BIODIVERSITY OF THE TERMITE (ISOPTERA) FAUNA IN CROP ENVIRONMENTS

by

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(2009 – 11 – 110)

THESIS

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Department of Agricultural Entomology

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DECLARATION

I hereby declare that this thesis entitled **"Biodiversity of the termite (Isoptera) fauna in crop environments"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled " **Biodiversity of the termite (Isoptera) fauna in crop environments**" is a record of work done independently by **Jyothy Narayanan (2009-11-110)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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JYOTHY NARAYANAN

Dedicated to my guide

and

beloved parents

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Introduction

1. INTRODUCTION

Termites (Insecta: Isoptera), better known as white ants constitute one of the most significant and fascinating eusocial insects living in a highly organised system of small to large communities in different ecosystems. A termite colony comprises of different castes which are morphologically and functionally distinct. It includes functional reproductives/ 'royal pair' of king and queen, sterile soldier and worker castes and the immature stages or nymphs. About 40-60 per cent of the total soil macrofaunal biomass in tropical ecosystem is constituted by the termites (Wood and Sands, 1978).

Rajagopal (1983) had reported that there was a lot of difference in the opinion among the taxonomists regarding the number of families in the order Isoptera. According to Krishna (1969), the order Isoptera was divided into six families *viz.*, Mastotermitidae, Kalotermitidae, Hodotermitidae, Rhinotermitidae, Serritermitidae and Termitidae. But Roonwal (1981) added Termopsidae, Stylotermitidae and Indotermitidae as three more new families to the above classification. All the families except Termitidae are considered as primitive, and about 75 per cent of the known species of termites belong to Termitidae (Rajagopal, 1983). The publication with respect to the first scientific work on termites in India was carried out by Konig in 1779. However, the taxonomic studies relating to the isopteran fauna is still under infancy in India. Identification of termite species is a challenging task due to their subterranean and hidden nature of living, ambiguity in morphological characters, the difficulty of collecting morphologically distinct castes like soldiers and alates, geographical variations, and the overall lack of systematic termite studies (Wang *et al.*, 2009). But the characters present in the alate and soldier caste facilitate easy identification up to the genus level (Harris, 1971).

Termites have a wide range of feeding habits and the information regarding their feeding guild is of utmost importance in distinguishing the beneficial genera and the pestiferous genera, so that effective pest management options can be initiated. Out of the 270 species of termites known so far from India, about 40 species are reported to damage various agricultural crops (Roonwal, 1981). Majority of the pest species are mound builders or subterranean nest builders which are known to attack a large variety of plants in agriculture, horticulture and forestry. Some of the identified termite species were associated with specific crops (Reddy, 1962). Termite damage is extremely difficult to be assessed and quantified, and in India the damage caused by termites to agricultural crops and their products run into several millions of rupees per year (Rajagopal, 1983). Severe loss has been recorded on highly susceptible crops such as wheat and sugarcane in northern India, maize, groundnut, sunflower and sugarcane in southern India, tea in north eastern India and cotton in western India (Rajagopal, 2002). Proper identification of termite species and knowledge on their distribution are the first steps in developing environmentally compatible/ sustainable integrated pest management (IPM) strategies (Wang *et al.*, 2009).

Termites have varied nesting habits, and thereby ecologically they can be grouped into wood dwellers and ground dwellers. Wood dwelling termites may be either damp-wood termites or dry-wood termites and the ground dwellers may be either subterranean (soil-dwelling) or aerial mound-building termites (Thakur, 2000). Mound building termites construct large epigeal earthen mound known as 'termitarium'. Harris (1971) cited by Thakur (2000) commented that termitaria have gained much more attention because the morphometry of the mounds vary from species to species. The mounds may form a perennial source of termite colonization and infestation.

Termites exert many positive effects on soil formation and particle turnover (Lee and Wood, 1971; Lavelle, 1997) as well as improving the soil properties such as porosity and water infiltration (Mando *et al.*, 1996; Bignell and Eggleton, 2000). They form subterranean tunnels and chambers, which aid in the redistribution of soil layers by increasing aeration, porosity and drainage, and hence they are also referred to as "soil engineers" (Jones *et al.*, 1994; Lavelle *et al.*, 1997; Folgarait, 1998). In turn, these effects can influence the distribution of vegetation and other biota in different natural and agro based ecosystems (Spain and McIvor, 1988; Dawes-Gromadzki and Spain, 2003). They are also considered as potential bioindicator taxa, reflecting the disturbance, fragmentation or destruction of habitats (Jones and Eggleton, 2000). In India, termites are widely distributed in red soils, sandy loams, lateritic and red loam soils. Termite modified soil is more fine textured than that of the adjacent soil as they bring in fine soil particle for building mounds. These soils are having higher nutrient status than the surrounding soil and it is considered to be more productive (Shrikande and Pathak, 1948).

Termite mounds are strongly influenced by weather parameters and by the ecology of the environment in which they exist. Atmospheric temperature and humidity are two dominant environmental factors that influence termite activity (Rajagopal, 1983).

The lack of sufficient research on ecological relationships among termite species, favourite host plant species, and probable correlations with different edaphic and climatic factors serve to make things worse (Wardell, 1987). So the information regarding the habits and habitats of various termites is of considerable importance in determining the possible approaches either for their conservation as beneficial fauna or management if they are found pestiferous.

With the above ideas under consideration, the present study on termite fauna in KAU campus, Vellanikkara was undertaken with the following objectives:

1) Identification of the faunal composition of termite genera in selected crop environments *viz.*, mango, cashew, cocoa and coconut systems at Vellanikkara tract of Thrissur district, Kerala.

2) Determination of the feeding habits of the termite genera and their nesting aspects in the selected systems.
3) Preparation of a primary termite colonisation map in selected plantation and orchard systems at Vellanikkara.
4) Determination of the morphometric features of the mounds and physical properties of the soil in the crop environments.
5) Observation on the influence of temperature and relative humidity on the termite colonisation pattern in the crop environments.

Review of Literature

2. REVIEW OF LITERATURE

Termites are one of the most dominant groups of soil macro fauna known to play an important role in the rapid recycling of organic matter in the ecosystem. There are over 2200 species of termites recorded from all over the world. Out of the 300 species of termites reported from India, about 35 species have been found to damage agricultural crops and timber (Rajagopal, 2002). The identification of termite genera is of utmost importance in distinguishing the beneficial and harmful genera, so that ecological pest management options can be initiated.

The various information from literature which support the study are outlined in this chapter.

2.1. TERMITE SURVEY AND SAMPLING METHODS

Donowan *et al.* (2002) conducted a termite survey by the transect method at three different altitudes in forests within the Nyika Plateau in northern Malawi to assess the termite diversity and to determine their feeding groups.

In a study conducted by Dawes- Gromadzki (2005) to determine the termite species richness, frequency of occurrence and functional diversity at Holmes Jungle Nature Reserve in northern Australia, termites were sampled in leaf litter, wood, mound, soil and arboreal nest microhabitats.

Varma and Swaran (2007) recorded 11 species of termites coming under two families and four subfamilies through transect sampling in a young eucalyptus plantation in Kerala.

Hemachandra *et al.* (2010) adopted belt transect and random sampling method for sampling termite assemblages in a natural forest in Hantana hills and in a secondary forest in Sri Lanka, located at two different elevations.

2.2. FAUNAL COMPOSITION STUDIES OF TERMITES IN FOREST AND AGRO ECOSYSTEMS

Various workers have recorded the occurrence of different species, genera and families of termite fauna from different forest and agro ecosystems in the world.

Roonwal and Chhotani (1961) recorded a total of 34 species belonging to 3 families (Kalotermitidae, Rhinotermitidae and Termitidae) and 16 genera from Assam region of eastern India. 14 species were already known and 13 species and sub species were new to science. The family Termitidae was most richly represented with 4 sub families, 11 genera and 26 species and the genus best represented in the region was *Odontotermes* with 8 species.

Ahmad (1962) reported the occurrence of various termite species *viz.*, *Kalotermes beesoni* Gardner and *Neotermes pishinensis* Ahmad in the family Kalotermitidae, *Archotermopsis wroughtoni* (Desneux) and *Anacanthotermes macrocephalus* (Desneux) in Hodotermitidae, and *Odontotermes, Microtermes, Microcerotermes, Eremotermes, Amitermes, Angulitermes* and *Capritermes* in the family Termitidae from west Pakistan.

Fernando (1962) reported the occurrence of various termite species like *Cryptotermes perforans* Kemner, *C. dudleyi* Banks, *Neotermes militaris* Desneux, *N. greeni* Desneux, *Glyptotermes dilatatus* Bugnion and Popoff, *Coptotermes ceylonicus* Holmgren, *Odontotermes (Hypotermes) obscuriceps* Wasmann, *O.redemanni*

Wasmann, *Nasutitermes ceylonicus* Holmgren and *Hospitalitermes monoceros* Koenig from Ceylon.

Abe and Matsumoto (1978) described the genus composition and distribution of termites with reference to their feeding habits in a lowland tropical rainforest in West Malaysia. They classified the soldier termites into nasute type and mandibulate type (with large prominent mandibles and with twisted mandibles) based on their head shape and defense mechanism. 90 per cent of the recorded species belonged to the family Termitidae and the rest of the species belonged to Rhinotermitidae. The two genera *viz.*, *Hypotermes* and *Microcapritermes* were new to the fauna of West Malaysia.

In the Central Amazon, Bandeira (1979) studied the effect of deforestation on termite populations by assessing the distribution and diversity of these insects in primary forest areas, secondary forest areas and grazing areas, where a great majority of genera showed an equivalent distribution. The genus *Nasutitermes* was the commonest one with greatest diversity and was seen more frequently in grazing fields. The author suggested that the removal of primary vegetation and the resulting changes in microclimate would be responsible for the modification in distribution of some groups.

Abe (1984) reported 3 families, 5 genera and 7 species of termites from Krakatau islands and the adjacent area of Panaitan Island and West Java. Taxonomically, the lower termites belonging to Kalotermitidae and Rhinotermitidae dominated the area and the mainland of West Java was characterized taxonomically by the dominance of higher termites in the family Termitidae.

A study conducted by Bose (1984) revealed the occurrence of 18 species under five genera *viz.*, *Postelectrotermes*, *Neotermes*, *Glyptotermes*, *Procryptotermes* and *Cryptotermes* in the family Kalotermitidae from Southern India. Only one species *Stylotermes fletcheri* Holmgren and Holmgren in the family Stylotermitidae and five species in family Rhinotermitidae were known from southern India. The family Termitidae comprised of four sub families *viz.*, Apicotermitinae, Termitinae, Macrotermitinae and Nasutitermitinae. A total of 9 species in Apicotermitinae, 20 in Termitinae, 22 in Macrotermitinae and 18 species belonging to 8 genera in Nasutitermitinae were reported by the author.

Abe (1990) reported atleast 9 species of termites namely *Macrotermes michaelseni*, *Odontotermes* sp., *Microtermes* sp., *Synacanthotermes* sp., *Microcerotermes* sp., *Amitermes* sp., *Pericapritermes* sp., *Cubitermes* sp. and *Anoplotermes* sp. from the grasslands of Kenya.

Gui-xiang and Zi-vong (1990) reported termites belonging to four families representing 43 genera and 385 species from China. Among them the genera of economic importance were *Cryptotermes*, *Reticulitermes*, *Coptotermes*, *Odontotermes* and *Macrotermes*.

By analyzing the termite fauna in primary forests of two Brazilian Amazon localities, Constantino (1992) confirmed that representatives of the sub family Nasutitermitinae, especially the genus *Nasutitermes* were the prevalent group, both in number and abundance of species. The species composition and diversity varied among different sites and apparently they did not show any correlation with climate or type of vegetation.

Martius (1994) reviewed the diversity and importance of termites in the rainforests and flood plain forests of Amazonia with 26-90 species and less than 15 species of termites, respectively. He reported that the family Kalotermitidae represented 0-12% of the total population, Rhinotermitidae (3-25%) and the rest by

Termitidae where 50% of the species was represented by Nasutitermitinae where the genus *Nasutitermes* accounted for nearly 25%.

Jones and Brendell (1998) commented on the taxonomic composition of termite assemblage at Pasoh Forest Reserve where the lower termites Kalotermitidae and Rhinotermitidae represented 15 per cent of the assemblage and the rest comprised of members of the family Termitidae. The Nasutitermitinae and Termitinae were the dominant sub families with roughly one third of the recorded species and the Macrotermitinae constituted 16 per cent of the species.

A study was conducted by Martius *et al.* (1999) to investigate the genus richness of termite fauna present in a semi-arid area in Brazil where they recorded eight genera belonging to three families *viz.*, Termitidae, Rhinotermitidae and Kalotermitidae from various nests and mounds, dead wood, and cardboard baits buried 10 cm deep in the soil.

Scheffrahn *et al.* (2001) reported that deliberate surveys and submitted samples yielded five new termite species from Georgia which included *Coptotermes formosanus* (Family: Rhinotermitidae), and *Calcaritermes nearcticus*, *Cryptotermes brevis*, *Incistitermes minor* and *Kalotermes approximates* (Family: Kalotermitidae), bringing the total number of termite species in Georgia to nine.

Donowan *et al.* (2002) conducted termite survey at three different altitudes in forests within the Nyika Plateau in northern Malawi, and found that termite diversity was the highest in the mid- altitude site and the lowest in the Juniper forest. All species belonged to the family Termitidae and in the sub-families Macrotermitinae, Termitinae and Apicotermitinae with the latter as the predominant sub family in which one new soldierless genus was also identified.

Primanda *et al.* (2003) recorded six termite species *viz.*, *Coptotermes curvignathus, Schedorhinotermes javanicus, Macrotermes gilvus, Microtermes insperatus, Odontotermes grandiceps* and *O. javanicus* in a survey of termite fauna conducted in the UI campus at Depok, Indonesia.

Laffont *et al.* (2004) recorded 26 species in 15 termite genera from three National Parks of the northeast region of Argentina. It included various genera like *Rugitermes* Holmgren and *Tauritermes* Krishna (Kalotermitidae), *Heterotermes* Frogatt (Rhinotermitidae), *Cornitermes* Wasmann, *Cortaritermes* Mathews, *Diversitermes* Holmgren, *Nasutitermes* Dudley, Velocitermes Holmgren (Nasutitermitinae), Amitermes Silvestri, *Microcerotermes* Silvestri, *Neocapritermes* Holmgren, *Termes* Linne (Termitinae), *Anoplotermes* Muller, *Aparatermes* Fontes and *Ruptitermes* Mathews (Apicotermitinae) of the family Termitidae. The family Termitidae and sub family Nasutitermitinae was the best represented at the three sampled areas with a total of 13 species.

Mathew (2004) listed the termite species identified from various parts of Kerala. It included *Anacanthotermes viarum* (Family: Hodotermitidae), some species of *Cryptotermes, Neotermes* and *Postelectrotermes* of the family Kalotermitidae, *Heterotermes ceylonicus* (Holmgren) and *H. malabaricus* Synder of the family Rhinotermitidae and several species from various genera like *Ampoulitermes, Angulitermes, Ceylonitermes, Dicuspiditermes, Emersonitermes, Euritermes, Homallotermes, Macrotermes, Microtermes, Nasutitermes, Odontotermes, Pericapritermes* and *Procapritermes* of the family Termitidae.

A study was conducted by Sornnuwat *et al.* (2004) to identify the termite species present in Thailand. Accordingly, they reported eleven new genera *viz.*, *Archotermopsis, Neotermes, Incisitermes, Parrhinotermes, Reticulitermes,* *Synhamitermes*, *Prohamitermes*, *Homallotermes*, *Angulitermes*, *Longipeditermes* and *Lacessititermes*, based on morphological identification of the soldier caste.

A study was conducted by Dawes- Gromadzki (2005) to determine the termite species richness, frequency of occurrence and functional diversity at Holmes Jungle Nature Reserve in northern Australia. He recorded five species from five genera and three families *viz.*, Mastotermitidae, Rhinotermitidae and Termitidae including the first record of *Ephelotermes taylori* (Hill) from the monsoon forest in Australia. The family Termitidae was dominant representing 70 per cent of termite occurrences. *Nasutitermes graveolus* (Hill) occurred most frequently representing 61 per cent of termite encounters. *Mastotermes darwiniensis* Froggatt and *Coptotermes acinaciformis* Froggatt constituted 22 per cent and 12 per cent of the termite assemblage sampled, respectively.

Scheffrahn *et al.* (2006) recorded twenty seven species of termites from three families and 12 genera in a survey conducted in 33 islands of the Bahamas and Turks and Caicos (BATC) archipelago. The list included species like *Cryptotermes brevis* (Walker), *Incisitermes bequaerti* (Snyder), *Neotermes castaneus* (Burmeister), *Procryptotermes corniceps* (Snyder), *Coptotermes gestroi* Wasmann, *Heterotermes cardini* (Snyder), *Prorhinotermes simplex* Hagen, and *Reticulitermes flavipes* Koller of the family Rhinotermitidae, and *Anoplotermes bahamensis* n. sp., *Nasutitermes corniger* (Motschulsky), *Parvitermes brooksi* (Snyder), and *Termes hispaniolae* Banks of the family Termitidae.

In a study conducted by Ackerman *et al.* (2007) in central Amazonia, eighteen termite species were identified and the most commonly encountered species were *Subulitermes microsoma* (Silvestri) and *Anhangatermes macarthuri* Constantino. Eight of the fifteen mounds in the study hosted two or more species, and from a single mound, four species namely *Cornicapritermes mucronatus* Emerson, *Nasutitermes guayanae* (Holmgren), *Neocapritermes angusticeps* (Emerson) and *Subulitermes microsoma* (Silvestri) were recorded.

Calderon and Constantino (2007) surveyed the termite fauna of a plantation of *Eucalyptus urophylla* in central Brazil and identified 28 termite species belonging to Termitidae and Rhinotermitidae. The species richness in the area was low when compared to the original native fauna in Brazil.

The status of termite was studied by Tripathi *et al.* (2007) in silvopastoral systems in the Indian Thar desert where the recorded species were *Anacanthotermes macrocephalus*, *Eremotermes neoparadoxalis*, *Microcerotermes tenuignathus*, *Microcephalus raja* and *Odontotermes bellahunisensis*. Of these, *A. macrocephalus* of the family Hodotermitidae and *E. neoparadoxalis* of the family Termitidae were predominant and showed the highest diversity index of 0.35. The representatives of the family Termitidae contributed 56.31 per cent of total faunal composition.

Vu *et al.* (2007) conducted a study to identify the subterranean termite species, their habitat preferences and nesting habits in a lowland and lower mountain evergreen and limestone forest in northern Vietnam. A total of fifteen species in eight genera and two families were identified, where, Termitidae was the dominant family with six genera and 12 species. The genus *Odontotermes* contained the largest number of species. Five species namely, *O. maesodensis* Ahmad, 1965, *Nasutitermes ovatus* Fan, 1983, *Pericaptitermes latignathus* (Holmgren, 1913), *P. nitobei* Shiraki, 1909 and *Bulbitermes laticephalus* Ahmad, 1965 were new records for northern Vietnam.

