	59	02.7	000.0
Dec	52	0.00 (1.00)	18.9	6.1	94	65	04.6	010.2
Dec-Jan	1	0.00 (1.00)	17.1	5.9	97	74	03.1	001.6
Jan	2	0.00 (1.00)	16.1	7.5	96	79	02.6	003.6
Jan	3	0.00 (1.00)	17.4	9.3	94	73	03.0	105.8
Jan	4	0.00 (1.00)	17.5	9.2	94	79	01.6	000.0
Jan-Feb	5	2.81 (1.95)	16.2	9.4	96	72	02.2	000.0
Feb	6	2.38 (1.83)	22.5	8.9	91.9	60.3	6.17	0.33
Feb	7	1.25 (1.49)	20.0	7.0	95.1	58	6.53	13.31
Feb	8	1.93 (1.71)	22.9	10.2	90.6	57.3	3.91	0.00
Feb-March	9	1.18 (1.47)	23.4	11.3	89.57	47.1	6.06	11.63
CD at 5%		0.40(0.10)						
Sem±		0.14(0.03)						

Values in parentheses are Square root transformation (x+1) values

4.1.4.1 Seasonal incidence of *Emmalocera depressella* during 2013-14

The data on pest incidence showed that the per cent infestation by root borer varied from 0.82 to 6.95 per cent during the crop season 2013-14 (Table 4.1e and Figure 4.1.4). The root borer started its activity in the month of May in which maximum infestation of root borer was observed in the second week of May (19^{th} standard week) with 6.95 per cent infestation when the maximum and minimum temperature was 38.7^{0}C and 19.7°C respectively, 56.7 per cent maximum relative humidity, 26 per cent minimum relative humidity, and 07.9 sun shine hours with negligible rainfall. Thereafter, the pest population started gradually declining in the month of June up to last week with the infestation percentage 1.04 per cent. In the second week of July the infestation was greatly reduced with increase in rainfall and after that the incidence gradually declined to zero level in the month of August. These findings are in accordance with the finding of **Gupta and Avasthy (1954)**. While **Sulaiman (1954)** reported that root borer *Emmalocera depressella* started its activities in March and goes on increasing in number until July. From August it started decreasing during the months of September and October, it disappeared altogether. **Singh (1983)** also observed that maximum incidence of the pest was observed in the month of May and June.

4.1.5 Sugarcane Black bug, *Cavelerius sweeti* Slater

The black bug was considered as a minor sucking pest. Both nymphs and adults were found in the leaf whorl and under the sheathing bases of leaves. The leaves of attached plants turned pale yellow and individual leaves show deep brown spots.

4.1.5.1 Seasonal incidence of *C. sweeti* during 2013-14

The pest started its activity in the month of May. Data revealed that the pest population varied from 1.5 per tiller to 5.9 per tiller during the 18^{th} standard week to 29^{th} standard week (Table 4.1f and Figure 4.1.5). The pest population was observed in the leaf whorl up to June first week. Later on, the population observed in the leaf sheath as well as in leaf whorl. The maximum population of black bug was observed in the fourth week of June (25^{th} standard week) with 5.9 per tiller when the maximum and minimum temperature was 31.3^{0}C and 25.2°C

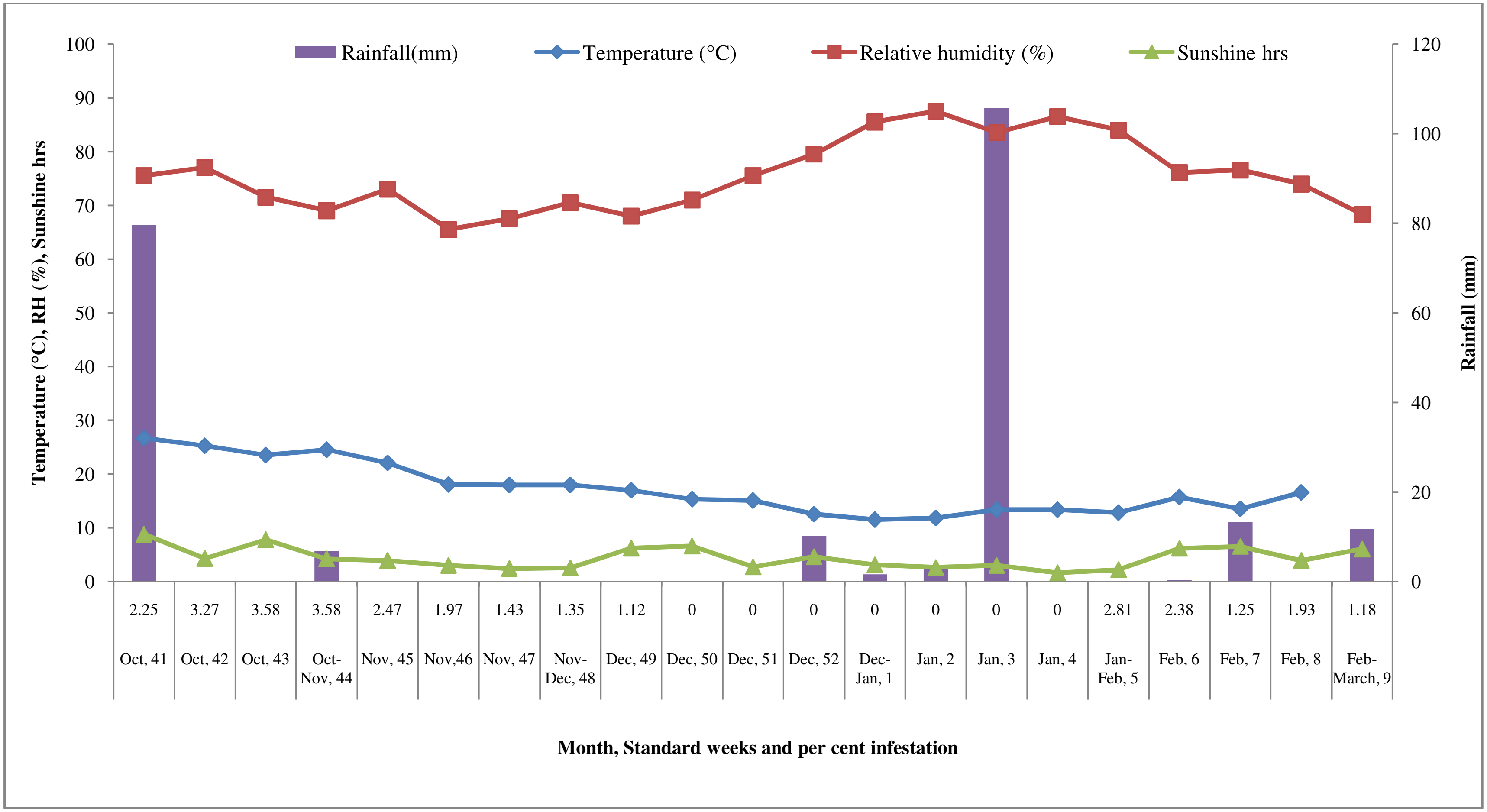


Fig. 4.1.3: Effect of weather parameters on seasonal incidence of Sugarcane Stalk Borer, *S. auricilius* during 2013-14

Table 4.1e: Seasonal incidence of Sugarcane Root borer, *Emmalocera depressella* Swinhoe during crop season from March 2013 to March 2014

Months/week	Standard week	Mean per cent infestation (%)	Weather parameters					
			Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
			Max.	Min.	0700am	1400pm		
May	18	0.82 (1.32)	38.9	19.1	60	23	10.1	000.0
May	19	6.95 (2.81)	38.7	19.7	56.7	26	07.9	001.2
May	20	5.19 (2.48)	38.4	23.8	60.4	31.6	08.8	000.0
May	21	4.47 (2.33)	39.2	29.1	70	44.4	04.3	000.0
May-Jun	22	3.39 (2.09)	37.9	25.8	67	41	07.8	000.0
Jun	23	3.96 (2.22)	35.2	27.0	75	56	04.2	023.6
Jun	24	2.43 (1.84)	33.6	25.2	80	66	03.9	119.8
Jun	25	1.04 (1.39)	31.3	25.2	87	70	03.0	173.0
CD at 5%		1.12 (0.32)						
Sem±		0.37(0.10)						

Values in parentheses are Square root transformation (x+1) values

Table 4.1f: Seasonal incidence of Sugarcane Black bug, *Cavelerius sweeti* Slater during crop season from March 2013 to March 2014

Months/week	Standard week	Number of insects per plant	Weather parameters					
			Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
			Max.	Min.	0700am	1400pm		
Apr-May	18	1.9 (1.7)	38.9	19.1	60	23	10.1	000.0
May	19	1.6 (1.6)	38.7	19.7	56.7	26	07.9	001.2
May	20	2.5 (1.8)	38.4	23.8	60.4	31.6	08.8	000.0
May	21	2.9 (1.9)	39.2	29.1	70	44.4	04.3	000.0
May-Jun	22	4.8 (2.4)	37.9	25.8	67	41	07.8	000.0
Jun	23	5.2 (2.4)	35.2	27.0	75	56	04.2	023.6
Jun	24	5.3 (2.5)	33.6	25.2	80	66	03.9	119.8
Jun	25	5.9 (2.6)	31.3	25.2	87	70	03.0	173.0
Jun-Jul	26	3.5 (2.1)	31.1	25.2	91.6	71.6	02.4	287.0
Jul	27	2.5 (1.8)	32.3	25.3	90.6	73.1	02.5	154.8
Jul	28	2.1 (1.7)	32.4	26.3	87	70.7	06.2	037.2
Jul	29	1.5 (1.5)	31.3	25.5	90.7	77	02.6	097.8
CD at 5%		0.16(0.03)						
Sem±		0.06(0.01)						

Values in parentheses are Square root transformation (x+1) values

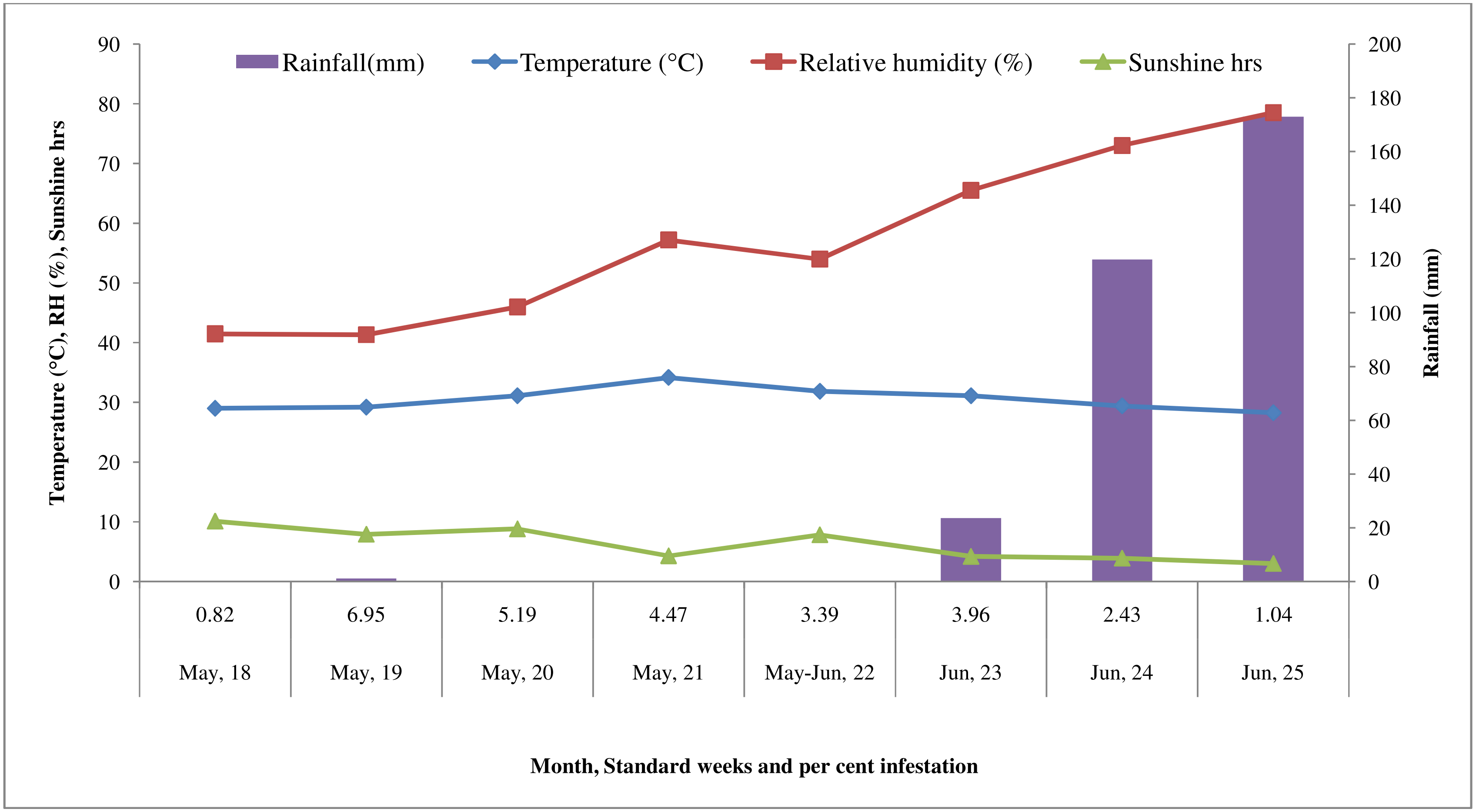


Fig. 4.1.4: Effect of weather parameters on seasonal incidence of Sugarcane Root Borer, *E. depressella* during 2013-14

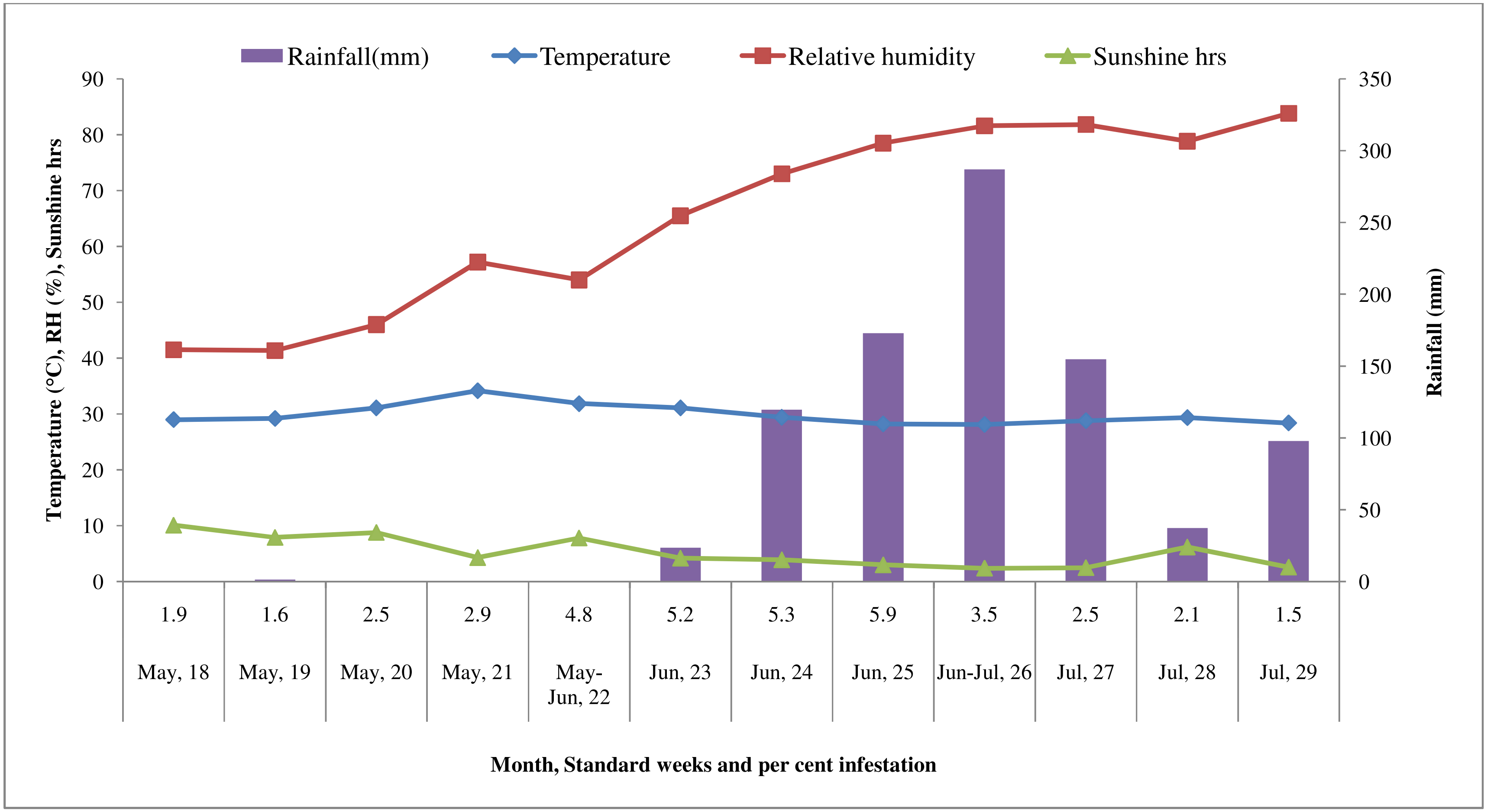


Fig. 4.1.5: Effect of weather parameters on seasonal incidence of Sugarcane Black bug, *Cavelerius sweeti* during 2013-14

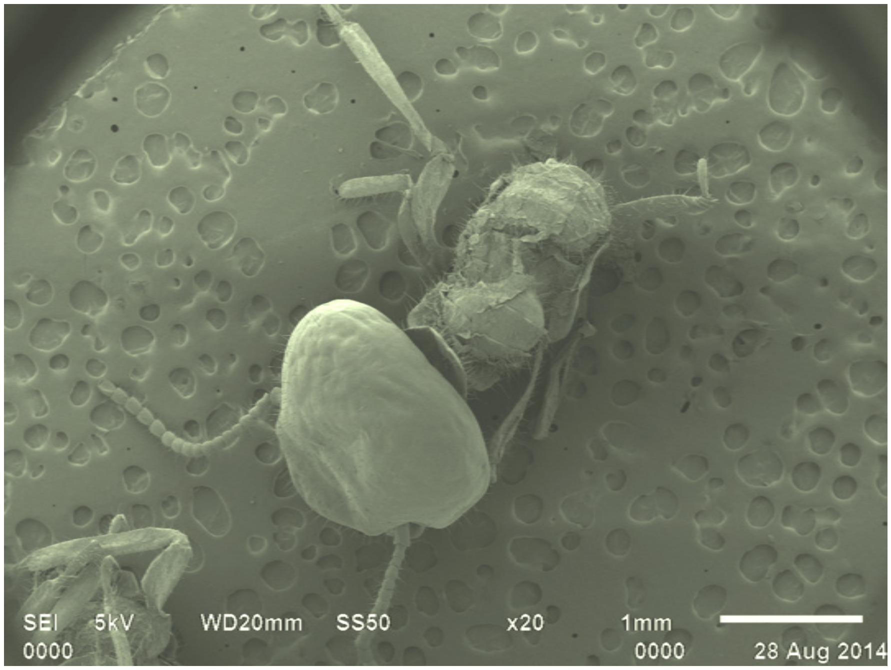
respectively, 87 per cent maximum relative humidity, 70 per cent minimum relative humidity, and 02.4 sun shine hours with 287 mm rainfall. Thereafter, the pest population started gradually declining in the month of July up to last week with 1.5 per tiller pest population. After that, the infestation was greatly reduced in later month of crop season 2013-14. These observations are in accordance with the experimental findings of **Pandey and Singh (2014)**, who reported that *C. sweeti* population varied from 1.4 per tiller to 6.2 per tiller during the 11th standard week to 25th standard week.

4.2 Termite fauna at Pantnagar during 2012-13 and 2013-14

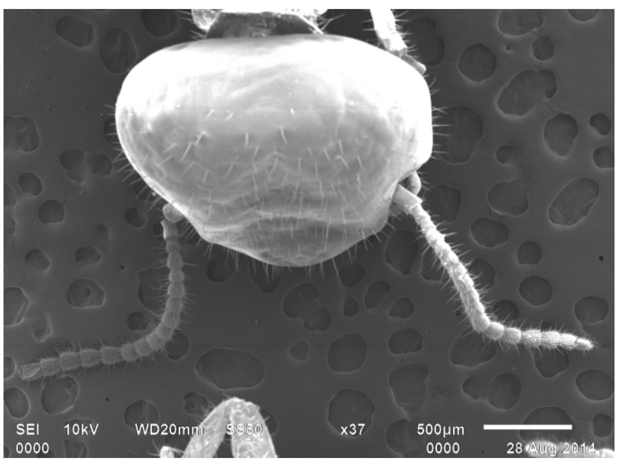
The identification of collected termite specimen showed different species of termite available in Pantnagar campus area. A total of nine termite species were found in different habitats which belong to six genera, three sub-families Amitermitinae, Termitinae and Macrotermitinae of Family Termitidae while two sub-families Heterotermitinae and Coptotermitinae of family Rhinotermitidae. Out of nine species, eight species were found as attacking on different plant species and utilizing them as a good host for their colony development while one species attacked on wooden structure, books, photo frame etc. (inside home) and identified as most serious threat to wooden articles. The member of sub-family Macrotermitinae, the *Odontotermes* sp. found predominant in this area causing severe damage to different plants as well as found in diversified habitats (Table 4.2 & Plate 3, 4). As observed by **Sen-Sarma (1974),** *Odontotermes* represents the most dominant genus of Indian termites with over forty species. However, two species, *Microtermes mycophagus* (Desneux) and *M. obesi* Holmgren infested several agricultural crops and *timber-in-service* also and considered as major threat to agricultural crops. The subfamily Amitermitinae represented by *Microcerotermes beesoni* Snyder that found on dead stump of *Poplar* sp. and *Mangifera indica* where they were found to forage on dead tissues. Termites have the ability to remove plant debris locking them up in their nest underground in a non-available form to the plants, thus reducing the fertility status of the soil **(Rajagopal, 2002)**. The *Angulitermes* sp. was found in soil under the heap of grass not recorded as a pest species during the study.

Table 4.2: Comprehensive list of termites, recorded from Pantnagar university campus and nearby areas and their pest status

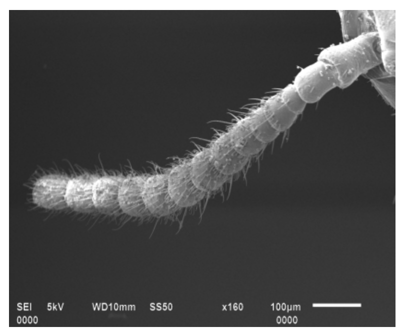
Taxa	Host	Severity
Family: Rhinotermitidae		
Sub-family: *Coptotermitinae*		
Coptotermes heimi (Wasmann)	*Grevillea robusta; Mangifera indica; Cassia fistula*	Minor pest (attacks on live trees bark)
	Saccharum officinarum	Major pest (remove the inner content of the cane sets and fill soil, on the other hand in mature plant completely girdle the root zone)
Sub-family: *Heterotermitinae*		
Heterotermes indicola (Wasmann)	Wooden structures & paper materials	Major wood destroying termite (indoor)
Family: Termitidae		
Sub-family: *Amitermitinae*		
Microcerotermes beesoni Snyder	Dead stump of *Poplar* sp. and *Mangifera indica*	-
Sub-family: *Termitinae*		
Angulitermes sp.	Under heap of grass	Grass feeder termite
Sub-family: *Macrotermitinae*		
Odontotermes sp.	*Mangifera indica*	Minor (bark feeder)
Odontotermes brunneus (Hagen)	*Tectona grandis* (Tg); *Lagerstroemia parviflora*	Major (completely remove the bark in case of Tg)
	Saccharum officinarum	Major pest (remove the inner content of the cane sets and fill soil and in mature plant completely girdle the root zone)
Odontotermes feae (Wasmann)	Sampled from soil	-
Microtermes mycophagus Desneux	Several agricultural crops and timber-in-service	Major (minor-wood destroying termite)
Microtermes obesi Holmgren	Several agricultural crops and timber-in-service	Major (minor-wood destroying termite)