Sathe and Chougale (2008) reported 32 species of termites belonging to various genera such as *Odontotermes*, *Microtermes*, *Trinervitermes*, *Microcerotermes*, *Heterotermes*, *Eremotermes*, *Coptotermes*, *Cryptotermes*, *Angulitermes*, *Neotermes*, *Rhinotermes* and *Reticulitermes* from the Western Ghat region of Sindhudurg district in Maharashtra, India. They reported the genus *Odontotermes* as most dominant genera followed by *Microtermes*, *Eremotermes* and *Heterotermes*.

Dawes- Gromadzki (2008) assessed the termite species diversity, frequency of occurrence and functional diversity in a savanna woodland reserve in northern Australia. He recorded sixteen termite species from nine genera and three families *viz.*, Mastotermitidae, Rhinotermitidae and Termitidae, including the first record of *Ephelotermes taylori* (Hill), and the first official record of *Macrognathotermes errator* Miller. The family Termitidae represented 69 per cent of termite occurrences where the wood/soil interface feeder *Nasutitermes eucalypti* (Mjoberg) represented 30 per cent of encounters.

In a termite survey conducted by Li *et al.* (2008) in Lanyu Island, a total of 6 species in 6 genera and 3 families were identified. These included *Cryptotermes domesticus* (Haviland) and *Neotermes koshunensis* (Shriaki) of Kalotermitidae, *Coptotermes formosanus* Shiraki, *Prorhinotermes japonicas* (Holmgren) and *Reticulitermes flaviceps* (Oshima) of Rhinotermitidae and *Nasutitermes takasogoensis* (Shiraki) of Termitidae.

Ackerman *et al.* (2009) compared the termite assemblage of a primary forest site with a palm-based and home garden agro forest using a rapid biodiversity assessment protocol in Amazonia. The termites collected belonged to two families *viz.*, Rhinotermitidae and Termitidae where three Termitidae sub-families *viz.*, Apicotermitinae, Nasutitermitinae and Termitinae were identified. Thirty per cent of the species encountered belonged to Apicotermitinae and fifty seven per cent of species were soil feeders. The most commonly encountered species was *Heterotermes tenuis* (Hagen).

Surveys were conducted by Shanbhag and Sundararaj (2009) to assess species composition and extent of infestation of termites in selected eucalyptus plantations of south India. The study revealed that termite infestation was more in young trees compared to mature trees. They reported that termites belonging to the genus *Odontotermes* Holmgren were found to cause maximum infestation.

Hemachandra *et al.* (2010) conducted a study to compare termite assemblages at two different elevations consisting of a natural forest in the Hantana hills and a secondary forest in Sri Lanka with a view to identify their distinctiveness. The collected termite fauna belonged to the family Termitidae, and a total of 11 species coming under four genera and three sub families were identified. Out of this, nine species were reported from the secondary forest and two species *viz.*, *Ceylonitermellus hantanae* and *Dicuspiditermes incola* confined only to the natural forest at higher elevation.

Kumar and Pardeshi (2011) recorded 15 termite species from a study area in Gujarat comprising of four selected crops *viz.*, sugarcane, wheat, cotton and castor and out of which only five species were found as pests of these crops. *Odontotermes obesus* was the dominant species and recorded as a pest of all the four crops.

2.3. FEEDING HABITS OF THE TERMITES

Termites feed on a wide variety of cellulosic materials like wood, grasses, herbs, leaf litter, dung and humus. Various authors commented on the diverse feeding habits of the termites as detailed below.

Abe (1984) commented on the dominance of wood feeding termites in the Krakatau islands and the adjacent Panaitan Island, while, the main land of West Java was characterized ecologically by the dominance of both wood and humus feeders constructing their nests in the soil.

Abe (1990) broadly divided the food habits of termites into 5 categories *viz.*, living grasses, dead plant materials on the ground, dead roots of grasses, soil and dung of which, living grasses were sometimes consumed by *Macrotermes michaelseni* and *H. mossambicus*, dead plant materials by *Macrotermes*, *Odontotermes*, *Microtermes* and *Synacanthotermes*, dead roots by *Amitermes* and *Microcerotermes* and soil by *Cubitermes*, *Pericapritermes* and *Anoplotermes*.

Termite fauna appeared to be highly diversified in their feeding habits and divided into the main trophic groups as foraging, fungus-growing, xylophagous and humivorous species (Tano, 1990).

Constantino (1992) by analysing the termite fauna in primary forests of two Brazilian Amazon localities commented that most of the species present were xylophagous and largely limited to rotten wood followed by the humivorous species.

DeSouza and Brown (1994), in a pioneering study of forest fragments, studied termite communities in the Amazon forest and in fragments of neighbouring isolated reserves. They suggested the prevalence of geophagous termites in the forest fragments but in the fragments of neighbouring isolated reserves, litter feeders and those with a feeding habit between geophagy and xylophagy were more prevalent.

Jones and Brendell (1998) arranged the recorded termite genera from Pasoh Forest Reserve in peninsular Malaysia into five functional groups as soil-feeding, wood feeding, soil/ wood feeding, litter-feeding and lichen-feeding termites. About 54 per cent of the recorded species in the Pasoh assemblage were wood-feeders and about 5 per cent of the species feed on both wood and leaf- litter. The soil-feeders constituted 31 per cent and the termites that feed on highly decayed soil-like wood represented 6 per cent of the total recorded species and lichen-feeders accounted for only 4 per cent.

Martius *et al.* (1999) reported that the nest-builder guild was represented by *Nasutitermes*, *Costrictotermes* and *Microcerotermes* with about 1-3 nests/ ha. During the dry season of 1996, wood-inhabiting genus of *Neotermes* (Kalotermitidae) were abundant in dead branches attached to the trees. *Heterotermes* (Rhinotermitidae) and *Amitermes* and *Termes* (Termitidae) were associated with dead wood on the ground.

Constantino (2002) classified the termite genera identified from a primary forest, palm-based and home-garden agro forest into various feeding guilds based on known feeding habits as soil feeders, litter feeders, soil/wood interface feeders, wood feeders and pest species. The proportion of soil/wood interface feeders was reduced in the agro forests and soil feeders were found to be more prevalent there. None of the termite species encountered in the study were known to be pest termites of the plant species except *Rhinotermes marginalis* (Linnaeus) which was considered to be a minor agricultural pest in Amazonia.

Donowan *et al.* (2002) conducted termite survey by the transect method at three different altitudes in forests within the Nyika Plateau, northern Malawi and found that the assemblages were dominated by soil-feeding termites in the Termitidae coming under the sub-families Apicotermitinae and Termitinae.

When Bandeira *et al.* (2003) identified the termite fauna in six environments with varying levels of disturbance in *Brejo dos Cavalos* (PE), they confirmed a decrease in diversity as disturbances became more profound. Termites feeding on humus were more affected than those feeding on intermediate food. Concomitantly, those feeding on wood showed more resilience and some favoured species in areas of secondary forests showed a tendency to disappear in agricultural areas with less available wood.

In an investigation of the termite fauna conducted by Sena *et al.* (2003) in a *cerrado* fragment in the Guaribas Biological Reserve, in *Mamanguape*, (PB), it was reported that most of the species were xylophagous while the largest frequency of transects was seen in the humivorous species.

Dawes- Gromadzki (2005) reported that the sampled areas at Holmes Jungle Nature Reserve in northern Australia were represented by four nesting habits namely arboreal, epigeal, hypogeal and within wood. The arboreal nest builder *Nasutitermes graveolus* (Hill) accounted for 61 per cent of termite encounters and 80 per cent of samples collected and the epigeal mound building species were rare. Species were also assigned to one of six feeding groups based on information from the literature and direct observation. The feeding groups were modified from Tayasu *et al.* (1998) and Jones (2000) and comprised of wood feeders, wood/soil interface feeders, soil feeders, grass- harvesters, litter feeders and polyphagous feeders. *Mastotermes darwiniensis* Froggatt with their nesting habits in wood were found both in lying and standing dead wood. *Coptotermes acinaciformis* Froggatt were found to build mounds or nests in wood and *Schedorhinotermes actuosus* (Hill) were subterranean nest builders found in standing dead wood. *Nasutitermes graveolus* (Hill) were arboreal in their nesting habits and seen in carton runways and lying dead wood. *Ephelotermes taylori* (Hill) were mound builders or subterranean nest builders with lying and standing dead wood as their microhabitats.

Calderon and Constantino (2007) surveyed the termite fauna in a plantation of *Eucalyptus urophylla* in central Brazil and suggested that the plantation was having much lower proportion of soil-feeders and higher proportion of litter-feeders when compared to the original native fauna.

Dawes- Gromadzki (2008) reported that wood and wood/ soil interface feeders were the most common in Australian tropical savanna termite assemblages. They also commented that soil feeders and live wood feeders were less common and grass-harvesting species were absent. They reported frequent encounters of termites in epigeal mounds and lying dead wood.

Hemachandra *et al.* (2010) put the termites recorded from a natural forest in the Hantana Hills and a secondary forest in Sri Lanka into different feeding groups based on their taxonomic identity. Termites of the natural forest were found to be exclusively true soil feeders and those of the secondary forests were wood feeders.

2.3.1. Termites as pests of tree crops

Termites cause damage to various agricultural crops including plantation and orchard crops, and the pest status of termites is reviewed in this section.

Kumar and Singh (1994) reported termites as one of the major nursery pests of fruit trees and they were found abundantly in sandy and sandy loam soils. They reported the important termite species which caused injury to the fruit crops in nurseries as *Anacanthotermes macrocephalus*, *Microcerotermes minor*, *M. unicolor*, and many species of the genus *Odontotermes* like *O. obesus*, *O. distans* and *O. wallonensis*. They also reported that besides the damage caused to seedlings in fruit nurseries, termites also damage almost all the fruit trees in orchards throughout India. They listed several species of *Neotermes* like *N. assumthi*, *N. bosei* and *N. fletcheri* as pests of living fruit trees like *Mangifera indica* in South India. They also reported *Microtermes unicolor*, *M. obesi*, *M. mycophagus* and *Odontotermes* as the termite species which damage fruit trees in India and *Coptotermes heimi* was found to damage inside the main stem of living trees of mango and mulberry.

Sen-Sarma (1994) listed *Coptotermes heimi*, *Eremotermes paradoxalis*, *Odontotermes assumthi*, *O. distans*, *O. indicus*, *O. microdentatus*, *O. obesus*, *Microtermes mycophagus*, *M. obesi* and *Trinervitermes biformis* as serious pests of agricultural crops in South Asia.

Butani (1993) reported 13 termite species as pests on mango trees in India *viz.*, *Neotermes bosei* Synder, *N. mangiferae* Roonwal and Sen-Sarma, *N. megaoculatus megaoculatus* Roonwal and Sen-Sarma, *Stylotermes fletcheri* (Holmgren), *Coptotermes heimi* (Wasmann), *Heterotermes indicola* (Wasmann), *Microtermes edentates* (Wasmann), *M. obesi* Holmgren, *Odontotermes assmuthi* Holmgren, *O. feae* (Wasmann), *O. obesus* (Rambur), *O. wallonensis* (Wasmann), *Trinervitermes biformis* (Wasmann) and *T. rubidus* (Hagen). Of these, the most destructive one found all over India was *O. obesus*.

Rajagopal (1983) listed some termite species injurious to the crops of agriculture, horticulture, forest and wood work of the buildings in India. It included species like *Bifiditermes beesoni* (Gardner), *Glyptotermes ceylonicus* (Holmgren), *Neotermes assmuthi* Holmgren, *N. mangiferae* Roonwal and Sen-Sarma and *Postelectrotermes bhimi* Roonwal and Maiti of the family Kalotermitidae, *Anacanthotermes macrocephalus* (Desneux) and *A. viarum* (Koenig) of the family Hodotermitidae, *Coptotermes ceylonicus* Holmgren, *C. heimi* (Wasmann), *Heterotermes indicola* (Wasmann) and *H. malabaricus* of Rhinotermitidae, *Stylotermes bengalensis* Mathur and Chhotani and *S. fletcheri* Holmgren and Holmgren of Stylotermitidae and some species in Termitidae, like *Dicuspiditermes fletcheri* (Holmgren and Holmgren), *Eremotermes dehraduni* Roonwal and Sen-Sarma, *Microcerotermes beesoni* (Synder), *M. minor* Holmgren, *Nasutitermes indicola* Holmgren and Holmgren, *Odontotermes assmuthi* Holmgren, *O. brunneus* Hagen, *O. feae* (Wasmann), *O. horni* (Wasmann), *O. malabaricus* Holmgren and Holmgren and *O. obesus* (Rambur).

Samra *et al.* (1979) conducted survey of twenty four mango orchards and observed that an average of 66.19 per cent trees was infested by *Odontotermes wallonensis.*

Reddy (1962) reported that *O. obesus* and a few other congeneric species were known to be largely responsible for damage to fruit trees in various parts of India. *O. obesus* was a pest of coconut palms and *Coptotermes ceylonicus* Holmgren were infesting living rubber plants in South India.

2.3.2. Termites as pests of forestry

Termites are also well known pests in forest nurseries and young plantations which is supported by various literature.

Nair and Varma (1985) reported nine species of termites found to feed on live roots of eucalyptus in their study in recently cleared natural forest planted with *Eucalyptus tereticornis* and *E. grandis* in Kerala. This included one species of *Eurytermes*, two of *Pericapritermes*, one of *Microtermes* and five of *Odontotermes.* Some of the root-feeding species were also found in other microhabitats. A few species caused sub-lethal injury to the bark of the stem.

Thakur (1990) reported that the most widespread damage to the plantation forestry was caused by some species of the genera *Macrotermes* and *Odontotermes* namely, *M. estherae, O. distans, O.feae, O. indicus, O. microdentatus, O. obesus* and *O. wallonensis.*

Thakur and Sen-Sarma (1994) reviewed the status of termites as a pest of forest nurseries and plantations. They recorded *Anacanthotermes macrocephalus,* *Microcerotermes minor*, *Odontotermes distans*, *O. indicus*, *O.microdentatus*, *O. obesus* and *O. wallonensis* as pests of forest nurseries.

Varma and Swaran (2007) recorded 11 species of termites, falling under two families and four sub families through transect sampling in a young eucalyptus plantation in Kerala. The subfamily Macrotermitinae dominated with eight species while the other three subfamilies were represented by a single species each. Of the total termite samples collected, 40 per cent belonged to the single species *O. obesus*, which was found to be the major pest species.

2.4. PREPARATION OF A PRIMARY TERMITE COLONIZATION MAP

A termite faunal distribution map can give an idea regarding their distribution and abundance pattern in particular localities.

Primanda *et al.* (2003) conducted an inventory and spatial analysis of the termite fauna in UI campus, Indonesia and they depicted the located termite nests of the identified species in an already prepared map of the campus. Finally, they inferred that there was random distribution of termites in the UI campus.

2.5. MORPHOMETRY OF THE AERIAL MOUNDS

Studying the morphometry of mounds of termites proved very useful in identifying the different species which varies in their nest construction and morphometric features.

Lee and Wood (1971) recorded that the termite mounds were small domed to conical structures with only few centimeters in height and diameter. They also reported the colossal mounds built by some species of *Macrotermes* to reach 9 m or more in height and 20-30 m in diameter at the base. According to the authors, the mounds in various ecosystems were not static objects but were continually being eroded by rainfall. The occupied mounds were repaired and enlarged by the termites while abandoned mounds were gradually eroded away.

Rajagopal (1983) commented that *O. obesus* would build tall, sub-cylindrical mounds up to 3- 4 metres in height with a series of buttresses around them. He also reported the mounds of *O. redemanni* and *O. microdentatus* as dome shaped, low in height with sub conical outgrowths without any buttresses. The mounds built by *O. wallonensis* were dome shaped with open chimney-like outgrowths for ventilation.

Bagine (1990) suggested that the genus *Macrotermes* would build tall and bare conical mounds, typically 100 to 500 cm high and 100 to 200 cm in diameter in Kilifi district around Malindi.

Martius (1990) recorded the average heights and diameter of the nests of *Anoplotermes* sp. in seasonally flooded riverine forests of the Amazon in Brazil as 4.8 m and 0.2 m, respectively with a mean nest volume of 0.075 m^3.

Rajagopal (1990a) reported that the earthen nest of *Odontotermes obesus* was tall and sub cylindrical without any opening on the surface and the basal diameter of the nest was found to vary from 1.25 to 2.00 m and the height up to 3.00 m. The nest of *O. redemanni* was dome shaped at the base, sub conical and without any opening on the surface. The basal diameter was found to be irregular with varied size and a maximum height of 2.00 m was noticed. *O. wallonenesis* was reported to construct an extremely hard and compact dome shaped nest with diameter of 1.00 to 2.50 m and a height of 1.50 m.

In a study conducted by Tano and Lepage (1990) to calculate the growth rates of nests of *Macrotermes bellicosus*, by measuring certain nest parameters like height and basal area, it was found that the mound size varied between 0.07 to 3.00 m in height, 0.025 to 7 m^3 in volume and 0.5 to 25.5 m^2 in basal area. They also reported an increase of mound height from 0.80 m to 3.20 m within a year which in turn involved processing of several m^3 of soil. A fluctuation in nest density within short periods was also noted. They also reported dramatic variations in nest density between years from 14.3 nests/ ha down to 0.8 nest/ ha on a lateritic plateau of Cote d' Ivoire, and from 0.09 to 0.51/ ha in Tsavo East National Park in Kenya.

Martius (1994) commented that termite nests occured at a density of 60- 123 nests/ ha in the rainforests and at 37- 93 and 105- 262 nests/ ha in the lower and upper floodplain forests of Amazonia, respectively.

Asawalam *et al.* (1999) recorded a density of 112 mounds/ ha for the termite genus *Nasutitermes* in the study area at southern Nigeria when it was enumerated in 15 randomly selected plots measuring 50 × 50 m. The mean height of the mounds was 0.85 m and the basal circumference at 5 cm height was 0.91m.

Laffont *et al.* (2004) recorded the mound height and diameter of each termite species identified from the three national parks of Argentina.

In a study conducted by Ackerman *et al.* (2007) in central Amazonia, the abundance of the termite mounds in the study site was found to be 760/ ha although it covered only 3 per cent of the area. The geometric mean basal area of the mounds was 0.29 m^2.

2.6. PHYSICAL PROPERTIES OF THE SOIL

Termites play an important role in modifying the soil properties and the termite modified soil has enhanced nutrient content as evidenced by the work of various authors.

There are higher nutrient levels in the mound soils of *Odontotermes* spp. than in the surrounding soils. (Shrikande and Pathak, 1948; Banerjee and Mohan, 1976).

Samra *et al.* (1979) observed that the termite soil had significantly more organic carbon, calcium, magnesium, available nitrogen, silt and clay than the surrounding soil.

Rajagopal (1983) reported that termite soils were characterized by higher proportion of finer fractions like clay, silt and fine sand when compared with the surrounding soil.

Filho *et al.* (1990) reported that the material of the mound, especially the core was richer in nutrients than the local soil, after conducting the analysis of chemistry and texture of the soil in and around the mound of the termite *Cornitermes cumulans* in Sao Paulo, Brazil. The whole external layer of the mound contained more clay than the rest of the mound. They also suggested that the soil at 50 cm depth may have played an important role on the formation of external layer of the mound, owing to the similarity in composition with regard to sand, silt and clay content.

Lepage and Abbadie (1990) commented that termitogenic soil was richer in finer particles. Bisht and Bisht (1991) commented that the termite modified soil had more silt, clay and organic carbon.

Hulugalle and Ndi (1993) studied the effect of land use on 3 different land use types in modifying the soil properties of *Microtermes* termite mounds in a humid forest zone of southern Cameroon. The surrounding soil consisted of 58.5 per cent sand and 25.6 per cent clay while the soil from mound surfaces consisted of 39.9 per cent sand and 47.9 per cent clay.

McComie and Dhanarajan (1993) reported that the mounds of the fungus-growing termite *Macrotermes carbonaeius* (Hagen) in Penang, Malaysia contained significantly larger proportion of clay than the adjacent soil and the largest clay content was found in the brood chamber.

Debruyn and Conacher (1995) examined the texture and selected chemical properties of two soil types found in the mounds and foraging galleries of two mound-building termite species *viz., Drepanotermes tamminensis* and *Amitermes obeuntis* in a semi-arid region and open woodland vegetation of Western Australia. When the soil properties of the termite modified soil were compared with soil unaffected by termite activity it was found that both mounds and foraging galleries had significantly higher clay contents, increased organic carbon, and lower pH than the surface soil.

A study was conducted by Maduakor *et al.* (1995) to compare some physical and chemical properties of the mounds of two common termites *Macrotermes* and *Cubitermes* in southeastern Nigeria. They found that the per cent sand and silt was greater in *Cubitermes* mounds than in *Macrotermes* mounds but the percentage clay was lesser in *Cubitermes* mounds.

The effect of three different land use on soil properties of *Microtermes* mounds in Typic Paleudult was studied by Ekundayo and Aghatise (1997) in the humid rainforest zone of Midwestern Nigeria. They reported that there was no significant difference in the soil textural characteristics among the various sampling locations of the three land use types. The soil at the experimental site was sandy-clay, kaolinitic, isohyperthermic and Typic Paleudult with a sandy clay loam (83% sand, 3.7% silt, 13.3% clay) sub soil. The sand and silt contents were lower and clay content was higher on mound surfaces than in the surrounding soil. There was no significant variation in silt content between the various sampling points of the three land use types.

Asawalam *et al.* (1999) conducted a study aimed at characterizing the effects of the activity of termites of the genus *Nasutitermes* on the physico- chemical properties of the acid sandy soils of southern Nigeria. There were significantly higher proportions of clay and silt in the mounds of the *Nasutitermes* than in the surrounding top soil and the proportion of sand particles (74%) was significantly lower than the values for the adjacent soil (93%). The mean percentage of finer mineral particles, namely clay and silt were 3 times and 7 times more in the mounds than in the surrounding soil. They also noted the soil colour of the mounds using the Munsell Colour Chart and found that moist colour of the termite mound was dark reddish-brown (5YR 3/2) and the dry colour was dark brown (7.5 YR 4/2).

In a study conducted to assess the physical and chemical properties of the biogenic structures created by ecosystem engineers like earthworms, termites and ants, Decaens *et al.* (2001) found that the termitarial soil had low bulk density and constituted of aggregates of size 8-9 mm. It was high in organic carbon and assimilizable nutrients.

Jouquet *et al.* (2002) commented that termites of the subfamily Macrotermitinae played an important role in tropical ecosystems as they were modifying the soil physical properties thereby making food available for other organisms. They also suggested that clay was an important component in the architecture of Macrotermitinae termite nests and it was postulated that termites could modify the mineralogical properties of some clays.

Jouquet *et al.* (2005) reported that fungus-growing termites (Isoptera, Macrotermitinae) played an important role in tropical ecosystems in modifying soil physical properties. They reported that the two species *viz.*, *Ancistotermes cavithorax* and *Odontotermes nr pauperans* significantly modified soil texture and the genus *Odontotermes* exerted greater effect on soil properties.

Miranda and D' Cruz (2005) reported that gravel was totally absent in termitarial soil of the two species *Macrotermes estherae* and *Trinervitermes biformis.* There was no significant variation in the proportion of coarse sand, fine sand and clay fractions between the nest soil and surrounding soil of *M. esthrae* whereas the gallery soil of *T. biformis* contained significantly higher proportions of coarse sand, fine sand, silt and clay than the adjacent soil. The study indicated that the termitaria soil could be used as a cheap and eco-friendly soil medium.

Ackerman` *et al.* (2007) investigated the chemical, physical and hydraulic properties of termite mounds at an 8- year old secondary forest site, and their effects on the development of native plant species. Twenty termite mounds and soil control areas were sampled and found that the soil texture differed only slightly between the termite mound and adjacent soils, although their differences were significant. Slightly less clay and more silt and sand were found in the termite mounds than in the adjacent soil.

In a study conducted by Asawalam and Jhonson (2007) to characterize soils modified by soil fauna it was confirmed that faunal modification alters particle size distribution and textural classes of soils. Mound samples of *Cubitermes* sp. and *Macrotermes* sp. and surface soil at 0-15 cm depth were collected by the authors from a citrus orchard of Michael Okpara University of Agriculture, Umudike and particle-size analysis was carried out by the hydrometer method developed by Bouyoucos, 1951. The proportion of sand in the nasute termite mound was significantly lower than the percentage sand content in the unmodified soil. *Macrotermes* termite mound contained a similar proportion of sand compared to the unmodified soil. Percentage silt content in nasute termite mound was higher than that of *Macrotermes* mound and the unmodified soil. The clay contents of the termite modified soils were significantly higher than those in the unmodified soil.

Sarcinelli *et al.* (2009) reported that clay content in termite mounds was usually twenty per cent higher than in nearby soils.

2.7. INFLUENCE OF CROP ECOLOGY ON TERMITE COLONIZATION

Atmospheric temperature and relative humidity are two dominant environmental factors which strongly influence the termite colonization pattern as supported by various literatures described below.

Cheema *et al.* (1962) reported moisture and temperature as inseparable environmental factors of termites, and they had undertaken a study to record the temperature and humidity of the fungus garden of the higher termite, *Odontotermes obesus* (Rambur). They reported that the temperature of the fungus garden remained more or less constant during a day or during succeeding days, but showed appreciable variation from season to season and the changes in the atmospheric temperature did not bring about a corresponding change in the temperature of the fungus garden on any particular day. The temperature of the fungus garden was also comparatively higher than that of the adjacent soil and the relative humidity was found to vary between 85 and 95 per cent. There could be wide variation in temperature but the requirement of humidity appeared to be more specific.

The temperature fluctuations from 9.0 to 49.0^{0}C and 7.6 to 47.0^{0}C controlled the foraging activity of *Gnathotermes perplexus* (Bank) and *Heterotermes aureus* (Synder), respectively (Collins *et al.*, 1973).

Agarwal (1980) reported that there was no diurnal fluctuation in temperature and relative humidity inside the mound of *Odontotermes obesus* (Rambur), and the fluctuations throughout the year were within a narrow range of 4° C and 4%, respectively.

Rajagopal (1983) suggested atmospheric temperature and humidity as two dominant environmental factors that influence termite activity. The temperature in occupied mounds would be always 8-10^{0}C higher than in the unoccupied mounds due to the production of metabolic heat. The mean daily temperature in the nest was approximately 30^{0}C and not varied more than 0.5^{0}C throughout the year but the diurnal fluctuations in ambient temperature vary and sometimes exceed 3^{0}C difference. He also reported that the duration and daily pattern of foraging was partly dependent on temperature with a lower threshold of 35^{0}C, and temperature beyond these points restricted foraging in *Trinervitermes geminates* (Wasmann). A constant temperature of 28- 30^{0}C in the fungus gardens of Macrotermitinae was also reported by the author.

Rajagopal (1990b) commented that the genus *Odontotermes* forage throughout the year, and the intensity of foraging was related to the seasonal weather conditions with the maximum foraging activity during post monsoon period from October to January when there was sufficient ground moisture. The optimum temperature and relative humidity for foraging activity was 19- 25^{0}C and 70- 80 %, respectively. These observations indicated that they would avoid higher temperature (>26^{0}C), cold temperature (<17°C) and continuous rainfall for foraging. He also commented that *O. wallonensis* was capable of maintaining a nest temperature higher than the atmospheric temperature from 27^{0}C to 30^{0}C.

Korb and Linsenmair (2000) quantitatively analysed the effect of fluctuating ambient temperature and mound characteristics on mean nest temperature in the fungus-cultivating termite *Macrotermes bellicosus* in Cote d' Ivoire. They suggested that abiotic heat production via solar radiation alone yielded nest temperatures that corresponded to mean ambient temperatures. Only large colonies attained constant nest temperature of 30^0C which were largely independent of external ambient temperature.

Materials and Methods

3. MATERIALS AND METHODS

The main objective of the study was to identify the faunal composition of the termite genera and their association in different crop environments of Vellanikkara tract in Thrissur district. The study was carried out in the instructional farm of the College of Horticulture, Vellanikkara during 2010-11. The abundance and distribution of termite genera was also estimated to prepare a primary termite colonisation map for the selected cropping systems in Vellanikkara.

The major areas of the investigation included a survey on the faunal composition in the selected cropping systems *viz.*, mango, cashew, cocoa and coconut with the collection and identification of the termite fauna up to the family/ genus level. Morphometry of the aerial mounds, determination of physical properties of the soil, influence of temperature and relative humidity on the termite association in different crop environments were also undertaken. Finally, a primary termite colonisation map in selected cropping systems of the Vellanikkara tract was also prepared.

The materials and methods of the study are as detailed hereunder.

The instructional farm of College of Horticulture, Vellanikkara is situated at $10^0\,31'$ N latitude and $76^0\,13'$ E longitude and at 40 m above MSL. The farm area comprises of diverse vegetation and numerous cropping systems like coconut, cashew and cocoa plantations, mango orchards and vegetable fields. The region under study experiences a humid tropical climate with mean minimum temperature of 23^0C, maximum temperature of 34^0C, relative humidity of 73 per cent and an annual rainfall of 3000 mm. The farm area was previously occupied by extensive rubber plantations and later got cleared into the present cropping systems. The tree residues present in the subsoil prompted the termite colonisation in these areas.

3.1. SURVEY ON THE TERMITE FAUNAL COMPOSITION IN THE SELECTED CROPPING SYSTEMS

A preliminary survey was conducted throughout the instructional farm area at Vellanikkara during February 2010, by employing the transect walking method. The surveyed areas included relatively undisturbed open fields, fallow lands, border areas near to the fields as well as to the roads and various plantation and orchard systems. Qualitative observations and the prevalence of termite colonisation as evidenced by the presence of termite mounds, mud tubes and earthen coverings on tree trunks, dead wood, dead stumps, and over the grass stubbles were randomly observed during the survey. Based on the extent of occurrence of termitaria in terms of the density per unit area (200 sq. m), as well as the presence of mud tubes/ earthen coverings on trees, four crop environments *viz.*, mango orchard, cashew, cocoa and coconut plantations were selected for the study (Plate 1 and 2). From each of the above selected crop environment, 200 sq. m area was selected as fixed plots for conducting the study. Further, twenty trees each from the different crop environments were selected at random from the fixed plots and the number of trees having mud tubes out of the randomly selected trees was noted along with the density of termitaria in each of the fixed plots. The light intensity in mango, cashew and cocoa based systems was also measured using the Light Meter (Model: LX-1102) given in Plate 3. The major weed flora growing on the soil surface as well as near to the mounds in the experimental area was also noted.

3.2. COLLECTION AND IDENTIFICATION OF FAUNAL COMPOSITION OF TERMITES

3.2.1. Collection of soldier termites from different crop environments

Soldier castes were collected from the selected plots mentioned in 3.1 during the study period from July, 2010 to November, 2010. Termites were collected by random sampling from unit area under different crop environments.

Plate 1. Termite colony sites

1A. Mud tubes

1B. Earthen coverings

IC. Termitaria

Plate 2 . Study sites

2A. Mango orchard

2B. Cashew plantation

2C. Cocoa plantation

2D. Coconut plantation

Sampling was done by walking across the area diagonally in a zig-zag manner. Samples from ten points with an interpoint distance of two metre were taken across each diagonal thereby a total of twenty sampling points per unit area (200 sq. m) of the selected crop environments were sampled. Each sampling site was observed for all features of the microhabitat such as earthen mounds, dead and decaying wood, dead stumps, fallen logs, leaf litter, soil, mud tubes on trees and base of tree trunks.

From the earthen mounds in the selected plots, soldiers were collected by using a special technique called 'glue trap technique' given in Plate 4. In this technique, a 20 cm long glass rod was taken and a thin layer of fevicol MR was coated uniformily over the entire length. The termite mound was opened by breaking 1 sq. cm area at the mid-point of its side slope and the sticky glass rod was inserted into the mound and tapped for two minutes for provoking the soldiers to bite upon the rod and were trapped. Then the glue trap was taken out carefully and washed with water to dislodge the trapped soldiers. It was then transferred to vials containing 70% ethyl alcohol. Sampled populations were labelled/ numbered and kept under refrigeration at 18-20^{0}C.

Digging and turning up the surface-laden litter with a small hand spade was also adopted to collect the soldiers wherever it was applicable. Soldiers coming out were collected by using a small fine camel hair brush and they were preserved in glass vials containing 70% ethyl alcohol, labelled/ numbered and kept under refrigerated condition at 18-20^{0}C.

The number of termites samples obtained out of 20 sampling points in a unit area of 200 sq. m from the selected systems were recorded.

Apart from the above samplings, termites were also randomly sampled from the adjoining open fields in and around the instructional farm for comparative studies.

3.2.2. Identification of the collected termite specimens

The specimens showing variation in external morphological characters were sorted out and preserved in labelled glass vials containing 70% ethyl alcohol and kept under refrigeration at around 18-20^0 C. It was then identified up to the family/ genus level using relevant taxonomic keys of Bose (1984), Roonwal and Chhotani (1961) and Sornnuwat *et al.* (2004) given in Appendices I, II and III. Soldier castes were observed under stereomicroscope at magnifications of 20 X and 40X.

3.2.3. Categorisation of the termite genera based on feeding habits

The feeding habits of the collected termite genera along with their microhabitats were recorded based on visual observation and compared with information from various literatures and they were grouped into the respective categories.

3.2.4. Measurement of richness, diversity and dominance of termite genera

The genus richness of the termite genera present in Vellanikkara in the selected systems of mango, cashew, cocoa and coconut was calculated. Various other indices *viz.*, Simpson-Yule diversity Index, Shannon-Weiner diversity Index, Evenness Index and Berger-Parker Dominance Index were also worked out as follows:

i) Genus richness is the total number of genera present in the community where the value ranges from 0- ∞.
ii) Simpson-Yule diversity Index (D) is a diversity index proposed by Simpson (1949) to describe the probability that a second individual drawn from a population should be of the same species as the first (Southwood and Henderson, 2000). It is the simplest measure of the character of a community that takes into account both the abundance pattern and the species richness and its value ranges from one to the total number of species (S). An index of 1 indicates that all individuals in the area belong

Plate 3. Light meter

Plate 5. Temperature humidity meter

to a single species and when D= S every individual belong to a different species.

$$D = 1 \Big/ \sum_{i=1}^{S} p_i^2 \quad \text{(Range = 1- S)}$$

where, S = total number of species in the community (*ie.* richness)

P_i = proportion of total number of individuals composed of i^{th} species

iii) Shannon- Weiner Diversity Index (H) is the most commonly used index in ecological studies owing to the fact that it is dimensionless, independent of sample size and expresses the worth of each species (Kochsick *et al.*, 1971). This index is a unique indicator of environmental stress as the sensitive species gradually shift or get eliminated from a habitat with the increase in magnitude of environmental stress. A decrease in the value of this index indicates an increase in the magnitude of environmental stress on the species (Cairns and Dickson, 1971).

$$H = -\sum_{i=1}^{S} P_i \ln P_i \quad \text{(Range = 0- ln S)}$$

where, P_i = proportion of total number of individuals composed of i^{th} species

ln = natural logarithm

iv) Evenness Index (E) is the ratio of the observed diversity to the maximum possible for the observed species number (Southwood and Henderson, 2000). It is a measure of the uniformity of different species in a community and the value increases as the environment becomes favourable for a number of species (Mitra, 2000).

$$E = H \Big/ \ln S \quad \text{(Range = 0- 1)}$$

where, H = Shannon-Weiner Diversity Index

S = total number of species in the community

ln = natural logarithm

v) Berger-Parker Dominance Index (d) is a simple dominance measure that is easy to calculate (May, 1975). It refers to the proportion of total catch, N_T, that is due to the dominant species, N_{max} (Southwood and Henderson, 2000).

$$d = \frac{N_{max}}{N_T} \qquad (\text{Range} = 0\text{-}1)$$

where, N_{max} = number of individuals in the most abundant species

N_T = total catch of all the individuals

3.3. PREPARATION OF A PRIMARY TERMITE COLONISATION MAP IN SELECTED PLANTATION AND ORCHARD SYSTEM

The blocks of study area in the instructional farm where the selected mango, cashew, cocoa and coconut based systems present were demarcated on an already existing GIS map of the campus prepared by the Centre for Land Resources Research and Management, Thrissur and is given in Figure 1. The different termite genera identified from the selected 200 sq. m area of each crop environment were marked in the form of circles of different colours and of varying diameter based on their relative abundance and colonisation pattern.

3.4. MORPHOMETRIC OBSERVATIONS OF THE AERIAL MOUNDS OF TERMITES

Morphometric observations of the mounds present in the selected fixed plots of the mango, cashew and cocoa were taken at monthly intervals from July, 2010 to February, 2011.

Plate 4. Termite trapping technique

4A. Termite mound with hole of 1 sq. cm

4B. Soldiers stuck on the glue coated glass rod

4C. Detached soldier collection from the glue trap

Density of termitaria (total number in 200 sq. m area) and the number of buttresses or conical mounds per termitarium were recorded at monthly intervals from all the locations.

The height and circumference at five centimetre above the ground level of the largest and smallest mounds in each termitarial units were also recorded. The height of the mounds were taken with the help of two parallel iron rods placed at the height of topmost point and the ground level and the difference measured using a metre scale. The circumference of the mounds were taken by winding a long thread around the base of the mounds five centimetre above the ground level and then measured using a metre scale.

The mean height and basal circumference in centimetre were recorded from which the mean external volume/ above ground volume ($1/3\pi r^2h$) of the mounds were calculated by presuming conical shape for the mounds.

3.4.1. Statistical Analysis

The relative per cent increase in mean external volume of the mounds in three crop environments were calculated and the data were subjected to statistical analysis by performing CRD and ANOVA using the Statistical Package for Social Sciences (SPSS).

3.5. PHYSICAL PROPERTIES OF THE SOIL

Colour and texture of the soil from the mound as well as the adjacent areas from all the three crop environments *viz*., mango, cashew and cocoa was recorded using standard observation charts and by standard method of analysis.