Dorsal view of *Odontotermes feae*

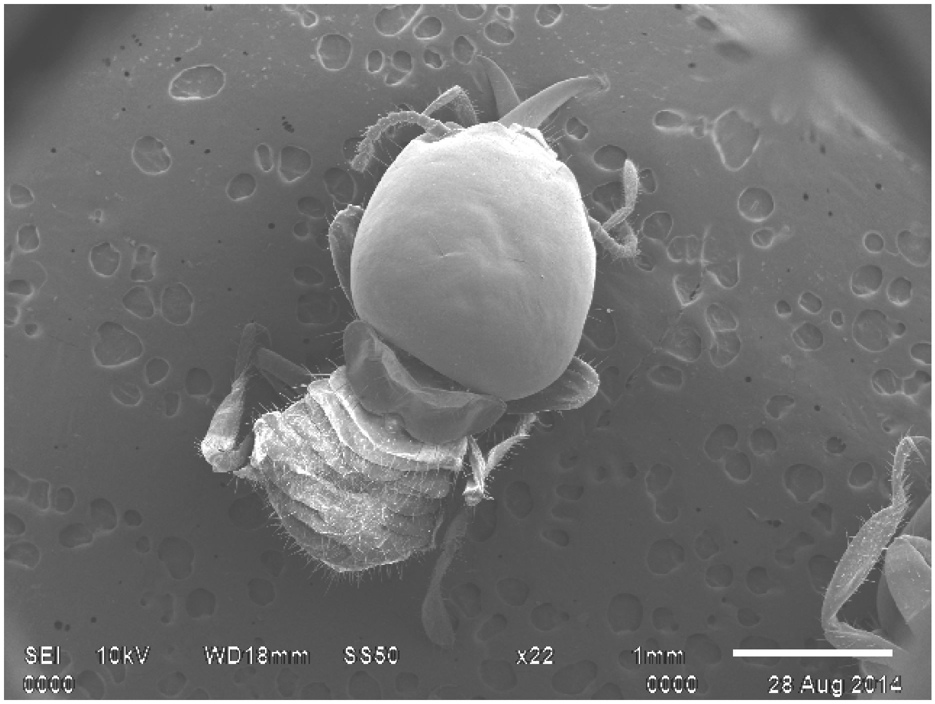


Dorsal view of Head region of *O. feae*

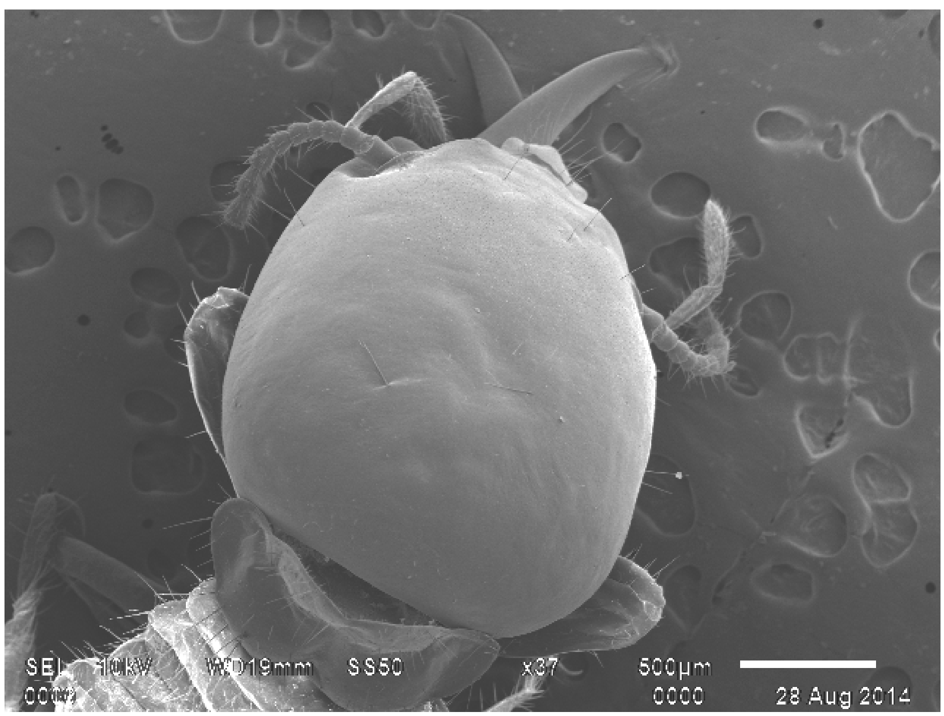


Termite antenna

Plate 3: Scanned Electron microscopic (SEM) photographs of *Odontotermes feae*

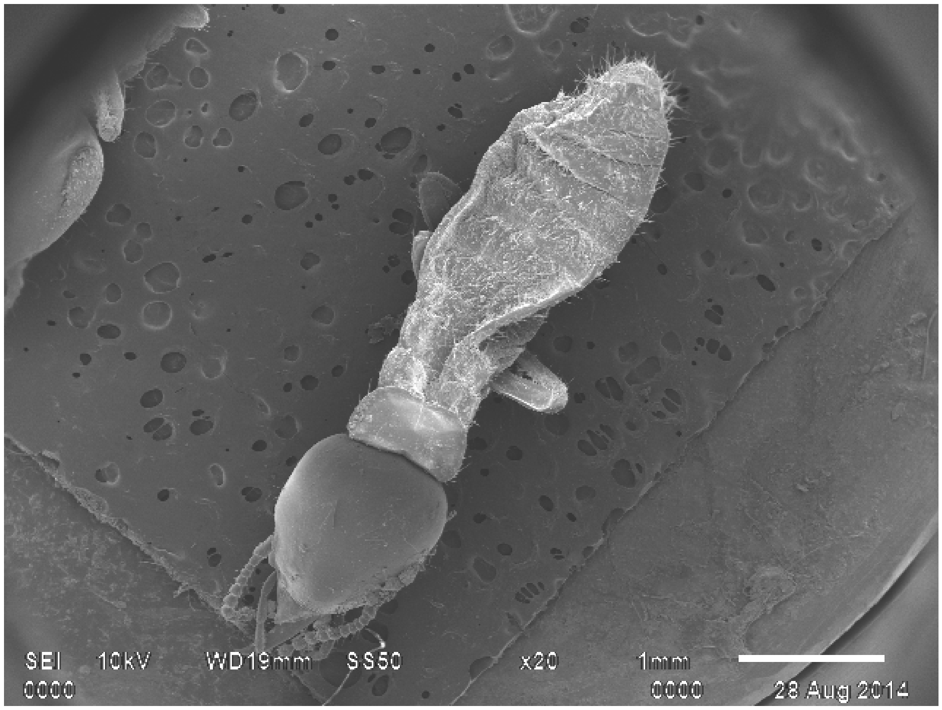


Dorsal view of *Odontotermes brunneus*

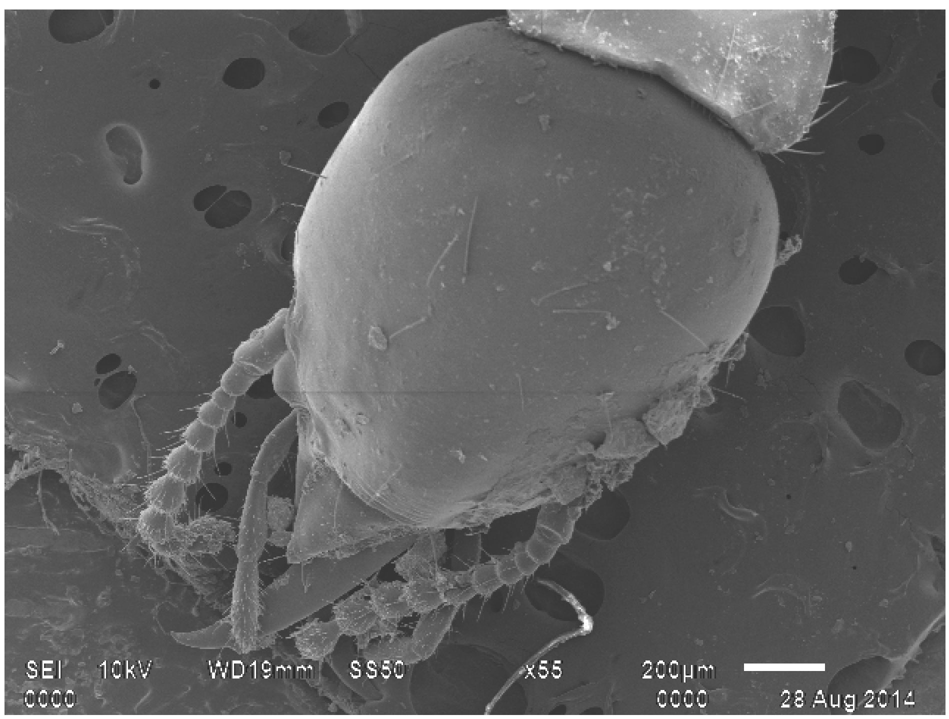


Dorsal view of Head region of *O. brunneus*

Plate 4: Scanned Electron microscopic (SEM) photographs of *Odontotermes brunneus*

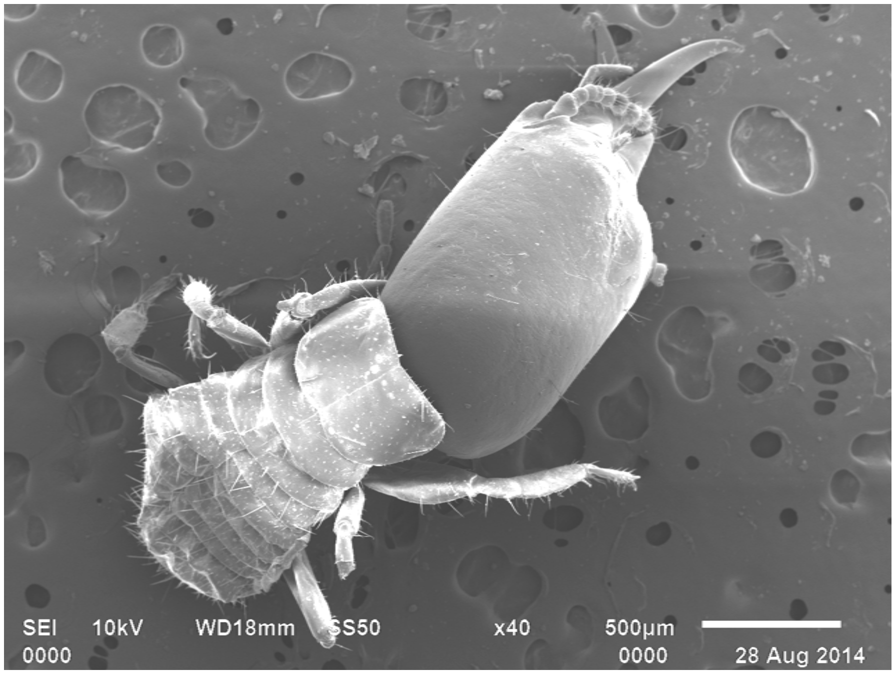


Dorsal view of *Coptotermes heimi*

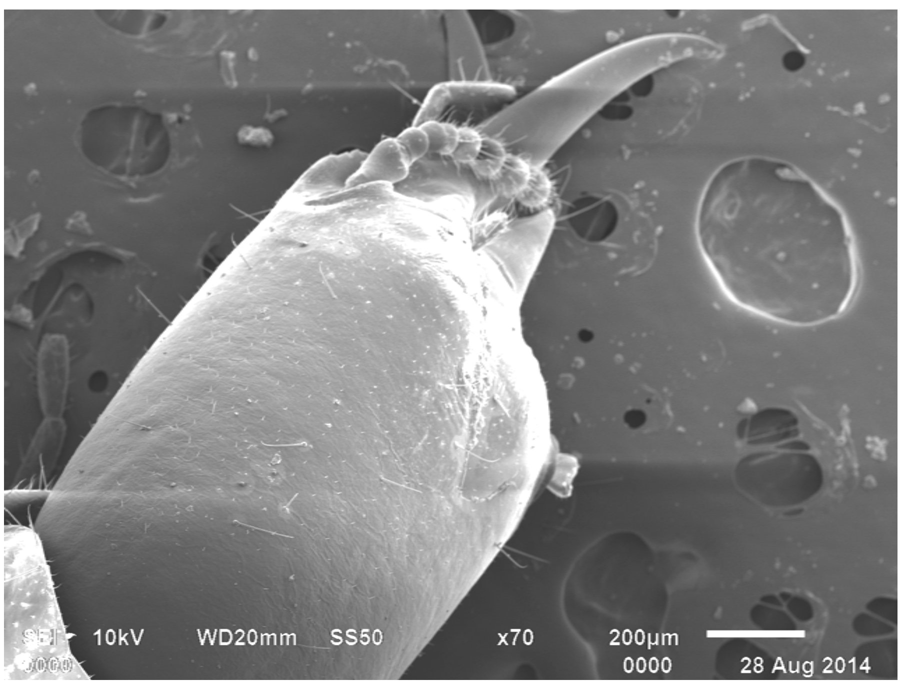


Dorsal view of Head region of *C. heimi*

Plate 5: Scanned Electron microscopic (SEM) photographs of *Coptotermes heimi*



Dorsal view of *Heterotermes indicola*



Dorsal view of Head region of *H. indicola*

Plate 6: Scanned Electron microscopic (SEM) photographs of *Heterotermes indicola*

During study, it was observed that, among the three plant species infested, *Grevillea robusta* were severely attacked by *Coptotermes heimi* (Wasmann) (Plate 5). According to **Roonwal (1970),** the genus *Coptotermes,* is distributed throughout the tropics. *C. ceulonicus* Holmgren occurs in the Western Ghats of India and Sri Lanka. *C. heimi* is a common, polyphagous species that attacks over thirty-five different plant species in India. However, *H. indicola* (Wasmann) was collected from structures (indoors) (Plate 6). This species severely damage the wooden parts and form the mud tunnels on walls for moisture requirement. These are called subterranean termites which live in soil usually enter the houses through the cracks in foundations, floors and wall, spread runways up to the structural wood. **Rajagopal (2002)** reported that *H. indicola* is primarily tropical in its distribution, but also found very commonly in temperate areas of the sub-Himalayan regions, up to elevations of 1980m.

4.3 Field efficacy of Spinetoram against sugarcane termite during 2013-14

Field data presented in Table 4.3 showed the efficacy of insecticides against termites in sugarcane crop during 2013-14.The damages caused by termites to the planted Setts and sett buds were observed in different treatments and the data obtained were transformed to per cent infestation. The summarized data indicated that all treatments proved to be significantly superior to untreated control.

Germination per cent

Data on germination per cent showed that Spinetoram treatments as spray over setts had not affected the germination adversely instead resulted in increased germination over untreated check. Germination in untreated check in the experiment was 39.32 per cent while it was 51.26 per cent (T_1) and 49.89 per cent (T_2) in the Spinetoram treatments. Similarly, increased germination in other insecticide treatments *viz*., Imidacloprid, Fipronil and Chlorpyrifos, was also observed in the experiment. Germination per cent in Chloropyrifos treatment (T_5) was recorded 49.43 per cent followed by Fipronil treatment (T_4) 48.46 per cent and Imidacloprid treatment (T_3) 46.47 per cent. Increase in germination is attributed to the control of termites in the treatments. Such increase in germination of setts due to insecticides treatment has been reported in an earlier study also (**Anonymous, 1998**).

Table 4.3: Evaluation of bio-efficacy of Spinoteram compared to Imidacloprid, Chloropyrifos and Fipronil against Termites in Sugarcane

S. No.	Treatment	Germination (%)	% Bud damage by termites (30 DAP)	% Plant damage (Weeks after planting)			% Incidence of termites at harvest	Yield (t/ ha)	% Increase over check
				6WAP	8WAP	10 WAP			
1.	Spinetoram 12 SC 750 ml/ ha spray over setts and cover	51.26	0.0(1.0)	5.0(2.2)	7.5(2.4)	10.0(3.0)	2.5 (1.6)	75.66	24.25
2.	Spinetoram 12 SC 1500 ml/ ha spray over setts and cover	49.89	0.0(1.0)	0.0(1.0)	2.5(1.6)	5.0(2.1)	0.0(1.0)	76.10	24.97
3.	Imidacloprid 17.8% SL 350 ml/ ha spray over setts and cover	46.47	8.4(3.0)	12.5(3.3)	15.0(3.9)	17.5(4.2)	15.0(3.9)	70.83	16.32
4.	Fipronil 0.3% G 20 kg/ha soil application	48.46	3.3(1.9)	7.5(2.8)	7.5(2.7)	10.0(3.0)	10.0(3.0)	71.93	18.13
5.	Chloropyrifos 20 EC 5 lit./ ha spray over setts and cover	49.43	6.7(2.7)	10.0(3.0)	10.0(3.0)	15.0(3.9)	12.5(3.6)	72.60	19.23
6.	Untreated check	39.32	19.9(4.5)	22.5(4.8)	25.0(5.0)	35.0(5.9)	27.5(5.2)	60.89	-
	CD at 5%	3.35	6.8(0.9)	11.1(2.0)	11.2(1.9)	8.9(1.5)	10.4(1.5)	4.50	-
	SEm±	1.11	2.3(0.3)	3.6(0.6)	3.7(0.6)	2.9(0.5)	3.44(0.5)	1.49	-

%= Per cent; WAP= Weeks After Planting; DAP= Days After Planting
Values in parentheses are Square root transformed (x+1.0) value

Per cent sett bud damage

Results on per cent sett bud damage revealed that nil bud damage due to attack of termite, recorded in Spinetoram treatments (T_1 and T_2). While, maximum sett bud damage (8.4 per cent) was recorded in Imidacloprid treatment (T_3) followed by 6.7 per cent in Chloropyifos treatment (T_5) and 3.3 per cent in Fipronil treatment. All treatments proved superior as against maximum bud damage 19.9 per cent in untreated check.

Per cent plant damage

Perusal of data presented in Table 4.3 indicated that all treatments gave better results compared to untreated control. No infestations of termites was recorded under Spinetoram, 1500 ml/ ha spray over setts (T_2) while at lower dose of Spinetoram, 750 ml/ ha spray over setts (treatment T_1) the termite infestation was 5.0 per cent at 6 weeks after planting (WAP). The infestation of termites in Imidacloprid treated (T_3) plot was recorded 12.5 per cent, 10 per cent in Cholorpyrifos (T_5) and 7.5 per cent in Fipronil treatment (T_4) while maximum in control, 22.5 per cent at 6 WAP.

At 8 WAP, Spinetoram treatment showed termite infestation of 2.5 per cent in T_2 and 7.5 per cent in treatment T_1. In Imidacloprid treatment (T_3) termite infestation of 15.0 per cent was recorded. However no difference in infestation percentage was recorded in other insecticidal treatment compared to previous fortnight. While 25.0 per cent plant damage was observed in control.

Slightly higher infestation of termites was observed in different treatments at 10 WAP. Spinetoram treatment showed termite infestation of 5.0 per cent in T_2 while 10 per cent in treatment T_1. In other insecticidal treatments, maximum infestation of 17.5 per cent was recorded in Imidacloprid treatment (T_3) followed by 15.0 per cent in treatment T_5 and minimum infestation of 10.0 per cent in treatment T_4. While 35.0 per cent damage recorded in control plots at 10 WAP.

Per cent incidence of termites at harvest

It is evident from data that at harvest, the nil incidence of termite was recorded in Spinetoram, 1500 ml/ ha spray over setts (T_2) while 2.5 per cent incidence in treatment T_1. The termite incidence in fipronil treated plots showed 10.0 per cent infestation. Slightly higher infestation of 12.5 and 15.0 per cent was recorded in treatment T_5 and T_3, respectively and maximum termite infestation of 27.5 per cent obtained in control plots.

These findings are in concurrence with the findings of **Singh *et al.* (2010), Singh *et al*. (2002) Singh and Singh (1998, 2001), Singh and Singh (2002), Santharam *et al*. (2002)** and **Delgarde and Rouland-Lefeure (2002), Singh and Singh (2003)** and **Gautam (2005)** against *Odontotermes obesus* Rambur in sugarcane.

Yield (t/ha)

Data showed that cane yield was significantly high in all the insecticidal treatments ranging from 70.83 to 76.10 tonnes per ha while it was 60.89 tonnes per ha in the untreated check. The yield in Spinetoram treatment T_2 was 76.10 t/ha which was at par with Spinetoram treatment T_1 i.e. 75.66 t/ha with 24.97 and 24.25 per cent increase in yield over untreated check. However, in other insecticidal treatments the yield was less than Spinetoram treated plots. The yield in treatment T_5 was recorded 72.60 t/ha with per cent increase over check was 19.23. While in case of treatment T_4, the yield was 71.93 t/ha with 18.13 per cent increase and 70.83 t/ha yield was recorded in treatment T_3 with 16.32 per cent higher yield as against control plots.

Increased yield of cane in the treatments was attributed to the control of termites damaging setts, resulting in better germination which ultimately led to harvesting of higher number of millable canes **(Santharam *et al.,* 2002).**

4.4 Determination of toxicity of two insecticides against worker termites, *Odontotermes brunneus* (Hagen)

The Abbott's correction formula was used to convert per cent mortality data to corrected per cent mortality **(Abbott, 1925).** It was further subjected to probit analysis following **Finney (1971)** in order to compute LC values. The data has been presented in Table 4.4a, 4.4b, 4.4c and 4.4d and Fig. 4.4.1 and 4.4.2.

Dosage mortality response (LC_{50})

Data revealed that the LC $_{50}$ value of Spinetoram was 281 ppm with fiducial limit between 205 to 538 ppm and 141 ppm with fiducial limit 78.1 to 200 ppm at 6 and 12h after exposure, respectively.

Table 4.4a: Toxicity of insecticides against worker termites, *Odontotermes brunneus* (Hagen)

Treatment	Concentration (ppm)	Abbott's per cent corrected mortality					
		6 HAE	12 HAE	18 HAE	24 HAE	48 HAE	72 HAE
Spinetoram	(60) 0.006	20.00	36.66	53.33	70.00	90.00	100
	(120) 0.012	30.00	43.33	60.00	76.66	93.33	100
	(180) 0.018	33.33	50.00	66.66	80.00	100	100
	(240) 0.024	43.33	60.00	73.33	90.00	100	100
	(300) 0.03	53.33	63.33	80.00	93.33	100	100
	(360) 0.036	60.00	76.66	86.66	96.66	100	100
Imidacloprid	(19.5) 0.001	6.66	13.33	26.66	33.33	56.66	50.00
	(58.7) 0.005	10.00	30.00	36.66	50.00	66.66	73.33
	(99.6) 0.009	13.33	36.66	43.33	63.33	76.66	83.33
	(124) 0.012	16.66	40.00	50.00	73.33	83.33	86.66
	(178) 0.017	23.33	46.66	56.66	83.33	90.00	93.33
Rynaxypyr	(200) 0.02	53.33	76.66	83.33	96.66	100	100
Chlorpyriphos	(1000) 0.1	46.66	63.33	76.66	93.33	100	100

*HAE= Hours After Exposure

Table 4.4b: Dosage mortality response of worker termites *Odontotermes brunneus* (Hagen) against Spinetoram 12 SC at 6, 12, 18, 24 and 48 hours after exposure

Hours	LC values in ppm			Chi Square	Regression equation Y= a+bx
	LC_{30}	LC_{50}	LC_{90}		
6	119 (58.5-165)	281 (205-538)	2320 (572-9410)	0.932	Y= 3.972+0.215x
12	54 (24.9-117)	141 (78.1-200)	1500 (417-5390)	1.581	Y=4.419+0.202x
18	22.8 (6.28-83.1)	62.3 (11.1-101)	737 (273-1980)	1.201	Y=4.847+0.200x
24	13.9 (3.3-58.6)	31.9 (12.0-84.4)	244 (167-608)	2.068	Y=5.176+0.262x
48	16.1 (3.2-34.7)	24.6 (0.2-44.9)	170 (82-432)	8.141	Y=5.1+0.781x

The values in parentheses are fiducial limits; LC= Lethal Concentration

Table 4.4c: Dosage mortality response of worker termites *Odontotermes brunneus* (Hagen) against Imidacloprid 17.8 SL at 18, 24, 48 and 72 hours after exposure

Hours	LC values in ppm			Chi Square	Regression equation Y= a+bx
	LC_{30}	LC_{50}	LC_{90}		
18	36.5 (2.5-60.8)	119 (74.8-598)	2209 (167-3919)	0.073	Y=4.231+0.191x
24	26.7 (15.7-45.6)	52.5 (33.5-69.3)	276 (143-532)	0.178	Y=4.271+0.341x
48	10.1 (3.06-33.8)	21.8 (4.49-39.4)	157 (12-355)	0.200	Y=4.883+0.275x
72	119 (58.5-165)	281 (205-538)	2320 (572-9410)	0.932	Y=4.796+0.346x

The values in parentheses are fiducial limits; LC= Lethal Concentration

Table 4.4d: Relative toxicity of insecticides against worker termites *Odontotermes brunneus* (Hagen) at 18, 24 and 48 hours after exposure

Hours	Relative toxicity(RT) at LC values					
	RT at LC_{30}		RT at LC_{50}		RT at LC_{90}	
	Spinetoram	Imidacloprid	Spinetoram	Imidacloprid	Spinetoram	Imidacloprid
18	1.60	1.00	1.91	1.00	2.99	1.00
24	1.92	1.00	1.64	1.00	1.13	1.00
48	1.00	1.59	1.00	1.12	1.00	1.08

Relative toxicity= LC value of least toxic insecticide/LC value of candidate insecticide
LC= Lethal Concentration

At 18h after exposure, at all three LC levels, Spinetoram was more toxic insecticide (LC_{30} = 22.8, LC_{50} = 62.3 and LC_{90} = 737 ppm) than Imidacloprid (LC_{30} = 36.5, LC_{50} = 119 and LC_{90} = 2209 ppm). Considering the relative toxicity (RT) value of Imidacloprid as unity (being least toxic) a comparative dose mortality response expressed in terms of relative toxicity indicated that Spinetoram was 1.60 (RT_{30}), 1.91 (RT_{50}) and 2.99 (RT_{90}) times more toxic than Imidacloprid at 18h after exposure.

At 24h after exposure, at all three LC levels, Spinetoram was more toxic insecticide (LC_{30} = 13.9, LC_{50} = 31.9 and LC_{90} = 244 ppm) than Imidacloprid (LC_{30} =26.7, LC_{50} = 52.5 and LC_{90} = 276 ppm). The data on relative toxicity indicated that Spinetoram was 1.92 (RT_{30}), 1.64 (RT_{50}) and 1.13 (RT_{90}) times more toxic than Imidacloprid.

However, at 48h after exposure, at all three LC levels Imidacloprid was more toxic as values being 10.1 ppm (LC_{30}), 23.9 ppm (LC_{50}), 97 ppm (LC_{90}) and Spinoteram showed less toxicity (LC_{30} = 16.1, LC_{50} = 21.8 and LC_{90} = 170 ppm) and Imidacloprid was 1.59 (RT_{30}), 1.12 (RT_{50}) and 1.08 (RT_{90}) times more toxic than Spinetoram.

Our observations are in accordance with the findings of **Iqbaal *et al*. (2013)** where the order of average toxicity of insecticides against *Microtermes mycophagus*, reported from highest to lowest was: Chlorfenapyr > Spinosad > Thiamethoxam > Fipronil > Indoxacarb > Imidacloprid.

The difference in the toxicity of the tested insecticides might result because of the difference in their modes of action. **Su *et al.* (1987)** reported that slow-acting toxicants required a longer time to kill termites at low concentrations than at high concentrations. The level of mortality and the speed of death were dependent on concentration.

Manzoor *et al.* (2012) reported that *Heterotermes indicola* when treated with Imidacloprid, Chlorfenapyr, Bifenthrin, Fipronil, Bifenthrin, and Cadusafos, it took more than 8 hours to obtain 97% mortality with LC50 values for *H. indicola* were 346.75, 75.86, 14.45, 1.05, 0.46 for Imidacloprid, Chlorfenapyr, fipronil, Bifenthrin, and Cadusafos, respectively after 8 hrs of exposure. He also mentioned that Imidacloprid, Chlorfenapyr and Fipronil are slow acting insecticides and showed less mortality when compared to Bifenthrin.

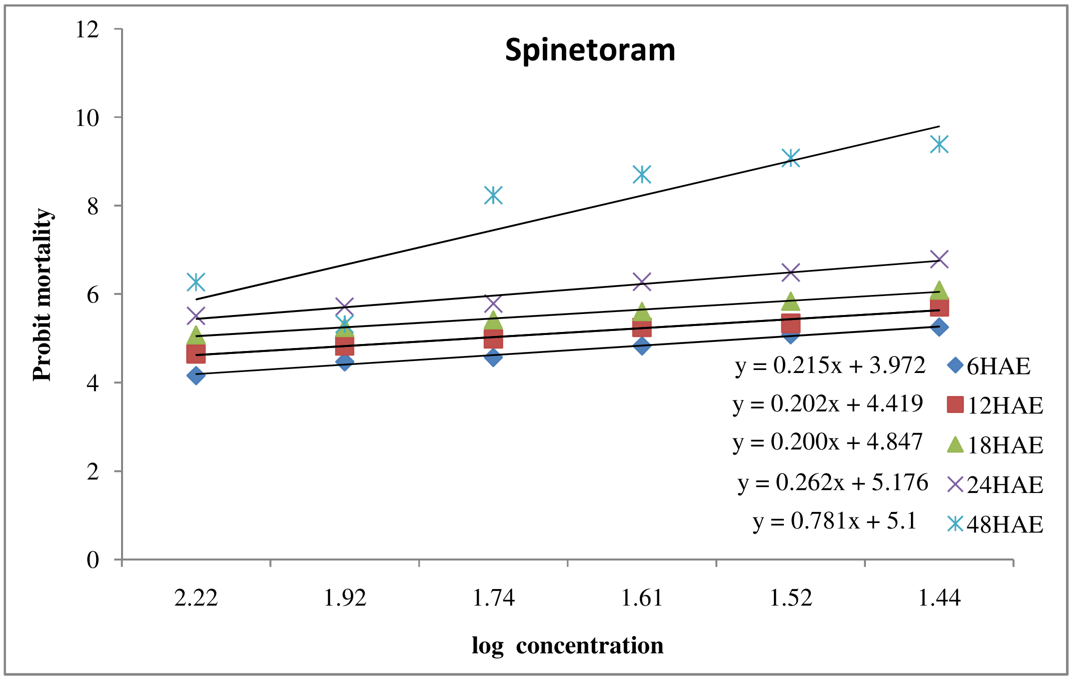


Fig. 4.4.1: Dosage-mortality response of Spinetoram 12 SC against worker termites *Odontotermes brunneus* (Hagen)

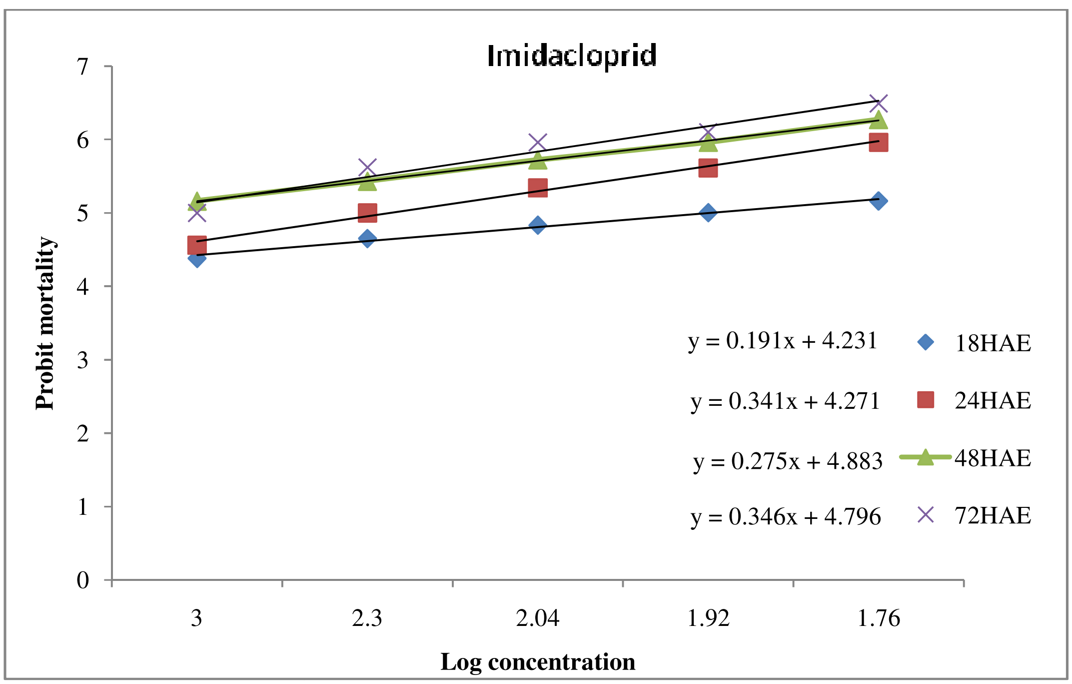


Fig. 4.4.2: Dosage-mortality response of Imidacloprid17.8% SL against worker termites *Odontotermes brunneus* (Hagen)

4.5 Assessment of Sentricon Colony Elimination System using Hexaflumuron bait on termites in household ecosystem

(A) Structure for study: At home 1

Six blank (dummy bait) in-ground (IG) stations as monitoring devices were installed on 16th Sep, 2013, five stations had active termite feeding on the monitoring devices (Table 4.5a & Plate 7). The data presented in Table 4.5b and Figure 4.5.1 revealed that on 14th Oct 2013, one station was replaced with Hexaflumuron-treated baits as much activity of termites was observed while other three stations were replaced on 28th Oct 2013 and one was replaced on 11th Nov 2013. The other one station remained blank with dummy bait. The termites continued to feed on these baits in the presence of Hexaflumuron, a chitin synthesis inhibitor. The feeding activity of termites, however, was declining in the month of December and January. By second fortnight of January 2014, the termites ceased their feeding activity and no termites were found in any stations except one in which again termite infestation was observed in the month of March but only for 22 days in which they consumed 7.2 g of bait. The termites consumed a total of 79.4 g of baits with 397mg of baits containing Hexaflumuron in total baiting period of 70-160 days (Table 4.5c). Continuous monitoring up to 22nd September 2014, showed no termite activity within the original baited station.

Six above-ground (AG) Hexaflumuron bait station were installed over active mud galleries on 16th Sep 2013 (Plate 8&9). All stations were found infested with termites on 30th Sep 2013 (Table 4.5d, Figure 4.5.2). The termites ceased their feeding activities by 25th Nov 2013, 70 days after baiting. The termites consumed 35.02 g baits including 175.1 mg of baits containing Hexaflumuron (Table 4.5e). The stations were monitored up to 22nd September 2014 (more than 6 months), but no infestations were observed.

(B) Structure for study: At home 2

Out of seven blank IG stations that were installed on 19th Sep 2013, five were infested which replaced with Hexaflumuron-treated bait up to 17th Oct 2013 and other two remained with dummy baits (Table 4.5a). In three stations, no termite activity was recorded as of 09th Jan 2014, 98 days after baiting. While in two stations, infestation of termites again observed in the beginning of March, continued to feed on bait till 17th April 2014. But after that no activity of termites was observed in any station. Monitoring continued up to 18th September 2014 (Table 4.5f, Figure 4.5.3). The termites consumed a total of 98.6 g of bait containing 493 mg of Hexaflumuron within a baiting period ranging from 55-181 days (Table 4.5g).

Five above-ground (AG) Hexaflumuron bait station were installed over active mud galleries on 19th Sep 2013, three were found infested on 3rd Oct 2013 while two were not infested throughout the study period. By 26th Dec 2013, after 55-98 days of baiting, termites ceased their activity (Table 4.5h, Figure 4.5.4). The termites consumed a total of 67 g of baits containing 335 mg of Hexaflumuron (Table 4.5i). After 26th Dec 2013 no termite activity was observed in the Sentricon stations till 18th September 2014.

(C) Structure for study: At home 3

Data presented in Table 4.5a revealed that out of six blank (dummy bait) IG station were installed on 21 Sep, 2013, three stations had active termite feeding which replaced with Hexaflumuron-treated bait on 19th Oct 2013 and other three were not infested by termites so remained with dummy baits only. From 11th Jan 2014 to 20th September 2014, no observable feeding was found on the monitoring traps and Sentricon stations (Figure 4.5.5). Termites consumed 52.6 g of bait containing 263 mg of Hexaflumuron. The time requirement from initial baiting to colony elimination was ranging from 83 to 97 days (Table 4.5j& 4.5k).