3.5.1. Determination of soil colour

Soil colour was determined during both wet season (October, 2010) and dry season (March, 2011) by using Munsell soil colour chart. About 250 g of the soil samples were collected from three selected mounds of each cropping system. The soil samples from the adjacent areas were collected at 0-15 cm depth from the termite uninfested zones, two metre away from the mounds. The composite soil samples were prepared by the repeated quadrat technique. The soil samples were then sealed in polythene covers and labelled to determine the colour. The closest matching colour comparable with the chart as per the notations of the Munsell colour chart was then noted and documented.

3.5.2. Determination of soil texture

3.5.2.1. Soil texture by the standard feel method

Soil texture of a portion of the soil samples out of 250 g soil samples taken from three locations on the mounds as well as the adjacent soils was determined by the standard feel method. Soil samples were collected by the same procedure as in the case of the soil colour in 3.5.1. The collected samples were then sealed in polythene covers and labelled to determine the soil texture. A small portion of the soil sample was moistened and mixed thoroughly in a Petri dish so as to form a soft ball and then worked until stiff and squeezed out between thumb and fore-finger. The feel properties like the feel to finger, the ease of forming ball, stickiness or grittiness or whether it forms soil ribbons or merely crumbles on squeezing, etc. were noted to determine the textural class of the soil.

3.5.2.2. Soil texture by particle size analysis

Analysis of the particle size of the soil samples from the selected cropping systems was conducted to determine the per cent clay, silt, sand and gravel content of the samples. Small mound slices of 500 g weight each and the adjacent soil (500 g) were taken from the selected crop environments to determine the grain size in the samples.

Particle size analysis of the dry soil samples were determined by the hydrometer analysis for the fine grained samples and mechanical sieve analysis for the coarse grained samples.

3.5.2.2.1. Preparation of soil sample for grain size analysis

Fifty gram of the oven dried soil samples were accurately weighed and 100 ml of the dispersing agent (deflocculating agent) namely, sodium hexametaphosphate was added to have proper dispersion of the soil. For preparing this deflocculating agent, 40 g of the chemical was dissolved in 1000 ml of distilled water. In the next morning, the soil suspension was washed through 75 μ (0.075 mm) sieve using a jet of distilled water and transferred into 1000 ml measuring glass jar. More distilled water was added to make up the volume to exactly 1000 ml in the glass jar. The material retained on 75 μ sieve was collected and put in the oven for drying.

3.5.2.2.2. Hydrometer analysis

The soil suspension in the jar was shaken vigorously and a stopwatch was started immediately. The hydrometer was immersed gently into the solution and it was allowed to float freely. The hydrometer readings were taken at 1 min, 2 min, 5 min, 15 min, 30 min, 60 min, 4 hours, 10 hours and 24 hours. After each reading, the hydrometer was taken out and rinsed with distilled water and allowed to stand in a jar containing distilled water. The test observations were recorded and calculations were done.

3.5.2.2.3. Sieve analysis

Sample which was retained on 75 μ sieve was dried in the oven and put on a set of sieves which were arranged one over the other in the order of their mesh size. The largest aperture sieve was kept at the top and the smallest one was kept at the bottom with a receiver kept at the bottom and a cover kept at the top of the whole assembly. The dried sample was kept in the top sieve and the whole assembly was thoroughly shaken in a sieve shaking machine. The portion of soil samples retained on each sieve was separately weighed. The sieves used in the lab were of aperture sizes 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.425 mm, 0.3 mm, 0.15 mm and 0.075 mm. Calculations were done on the basis of the weight of sample retained on each sieve.

In the Indian standard classification of soil, particles with diameter in between 4.75 mm and 0.075 mm is termed as sand, in between 0.075 mm and 0.002 mm is termed as silt and particles of size below 0.002 mm is termed as clay.

3.5.2.2.4. Statistical analysis

The mean particle size distribution of the mound soil and of the adjacent soil samples from the three crop environments were subjected to statistical analysis for CRD and the mean variances were tested by Duncan's Mutiple Range Test (DMRT) using SPSS.

3.6. INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON THE TERMITE COLONISATION

Temperature and relative humidity of the external and internal ambience of the mounds were taken on every Wednesday between 10.30 am and 1.30 pm from mid-September 2010 to mid-January 2011 using the equipment Temperature humidity meter (Model- HT- 3006HA) which is shown in Plate 5. Observations of three termitaria from the selected crop environments were taken.

Atmospheric temperature and relative humidity were noted by holding the equipment and three values were recorded when minimum fluctuations in the dial reading were shown. For measuring temperature and relative humidity inside the mounds, the sensor of the equipment was wrapped up with tissue papers (6×6 cm^2) and tied around with a rubber band to protect it against wear and tear. Temperature and relative humidity conditions inside the mounds were recorded by poking the sensor rod through three holes made at the middle height of the mounds 15 cm apart. A total of three readings were taken from three holes when minimum fluctuations were exhibited from a mound.

3.6.1. Statistical analysis

The mean weekly temperature and relative humidity inside the mounds and of the external ambience was calculated and subjected to t test analysis using

SPSS to find out the significant difference in temperature and relative humidity inside the mounds and of the external ambient conditions.

Results

4. RESULTS

4.1. SURVEY ON THE TERMITE FAUNAL COMPOSITION IN THE SELECTED CROPPING SYSTEMS

A preliminary survey was conducted throughout the instructional farm area of Vellanikkara tract during February 2010 by the transect walking method. The survey was undertaken to investigate the termite colonization as influenced by the human intervention in various cropped areas of Vellanikkara tract. The area surveyed included relatively undisturbed open fields, fallow lands, border areas near to the fields as well as to the roads and various plantation and orchard systems.

Mud tubes/ earthen coverings were seen on the tree trunks of various trees like mango, cashew and coconut palms. Earthen coverings were also noted over the stubbles of grasses, dead wood and dead stumps present in relatively undisturbed open fields and in border areas near to the fields as well as to the roads. When the mud tubes/ earthen coverings were broken, the foraging worker castes were not noticed.

The fixed plots *viz.*, the mango orchard, cashew, cocoa and coconut plantation selected for the study were demarcated on an already existing GIS map of the campus and is depicted in Figure 1. The preliminary observations taken from the selected crop environments is presented in Table 1. Qualitative observations taken from the selected systems are mentioned below.

4.1.1. Mango orchard

The trees in the orchard were very old having more than twenty years of age and seemed to be unattended and unproductive. Earthen coverings were seen at a height of 1.50 to 4.00 m above ground level on fifteen trees out of twenty randomly selected trees in the orchard. Numerous small and medium sized mounds were present in the plot and the density of the mounds per 200 sq. m area was six. The trees in the orchard were in flushing/ flowering stage. It was a

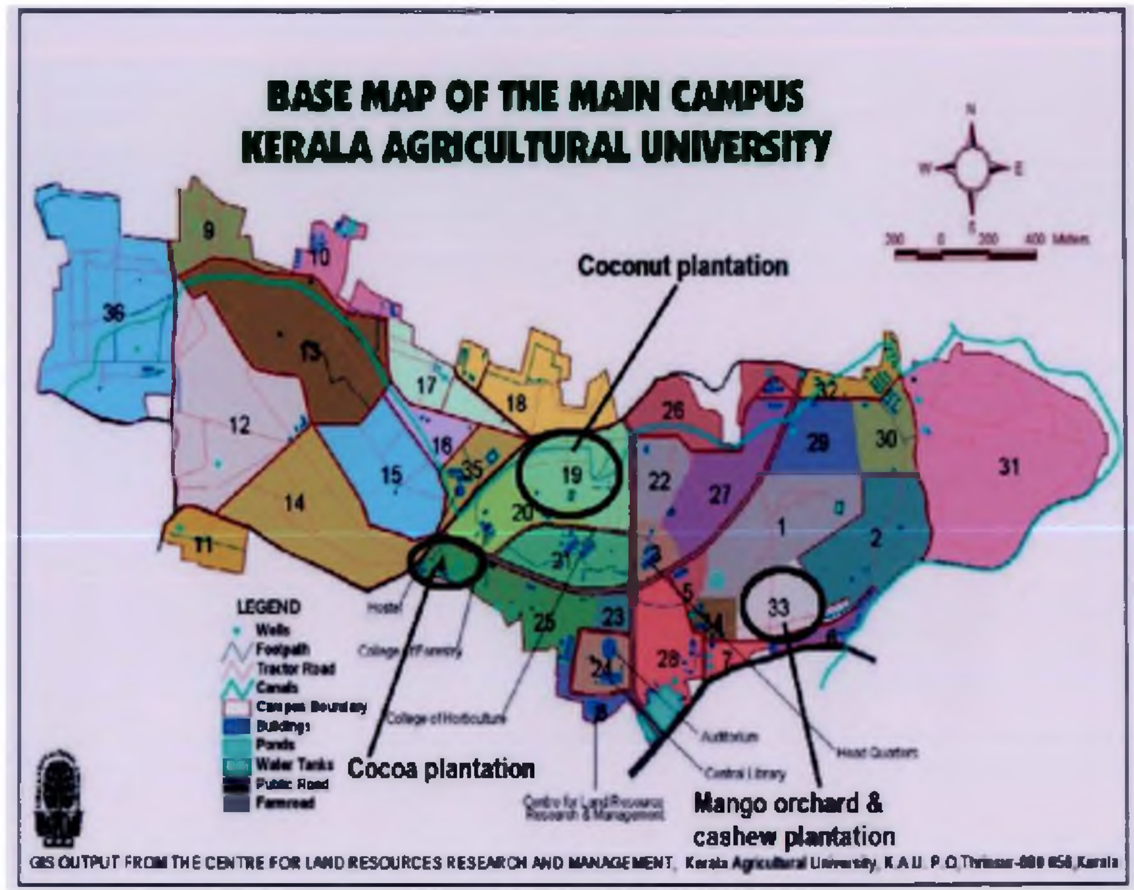


Figure 1. Demarcated study area

weedy orchard and the major weed flora noticed growing over the mounds or near to its vicinity included *Ficus hispida*, *Mitracarpus villosus*, *Eupatorium odoratum*, *Hemidesmus indicus* and some grass species like *Axonopus compressus*. The plot was having an undulating terrain and it was not well managed and left unirrigated. The plot was having a lot of dead and decaying matter like dead wood and leaf litter. It was a shady area where the light intensity was found to be 4.71 per cent.

4.1.2. Cashew plantation

The cashew plantation was relatively old and senile having trees more than thirty years of age. The trees were in the fruiting stage. The plot was more weedy and small mounds were observed at a density of four per 200 sq. m area of the plot. The dominant broad leaved weeds present in the system were *Centrosema pubescens*, *Sida* sp., *Mitracarpus villosus* and *Ficus hispida*. The dominant grass species were *Urena lobata*, *Axonopus compressus*, *Stenotaphrum secundatum*, *Brachiaria mutica* and *Desmodium trifolii*. Mud tubes/ earthen coverings were noticed on tree trunks at a height of 0.50 to 1.50 m from the ground level. It was observed in twelve trees out of twenty randomly selected trees per 200 sq. m. The plantation was not as shady as that of the mango orchard and the light intensity was found to be 31.77 per cent. It was comparatively a levelled plot which was not irrigated and left undisturbed. The amount of dead/ decaying wood was less but considerable amount of leaf litter was present in the system.

4.1.3. Cocoa plantation

The cocoa plants were younger and less than ten years of age, and it was intercropped in rubber plantation under tapping. The plot was shady and the incident light intensity was found to be only 9.77 per cent. The plot was also well littered and there was presence of dead wood at many places. Small to relatively large mounds were observed with a density of five mounds per 200 sq. m. The plot was well managed and frequently irrigated so that there was little or no weed flora. Mud tubes/ earthen coverings were not observed on tree trunks.

Table 1. Preliminary observations from crop environments

Crop environment	Age of the crop (in years)	No. of trees with mud tubes/ earthen coverings per 20 randomly trees	Density of mounds per 200 sq. m
Mango orchard	> 20	15	6
Cashew plantation	> 30	12	4
Cocoa plantation	<10	Nil	5
Coconut plantation	>25	9	Nil

Table 2. No. of termite samples from selected crop environments in Vellanikkara

Crop environment	No. of termite samples
Mango	22
Cashew	17
Cocoa	11
Coconut	11

4.1.4. Coconut plantation

The observed coconut plantation was more than twenty five years of age. The palms were very tall and the earthen mounds were not observed anywhere. Mud tubes at a height of 0.50 to 2.00 m were observed in nine palms out of twenty randomly observed palms per 200 sq. m area. There were frequent human interventions in the plantation for performing intercultural operations. Decaying fronds, coconut husk and mulches were noticed in the coconut basin.

4.2. COLLECTION AND IDENTIFICATION OF THE FAUNAL COMPOSITION OF TERMITES

4.2.1. Collection of soldier termites from different crop environments

A new special method of collection *viz.*, "glue trap technique" was designed and standardised for trapping the soldiers by provoking them to bite upon a glue coated glass rod inserted into the mounds and it is given in Plate 4. The biting/ defending tendency of the provoked soldiers were utilised for entrapping them upon the inserted foreign object inside the mounds. The termite soldiers were found to get stuck on to the glue coated glass rod when the same was introduced inside the mound and tapped. But very few or no workers stuck on the glue rod.

The soldier termites were collected from 20 sampling points in 200 sq. m area of the selected crop environments. The number of termite samples obtained from different crop environments is listed in Table 2. Out of the 20 sampling points per 200 sq. m area, 22 samples were obtained from mango orchard and 17 from the cashew based system. From both cocoa and coconut plantations, 11 samples of termites were obtained. Apart from this, 15 samples were obtained by random sampling from open fields in Vellanikkara.

Observation

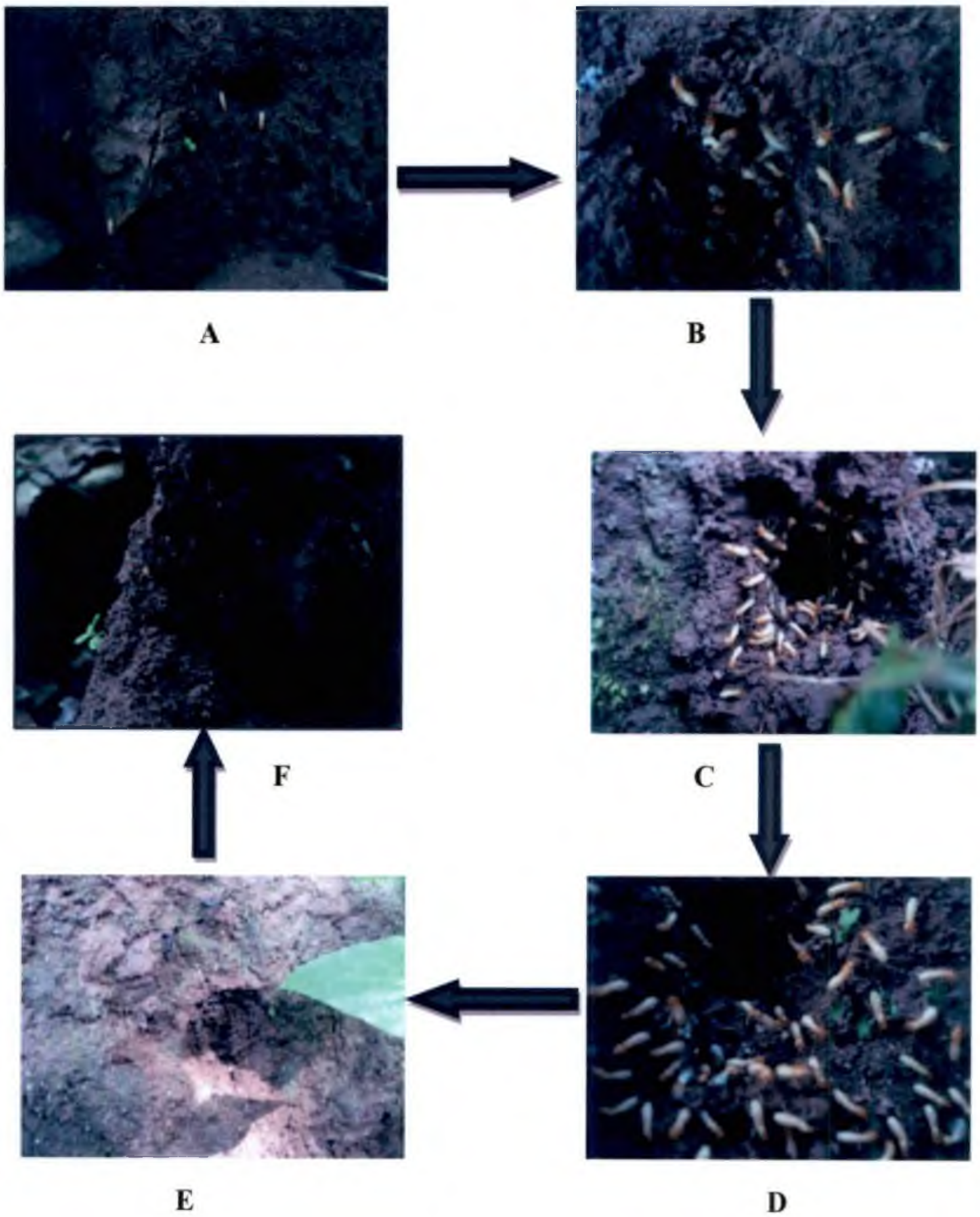
Collection of soldiers from the mounds was found very difficult during the rainy months of July, 2010 and August, 2010 as the soldiers were not coming out easily from inside the mounds. Moisture status in the mounds as well as in the soil was found to be very high. No mud tubes were observed on the trees. Some of the soldiers were observed to emit a white sticky fluid which might be their defensive secretion. Some other soldiers inflicted painful bites when handled with our fingers. Immediately after opening the termite nests some predatory ants (*Camponotus* sp.) were seen wandering around the nest in search of their prey. Even if only a small hole was made on the mounds, it was noticed that the termite workers immediately closed the opening within 5-10 minutes and they were found to be assisted by the soldiers who are the defenders of the colony. The various stages of mending of a damaged hole on a termitarium by termite workers protected by soldiers is given in Plate 6.

Most of the palms in the coconut garden were having dried roots at the basal portion and there was indication of termite infestation on palm trunks. Termites were observed to be present mostly on the soil and under decaying fronds and coconut husk on the coconut basins.

During later periods of collection from September, 2010 to November, 2010, mud tubes were observed in some of the trees in the mango orchard, and cashew and coconut plantation, while, it was not noticed in cocoa plants.

Soldiers with varied type of mandibles, head shapes, flat/ saddle-shaped pronotum and with or without fontanelle were observed in the collection. Different termite genera were observed from the same sampling points in few cases.

Plate 6. Mending of a damaged termitarium by the termite workers



4.2.2. Identification of the termite genera

The collected termite genera were identified up to the family/ genus level by running the taxonomic identification keys given by Bose (1984), Roonwal and Chhotani (1961) and Sornnuwat *et al.* (2004) given in Appendices I, II and III.

A total of nine termite genera belonging to two families and five sub-families were identified from various crop environments of the Vellanikkara tract and it is given in Table 5 and Plate 7. Out of nine, two genera belonged to the family Rhinotermitidae and under the sub-families Heterotermitinae and Coptotermitinae. Rest of the seven genera belonged to the family Termitidae and under the sub-families Macrotermitinae, Termitinae and Nasutitermitinae. Under the family Termitidae, two genera *viz.*, *Odontotermes* and *Microtermes* belonged to the sub-family Macrotermitinae. Three different variants in the genus *Odontotermes* were observed and were indicated as *Odontotermes* sp.1, 2 and 3. The remaining termite genera *viz.*, *Microcerotermes*, *Dicuspiditermes*, *Homallotermes* and *Procapritermes* belong to the sub-family Termitinae and the genus *Nasutitermes* belongs to the sub-family Nasutitermitinae. Under the family Rhinotermitidae, the genus *Heterotermes* belongs to the sub-family Heterotermitinae and *Coptotermes* belongs to the sub-family Coptotermitinae. A dichotonomous key was prepared for the termite genera identified from Vellanikkara and presented in Table 3.

The distribution of termite genera in selected crop environments in Vellanikkara is presented in Table 4. *Odontotermes* sp.1 was the most widely distributed genus present in all the selected crop environments making a total of 41 encounters from all the systems. It was followed by the genus *Microcerotermes* which was encountered a total of 8 times from cashew, coconut and open fields. *Odontotermes* sp. 2 was present in all the systems except cocoa. The genus *Nasutitermes*, confined only to the mango orchard and cashew plantation, was also encountered seven times in total. The genera *viz.*, *Procapritermes* and *Dicuspiditermes* were present only in cashew and cocoa

Table 3. Key to the genera of termites identified from Vellanikkara

1	Pronotum saddle shaped	2
-	Pronotum flat	8
2	Fontanelle present	3
-	Fontanelle absent	6
3	Fontanelle distinct/ small	4
-	Fontanelle not distinct	5
4	Fontanelle distinct, mandibles distinctly asymmetrical, left mandible slender and moderately bent in middle, right mandible straight and blade like and head sub rectangular	*Homallotermus*
-	Fontanelle small, mandibles symmetrical, curved inwards at tips and inner margin of mandibles serrated, head long and rectangular	*Microcerotermes*
5	Mandibles distinctly asymmetrical with tip of left mandible narrow and bent in the form of hook, antenna 14 segmented	*Procarpitermes*
-	Mandibles distinctly asymmetrical with tip of left mandible broad and without hook, antenna 13 segmented	*Dicuspiditermes*
6	Mandibles degenerate and head produced into a nasute	*Nasutitermes*
-	Mandibles well developed and head not produced into nasute	7
7	Mandibles asymmetrical, left mandible with a distinct tooth on inner margin at varying positions and right mandible with minute tooth like projection or somewhat elongated ridge like area	*Odontotermes*
-	Mandibles symmetrical thin, delicate and weakly curved apically, inner margin of mandibles are smooth and without any serration, head oval and smaller compared to body	*Microtermes*
8	Fontanelle wide and placed near to clypeus, mandibles symmetrical, slender and the inner margin is smooth without any serrations, head capsule pear shaped	*Coptotermes*
-	Fontanelle small and placed much behind the clypeus, mandibles asymmetrical, inner margins smooth but left mandible with four low protuberances at base, head capsule parallel sided	*Heterotermes*

Plate 7. Termite genera identified from the Vellanikkara tract

7A. *Odontotermes* (40X)
(species yet to be identified)

7B. *Microcerotermes* (40X)

7C. *Nasutitermes* (40X)

Plate 7 continued.

7D. *Procapritermes* (40X)

7E. *Dicuspiditermes* (50X)

7F. *Homallotermes* (50X)

7G. *Microtermes* (50X)

7H. *Coptotermes* (40X)

7 I. *Heterotermes* (40X)

Table 4. Distribution of termite genera in different crop environments in Vellanikkara

Termite genera	Crop environments					Total
	Mango	Cashew	Cocoa	Coconut	Open fields	
Odontotermes sp. 1	13	3	9	6	10	41
Odontotermes sp. 2	2	3	×	1	1	7
Odontotermes sp. 3	×	×	×	×	1	1
Microcerotermes sp.	×	4	×	2	2	8
Nasutitermes sp.	5	2	×	×	×	7
Microtermes sp.	×	×	×	2	×	2
Procapritermes sp.	×	2	2	×	×	4
Dicuspiditermes sp.	×	1	1	×	×	2
Homallotermes sp.	×	3	×	×	×	3
Coptotermes sp.	×	×	×	×	1	1
Heterotermes sp.	3	×	×	×	×	3
Total	23	18	12	11	15	79

(× indicates absence of termite encounters)

plantation which were encountered four times and two times, respectively. Three genera *viz.*, *Microtermes*, *Homallotermes* and *Heterotermes* were encountered exclusively in coconut, cashew and mango based systems, respectively. *Microtermes* was encountered twice and *Homallotermes* and *Heterotermes* were encountered thrice in the above systems. *Coptotermes* and *Odontotermes* sp. 3 were encountered only once from the open fields.

4.2.2.1. Microhabitats and feeding habits of the termites in Vellanikkara tract

. The microhabitats and feeding habits of the identified termite genera in Vellanikkara tract is given in Table 5. The genus *Odontotermes* was found to be dominant among the termite fauna identified from the Vellanikkara tract and it was collected from various sites like epigeal mounds, dead wood, mud tube and basal part of tree trunks which is given in Plate 8A. The genus *Microtermes* was collected from soil underneath coconut husk and fronds. The genera *viz.*, *Procapritermes*, *Dicuspiditermes* and *Homallotermes* were collected from small epigeal nest at the tree base, soil, leaf litter and root debris and it is shown in Plate 8D and Plate 8E, respectively. *Microcerotermes* was collected from basal part of trunk, dead wood and mud tubes, and the genus *Nasutitermes* was collected from mud tubes (Plate 8C and 8B). *Coptotermes* was sampled from the basal portion of a cut down tree and the genus *Heterotermes* from soil near a dead stump as well as from dead wood.

Under the family Termitidae, the genera *viz.*, *Odontotermes*, *Microcerotermes* and *Nasutitermes* were found to be wood feeders whereas *Procapritermes*, *Dicuspiditermes*, *Homallotermes* and *Microtermes* were found to be soil/ humus feeders. Under the family Rhinotermitidae, both *Heterotermes* and *Coptotermes* were found to be wood feeders

4.2.3. Diversity, richness and dominance of the termite genera in Vellanikkara

The diversity, richness and dominance of the termite genera in Vellanikkara tract was measured by means of various indices *viz.*, Simpson-Yule

Table 5. Taxonomic position, microhabitats and feeding habits of the identified termite genera from selected crop environments of the Vellanikkara tract

Taxonomic position	Microhabitats	Feeding habits	Crop environment
Family: Termitidae Sub family: Macrotermitinae			
Odontotermes sp. 1	Epigeal mounds, dead wood, mud tube, soil	Wood feeders	Mango, cashew, cocoa, coconut, open fields
Odontotermes sp. 2	Dead wood, mud tubes, basal part of trunk of the trees	Wood feeders	Mango, cashew, coconut
Odontotermes sp. 3	Basal portion of a cut down tree	Wood feeders	Open field
Microtermes sp.	Soil under coconut husk and frond	Soil/ Humus feeders	Coconut
Sub family: Termitinae			
Microcerotermes sp.	Nest at basal part of trunk, dead wood, mud tubes	Wood feeders	Mango, cashew, coconut,oil palm in an open field
Homallotermes sp.	Soil and root debris, small epigeal mounds	Soil/ Humus feeders	Cashew
Dicuspiditermes sp.	Small epigeal nest at the base of trees, soil, leaf litter	Soil/ Humus feeders	Cashew, cocoa
Procapritermes sp.	Small epigeal nest at the tree base, soil, leaf litter	Soil/ Humus feeders	Cashew, cocoa
Sub family: Nasutitermitinae			
Nasutitermes sp.	Mud tubes, soil and leaf litter	Wood feeders	Mango, cashew
Family: Rhinotermitidae Sub family: Heterotermitinae			
Heterotermes sp.	Soil near a dead stump, dead wood	Wood feeders	Mango
Sub family: Coptotermitinae			
Coptotermes sp.	Basal portion of a cut down tree	Wood feeders	Open field

Plate 8. Microhabitats of the termites identified from the Vellanikkara tract

A. Odontotermes

8.A1. Earthen mound

8.A2. Dead wood

8.A3. Leaf litter

8.A4. Mud tube

Plate 8 continued.

B. *Nasutitermes*

8B. Nest at the base of mango tree (Inset termites emerging from broken mud tube)

C. *Microcerotermes*

8C. Nest at the base of cashew tree

D. *Procapritermes* and *Dicuspiditermes*

8D. Nest at the base of cashew tree (Inset termites in soil and root debris)

E. *Homallotermes*

8E.Nest at the base of cashew tree

Diversity Index (D), Shannon-Weiner Diversity Index (H), Evenness Index (E) and Berger-Parker Dominance Index (d) and it is given in Table 6.

The genus richness of the termite fauna present in the Vellanikkara tract was found to be 9. The value of Simpson-Yule diversity Index was found to be 2.44 in the range of 1-9. The Shannon-Weiner Index representing the diversity of the genera due to environmental stress and selection was recorded to be 1.38 in the range of 0-2.20 while the Evenness Index representing the even distribution of the available genera was worked out to be 0.63 in the range of 0-1. The most dominant genus found in the Vellanikkara tract was *Odontotermes* as proved by the Berger-Parker Dominance Index of 0.62 in the range of 0-1.

The diversity of termite genera found in different systems was also compared and given in Table 7. The genus richness was found to be the highest in cashew plantation with a value of 6, while in the mango, cocoa and coconut based systems it was found to be only 3. The Simpson-Yule diversity Index was found to be the highest for cashew with a value of 4.65 and it was followed by that in coconut with a value of 2.12 and in mango with a value of 2.04. The least value of this diversity index of 1.67 was recorded in cocoa. A similar trend was noticed in the values of the Shannon-Weiner diversity Index with the highest value 1.64 in the cashew plantation, followed by that with 0.91 in coconut system and 0.87 in mango orchard. The least index was found to be in the cocoa based system with a value of 0.73. The Evenness Index was found to be the highest in cashew plantation with a value of 0.92. It was followed by that in coconut based plantation with a value of 0.83 and then in mango orchard with a value of 0.79. The least Evenness index of 0.66 was observed in the cocoa plantation. The Berger-Parker Dominance Index when worked out for the most dominant genus *Odontotermes* in different crop environments was found to be the highest in the cocoa plantation with a value of 0.75 followed by that in mango and coconut based systems with the values of 0.65 and 0.64 respectively. The least value of the dominance index was recorded in the cashew based system with a value of 0.33.

Table 6. Diversity indices of the termite fauna in Vellanikkara

Sl No.	Diversity indices	Range	Value
1	Genus richness	0- ∞	9
2	Simpson-Yule diversity Index (D)	1- 9	2.44
3	Shannon-Weiner diversity Index (H)	0- 2.20	1.38
4	Evenness Index (E)	0- 1	0.63
5	Berger-Parker Dominance Index*(d)	0- 1	0.62

(*for the most dominant genus of all the systems)

Table 7. Diversity indices of the termite fauna in selected crop environments at Vellanikkara

Diversity indices	Range	Crop environments				
		Mango	Cashew	Cocoa	Coconut	Open fields
1. Genus richness	0- ∞	3	6	3	3	3
2. Simpson-Yule diversity Index*(D)	-	2.04	4.65	1.67	2.12	1.51
3. Shannon-Weiner diversity Index** (H)	-	0.87	1.64	0.73	0.91	0.63
4. Evenness Index (E)	0- 1	0.79	0.92	0.66	0.83	0.57
5. Berger-Parker Dominance Index***(d)	0- 1	0.65	0.33	0.75	0.64	0.80

*Range in cashew is 1- 6 and that in mango, cocoa and coconut is 1- 3

**Range in cashew is 0- 1.79 and that in mango, cocoa and coconut is 0- 1.10

*** For the most dominant genus in the respective systems

The diversity indices have also been worked out for the genera collected at random from the open fields in the Vellanikkara tract (Table 7). A total of three genera were obtained from the open field collections. The Shannon-Weiner diversity Index worked out was 0.63, while, the Simpson-Yule diversity Index was 1.51. The Evenness Index in the open field collection was found to be 0.57 and the Berger- Parker Dominance Index for the most dominant genus *Odontotermes* was 0.80.

4.3. PREPARATION OF A PRIMARY TERMITE COLONISATION MAP IN SELECTED CROP ENVIRONMENTS

A primary termite colonisation map was prepared and documented by depicting the identified termite genera based on their distribution and relative colonisation in selected crop environments, in an already prepared GIS map of the campus and it is depicted in Figure 2.

4. 4. MORPHOMETRY OF THE AERIAL MOUNDS

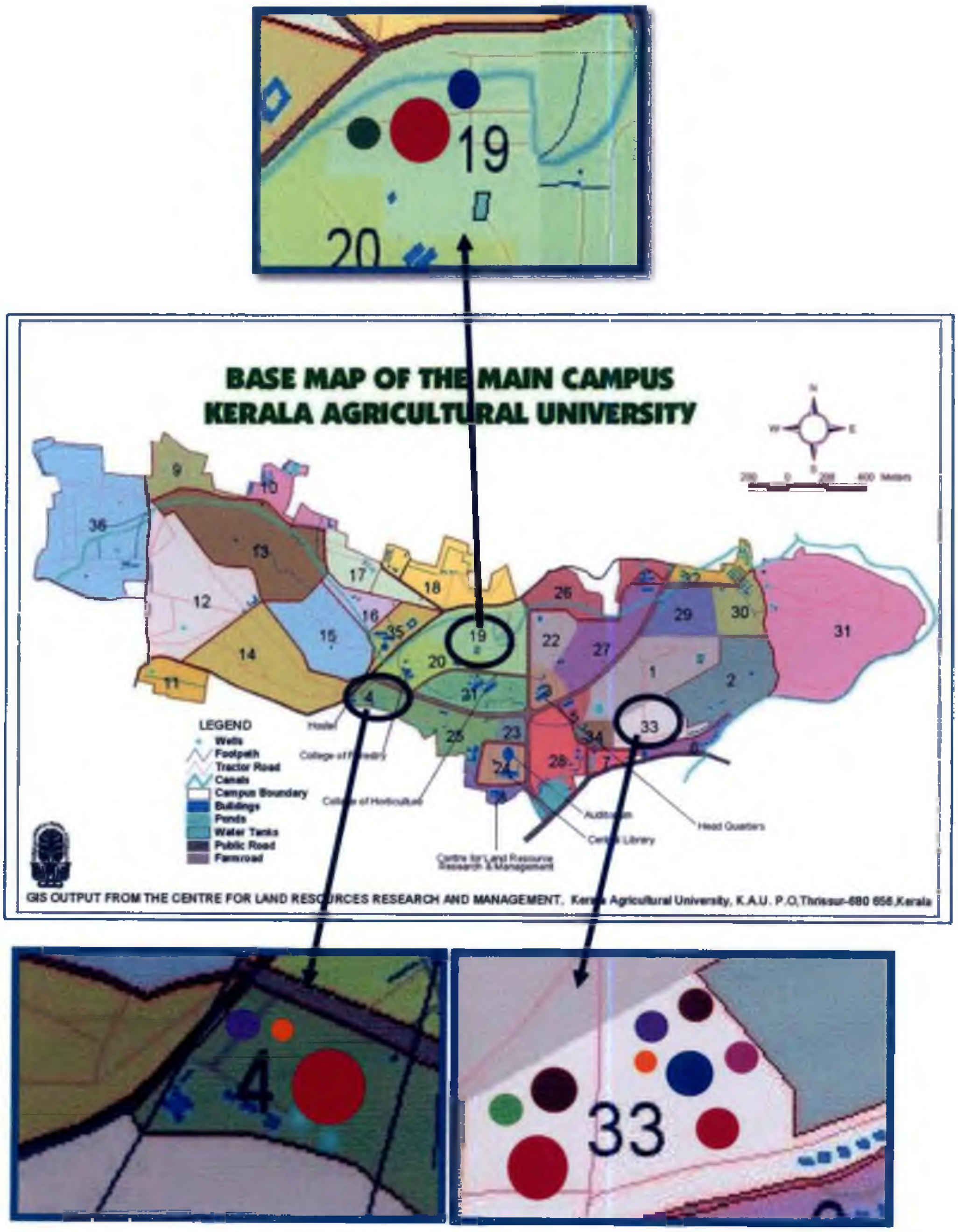
The morphometry of the aerial mounds (per 200 sq. m area) of the genus *Odontotermes* in selected crop environments were taken at monthly intervals from July, 2010 to February, 2011. The mound parameters *viz.*, density of the mounds, number of buttresses, height and basal circumference of the mounds (cm) along with its external volume (cm^3) were measured, documented and presented in Table 8.

4.4.1. Density of the mounds

The mean density of the mounds per 200 sq. m area was found to be constant throughout the period of observation from July, 2010 to February, 2011 and it was found to be 6, 4 and 5 in mango, cashew and cocoa based systems, respectively.

Figure 2. Primary termite colonisation map

(Block 19: Coconut plantation)



(Block 4: Cocoa plantation) (Block 33: Mango orchard and cashew plantation)

Figure 2 continued.

LEGEND

- ***Odontotermes***
- ***Microcerotermes***
- ***Procapritermes***
- ***Dicuspiditermes***
- ***Nasutitermes***
- ***Microtermes***
- ***Homallotermes***
- ***Heterotermes***

Table 8. Morphometric observations of the mounds in selected crop environments (mean of 8 observations per 200 sq. m)

Mound parameters	Crop environments		
	Mango	Cashew	Cocoa
Density of mound	6	4	5
No. of buttresses	7.38	5.10	6.55
Height (cm)	35.32	31.21	33.87
Basal circumference (cm)	122	88	149
External volume (cm^3)	29658	5723	63663

Table 9. Increase in external volume of the mounds in selected crop environments (per 200 sq. m area) from July'10 to Feb'11 (mean of 8 observations)

Month Interval	Relative per cent increase in external volume		
	Cashew	Cocoa	Mango*
July'10-Aug'10	2.15^{c}	2.38^{a}	0.64^{b}
Aug'10-Sep'10	34.39^{ab}	4.27^{a}	8.59^{a}
Sep'10-Oct'10	25.25^{abc}	12.96^{a}	2.58^{ab}
Oct'10-Nov'10	19.38^{abc}	20.84^{a}	
Nov'10-Dec'10	5.82^{bc}	7.41^{a}	
Dec'10-Jan'11	13.24^{abc}	6.75^{a}	
Jan'11-Feb'11	50.00^{a}	27.40^{a}	

*Observation in the mango orchard could not be completed due to its destruction

In a column, means superscripted by a common letter are not significantly different by Duncan's Multiple Range Test (p=0.05)

4.4.2. Number of buttresses

In addition to the density of mounds, the mean number of buttresses or small conical sub mounds around each main termitaria in all the three selected systems were also calculated and it was found to be 7.38, 5.10 and 6.55, respectively, in mango, cashew and cocoa based systems.

4.4.3. Mean height, basal circumference and external volume of the mounds

The mean height (cm) of the mounds present in mango, cashew and cocoa based systems were found to be 35.32, 31.21 and 33.87 cm, respectively. The mean basal circumference (cm) of the mounds were found to be the highest in cocoa based system with a value of 149 cm followed by the mounds present in the mango orchard with a value of 122 cm and the lowest value was noticed for the mounds present in the cashew system with the value of 88 cm. The mean external volume of the mounds were found to be the highest in the cocoa plantation with a value of 63663 cm^3 followed by the mounds present in the mango and the coconut based systems with the values 29658 and 5723 cm^3, respectively.