Six AG Hexaflumuron bait station were placed over active mud galleries on 21 Sep, 2013, four were infested by termites. After 14th Dec 2013, no termite activity was recorded in the stations up to 20th September 2014 (Figure 4.5.6). The termites consumed a total of 68 g of baits containing 340 mg of Hexaflumuron within a baiting period ranging from 54 to 82 days (Table 4.5l & 4.5m).

These results are in accordance with the findings of **Sajap *et al.* (2002)** who reported that termites continued to feed on the baits regardless the content of the matrix and eventually ceased feeding 35- 62 days after baiting had commenced. These colonies consumed 30.5-217 g of bait matrix or 152.5 to 1085.0 mg of Hexaflumuron.

Plate 7: Details of inspection of In-ground (IG) Station

Inspection of Above-ground Station

Plate8: Details of inspection of Above-ground (AG) Station

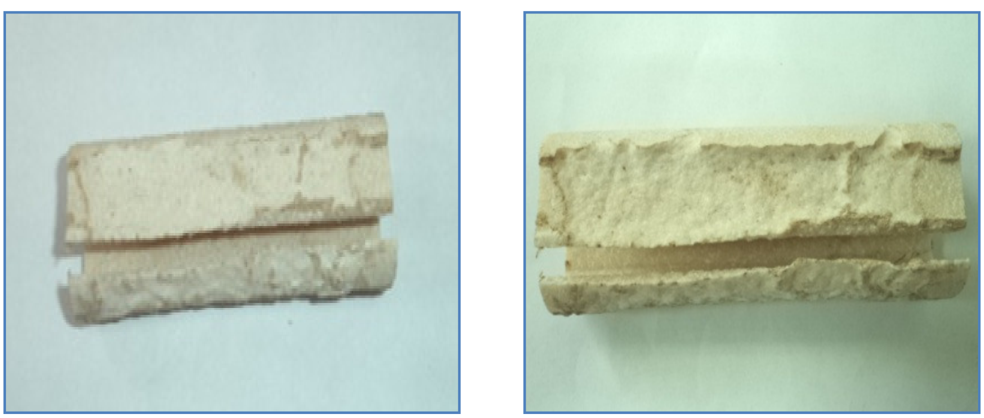


Plate 9: Hexaflumuron bait after baiting

Table 4.5a: Details of Installation of bait stations

Site	Date of installation	Number of IG bait station installed	Number of stations with active termite activity	Date of installation	Number of AG bait station installed	Number of stations with active termite activity
Home 1	16/09/2013	6	5	16/09/2013	6	6
Home 2	19/09/2013	7	5	19/09/2013	5	3
Home 3	21/09/2013	6	3	21/09/2013	6	4

IG= In-ground bait station; AG= Above-ground bait station

Table 4.5b: Data collection-Inspection: For Home 1 (IG stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3		Station no.4		Station no.5	
	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)
16 Sep/13	-	-	-	-	-	-	-	-	-	-
30 Sep/13	I^m	NA	I^m	A	I^m	NA	I^m	NA	I^m	NA
14Oct/13	I^m	A	I^m	5.2	I^m	NA	I^m	A	I^m	A
28Oct/13	I^m	6.8	**R**	2.9	I^m	A	I^m	6.1	I^m	8.5
11Nov/13	**R**	0.8	I	5.1	I^m	5.1	**R**	1.9	**R**	1.7
25Nov/13	I	2.7	I	3.4	**R**	2.5	I	3.8	I	5.1
9 Dec/13	I	4.2	**R**	2.2	I	3.9	I	4.9	I	4.7
23Dec/13	**R**	2.8	I	1.7	I	4.8	**R**	2.5	**R**	2.9
06Jan/13	I	1.7	I	1.2	**R**	0.0	I	1.5	I	1.5
20Jan/14	I	0.0	**R**	0.9	I	0.0	I	0.0	I	0.9
3 Feb/14	**R**	0.0	I	0.0	I	0.0	**R**	0.0	**R**	0.0
17Feb/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
3 Mar/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
17Mar/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
31Mar/14	I	0.0	I	0.0	I	3.1	I	0.0	I	0.0
7 Apr/14	I	0.0	I	0.0	I	2.2	I	0.0	I	0.0
21Apr/14	I	0.0	I	0.0	**R**	1.9	I	0.0	I	0.0
5 May/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
19May/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
2June/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
16June/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
30June/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
14July/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
28July/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
11Aug/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
25Aug/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
8 Sep/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
22 Sep/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0

Est.=Estimated; I^m = Inspected monitoring tube; I= Inspected hexaflumuron bait tube; R = Replaced with hexaflumuron bait; NA= No Activity; A= Active termites on monitoring tube

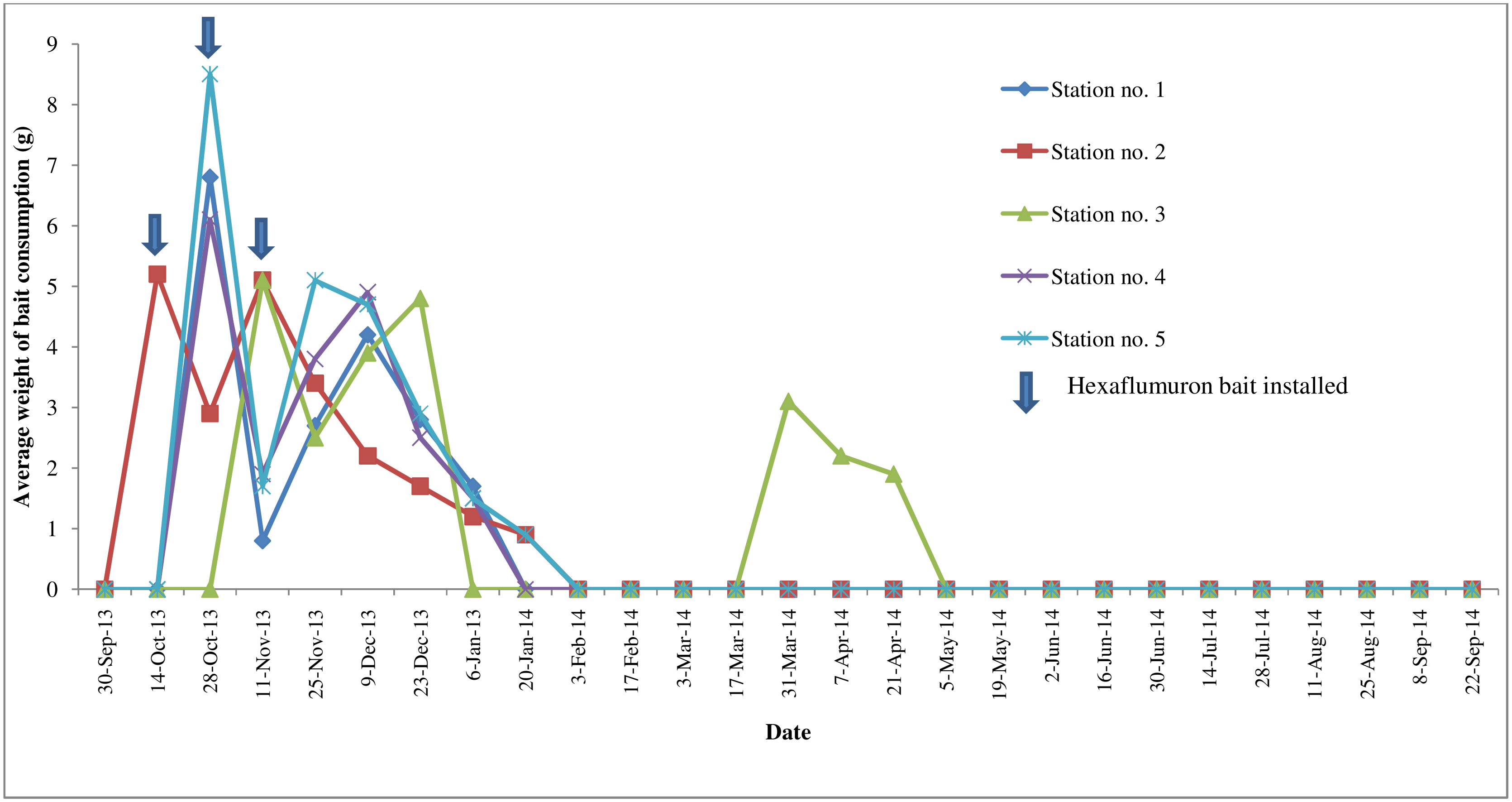


Fig. 4.5.1: Foraging activity of termite species on Hexaflumuron bait in In-ground stations at home 1

Table 4.5c: Hexaflumuron bait application to control termites in Home 1 (IG stations)

Station no.	No. of bait tubes used/colony	Bait matrix consumed(g)	Hexaflumuron consumed (mg)	Baiting period (Days)	Comments
1.	3	12.2	61	70	-
2.	3	17.4	87	97	-
3.	3	18.4	92	160	Re-infestation in month of March
4.	3	14.6	73	70	-
5.	3	16.8	84	84	-

Table 4.5d: Data collection-Inspection: For Home 1 (AG stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3		Station no.4		Station no.5		Station no.6	
	Est. number of termites	Bait consumed (g)	Est. number of termites	Bait consumed (g)	Est. number of termites	Bait consumed (g)	Est. number of termites	Bait consumed (g)	Est. number of termites	Bait consumed (g)	Est. number of termites	Bait consumed (g)
16 Sep/13	-	-	-	-	-	-	-	-	-	-	-	-
30 Sep/13	570	4.7	490	3.1	450	3.1	150	1.2	335	3.4	175	2.4
14Oct/13	240	2.3	265	1.9	130	1.3	135	0.77	124	1.3	97	1.5
28Oct/13	135	1.9	136	0.87	NA	0.0	150	0.13	110	0.93	75	0.56
11Nov/13	110	1.7	97	0.31	NA	0.0	52	0.2	70	0.45	40	0.10
25Nov/13	NA	0.9	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
9 Dec/13	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
23Dec/13	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
06Jan/13	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
20Jan/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
3 Feb/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
17Feb/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
3 Mar/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
17Mar/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
31Mar/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
7 Apr/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
21Apr/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
5 May/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
19May/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
2June/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
16June/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
30June/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
14July/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
28July/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
11Aug/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
25Aug/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
8 Sep/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
22 Sep/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0

Est.=Estimated, NA= No Activity; A= Active termites on monitoring tube

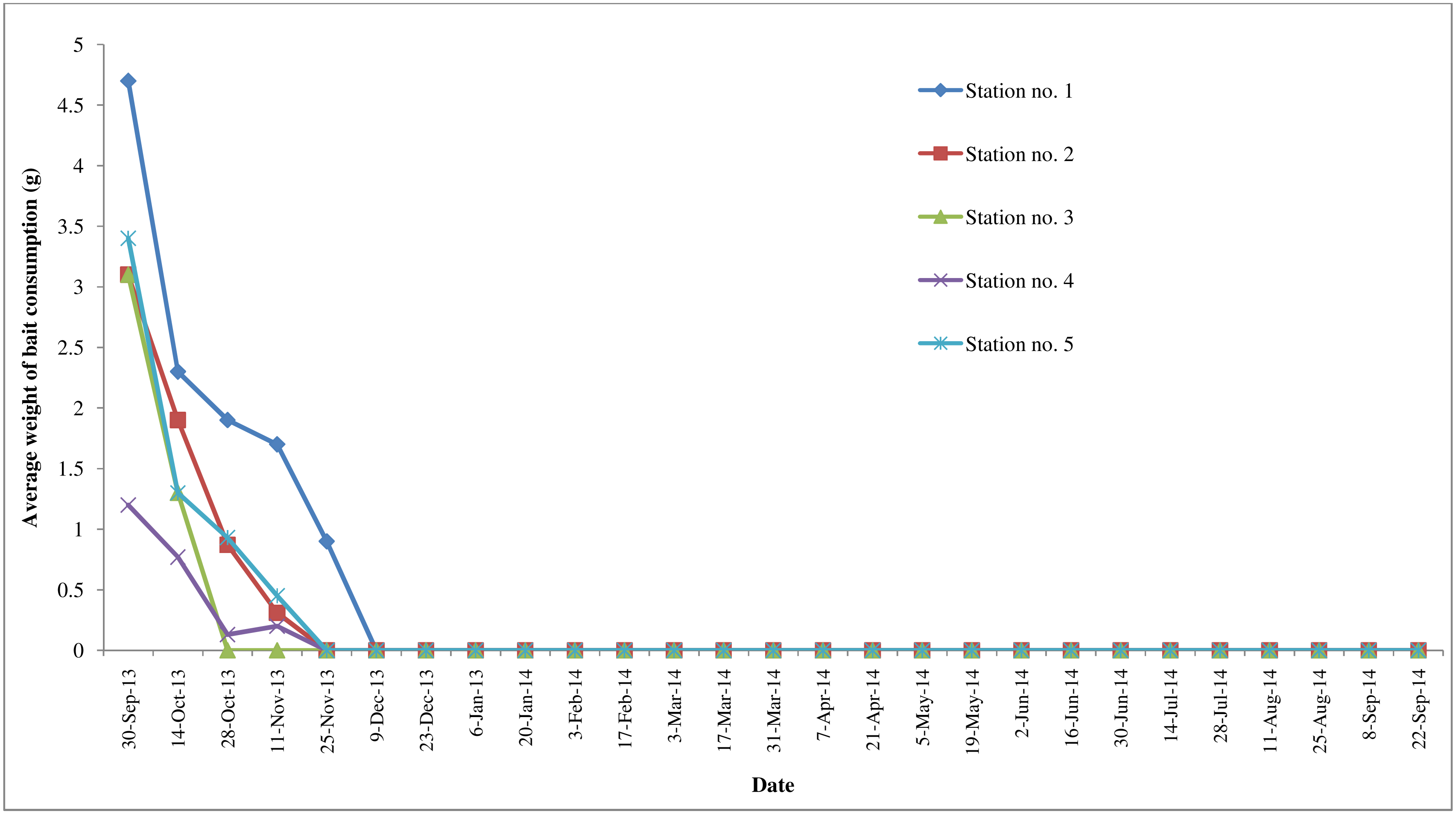


Fig. 4.5.2: Foraging activity of termite species on Hexaflumuron bait in Above-ground stations at home 1

Table 4.5e: Hexaflumuron bait application to control termites in home 1 (AG stations)

Station no.	Number of active termites/station	Number of bait tubes used/colony	Bait matrix consumed(g)	Hexaflumuron consumed (mg)	Baiting period (days)
1.	1055	1	11.5	57.5	70
2.	988	1	6.18	30.9	56
3.	580	1	4.4	22.0	28
4.	487	1	2.3	11.5	56
5.	639	1	6.08	30.4	56
6.	387	1	4.56	22.8	56