4.4.4. Relative per cent increase in external volume of mounds

The per cent increase in external volume of the mounds at monthly intervals was calculated and subjected to statistical analysis and the results are presented in Table 9. The relative per cent increase in external volume of the mounds in cashew based systems showed significant difference during two periods *viz.*, July'10- Aug'10 and Jan'11- Feb'11 where the highest per cent increase in volume was noticed during Jan'11- Feb'11 (50.00 %). The per cent increase in volume of the mounds in the cocoa plantation showed no significant difference during the period of observation but in mango, significant difference in the per cent increase in volume of the mounds was noticed during July'10- Aug'10 (0.64 %) and Aug'10- Sep'10 (8.59 %).

4.5. PHYSICAL PROPERTIES OF THE SOIL

The physical properties of the termitarial soil and the adjacent soil in selected systems were also compared in the study. The soil colour was determined

Table 10. Soil colour based on observation from the Munsell Colour Chart during wet season (October, 2010) and dry season (March, 2011)

Crop environment		Wet season				Dry season			
		Mound soil		Adjacent soil		Mound soil		Adjacent soil	
		Soil colour	Musell colour notation	Soil colour	Musell colour notation	Soil colour	Musell colour notation	Soil colour	Musell colour notation
Mango*	Mound 1	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/3	Not taken	Not taken	Not taken	Not taken
	Mound 2	Yellowish red	5YR 4/8	Yellowish red	5YR 4/8	Not taken	Not taken	Not taken	Not taken
	Mound 3	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/4	Not taken	Not taken	Not taken	Not taken
Cashew	Mound 1	Yellowish red	5YR 4/6	Dark reddish brown	5YR 3/3	Brown	7.5YR 5/4	Dark reddish brown	5YR 3/3
	Mound 2	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/4	Brown	7.5YR 4/4	Dark reddish brown	5YR 3/3
	Mound 3	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/3	Brown	7.5YR 5/4	Dark reddish brown	5YR 3/3
Cocoa	Mound 1	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/3	Brown	7.5YR 5/4	Dark reddish brown	5YR 3/3
	Mound 2	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/3	Brown	7.5YR 5/4	Dark reddish brown	5YR 3/3
	Mound 3	Dark reddish brown	5YR 3/3	Dark reddish brown	5YR 3/3	Brown	7.5YR 5/4	Dark reddish brown	5YR 3/3

*Soil colour could not be determined during the dry season due to the physical destroyal of the mounds.

during wet season and dry season by using the standard Munsell Soil Colour Chart. The soil texture was determined both by the standard feel method and by particle size analysis of the soil samples.

4.5.1. Soil colour

The colour of the mound soil and of the adjacent soil in the three selected systems namely mango, cashew and cocoa were noticed during one wet season (October, 2010) and one dry season (March, 2011) using the Munsell Soil Colour Chart and presented in Table 10.

4.5.1.1. Wet season colour

The colour of the mound soil in mango during the wet season was determined as dark reddish brown (5YR 3/3) except for the colour of the soil in one of the selected mounds where it was found as yellowish red (5YR 4/8). The colour of the adjacent soil in mango during the wet season was also found to be dark reddish brown (5YR 3/3, 5YR 3/4). The soil colour of the mounds in cashew during the wet season was found to be dark reddish brown (5YR 3/3) except for one mound where the colour was found to be yellowish red (5YR 4/6). The colour of the adjacent soil in cashew was found to be dark reddish brown (5YR 3/3, 5YR 3/4). In cocoa based system the colour of mound and adjacent soil during wet season was found to be dark reddish brown (5YR 3/3).

4.5.1.2. Dry season colour

During the dry season, the soil colour of the mounds in cashew was found to be brown (7.5YR 5/4, 7.5YR 4/4) and of the adjacent soil was found to be dark reddish brown (5YR 3/3). In cocoa plantation, the colour of the mound soil was found to be brown (7.5YR 5/4) and of the adjacent soil was found to be dark reddish brown. The soil colour in the mango orchard could not be determined during the dry season due to physical destroyal of the mounds.

Table 11. Particle size distribution of mound soil and adjacent soil in crop environments (mean of 3 values)

Crop environment	Mound soil				Adjacent soil			
	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
Mango	27	27	45	0	15	22	60	3
Cashew	31	20	49	0	18	21	59	2
Cocoa	26	25	50	0	16	28	56	0
	Sandy clay loam				Sandy loam			

Table 12. Influence of crop environments in the soil textural difference of the mound and adjacent soil (mean of 4 values)

Crop environment	Clay (%)	Silt (%)	Sand (%)
Mango	24.25^{a}	26.25^{a}	48.75^{a}
Cashew	27.50^{a}	20.25^{b}	51.75^{a}
Cocoa	23.25^{a}	25.50^{a}	51.25^{a}

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

4.5.2. Soil texture

The texture of the mound soil and of the adjacent soil was determined by feel method. The texture of the mound soil in all the selected systems were found to be silty clay loam while that of the adjacent soil was found to be sandy loam.

The collected soil samples were also subjected to particle size analysis and the mean per cent values are presented in Table 11. The clay content in the mound soil was higher than that of the adjacent soil in all the three systems namely mango, cashew and cocoa. The mound soil of the mango based system was found to have higher silt content than that of the adjacent soil. But the silt content in the mounds of cashew and cocoa based systems was slightly lower than that of the respective adjacent soil. The sand content in the mound soil was much lower than that of the adjacent soil in all the three systems. The adjacent soil was found to have more amount of coarser fractions consisting of sand and gravel. But gravel was not present in the adjacent soil collected from the cocoa based system. Gravel was also absent in the mound soil collected from all the systems. The clay content of the mound soil in mango ranged from 26-29 per cent and the silt and sand content ranged from 26-31 per cent and 40-48 per cent, respectively. The clay, silt and sand content of the mounds in cashew based system ranged from 27-34, 18-24 and 48-51 per cent, respectively. The clay content of the mounds in cocoa based system ranged from 23-27 per cent and the silt and sand content ranged from 23-27 per cent and 49-50 per cent, respectively.

4.5.2.1. Influence of crop environments in soil textural difference

Statistical analysis was done to determine the influence of different crop environments on textural difference in soil and the data are presented in Table 12. The per cent content of clay and sand particles in the soil samples collected from the three selected systems of mango, cashew and cocoa showed no significant difference among them but the silt content present in the soil samples of the cashew based system (20.25%) differed significantly between the other two systems. The mean per cent silt content in mango and cocoa systems were 26.25

per cent and 25.50 per cent, respectively. The mean per cent clay content present in mango, cashew and cocoa based systems were found to be 24.25, 27.50 and 23.25 per cent, respectively and the mean per cent sand content present in the respective systems were found to be 48.75, 51.75 and 51.25 per cent.

Observation

Change in the soil colour was noticed during wet and dry season. Soil samples from the mounds were found to be more sticky, had the tendency to form ball and ribbon on squeezing whereas soil samples from the adjacent soil was more gritty, had the tendency to form fairly firm ball and it had stained the fingers. Clay content of the mound soil sample was found to be high when compared to the adjacent soil sample.

4.6. INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON TERMITE COLONISATION

The weekly mean temperature and relative humidity inside the mounds and of its external ambience was measured by using Temperature humidity meter (Model- HT- 3006HA) given in Plate 5.

The temperature and relative humidity inside the mounds in all the three selected crop environments were found to be slightly higher than that of the external ambience. The temperature and relative humidity inside the mounds as well as outside in two of the selected systems *viz.*, mango (30.08^{0}C and 79.03% inside, 29.72^{0}C and 75.60% outside) and cocoa (29.81^{0}C and 75.22% inside, 29.28^{0}C.and 73.26% outside) differed only slightly while in the cashew based system, both temperature and relative humidity inside the mounds (31.72^{0}C and 75.22%) as well as the external ambience (31.02 ^{0}C and 67.13%) were found to be slightly higher than that of the other two systems.

Comparative analysis of the microclimate of the termitarial mounds in different crop environments was performed by means of t test and it is presented in Table 13. The weekly mean temperature and relative humidity inside the

Table 13. Comparitive analysis of the microclimate of the termitarial mounds in different crop environments (mean of 11 observations)

Crop environments	Temperature (^0C)			Relative humidity (%)		
	Inside mound	Outside mound	t value	Inside mound	Outside mound	t value
Mango	30.08	29.72	2.85**	79.03	75.6	4.53**
Cashew	31.72	31.02	4.07**	75.22	67.13	8.20**
Cocoa	29.81	29.28	7.36**	77.38	73.26	6.67**

(** indicates significant at p=0.01)

mounds and of the external ambience in selected crop environments were compared and it was found that both temperature and relative humidity inside the mounds were significantly higher than that of the external ambience in all the systems. The computed t value in all the cases indicated that there was significant difference between the means of temperature and relative humidity inside the mounds and its external ambience.

Discussion

5. DISCUSSION

5.1. SURVEY ON THE TERMITE FAUNAL COMPOSITION IN THE SELECTED CROPPING SYSTEMS

A preliminary survey was conducted at the instructional farm area of the College of Horticulture, Vellanikkara during February, 2010 covering various orchards and plantations of mango, cashew, cocoa and coconut by transect walk. The observations and inferences based on survey are discussed as follows:

In the selected orchards and plantations of the present study, mud tubes/ earthen coverings were noticed over the aerial parts of trees which indicated the prevalence of termites and termite colonisation in the area. Mud tubes/ earthen coverings were noticed on about 75 per cent of the randomly selected trees in mango, 60 per cent of the selected trees in cashew and about 45 per cent of the selected palms in coconut from an area of 200 sq. m. Samra *et al.* (1979) conducted survey in twenty four mango orchards and observed that an average of 66.19 per cent trees were infested by *Odontotermes wallonensis* and the findings of the present survey are in conformity with the observation of the authors. But mud tubes or earthen coverings were not noticed over the cocoa plants as these plants were found to be younger (<10 years of age) and were not having dead bark and branches.

Earthen coverings were also observed over the stubbles of grasses, dead wood and dead stumps present in relatively undisturbed open fields and in border areas near to roads and open fields, which indicated that termites forage on a variety of substrates rich in cellulose. This wider range of foraging by the termite population can be highlighted by the findings of Rajagopal (1983) where they reported that foraging was seen on grasses, trees, leaf litter, bark, dead wood, dung or any other cellulosic material. During foraging, the termite processions were consisting only of workers. The soldiers were guarding the procession by standing at certain points of intervals. Majority of the mound building and subterranean species construct underground galleries which extend several metres from their nest. They emerge from these and forage on the surface by constructing earthen runways. The worker castes will go for foraging by making earthen coverings or mud tubes over the tree trunks, but they were not noticed at any time of observation during the day time in the month of February, 2010. This observation is corroborated with the findings of the same author who reported that the foraging activity was seen either in cooler hours of the day or during the night.

In mango and cashew, earthen coverings were seen over the tree trunks up to four metre height. These trees were very old and senile (>30 years) and contained lot of dead and flaked out bark tissues. Roonwal (1954;1979) cited by Thakur (2000) had reported that the dead outer barks of all trees were liable to termite attack and the attack would usually occur under covered earthen tubes or mud plasterings over the bark. The termite workers would feed on thin layers of bark underneath these covers. The damage so caused, in most cases was found to be negligible, but at times it would expose the cambium portion of the stem and produce "girdling effects" resulting in the ultimate death of plants. Mud tubes were not noticed in cocoa plants as these plants were young (<10 years), succulent and not having much dead tissues. As the coconut palms were also very old (>25 years), mud tubes were observed in 65 per cent of the palms at a maximum height of 2 metres.

Weed flora including both broad leaved plants and grasses were found growing over the mounds and near to its vicinity in the mango orchard and cashew plantation and is given in Plate 9A and 9B. This is possibly due to the fact that termites might have improved the soil texture by increasing the water holding capacity of the soil which in turn favoured the growth of vegetation over the mounds. This progressive change in the soil has made the systems suitable for the growth of weed flora. The cashew plantation was dominated by the grass species which are indicators of dry land systems. However, weed growth was not noticed over the mounds in cocoa plantation which might be due to the fact that it was a well managed system with frequent human interventions.

Plate 9. Weed flora on termite mound and its vicinity

9A. In mango orchard

9B. In cashew plantation

The selected mango orchard was having a lot of dead and decaying matter like dead wood and leaf litter. Though dead and decaying woods were less in the cashew plantation, leaf litter was present in considerable amount. The cocoa plantation was, however, well littered with a lot of dead wood matter on the soil surface. The coconut basins were found to be littered with coconut husk, decaying fronds and mulches. The dead wood and leaf litter present in the systems provided more substrates for the termite foraging which in turn supported the termite population as remarked by Rajagopal (1983).

Termitarial mounds were seen on the ground soil of mango, cashew and cocoa based systems at a relative density of 6, 4 and 5 respectively per 200 sq. m. However, there were no mound formations in the coconut based plantations. The density of mounds was found to be the highest in mango followed by cocoa and cashew. It might be due to the influence of various factors such as shade factor, general condition of the crop plants such as age factor, productive/ senile phase of the plants, well managed/ under managed situations or irrigated/ unirrigated soil conditions, etc. The trees in the mango orchard and the cashew plantation was very old (25-30 years) and remained unproductive and the plots were under-managed with less human interventions. The light intensity was found to be the highest in cashew plantation with 31.77 per cent followed by cocoa with 9.77 per cent and mango orchards with 4.71 per cent when recorded during September to October 2010. The mean external ambient temperature in mango and cocoa was found to be in the range of 29-30^{0}C while in cashew it was found to be around 31^{0}C and the mean external ambient relative humidity was found to be around 73-76 per cent in mango and cocoa under more shade while it was around 67 per cent in cashew plantation with a low shade. The high mound density in mango and cocoa might be due to the similarity in microclimate *viz.*, low temperature and high RH in both the systems. At the same time the cocoa plantations were having reasonably high mound density in spite of its good management such as frequent irrigations and other intercultural operations including harvesting, weeding and plant protection operations. It might be due to the fact that it was an inter crop within an old rubber plantation with lot of residual leaf litter and dead wood accumulation. Manual intervention might have also intervened termite colonisation on the above ground parts of the host plants in mango and cashew but it was not observed in cocoa trees. At the same time, mound formations were not much affected below the ground level in all the systems including cocoa. However, the diversity of the termite genera was found to be the highest in cashew due to the relatively low disturbance, light exposure, lower relative humidity and higher temperature regime which might have supported the inter species competition and survivability, and *vice versa* within the cocoa system with a low diversity.

5.2. Identification of the faunal composition of the termite genera

The termite fauna identified from the Vellanikkara tract belonged to two families *viz.,* Termitidae and Rhinotermitidae. The identified termite genera belonged to three subfamilies in Termitidae and two subfamilies under Rhinotermitidae. A total number of nine termite genera were identified, of which seven genera were belonging to the family Termitidae and two genera in the family Rhinotermitidae. It shows that Termitidae is the dominant family in the region comprising of 77.8 per cent of the total genera identified. Roonwal and Chhotani (1961) reported that the family Termitidae was most richly represented in the Assam region with *Odontotermes* as the most dominant genus. The most dominant genus found in the Vellanikkara region was *Odontotermes* where it constituted 62.03 per cent of the total samples collected .The least dominant genus was found to be *Coptotermes* which constituted only 1.27 per cent. The dominant genus *Odontotermes* was identified from all the systems. This finding is in conformity with Sathe and Chougale (2008) who also reported that the genus *Odontotermes* was dominant in its distribution in the Western Ghat region. The percentage distribution of all the genera identified from the Vellanikkara tract is depicted in Figure 3.

5.2.1. Key characteristics for the identification of the genera

The soldier castes of the termites are the best suited morphs for the easy and reliable identification which are scientifically propounded by Bose (1984), Roonwal and Chhotani (1961) and Sornnuwat *et al.* (2004) based on the pronounced mandibular characteristics as well as pronotal and head capsule features which is given in Appendices I, II and III. A new special method of collection "glue trap technique" was designed and standardised for trapping the soldiers by provoking them to bite upon a glue coated glass rod inserted into the mounds (Plate 4). The biting/ defending tendency of the provoked soldiers was utilised for entrapping them upon the inserted foreign object inside the mounds. The mound was broken open at the mid-point of its side slope by one sq. cm area and a glass rod of 20 cm length was inserted and tapped for two minutes. It was the standard procedure adopted in all mounds to collect the soldiers which were got stuck on the glue trap. The collected soldiers were then washed out with water and kept under alcoholic preservation in glass vials for further identification.

The termite fauna were identified based on the available taxonomic keys proposed and practiced by Bose (1984), Roonwal and Chhotani (1961) and Sornnuwat *et al.* (2004) as well as by the description by Harris (1971). The most salient external features especially the mandibular and the head capsule characters and the shape of the pronotum were used for identifying the specimens.