Table 4.5f: Data collection-Inspection: For Home 2 (IG stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3		Station no.4		Station no.5	
	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)	Station action (I/ R)	Bait consumed (g)
19 Sep/13	I^m	-	I^m	-	I^m	-	I^m	-	I^m	-
03 Oct/13	I^m	2.5	I^m	A	I^m	A	I^m	A	I^m	3.5
17Oct/13	R	1.5	I^m	4.3	I^m	3.4	I^m	3.7	R	6.7
31Oct/13	I	3.9	R	4.1	R	2.8	R	3.7	I	3.5
14Nov/13	I	4.1	I	5.6	I	4.3	I	5.9	I	5.8
28Nov/13	R	5.6	I	2.9	I	5.9	I	5.3	R	1.2
12 Dec/13	I	1.9	R	1.7	R	3.6	R	0.0	I	0.0
26Dec/13	I	1.3	I	0.3	I	1.3	I	0.0	I	0.0
09 Jan/14	R	0.4	I	0.0	I	0.0	I	0.0	I	0.0
23Jan/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
06Feb/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
20Feb/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
06Mar/14	I	0.0	I	0.0	I	0.0	I	2.1	I	0.0
20Mar/14	I	0.0	I	0.0	I	1.5	R	3.8	I	0.0
03Apr/14	I	0.0	I	0.0	R	3.2	I	4.1	I	0.0
17 Apr/14	I	0.0	I	0.0	I	0.0	I	0.6	I	0.0
01May/14	I	0.0	I	0.0	I	0.0	R	0.0	I	0.0
15 May/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
29May/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
12June/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
26June/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
10July/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
24July/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
7Aug/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
21Aug/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
4Sep/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0
18Sep/14	I	0.0	I	0.0	I	0.0	I	0.0	I	0.0

Est.=Estimated; I^m = Inspected monitoring tube; I= Inspected hexaflumuron bait tube; R = Replaced with hexaflumuron bait; NA= No Activity; A= Active termites on monitoring tube

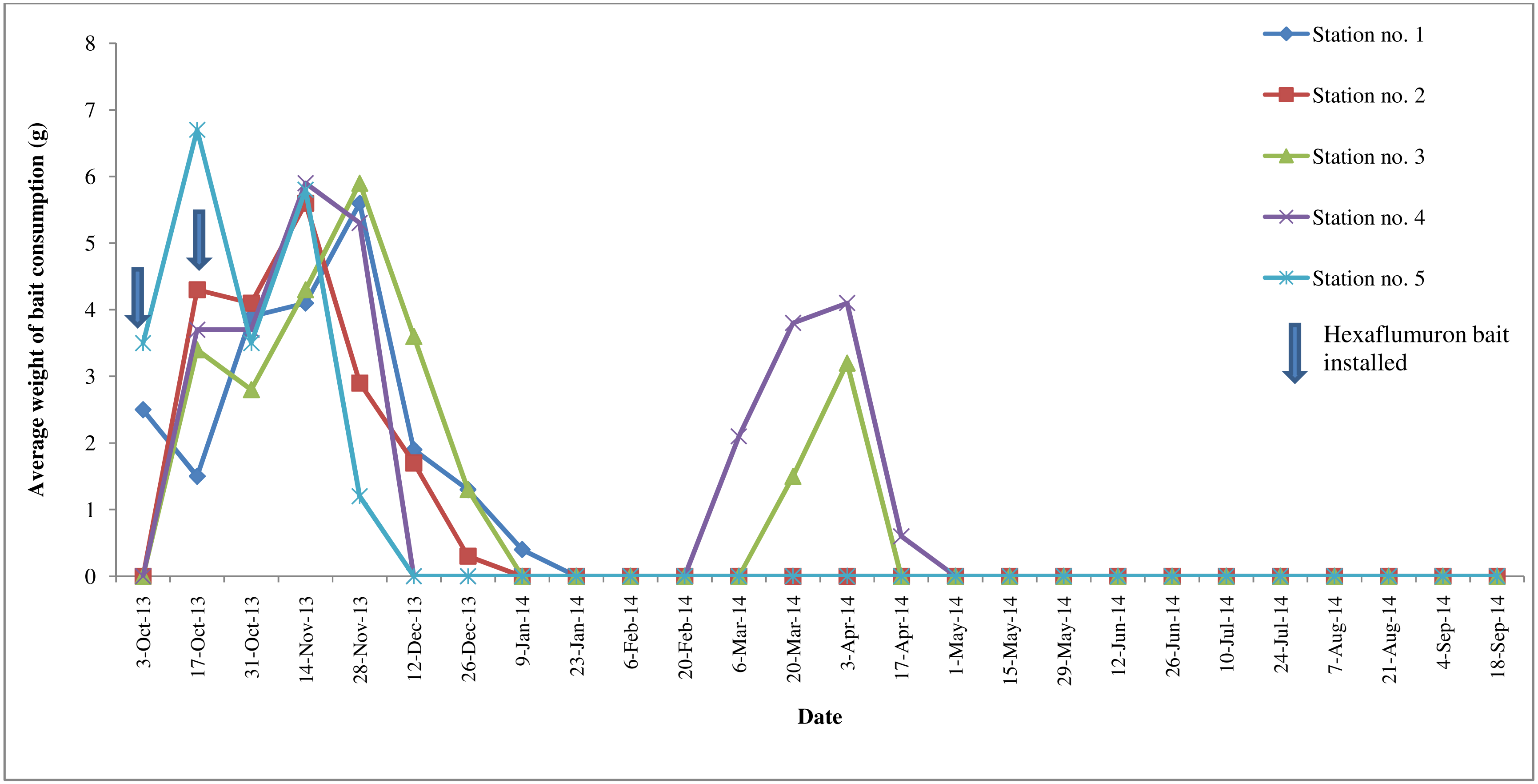


Fig. 4.5.3: Foraging activity of termite species on Hexaflumuron bait in In-ground stations at home 2

Table 4.5g: Hexaflumuron bait application to control termite in home 2 (IG stations)

Station no.	No. of bait tubes used/colony	Bait matrix consumed(g)	Hexaflumuron consumed (mg)	Baiting period	Comments
1.	3	18.7	93.5	98	-
2.	2	14.6	73	69	-
3.	3	22.6	113	167	Re-infestation
4.	4	25.5	127.5	181	Re-infestation
5.	2	17.2	86	55	-

Table 4.5h: Data collection-Inspection: For Home 2 (AG stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3	
	Estimated no. of termites	Bait consumed (g)	Estimated no. of termites	Bait consumed (g)	Estimated no. of termites	Bait consumed (g)
19 Sep/13	-	-	-	-	-	-
03 Oct/13	860	4.9	945	5.2	990	4.3
17Oct/13	700	5.3	1000	5.9	1400	6.1
31Oct/13	657	4.7	898	5.1	720	5.4
14Nov/13	482	2.9	560	3.3	280	2.5
28Nov/13	456	3.0	543	2.0	50	0.8
12 Dec/13	298	1.9	270	1.6	NA	0.0
26Dec/13	30	0.9	69	0.7	NA	0.0
09 Jan/14	NA	0.5	NA	0.0	NA	0.0
23Jan/14	NA	0.0	NA	0.0	NA	0.0
06Feb/14	NA	0.0	NA	0.0	NA	0.0
20Feb/14	NA	0.0	NA	0.0	NA	0.0
06Mar/14	NA	0.0	NA	0.0	NA	0.0
20Mar/14	NA	0.0	NA	0.0	NA	0.0
03April/14	NA	0.0	NA	0.0	NA	0.0
17 Apr/14	NA	0.0	NA	0.0	NA	0.0
01May/14	NA	0.0	NA	0.0	NA	0.0
15 May/14	NA	0.0	NA	0.0	NA	0.0
29May/14	NA	0.0	NA	0.0	NA	0.0
12June/14	NA	0.0	NA	0.0	NA	0.0
26June/14	NA	0.0	NA	0.0	NA	0.0
10July/14	NA	0.0	NA	0.0	NA	0.0
24July/14	NA	0.0	NA	0.0	NA	0.0
7Aug/14	NA	0.0	NA	0.0	NA	0.0
21Aug/14	NA	0.0	NA	0.0	NA	0.0
4Sep/14	NA	0.0	NA	0.0	NA	0.0
18Sep/14	NA	0.0	NA	0.0	NA	0.0

NA= No Activity; A= Active termites on bait tube; Est.=Estimated

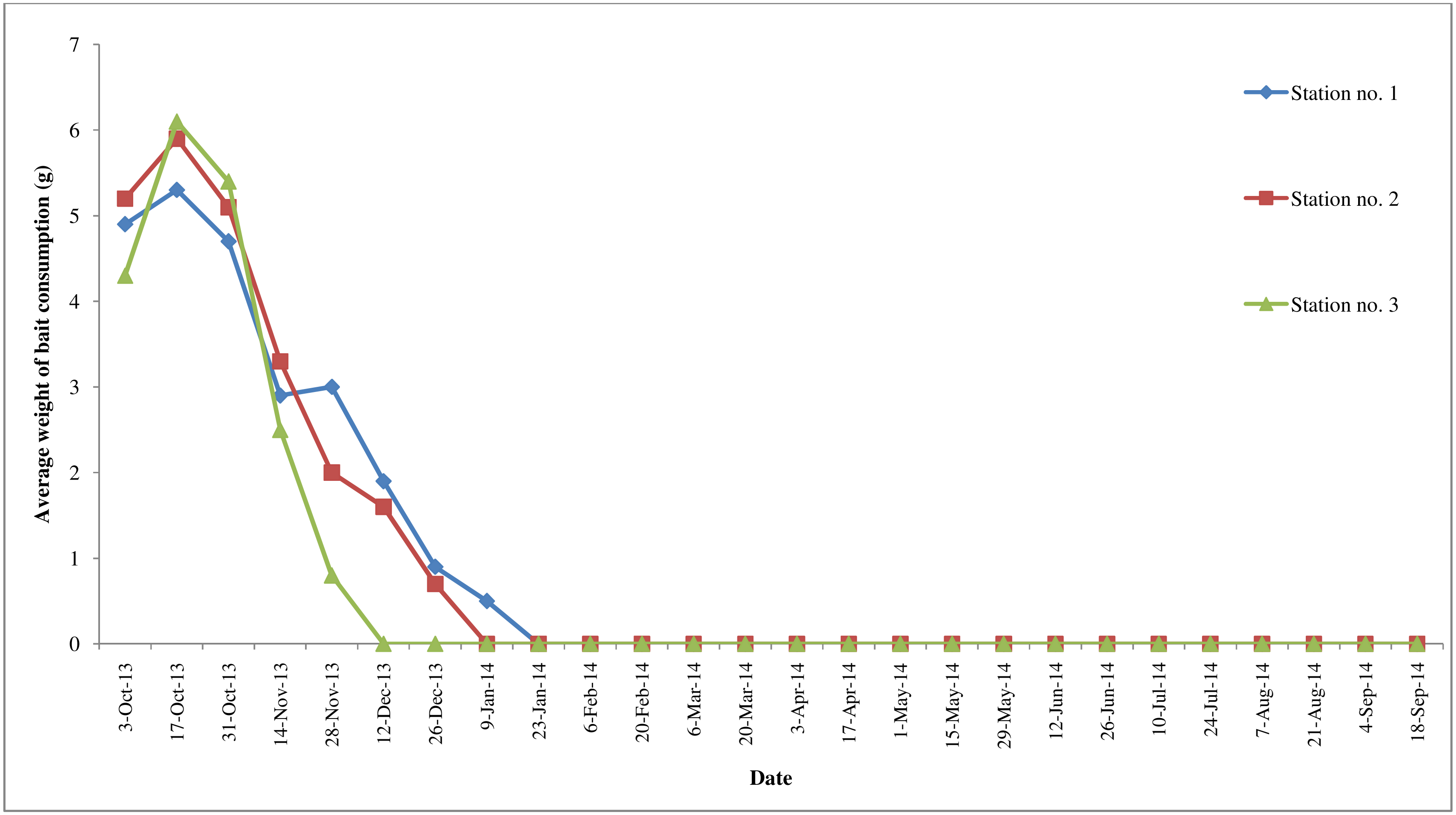


Fig. 4.5.4: Foraging activity of termite species on Hexaflumuron bait in Above-ground stations at home 2

Table 4.5i: Hexaflumuron bait application to control termites in home 2 (AG stations)

Station no.	No. of active termites/station	No. of bait tubes used/colony	Bait matrix consumed(g)	Hexaflumuron consumed (mg)	Baiting period
1.	3483	1	24.1	120.5	98
2.	4285	1	23.8	119	83
3.	3440	1	19.1	95.5	55

Table 4.5j: Data collection-Inspection: For Home 3 (In-ground stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3	
	Station action (I/R)	Bait consumed (g)	Station action (I/R)	Bait consumed (g)	Station action (I/R)	Bait consumed (g)
21 Sep/13	I^m	-	I^m	-	I^m	-
05Oct/13	I^m	2.3	I^m	A	I^m	2.3
19Oct/13	R	1.7	I^m	4.9	R	2.6
02Nov/13	I	3.9	R	3.7	I	3.6
16Nov/13	I	6.7	I	5.3	I	5.2
30Nov/13	R	4.7	I	3.7	R	3.9
14Dec/13	I	1.2	R	1.7	I	1.8
28Dec/13	I	0.4	I	0.9	I	0.8
11Jan/14	I	0.0	I	0.6	R	0.2
25Jan/14	I	0.0	I	0.0	I	0.0
08Feb/14	I	0.0	I	0.0	I	0.0
22Feb/14	I	0.0	I	0.0	I	0.0
08Mar/14	I	0.0	I	0.0	I	0.0
22Mar/14	I	0.0	I	0.0	I	0.0
05Apr/14	I	0.0	I	0.0	I	0.0
19Apr/14	I	0.0	I	0.0	I	0.0
03May/14	I	0.0	I	0.0	I	0.0
17May/14	I	0.0	I	0.0	I	0.0
31May/14	I	0.0	I	0.0	I	0.0
14June/14	I	0.0	I	0.0	I	0.0
28June/14	I	0.0	I	0.0	I	0.0
12July/14	I	0.0	I	0.0	I	0.0
26July/14	I	0.0	I	0.0	I	0.0
9Aug/14	I	0.0	I	0.0	I	0.0
23Aug/14	I	0.0	I	0.0	I	0.0
6Sep/14	I	0.0	I	0.0	I	0.0
20Sep/14	I	0.0	I	0.0	I	0.0

I^m = Inspected monitoring tube; I= Inspected hexaflumuron bait tube; R = Replaced with hexaflumuron bait; NA= No Activity; A= Active termites on monitoring tube; Est.=Estimated

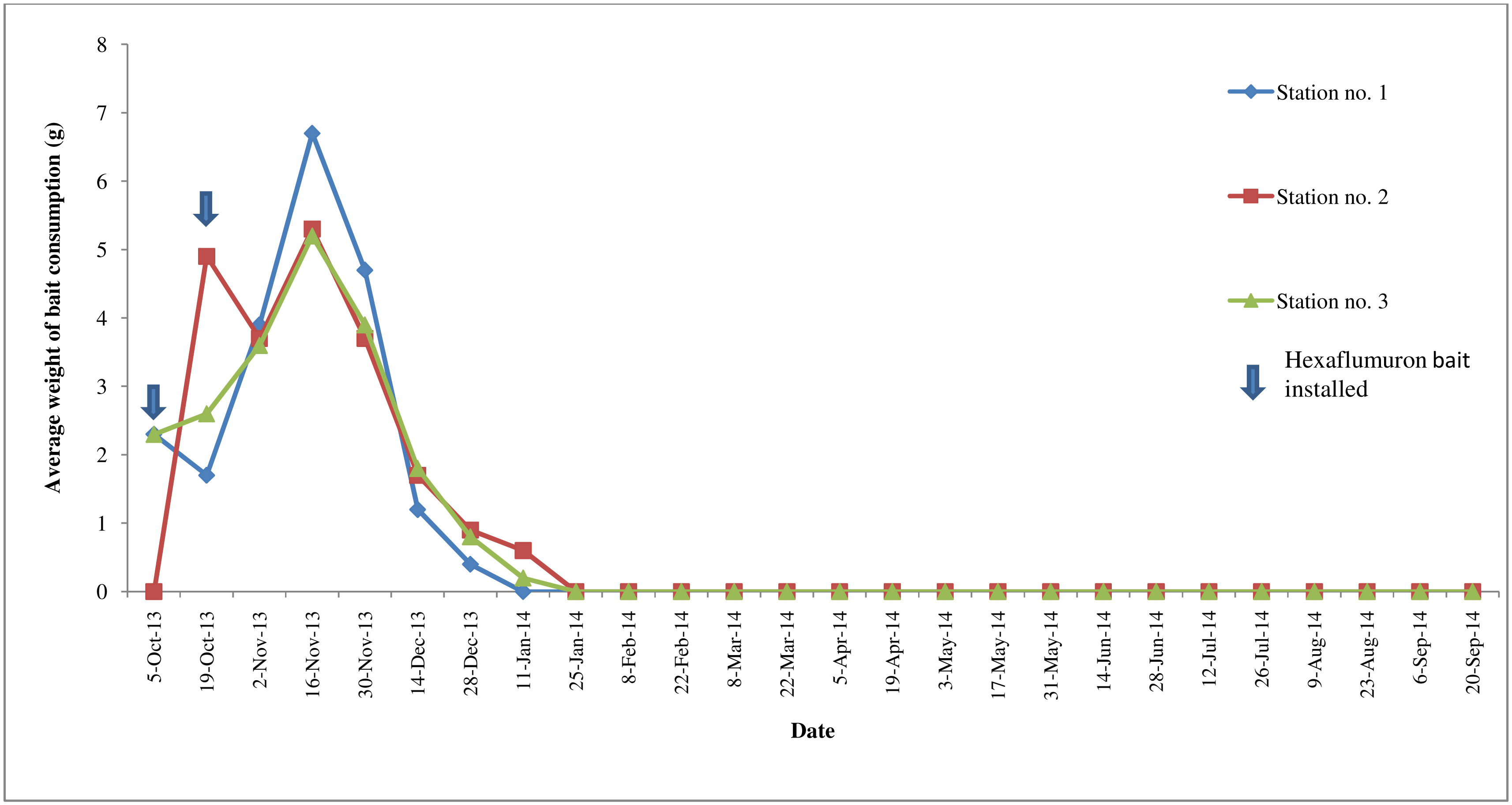


Fig. 4.5.5: Foraging activity of termite species on Hexaflumuron bait in In-ground stations at home 3

Table 4.5k: Hexaflumuron bait application to control termites in home 3 (IG stations)

Station no.	No. of bait tubes used/colony	Bait matrix consumed(g)	Hexaflumuron consumed (mg)	Baiting period
1.	2	18.6	93	83
2.	2	15.9	79.5	83
3.	3	18.1	90.5	97

Table 4.5l: Data collection-Inspection: For Home 3 (AG stations with active termite activity)

Date of observation	Station no. 1		Station no.2		Station no.3		Station no.4	
	Estimated no. of termites	Bait consumed (g)	Estimated no. of termites	Bait consumed (g)	Estimated no. of termites	Bait consumed (g)	Estimated no. of termites	Bait consumed (g)
22 Sep/13	-	-	-	-	-	-	-	-
05Oct/13	970	5.6	A	-	850	4.7	A	-
19Oct/13	1240	6.3	665	3.9	1130	5.8	1295	6.1
02Nov/13	835	5.3	1100	5.2	980	5.0	430	2.7
16Nov/13	765	4.1	872	4.7	170	1.3	170	1.9
30Nov/13	360	1.4	560	2.1	NA	0.0	35	0.3
14Dec/13	87	0.9	390	0.7	NA	0.0	NA	0.0
28Dec/13	NA	0.0	NA	0.0	NA	0.0	NA	0.0
11Jan/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
25Jan/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
08Feb/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
22Feb/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
08Mar/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
22Mar/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
05Apr/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
19Apr/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
03May/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
17May/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
31May/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
14June/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
28June/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
12July/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
26July/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
9Aug/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
23Aug/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
6Sep/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0
20Sep/14	NA	0.0	NA	0.0	NA	0.0	NA	0.0

NA= No Activity; A= Active termites on bait tube; Est.=Estimated

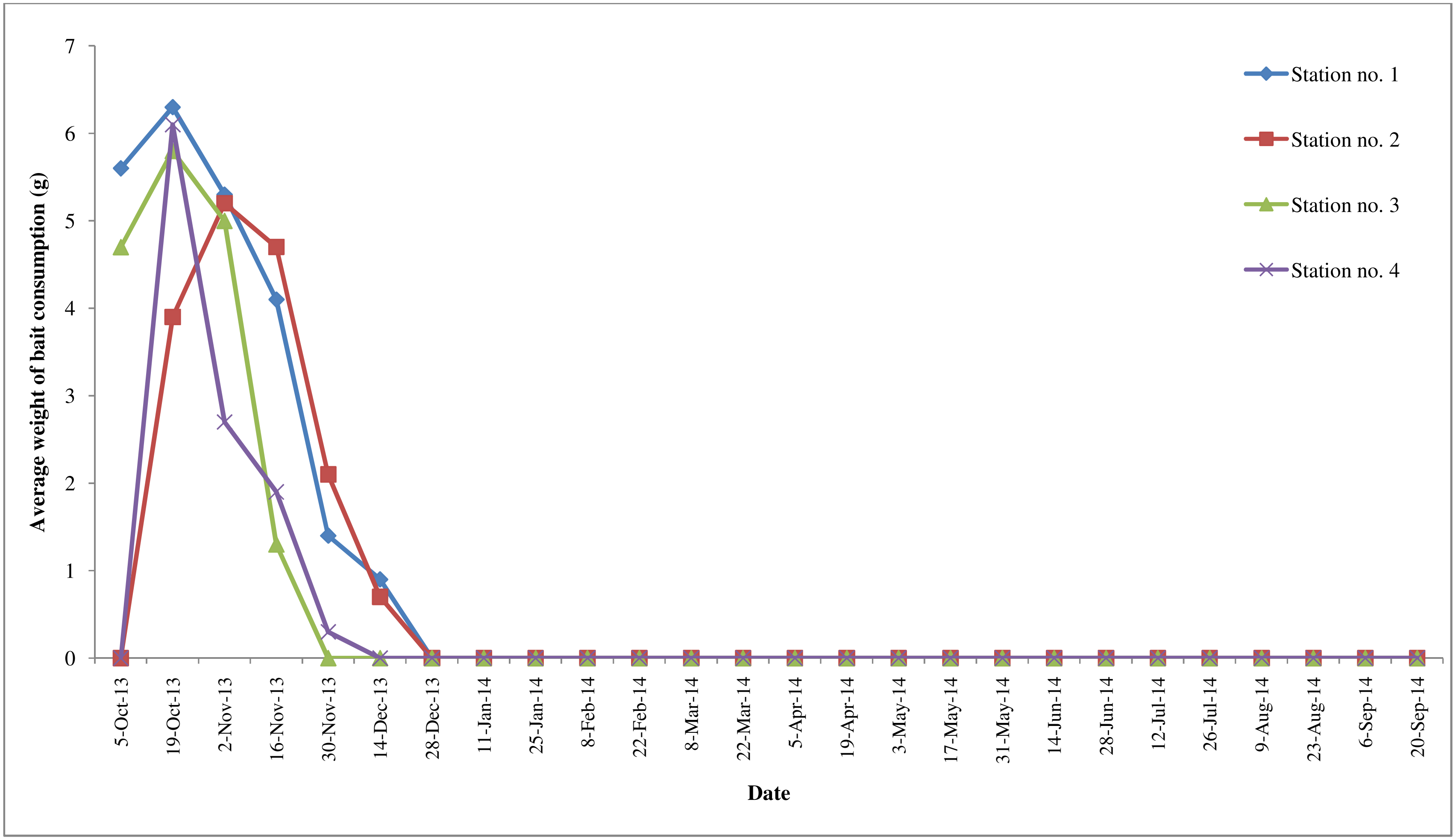


Fig. 4.5.6: Foraging activity of termite species on Hexaflumuron bait in Above-ground stations at home 3

Table 4.5m: Hexaflumuron bait application to control termites in home 3 (AG staions)

Station no.	No. of active termites/station	No. of bait tubes used/colony	Bait matrix consumed (g)	Hexaflumuron consumed (mg)	Baiting period
1.	4257	1	23.6	118	82
2.	3587	1	16.6	83	69
3.	3130	1	16.8	84	54
4.	1930	1	11	55	55

While in 2009, he conducted an experiment in which an improved, cellulosic bait matrix (Preferred Textured Cellulose, PTC) containing 0.5% Hexaflumuron was tested against field colonies of the subterranean termites *Coptotermes gestroi* and *Schedorbinotermes* sp. in Malaysia. All of the eight colonies were eliminated between 42-77 days (mean = 60 days) with estimated bait consumption of 22.93-167.00 g (mean = 60.17 g) which is equivalent to 114-835 mg of Hexaflumuron.

Prabhakaran (2001) also reported that five eastern subterranean termite colonies were eliminated after consumption of 112.6g to 571.2g of bait matrix over a period of 3 to 11 months.

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSION

Sugarcane is one of the most important industrial field crops in India. The present investigation, entitled "Studies on diversity of major insect-pest of sugarcane along with efficacy of some novel insecticides against termites in field and household ecosystem" was undertaken to investigate the insect pests associated with sugarcane, their seasonal incidence, as well as influence of abiotic factors on their activity. Effect of some novel insecticides as basal application and sett treatment against sugarcane termite and on yield was also studied. Apart from field ecosystem, efficacy of Chitin synthesis inhibitor against termite was also studied in household ecosystem.

The salient experimental findings of the study are summarized below:

1. A total of thirteen insect-pests along with various spider species were observed. Among which five insect species belonged to the order Lepidoptera that comprised of borer complex of sugarcane, four to Hemiptera, one to Coleoptera, one to Isoptera, and one to Orthoptera, one to Dermaptera and spider species belonged to Araneae (Arachnida).
2. The experiment on seasonal incidence of *C. infuscatellus* indicates that the activity started from first week of May (18^{th} standard week) to second week of July (27^{th} standard week) and the per cent infestation varied from 1.78 to 23.70 per cent with peak activity recorded in the fourth week of May (23.70 per cent).
3. The infestation of *S. nivella* occur in sugarcane variety CoP97222 from third week of May (20^{th} Standard week) to third week of October (42^{nd} Standard week) which is varied from 0.48 to 5.52 per cent. Maximum borer incidence was recorded during third week of June (5.52 per cent).
4. The stalk borer incidence started from second week of October and continued till first week of March with negligible or no activity during December and January month. The maximum incidence was recorded i.e. 3.58 per cent during fourth week of October (43^{rd} standard week).

5. The per cent infestation by root borer varied from 0.82 to 6.95 per cent during the month of May and June. Maximum infestation (6.95 per cent) of root borer was recorded in the second week of May (19^{th} standard week).

6. The black bug population varied from 1.5 per tiller to 5.9 per tiller during the 18^{th} standard week to 29^{th} standard week (May to July) with maximum population recorded in the fourth week of June.

7. High mean temperature, rainfall with high relative humidity favours the pest population buildup in sugarcane crop. Study of peak activity period of different pest is important from management point of view, as it is helpful in deciding the various control measures for getting sustainable yield.

8. A total of nine termite species were found in different habitats which belong to six genera, three sub-families Amitermitinae, Termitinae and Macrotermitinae of Family Termitidae while two sub-families Heterotermitinae and Coptotermitinae of family Rhinotermitidae. All nine identified species (*Coptotermes heimi* (Wasmann), *Heterotermes indicola* (Wasmann), *Microcerotermes beesoni* Snyder, *Angulitermes* sp., *Odontotermes* sp., *O. feae* (Wasmann), *O. brunneus* (Hagen), *Microtermes mycophagus* (Desneux) and *M. obesi* (Holmgren) recorded first time from Pantnagar area.

9. The results on field efficacy of newer insecticides against sugarcane termites showed higher germination percentage in all the treatments as compare to control. Nil sett bud damage was recorded in Spinetoram treated setts (Treatment T_1 and T_2) while maximum sett bud damage (19.9 %) was recorded in treatment T_6 (Control).

10. Minimum infestations of termites were recorded under Spinetoram, 1500 ml/ ha spray over setts (T_2) at 6, 8 and 10 weeks after planting as well as at harvesting time also.

11. Cane yield was significantly high in all the insecticidal treatments ranging from 70.83 to 76.10 tonnes per ha with maximum yield was recorded in treatment T_2 (76.10 tonnes per ha) while it was 60.89 tonnes per ha in the untreated check.

12. On the basis of the results summarized above, the order of efficacy of various treatments on sugarcane yield basis was: Spinetoram (1500 > 750 ml/ha) > Chloropyrifos > Fipronil > Imidacloprid > Control Increased yield of cane in the treatments was attributed to the control of termites damaging setts, resulting in better germination which ultimately led to higher yield.

13. Results on toxicity of two insecticides against worker termites, *Odontotermes brunneus* (Hagen) showed that Spinetoram was the more toxic insecticide at all three LC levels, the values were 22.8 ppm (LC_{30}), 62.3 ppm (LC_{50}) and 737 ppm (LC_{90}) at 18h; and 13.9 ppm (LC_{30}), 31.9 ppm (LC_{50}) and 244 ppm (LC_{90}) at 24HAE, respectively while imidacloprid was less toxic (LC_{30}=36.5 and 26.7 ppm, LC_{50}= 119 and 52.5 ppm, LC_{90}=2209 and 276 ppm) at 18 & 24HAE, respectively.

14. Determination of LC_{50} values of two insecticides *viz.*, Spinetoram and Imidacloprid against termite workers indicated high efficacy of Spinetoram (LC_{50} 31.9 ppm) as compare to Imidacloprid (LC_{50} 52.5 ppm).

15. *Sentricon termite colony elimination system* stations (In-ground as well as Above-ground) were installed at three sites and the populations were baited with bait containing 0.5% Hexaflumuron. Results of In-ground stations showed that the termite colonies were eliminated after consumption of 52.6 g to 98.6g of bait matrix (263mg to 493mg Hexaflumuron) over a period of 55 to 181 days.

16. In Above-ground stations, the termite population consumed 35.02 g to 68 g of bait matrix (175.1mg to 340mg Hexaflumuron) and required a period of 28 to 83 days to eliminate all termite activity.

17. From the results obtained by *Sentricon termite colony elimination system*, it can be concluded that termites did not detect the presence of toxicant (chitin synthesis inhibitor) in the baits and continued to feed on the baits regardless the content of the matrix until foraging activity of termites totally ceased. No evidence of re-infestation was detected in station (except three bait station) over six months that might happen due to death of termite members within colony.