Both mandibulate soldiers (with large, prominent and sickle-shaped mandibles) and nasute type soldiers (with vestigial mandibles where the rostrum prolonged into a snout) were identified from the Vellanikkara tract as highlighted by Abe and Matsumoto (1978). The soldiers with symmetrical, asymmetrical and twisted mandibles were also identified in the present study. Accordingly, seven termite genera were identified from the Vellanikkara tract belonging to the family Termitidae with saddle-shaped pronotum and two belonging to the family Rhinotermitidae with flat pronotum (Plate 10 and 11). The soldiers of two genera *viz.*, *Heterotermes* and *Coptotermes* identified in the family Rhinotermitidae were

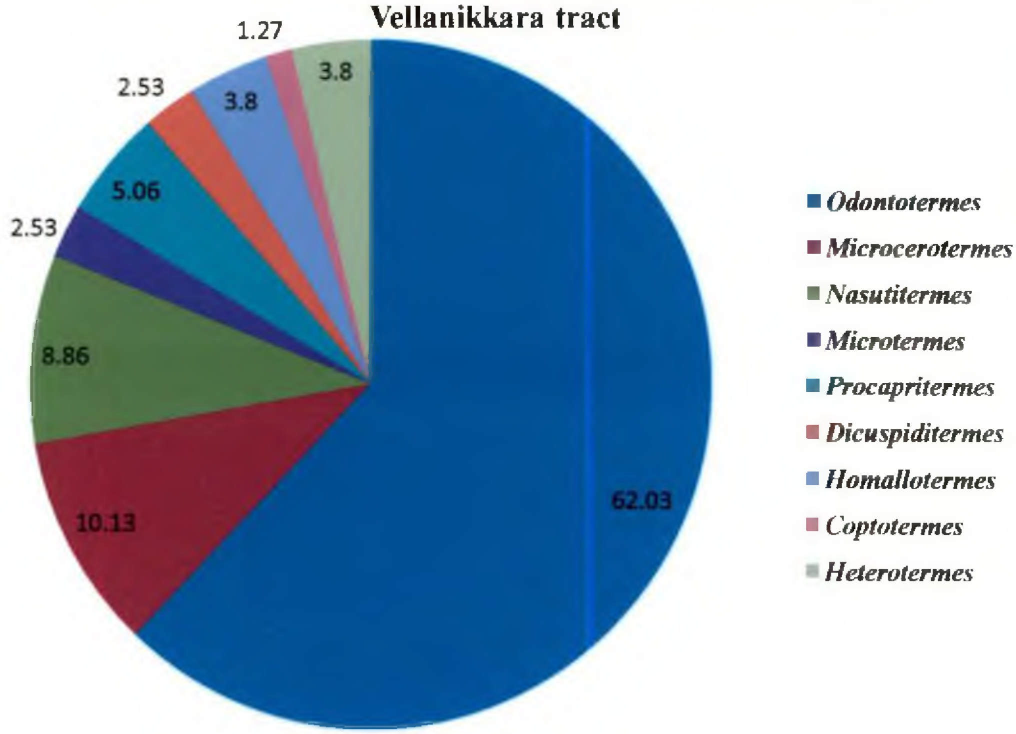


Figure 3. Distribution of termite genera identified from the Vellanikkara tract

found to have distinct fontanelle and it was found very prominent in the genus *Coptotermes* located very near to the clypeus. The soldier castes of the genus *Odontotermes* was found to have assymetrical mandible with a distinct marginal tooth at the left mandible (Plate 7A). The genus *Microcerotermes* had long rectangular dark brown head (with fontanelle) and sabre-shaped mandibles with serrations along the inner margin (Plate 7B). The soldiers of the genus *Microtermes* was found to be very delicate with symmetrical mandibles and with smooth inner margins (Plate 7G). The soldiers of the genus *Procapritermes* have twisted mandibles with the left mandible narrow and bent in the form of a hook (Plate 7D). *Dicuspiditermes* have the tip of its left mandible broad and not strongly bent (Plate E). The soldiers of the genus *Homallotermes* were having thin mandibles with its tip not bent in the form of a hook (Plate 7F). The nasute type soldier identified from the Vellanikkara tract belonged to the genus *Nasutitermes* which was found to have a relatively large pear-shaped head capsule with vestigial mandibles and a snout which project in front of head (Plate 7C). The soldiers of the genus *Heterotermes* possess rectangular head with small fontanelle and assymetrical mandibles with its inner margin non serrated but the left mandible with four low protuberences at the base and those of the genus *Coptotermes* is found to have a pear-shaped head with large fontanelle and symmetrical mandible with the inner margin smooth (Plate 7I and 7H).

5.2.2. Feeding habits of identified termite genera

A superficial classification of the termite genera based on their known feeding habits was attempted based on the feeding substrates of termites and by pooling information from various literature (Jones and Brendell, 1998; Constantino, 2002). Thakur (2000) reported that when termite diversity increases, there would be complete range of adaptation among them to get diverted to various food sources like living trees, herbs and humus.

The present study indicated that there are wood feeders and soil feeders in the family Termitidae while there are only wood feeders in the family

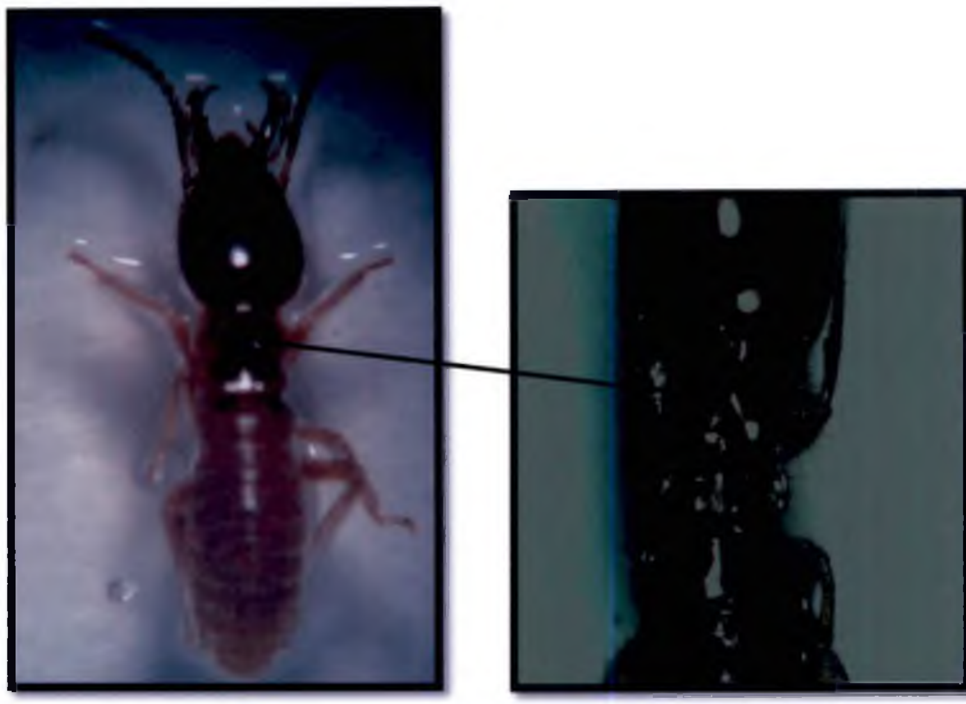


Plate 10. Saddle shaped pronotum in Termitidae (20X and 50X)

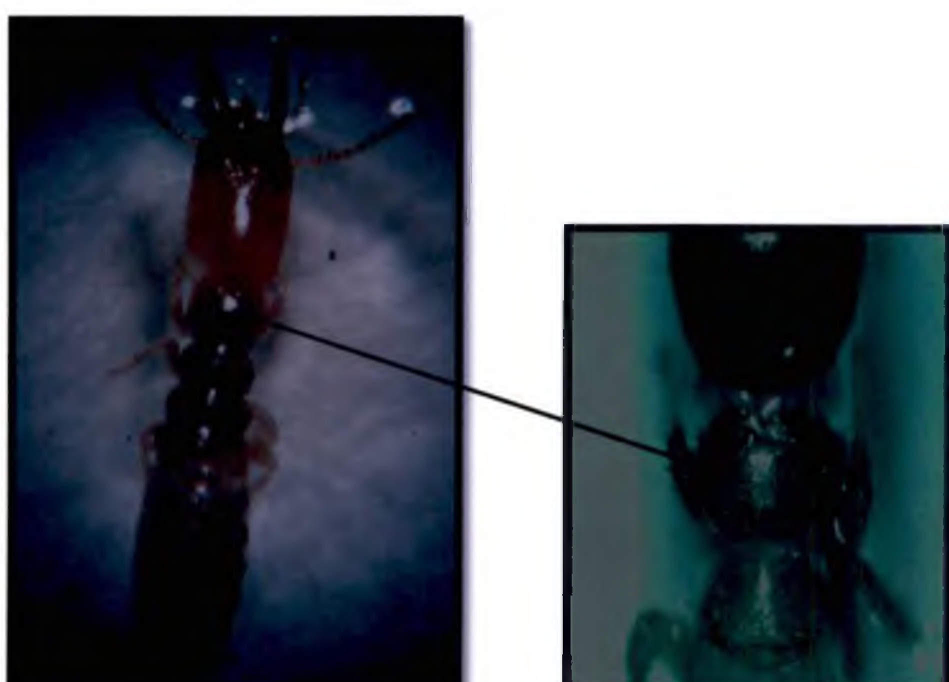


Plate 11. Flat pronotum in Rhinotermitidae (20X and 50X)

Rhinotermitidae. Harris (1971) reported that the members of the family Rhinotermitidae and Termitidae were small wood eating termites while Beeson (1993) commented that the members of the family Termitidae exhibited a wide range of feeding habits including wood, fungus, dead vegetable matter, grasses and soil. In the present study, 55.56 per cent of the identified termite genera were wood feeders and 44.44 per cent of the genera were soil feeders. Thus, wood feeders were found to be more dominant in the Vellanikkara tract than soil feeders. This is in conformity with the findings of Jones and Brendell (1998) who commented that 54 per cent of the identified termite species in Pasoh Forest Reserve in Malaysia were wood feeders while soil-feeders and the termites that feed on highly decayed soil-like wood constituted 31 per cent and 6 per cent, respectively. Dawes-Gromadzki (2008) also reported that wood and wood/ soil interface feeders were the most common in Australian tropical savanna termite assemblages which is also in corroboration with the findings of the present study.

The genus *Odontotermes* was categorised as wood feeders in the present study conducted at Vellanikkara. Harris (1971) commented that the genus *Odontotermes* consisted of a number of species feeding on wood and dead vegetation.

Procapritermes, *Dicuspiditermes*, *Homallotermes* and *Microtermes* were included as soil/ humus feeders in the study conducted at Vellanikkara tract. Harris (1971) reported *Microtermes* as a widely distributed soil dwelling termite and the members of the sub-family Termitinae which includes *Procapritermes*, *Dicuspiditermes* and *Homallotermes* as humus feeders. Rajagopal (1983) reported *Capritermes* as soil feeders which mostly feed on top soil rich in humus.

The genera *Microcerotermes* and *Nasutitermes* were listed as wood feeders in the present study which is in conformity with the report by Rajagopal (1983) who suggested that *Microcerotermes* and *Nasutitermes* genera was found to feed on wood and dry vegetation.

The termite genera coming under the Rhinotermitidae family *viz.*, *Heterotermes* and *Coptotermes* were identified as wood feeders in the present study. Beeson (1993) commented that the genus *Coptotermes* was found to feed exclusively on wood which in turn agreed with the findings of the present study. He also reported that one species of the genus *Heterotermes* viz., *H. indicola* was found to have wood as its staple diet. Harris (1971) reported *C. heimi* as serious pests of constructional timber and growing trees in some places.

5.2.3. Microhabitats of collected termite genera

Ecological classification of termites based on their sites of nesting was made in the study which would help in determining the possible approach to their management. Thakur (2000) reported about wood dwelling and ground dwelling termite species, where the wood dwellers could be either damp wood termites or dry wood termites and the ground dwellers could be subterranean (soil dwelling) forms or mound building forms.

The only one genus found to build large earthen mounds in mango, cashew and cocoa systems in the Vellanikkara tract was *Odontotermes*. The mound of this genus was found to be nearly sub cylindrical/ conical with a mean height of 31-35 cm and 5-7 mean number of buttresses or small conical sub mounds associated with the main mound (Plate 12 and 13). Rajagopal (1983) reported the principal mound building termite species in India as *O. obesus*, *O. redemanni*, *O. wallonensis* and *O. microdentatus*. Out of this, *O. obesus* was widely distributed in India which construct tall sub cylindrical mounds without any openings to outside and were up to 3-4 metres in height with a series of buttresses around them. Based on the above description it may be presumed that the genus identified can be *O. obesus* which needs further taxonomic confirmation. The mounds of *O. redemanni* and *O. microdentatus* as reported by the same authors were dome shaped without any external opening, low in height with sub conical outgrowths but without any buttresses which was not in conformity with the findings of the present study. Thakur (2000) reported that the

Plate 12. Termitaria

12A. In mango orchard

12B. In Cashew plantation

Plate 12 continued.

12C. In Cocoa plantation

mounds of *Odontotermes* would reach a height up to 2.5 metres above the ground and was a conspicuous feature in the deciduous forests all over the plains of northern India and in many parts of the peninsular India. The same genus was also collected from dead wood, mud tubes and basal part of tree trunks which indicated that there were both mound building and soil dwelling species in *Odontotermes* as supported by the report of Thakur (2000).

The other genera identified from the study *viz., Procapritermes* and *Homallotermes* were typical soil feeders collected from very small epigeal nests, soil and leaf litter in cashew and cocoa plantations (Plate 8D). Rajagopal (1983) had also reported in conformity that *Cubitermes*, *Termes* and *Capritermes* were soil feeders and mostly feed on top soil rich in humus and they would construct small mounds for nesting. The prominence of these two genera in the above mentioned crop environments indicated that they preferred to host in crop plants with a deciduous/ semi-deciduous character with abundant quantity of leaf litter on the soil floor. These species were reported to be typical soil feeders (Harris, 1971) which were facilitated by the fallen leaf litter remaining on the soil surface. The genus *Dicuspiditermes* was found to be associated with *Procapritermes* in all the samples at a ratio of 1:10 and thereby the genus *Procapritermes* might be considered as the dominant genus in the above systems. Harris (1971) reported thirty two species of *Capritermes* from India, Malaya and China. Rajagopal (1983) reported *D. fletcheri* and *D. incola* as pests injuring agriculture/ horticulture/ forestry crops in India.

Homallotermes genus was also collected from small epigeal mounds and soil and root debris (Plate 8E). Bose (1984) reported it as a soil inhabiting termite where the nest consists of narrow galleries below the ground surface near trees and plants, which is in conformity with the findings of the present study.

Microtermes was collected from soil underneath coconut husks and fronds near the coconut basin in the selected plantation for the study. Rajagopal (1983)

Plate 13. Buttresses associated with the main mound

13A. In mango orchard

13B. In cashew plantation

13C. In cocoa plantation

and Thakur (2000) commented *Microtermes* as soil dwelling termite genera. Harris (1971) reported that the genus *Microtermes* was prevalent in India.

The genus, *Microcerotermes* now identified from cashew, coconut and open fields at Vellanikkara were mostly collected from the nest at the basal trunk of the host trees, dead wood and mud tubes (Plate 8C). It was found to build a carton-nest at the tree base. Rajagopal (1983), Harris (1971) and Thakur (2000) also reported the genus *Microcerotermes* as typical carton-nest building termite which would feed on woody material with a high proportion of ligneous matter. It was not found to be present in the shaded systems like cocoa, but was found to prefer open systems like cashew, coconut and other open fields. Harris (1971) reported that *Microcerotermes* was a widely reported genus throughout the tropics and several species of it were recorded as minor pests of cocoa in some of the African countries. Rajagopal (1983) recorded a few species of the genus *viz., M. beesoni, M. minor, M. mycophagus, M. obesi* and *M. tenuignathus* as injurious to the crops of agriculture, horticulture and forestry in India.

Nasutitermes genus identified from here was collected only from mud tubes, soil and leaf litter in the mango orchard and cashew plantation which in turn was not able to be obtained from the cocoa and coconut plantations (Plate 8B). Thereby it could be inferred that this genus have a preference to the host environment with Anacardiaceae plants. The reasons for their non preference in other crop environments in this tract have to be further ascertained. The mud tubes over the tree trunks were observed to be made out of carton like material and extended to more than two metre height from the ground level. Thakur (2000), Beeson (1993) and Rajagopal (1983) also reported that the genus *Nasutitermes* was found to build carton nest. Rajagopal (1983) found one species of *Nasutitermes, viz., N. indicola* as a pest of agriculture/ horticulture/ forestry plants in India. Harris (1971) reported that *Nasutitermes* was having numerous species widely distributed in the tropics and the sub-family Nasutitermitinae was well represented in tropical Asia. He also reported *Macrotermes subtilis* and *N. nigritus* as building their nests on coconut palms where they were exploiting the wounds on the palm trunks. *N. costalis* from Puerto Rico and *N. rippertii* from Brazil were identified as occasional pests of palms by the same author, which was found to be in contrast with the present findings where this genus was not encountered from the coconut palms.

The genus *Heterotermes* was collected from dead wood found in the mango based systems in the Vellanikkara tract. Beeson (1993) commented that *Heterotermes indicola* was found to live in the fallen tree and stumps in forests, and Thakur (2000) reported the same species as an important subterranean termite species which was found in confirmation with the present study.

The genus *Coptotermes* under family Rhinotermitidae was collected from basal portion of a cut down tree in an open field at Vellanikkara tract and was having a less dominance as evidenced from the dominance index value of 0.07. Beeson (1993) and Thakur (2000) reported that the genus *Coptotermes* was subterranean in habit which they would build their nest at below ground level and in logs or fairly damp wood. Harris (1971) reported that the genus *Coptotermes* was present throughout the tropics with forty five described species.

Mathew (2004) had listed the various termite species identified from various parts of Kerala including the presently identified ones. It included *Anacanthotermes viarum* (Family: Hodotermitidae), some species of *Cryptotermes*, *Neotermes* and *Postelectrotermes* of the family Kalotermitidae, *Heterotermes ceylonicus* (Holmgren) and *Heterotermes malabaricus* Synder of the family Rhinotermitidae and several species from various genera like *Ampoulitermes*, *Angulitermes*, *Ceylonitermes*, *Dicuspiditermes*, *Emersonitermes*, *Euritermes*, *Homallotermes*, *Macrotermes*, *Microtermes*, *Nasutitermes*, *Odontotermes* , *Pericapritermes* and *Procapritermes* of the family Termitidae.

5.2.4. Measurement of Diversity Indices

Simpson-Yule diversity Index (D) with respect to species/ generic diversity of the insects in their natural habitat was found to be the highest in cashew based system with a value of 4.65 over a range of 1-6, while it was the lowest in cocoa system with a value of 1.67 over a range of 1-3 and of intermediate with a value of 2.04 in mango and 2.12 in coconut (Table 7). It highlights that cashew systems support more genera and species of termites followed by mango and coconut environments, while cocoa system is less favoured for termite diversity. The slightly higher D value in coconut as compared to mango indicated that coconut environment has more generic diversity than mango.

Shannon-Weiner diversity Index (H) indicating the numerical dominance of the individuals in each taxa in the total population of the insect community highlights the influence of the environmental stress on the sensitivity or the survivability of the individuals in a given ecological system. It was found to be the highest in cashew (1.64) with a range of 0-1.79 followed by that in coconut (0.91) and mango (0.87) with the least value in cocoa (0.73) where the value ranged from 0-1.10 (Table 7). The decrease in the H value in cocoa indicated an increase in the magnitude of environmental stress on the sensitive genera inhabiting there which in turn favour the dominance of a few adapted species. A decrease in the value of this index indicates an increase in the magnitude of environmental stress on the species (Cairns and Dickson, 1971).

Evenness Index (E) with a range of 0-1 is a measure of the uniformity of different species in a community and the value increases as the environment becomes favourable for a number of species (Mitra, 2000). This index E when determined for termite genera was found to be the highest in cashew (0.92) and lowest for cocoa (0.66). The E value for mango and coconut was 0.79 and 0.83, respectively (Table 7). The high E value in cashew indicated that the system is favourable for supporting a number of species which again corroborate the early indices. But the cocoa based system is unfavourable for supporting more species.

Berger-Parker Dominance Index (d) with a range of 0-1 is a simple dominance measure easy to calculate taxal dominance independent of species richness but influenced by the sample size was also determined for the dominant genus in the selected crop environments. Accordingly, *Odontotermes* sp. was found to be having the highest d value in cocoa (0.75) followed by mango (0.65) and coconut (0.64) and least for cashew (0.33) (Table 7). So it proves that irrespective of the crop environments and systems, *Odontotermes* is the most dominant genus in the Vellanikkara tract.

In the Vellanikkara tract, the D value with a range of 1-9 was found to be 2.44 which indicated that the diversity was less. H value whose value ranged from 0-2.20 was found to be 1.38 and E value of 0.63 indicated that the environment was more favourable for supporting a number of species. The most dominant genus found in the Vellanikkara tract was *Odontotermes* and the d value was found to be 0.62 (Table 6).