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Appendix

APPENDIX

Weekly weather data

STATION NAME **:** PANTNAGAR   **LONGITUDE** **:** 79 deg. 30' E
LATITUDE **:** 29 deg. N   **ALTITUDE** **:** 243.84 m. AMSL

Month	Date	Year	Metro Week No. (2012)	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
				Max.	Min.	0712 am	1412 pm					
Jan	**01-07**	**2013**	1	24.4	6.2	93	40	000.0	0	08.4	4.0	2.5
Jan	**08-14**	**2013**	2	24.2	8.9	81	49	000.0	0	05.7	3.3	3.5
Jan	**15-21**	**2013**	3	21.2	8.4	94	58	000.0	0	03.2	5.4	2.6
Jan	**22-28**	**2013**	4	16.0	6.9	96	72	000.0	0	01.0	3.1	0.9
Jan-Feb	**29-04**	**2013**	5	22.3	7.0	92	54	000.0	0	05.8	2.1	1.5
Feb	**05-11**	**2013**	6	21.7	9.8	94	58	048.3	3	04.7	5.8	2.9
Feb	**12-18**	**2013**	7	21.9	9.5	91	61	059.6	2	05.6	6.4	2.9
Feb	**19-25**	**2013**	8	22.9	10.1	91	57	024.2	1	06.6	4.6	2.3
Feb-Mar	**26-04**	**2013**	9	25.5	10.9	94	47	000.0	0	09.1	6.2	2.7
Mar	**05-11**	**2013**	10	29.0	13.2	90	46	000.0	0	08.9	3.4	3.1
Mar	**12-18**	**2013**	11	29.2	12.8	88	44	013.4	1	08.8	3.8	4.1
Mar	**19-25**	**2013**	12	29.9	15.2	88	43	000.0	0	08.3	2.5	3.6
Mar-Apr	**26-01**	**2013**	13	30.5	14.5	88	38	000.0	0	08.5	2.4	4.7
Apr	**02-08**	**2013**	14	33.3	14.8	79	24	000.0	0	10.3	7.1	7.0
Apr	**09-15**	**2013**	15	36.9	17.9	68	23	000.0	0	09.4	6.7	8.6
Apr	**16-22**	**2013**	16	34.7	18.2	61	29	008.4	1	09.4	7.3	7.8
Apr	**23-29**	**2013**	17	35.0	19.5	64	30	000.0	0	09.1	7.2	7.7
Apr-May	**30-06**	**2013**	18	38.9	19.1	60	23	000.0	0	10.1	7.4	11.4
May	**07-13**	**2013**	19	38.7	19.7	56.7	26	001.2	1	07.9	5.1	9.6
May	**14-20**	**2013**	20	38.4	23.8	60.4	31.6	000.0	0	08.8	3.0	9.1
May	**21-27**	**2013**	21	39.2	29.1	70	44.4	000.0	0	04.3	3.6	9.6
May-Jun	**28-03**	**2013**	22	37.9	25.8	67	41	000.0	0	07.8	3.0	8.8
Jun	**04-10**	**2013**	23	35.2	27.0	75	56	023.6	2	04.2	2.6	7.1
Jun	**11-17**	**2013**	24	33.6	25.2	80	66	119.8	4	03.9	8.8	6.1
Jun	**18-24**	**2013**	25	31.3	25.2	87	70	173.0	3	03.0	7.5	3.9
Jun-Jul	**25-01**	**2013**	26	31.1	25.2	91.6	71.6	287.0	4	02.4	5.9	3.6
Jul	**02-08**	**2013**	27	32.3	25.3	90.6	73.1	154.8	6	02.5	5.8	5.2
Jul	**09-15**	**2013**	28	32.4	26.3	87	70.7	037.2	2	06.2	7.5	4.6
Jul	**16-22**	**2013**	29	31.3	25.5	90.7	77	097.8	5	02.6	6.1	3.9
Jul	**23-29**	**2013**	30	32.4	25.6	85.4	68.6	095.8	5	04.5	5.8	4.7
Jul-Aug	**30-05**	**2013**	31	33.0	26.0	87	68	044.0	5	06.1	6.1	4.3
Aug	**06-12**	**2013**	32	32.1	25.3	91	74	175.6	6	05.2	7.4	4.5
Aug	**13-19**	**2013**	33	31.5	24.5	88	73	187.8	6	04.9	6.4	5.1
Aug	**20-26**	**2013**	34	33.6	25.9	87	65	012.4	2	07.3	2.6	3.9
Aug-Sep	**27-02**	**2013**	35	31.2	25.2	93	73	043.8	4	02.4	3.1	3.3
Sep	**03-09**	**2013**	36	32.1	23.6	91	69	005.2	2	06.4	5.6	4.1
Sep	**10-16**	**2013**	37	33.4	23.6	85	62	034.0	5	07.9	3.5	4.1
Sep	**17-23**	**2013**	38	32.8	23.8	81	65	005.4	1	08.7	3.6	3.7
Sep	**24-30**	**2013**	39	33.0	24.1	89	62	033.2	2	06.6	3.9	3.7
Oct	**01-07**	**2013**	40	30.3	23.1	82	67	006.8	1	04.2	4.9	3.6
Oct	**08-14**	**2013**	41	31.2	22.1	90	61	079.6	2	06.7	3.0	2.8
Oct	**15-21**	**2013**	42	30.4	20.1	91	63	000.0	0	05.5	3.4	2.3
Oct	**22-28**	**2013**	43	30.2	16.8	88	55	000.0	0	08.0	2.5	2.7
Oct-Nov	**29-04**	**2013**	44	30.2	18.8	85	53	006.8	1	05.5	4.8	3.6
Nov	**05-11**	**2013**	45	27.9	16.2	90	56	000.0	0	03.9	4.8	2.3
Nov	**12-18**	**2013**	46	27.1	9.0	93	38	000.0	0	01.9	9.0	2.2
Nov	**19-25**	**2013**	47	26.0	9.9	93	42	000.0	0	02.1	8.2	2.0
Nov-Dec	**26-02**	**2013**	48	26.4	9.5	92	49	000.0	0	04.6	6.0	1.6
Dec	**03-09**	**2013**	49	25.7	8.2	94	42	000.0	0	08.7	2.0	2.0
Dec	**10-16**	**2013**	50	23.2	7.4	93	49	000.0	0	06.6	2.5	1.3
Dec	**17-23**	**2013**	51	21.6	8.5	92	59	000.0	0	02.7	3.3	1.4
Dec	**24-31**	**2013**	52	18.9	6.1	94	65	010.2	1	04.6	4.4	1.6

Weekly weather data

STATION NAME : PANTNAGAR **LONGITUDE** : 79 deg. 30' E
LATITUDE : 29 deg. N **ALTITUDE** : 243.84 m. AMSL

Month	Date	Year	Metro Week No. (2012)	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
				Max.	Min.	0712 am	1412 pm					
Jan	**01-07**	**2014**	1	17.1	5.9	97	74	001.6	1	03.1	4.0	1.3
Jan	**08-14**	**2014**	2	16.1	7.5	96	79	003.6	2	02.6	3.2	1.0
Jan	**15-21**	**2014**	3	17.4	9.3	94	73	105.8	2	03.0	5.4	1.9
Jan	**22-28**	**2014**	4	17.5	9.2	94	79	001.4	1	01.6	4.5	1.0
Jan-Feb	**29-04**	**2014**	5	16.2	9.4	96	72	000.0	0	02.2	3.1	0.8
Feb	**05-11**	**2014**	6	22.5	8.9	91.9	60.3	0.33	1	6.17	4.41	2.01
Feb	**12-18**	**2014**	7	20.0	7.0	95.1	58	13.31	2	6.53	6.73	2.18
Feb	**19-25**	**2014**	8	22.9	10.2	90.6	57.3	0.00	0	3.91	6.33	1.99
Feb-March	**26-04**	**2014**	9	23.4	11.3	89.57	47.1	11.63	4	6.06	6.17	3.53
March	**05-11**	**2014**	10	25.0	10.3	88	46	0.00	0	07.6	3.7	2.68
March	**12-18**	**2014**	11	27.8	14.1	87	46	12.8	1	9.1	4.8	3.2
March	**19-25**	**2014**	12	28.7	14.2	83	39	0.00	0	7.9	4.4	2.9
Mar-Apr	**26-01**	**2014**	13	31.2	14.8	87	32	0.00	0	7.6	7.8	4.6
Apr	**02-08**	**2014**	14	32.5	15.1	82	31	2.2	1	10.4	6.3	5.4
Apr	**09-15**	**2014**	15	33.3	15.4	72	22	0.6	1	9.4	6.2	6.9
Apr	**16.22**	**2014**	16	32.5	15.4	75	29	10.2	2	7.4	5.4	5.6
Apr	**23.29**	**2014**	17	37.5	17.7	67	19	0.00	0	11.6	7.7	9.7
Apr-May	**30-06**	**2014**	18	37.0	20.5	62	30	14.4	1	9.5	7.4	7.8
May	**07-13**	**2014**	19	37.0	20.7	63	26.1	03.4	1	09.1	8.0	9.0
May	**14-20**	**2014**	20	36.6	20.5	67	23	0.0	0	10.6	12.6	10.8
May	**21-27**	**2014**	21	38.6	22.9	59	28	0.00	0	10.7	9.6	10.3
May-Jun	**28-03**	**2014**	22	37.4	25.4	68	38	21.2	1	9.5	8.1	8.5

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ABSTRACT

The present investigation was carried out at Norman E. Borlaug crop research centre of Govind Bhallabh Pant University of Agriculture and Technology, Pantnagar, Distt. Udham Singh Nagar (Uttrakhand). A total of thirteen insect-pests along with various spider species were observed in sugarcane field. Maximum activity of shoot borer and root borer was observed in the month of May while top borer and stalk borer in the month of June and October, respectively. Peak activity of black bug was observed in the month of June. A detailed deliberation on termites of Pantnagar Agriculture University Campus and nearby areas, on the diversity and pest status was undertaken which showed nine identified species (*Coptotermes heimi* (Wasmann), *Heterotermes indicola* (Wasmann), *Microcerotermes beesoni* Snyder, *Angulitermes* sp*.*, *Odontotermes* sp.*, O. feae* (Wasmann), *O. brunneus* (Hagen)*, Microtermes mycophagus* (Desneux) and *M. obesi* (Holmgren). Out of nine species, eight species were found as attacking on different plant species, various agricultural crops and *timber-in-service* also, while one species (*H. indicola)* attacked on wooden structure and paper materials. For the management of termites, efficacy of insecticides applications in sugarcane ecosystem as well as baiting techniques in household ecosystem was assessed. Results on insecticides application against termites in sugarcane crop showed the order of efficacy of various treatments as Spinetoram (1500 > 750 ml/ha) > Chloropyrifos> Fipronil > Imidacloprid > Control. As toxicity of two insecticides against workers of *O. brunneus* was determined in laboratory, it was found that at 24HAE, efficacy of Spinetoram (LC_{50} 31.9 ppm) was higher as compare to Imidacloprid (LC_{50} 52.5 ppm). In household ecosystem, baiting technique against termites through *Sentricon termite colony elimination system* proved effective. Results of In-ground stations showed that the termite colonies were eliminated after consumption of 52.6 g to 98.6g of bait matrix (263mg to 493mg Hexaflumuron) over a period of 55 to 181 days while, in Above-ground stations, the termite population consumed 35.02 g to 68 g of bait matrix (175.1mg to 340mg Hexaflumuron) and required a period of 28 to 83 days to eliminate all termite activity.

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उपाधि : पी0एच0डी0

मुख्य विषय : कीट विज्ञान

विभाग : कीट विज्ञान

उपविषय : पादप रोग विज्ञान

शोधग्रन्थ शीर्षक : **''गन्ने के प्रमुख कीटों की विविधिता एवं कृषि तथा घरेलू पारिस्थितिक तंत्र में नवीन कीटनाशकों की दीमक के विरूद्ध प्रभावकारिता का अध्ययन''**

सलाहकार : डा0 ए. के. कर्नाटक

सारांश

नार्मन ई. बोरलॉग फसल अनुसंधान केन्द्र पर गन्ने की फसल पर वर्ष 2013–14 में किये गये अध्ययन में कुल तेरह प्रमुख कीट एवं विभिन्न मकड़ी प्रजातियाँ पायी गयी। अध्ययन से पता चला है कि तना छेदक एवं जड़ छेदक की गतिविधि मई के महीने में अधिकतम होती है जबकि शीर्ष छेदक एवं डंठल छेदक की गतिविधि क्रमशः जून एवं अक्टूबर के माह में सर्वाधिक देखी गयी है। ब्लैक बग की गतिविधि जून माह में सर्वाधिक पायी गयी। पन्तनगर कृषि विश्वविद्यालय परिसर और आस–पास के इलाकों में दीमक की विविधिता पर एक विस्तृत विवेचना की गई जिसमें नौ विभिन्न प्रजातियाँ *कोप्टोटरमिस हिमी* (वाजमांन), *हेटेरोटरमिस इंडिकोला* (वाजमांन), *माइक्रोसीरोटरमिस बीसोनी* (स्नाइडर), *एग्यूलीटरमिस* स्पीसीज, *ओडोन्टोटरमिज* स्पीसीज, *ओ0 फ्रीई* (वाजमांन), *ओ. ब्रुनियस* (हेगन), *माइक्रोटरमिस माइकोफैगस* (डेसन्यूक्स) व *मा. ओबेसाई* (होल्मग्रीन) पायी गयी जिनमें से आठ प्रजातियों का प्रकोप विभिन्न पेड़ों पर, फसलों पर एवं लकड़ियों पर प्रभावी रूप से दिखाई दिया जबकि एक प्रजाति (*हे. इंडिकोला*) का घरों में व कागज पर आक्रमण पाया गया। दीमक के प्रबंधन के लिए नवीन कीटनाशकों की प्रभावकारिता का गन्ना पारिस्थितिकी तंत्र में एवं बेटिंग तकनीक का घरेलू पारिस्थितिक तंत्र में मूल्यांकन किया गया। इसके लिए गन्ने की फसल पर वर्ष 2013–14 में किये गये अध्ययन से प्रदर्शित हुआ कि स्पाइनैटोरैम (1500 > 750 मिलीग्राम/हें.) की प्रभावशीलता दीमक के विरूद्ध, अन्य कीटनाशको से सर्वाधिक पायी गयी है। इसके बाद अन्य कीटनाशक क्रमशः क्लोरपायरीफास, फिप्रोनिल एवं इमिडाक्लोप्रिड प्रभावी पाये गये। प्रयोगशाला में *ओ. ब्रुनियस* प्रजाति की वर्कर दीमकों के विरूद्ध, दो कीटनाशकों की विषाक्तता का अध्ययन किया गया जिसमें 24 घंटे के प्रदर्शन के बाद, एल.सी. 50 नियंत्रक रेखा पर स्पाईनेटैरेम (31.9 पी.पी.एम.), इमिडाक्लोप्रिड (52.5 पी.पी.एम.) की तुलना में अधिक विषाक्त पाया गया। घरेलू पारिस्थतिक तंत्र में दीमक के उन्मूलन के लिए सेंट्रिकान दीमक कालोनी उन्मूलन प्रणाली के माध्यम से दी गयी बेंटिग तकनीक प्रभावी पायी गयी। अध्ययन से प्राप्त परिणाम दर्शाते है कि दीमक कालोनी उन्मूलन के लिये जमीन में लगाये गये बेट स्टेशन में 52.6 ग्राम–98.6 ग्राम बेट मैट्रिक्स की खपत 55–181 दिन में हुई जबकि जमीन के उपर लगाये गये स्टेशन (दीवारों पर) में दीमकों ने 35.02 ग्राम–68.0 ग्राम बेट मैट्रिक्स का 28–83 दिन में उपभोग किया परन्तु इसके पश्चात् घर में दीमक की कोई गतिविधि छः माह तक नही देखी गयी।

अजीत कर्नाटक.
(ए.के. कर्नाटक)
सलाहकार

विजय लक्ष्मी राय
(विजय लक्ष्मी राय)
लेखिका