5.3. PRIMARY TERMITE COLONISATION MAP IN CROP ENVIRONMENTS

The primary termite colonisation map prepared and documented in Figure 2 by depicting the termite distribution, spread and colonization density with the identified genera showed that there is high influence of the agro ecological factors but low influence of edaphic factors in the faunal distribution of the termites in the different crop environments. A similar attempt was made by Primanda *et al.* (2003) in their work in UI campus, Depok, Indonesia with respect to termite species and its distribution in the campus area. The present termite generic distribution map prepared upon the crop environment if superimposed on a GIS map of the same location can throw much light on the influence of the edaphic, hydro geological and agro ecological factors in the faunal composition in the area. This ecological and bio systematic information can be utilized for the agro ecosystem management either with the management of pestiferous termite species or conservation of the beneficial termite fauna in the study area.

5.4. MORPHOMETRY OF THE AERIAL MOUNDS

5.4.1. Relative density of the mounds in different crop environments

The density of the mounds of *Odontotermes* genus in mango orchard and cashew as well as cocoa plantations was recorded to be 300, 200 and 250 per ha respectively. In this context, Asawalam *et al.* (1999) had also reported a density of 112 mounds/ha with genus *Nasutitermes* in southern Nigeria in a forest ecosystem. The density of *Nasutitermes* at Vellanikkara in plantation and orchard system could not be estimated as they were encountered predominantly from mud tubes only. It indicated that the Vellanikkara region was more prone to termite infestation by the mound building genus of *Odontotermes*.

The density of the mounds per unit area in all the selected systems was found to be constant during the period of observation from July, 2010 to February, 2011.This data showed that the termite colonization in these systems are relatively permanent without much disturbance to the existing crop environment and their productive management. Tano and Lepage (1990) reported a fluctuation in nest density of another genus *Macrotermes bellicosus* within a short period of time which was in contrast with the present findings of the study.

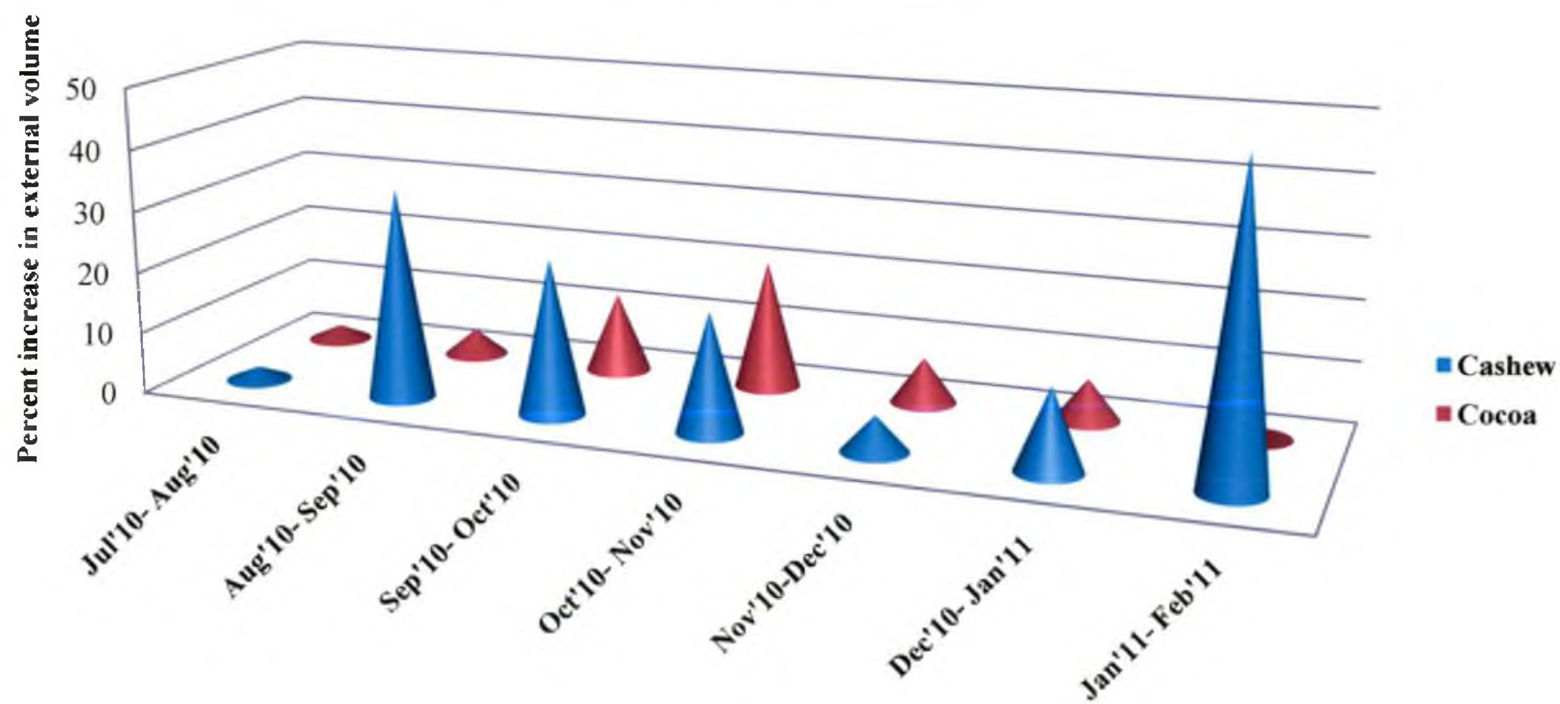
5.4.2. Number of buttresses

The number of buttresses around each main mound in the mango orchard ranged from 2 to 14 and that of the cashew and cocoa based systems ranged from 3 to 11 and 1 to 12, respectively. It again proves that species in the genus *Odontotermes* may be the same in all crop environments. Rajagopal (1983) had reported that *O. obesus* was widely distributed in India which construct tall and sub cylindrical mounds without any openings to outside and were up to 3-4 metres in height with a series of buttresses around them. But the lower heights recorded by the mounds of the genus *Odontotermes* at Vellanikkara indicated that the species in this tract may be different due to the prevailing agro ecological situation.

5.4.3. Mean height, basal diameter and external volume of the mounds

The mean height and basal diameter of the mounds of the genus *Odontotermes* measured in various systems in Vellanikkara ranged from 20.70-

Figure 4. Relative per cent increase in external volume of the mounds in cashew and cocoasystems from Jul'10 to Feb'11



71 cm in the mango orchard, 20.1-54.55 cm in the cocoa plantation and 25.83-38.56 cm in the cashew plantation. Likewise, the basal diameter of the mounds when determined was found to be in the range of 19.65-86.04 cm in the mango orchard, 10.41-144.51 cm in the cocoa plantation and 11.17-36.52 cm in the cashew based system. Based on these, the mean external volume of the mounds when calculated was found to be the highest (63663 cm^3) in cocoa plantation, followed by that in mango (29658 cm^3) and the least value was in cashew system (5723 cm^3). These values indicated that both mango and cocoa based systems consisted of relatively small to large sized mounds while in cashew all the mounds were of medium size. The difference in size might be due to the microclimatic variation present within each system. But Rajagopal (1990) reported that the earthen nest of *Odontotermes obesus* was tall and sub cylindrical without any opening on the surface and the basal diameter of the nest was found to vary from 1.25 to 2.00 m and the height up to 3.00 m which shows a deviation from the present study.

The relative per cent increase in external volume of the mounds in cocoa system showed no significant difference between them during the period of observation while significant differences were observed in cashew and mango based systems during July'10- Aug'10 and Jan'11- Feb'11 with a peak increase during Jan'11- Feb'11 (Table 9). This was found to be in conformity with the ideas of Lee and Wood (1971) who suggested that the mounds in various ecosystems were not static objects but were continuously being eroded by rainfall and occupied mounds were repaired and enlarged by the termites. At the same time, abandoned mounds were gradually being eroded away reducing the sizes. The relative per cent increase in volume of the mounds in cashew and cocoa from Jul'10 to Feb'11 is depicted in Figure 4.

5.5. MODIFICATION OF PHYSICAL PROPERTIES OF THE TERMITARIAL SOIL

The modification of the soil by the termite activities ascertained by subjecting the soil samples from mounds and adjacent area to various standard physical tests revealed the following changes in textural properties. The soil in Vellanikkara tract are in general typically of sandy loam type as evidenced by the GIS maps already prepared by Sajnanath (2000). The physical tests undertaken by the present study also conforms the above textural analysis in all the selected crop environment sites with maximum termite infestation levels.

5.5.1. Soil colour

The soil colour was determined by using the Munsell Soil Colour Chart and presented in Table 10. The colour of the mound soil and of the adjacent soil did not show any variation during the wet season, but the colour was found to vary during the dry season. The moist colour of the mound was found to be dark reddish brown and the dry colour was found to be brown. But the adjacent soil colour during the dry season remained dark reddish brown. Asawalam *et al.* (1999) reported that the moist colour of the termite mound was dark reddish-brown (5YR 3/2) and the dry colour was dark brown (7.5 YR 4/2) on the Munsell Colour Chart which was found in conformity with the present study.

5.5.2. Soil texture

The soil surrounding the termitaria was sandy loam while the termitarial soil was observed as sandy clay loam. The study conducted by Asawalam and Jhonson (2007) to characterize the soils modified by soil fauna highlighted their effects on agronomic properties and showed that faunal modification alters particle size distribution and textural classes of soils. A study conducted by Miranda and D' Cruz (2005) also indicated that the altered termitaria soil could be used as a cheap and eco-friendly soil medium.

The per cent clay, silt, sand and gravel of the collected soil samples were determined by doing the particle size analysis following the standard hydrometer method and mechanical sieve analysis (Table 11).

The clay content of the termite modified soils was found to be about 10-12 per cent higher than that of the adjacent soil in the present study. Sarcinelli *et al.* (2009) reported that clay content in termite mounds built mostly by the Nasutitermitinae sub-family was usually twenty per cent higher than in nearby soils which was found in conformity with the result obtained by analysing the mound soil sample built by *Odontotermes* sp.

It was also found that the sand fraction was lesser as compared to the soil around, which proves that the termites use more subsoil for the construction of the termitarium and thereby the termites are acting as natural agents for physical ploughing of the garden soils. Thakur (2000) reported that large quantities of sub-soil were brought to the surface by termites during the course of their nest building activities which in turn would have a beneficial effect in maintaining the soil fertility which was found in conformity with the present study conducted at Vellanikkara tract. In India, several workers have reported higher nutrient levels in the mound soils of *Odontotermes* sp. than the surrounding soils apart from the change in physical properties (Shrikande and Pathak, 1948).

Sand content was found to be less in the mound soil and the adjacent soil was found to have about 10-15 per cent more sand than that of the mound soil in the analysis conducted in the present study. The silt content of the mound soil and of the adjacent soil showed only slight variation. The silt content of the mounds in mango orchard was slightly higher than that of the adjacent soil. Asawalam *et al.* (1999) conducted a study in the acid sandy soils of southern Nigeria and found that there were significantly higher proportions of clay and silt in the mounds of the *Nasutitermes* than in the surrounding top soil. They also reported that the proportion of sand particles (74%) in the *Nasutitermes* mound was significantly lower than the values for the adjacent soil (93%). The mean percentage of finer mineral particles, namely clay and silt were 3 times and 7 times more in the mounds than in the surrounding soil. The significantly higher clay and silt contents in the termite mounds compared to the adjacent soil indicate preferential selection of finer soil particles and show the ability of termites to change the texture of the top soil by bringing to the soil surface reasonable quantities of finer soil particles.

Gravel was totally absent in the termite modified soil but it was present in the surrounding soil collected from mango and cashew based systems. Gravel was absent in the adjacent soil collected from the cocoa plantation. Miranda and D' Cruz (2005) reported that gravel was totally absent in termitaria soil of the two species *Macrotermes estherae* and *Trinervitermes biformis*. So we can expect that the soils modified by the termites may lack more coarser fractions like gravel.

Ackerman *et al.* (2007) found out that the soil texture differed only slightly between the termite mound and adjacent soils, although their differences were significant. They also suggested that slightly less clay and more silt and sand were found in the termite mounds than in the adjacent soil. However, in the present study, the clay content of the mound soil increased by about 10-12 per cent while the sand content decreased by about 10-15 per cent than that of the adjacent soil which was found to be in contrast with the findings of the above author. No significant difference were noticed in the per cent clay and sand content in all the three selected systems but per cent silt content in cashew system (20.25%) differed significantly between the other two systems of mango (26.25%) and cocoa (25.50%) (Table 12). But Miranda and D' Cruz (2005) reported that there was no significant variation in the proportion of coarse sand, fine sand and clay fractions between the nest soil and surrounding soil of *Macrotermes esthrae* which was found in confirmation with the result of the present study.

5.6. INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON THE MOUND FORMATION

From the present study it could be inferred that the mean temperature and relative humidity inside the mounds were significantly higher than that of the external ambience as confirmed by the statistical data analysis (Table 13). Agarwal (1980) reported that there was no diurnal fluctuation in temperature and relative humidity inside the mound of *Odontotermes obesus* (Rambur) and the fluctuations throughout the year were within a marginal difference of 4°C and 4 per cent RH. Rajagopal (1990) also found that *O. wallonensis* was capable of maintaining the higher mean nest temperature of 30^0C than the atmospheric temperature of 27^0C which is in conformity with the present observation but with a very narrow difference. Here the difference between the inside and outside temperature of the mound was 0.35^0C in mango system, 0.53^0C in cocoa and 0.69^0C in cashew plantations during the months of September 2010 to January 2011 when the diurnal mean weekly temperature regime in Vellanikkara was ranging in between 29.27 and 31.02^0C only. Rajagopal (1983) also reported the same trend that the mean daily temperature in the nest will be approximately 30^0C which did not vary more than 0.5^0C throughout the year, but the diurnal fluctuations in ambient temperature vary and sometimes exceed 3^0C difference. However, Korb and Linsenmair (2000) found that only large colonies of *Macrotermes bellicosus* would maintain a relatively constant nest temperature of 30^0C which was influenced by the abiotic heat production via solar radiation and corresponded to the mean ambient temperatures outside. It should be considered that both *Odontotermes* and *Macrotermes* belong to the same subfamily Macrotermitinae under Termitidae with the possible similarity in their climatic adaptations and agro ecological preferences.

The differential RH between the inside and outside ambience of the mounds were 3.51 in mango, 1.66 in cocoa and 8.11 in cashew systems. The RH range of 75-79 per cent and temperature range of 30 ± 1^0C recorded in all the mounds in different crop environments corroborate the chances of existence of sibling species within the same genus *Odontotremes* as influenced by the crop environments in the study area.

The cashew plantation was found to be relatively an open system with the higher incident light intensity (31.77%), while, the mango and cocoa based systems were relatively under more shade with very low per cent light intensity of 4.71 and 9.77, respectively. With the increasing outside temperature and incident light intensity in cashew plantations, the termite species constructed relatively smaller mounds to escape from the heat from outside. Because of low temperature under more shaded condition, the termite mounds in cocoa and mango based systems were found to be of medium to large size to facilitate more absorption of incident heat radiation through the enhanced surface area of the mounds.

Summary

6. SUMMARY

The study entitled as the 'Biodiversity of the termite (Isoptera) fauna in crop environments' was carried out in the instructional farm area of the College of Horticulture, Vellanikkara during 2010-11. The investigation was done with the main objective of identifying the termite species associated with a few of the selected crop environments *viz.*, mango, cashew, cocoa and coconut based systems up to the family/ genus level. The feeding habits of the identified termite genera along with the agro ecological features were then determined with an attempt to prepare a termite colonisation map in the associated crop environments at Vellanikkara.

A preliminary survey was conducted throughout the campus area to select the termite prone plantation and orchard systems for the isopteran study. During the survey, the extent of mud tube formation on tree crops and the relative density of the mounds per unit area in the selected crop environments were recorded and evaluated. Accordingly, four fixed plots *viz.*, one in mango orchard and three in cashew, cocoa and coconut plantations each were selected for the study by demarcating a unit area of 200 sq. m in these systems. The experimental observations were recorded as per the procedures and standards as prescribed in the technical programme based on the objectives set forth.

The salient findings of the study can be summarised as follows:

1. A total of nine termite genera coming under 2 families and 5 subfamilies were identified by the present taxonomic study, which were *Odontotermes*, *Microtermes*, *Microcerotermes*, *Procapritermes*, *Dicuspiditermes*, *Homallotermes* and *Nasutitermes* in the family Termitidae and *Coptotermes* and *Heterotermes* in the family Rhinotermitidae.

2. The genus *Odontotermes* collected from earthen mounds, dead wood, mud tubes, etc. were considered as wood feeders and *Microtermes* sampled from soil under coconut husk and fronds were put under soil/ humus feeders. *Microcerotermes*

and *Nasutitermes* collected from the basal part of tree trunks and from mud tubes, respectively were building carton nests at tree base and were categorised as wood feeders. Three genera *viz.*, *Procapritermes*, *Dicuspiditermes* and *Homallotermes* collected from small epigeal nests at tree bases, soil, leaf litter and root debris were identified as soil/ humus feeders. *Heterotermes* collected from dead wood and *Coptotermes* collected from dead cut wood of a tree were grouped as wood feeders.

3. The genus *Odontotermes* was found to be the most dominant termite genera in the Vellanikkara tract constituting 62.03 per cent of the total termite collections, followed by *Microcerotermes* (10.13 per cent) and *Nasutitermes* (8.86 per cent). The least dominant genus was found to be *Coptotermes* constituting only 1.27 per cent of the total encountered samples.

4. The diversity, richness and dominance of the termite genera in Vellanikkara tract was measured by means of various indices *viz.*, Simpson- Yule Diversity Index (D), Shannon- Weiner Diversity Index (H), Evenness Index (E) and Berger-Parker Dominance Index (d). The genus richness indicating the total number of genera present in the whole community of termites was found to be 9 at Vellanikkara. The value of Simpson-Yule diversity Index with a range of 1- 9 was found to be 2.44 indicating that the area is not that diverse with termite fauna, and that of the Shannon-Weiner Diversity Index with a range value of 0 - 2.20 was found to be 1.38 indicating that the available fauna is moderately distributed among its genera in the region. The Evenness Index with a range of 0 - 1 indicating the evenness of the genera recorded was found to be 0.63 with a fairly high degree of evenness among the genera observed in the region. Berger Parker Dominance Index (ranging from 0 - 1) for the most dominant genus *viz.*, *Odontotermes* was found to be 0.62 highlighting its dominance over other species in the area.

5. The richness, diversity and the dominance of the termite genera found in different crop environments of the Vellanikkara tract were also compared. The genus richness was the highest in cashew plantation with a value of 6 followed by other three systems with the value of 3 each. The highest D value of 4.65 and H value of 1.64 in cashew system indicated that there is more generic diversity in this system. The E value with range 0- 1 was also the highest in cashew based system (0.92) indicating a more or less even distribution of termite genera in this system which support more termite colonization. The corresponding index values were the least in cocoa plantation where there was less termite diversity with an uneven distribution, favouring the dominance of a few genera and the fact that the shady, humid and cool microclimate of cocoa plantations do not support termite fauna. The Berger- Parker Dominance Index (with range 0 - 1) when worked out for the most dominant genus *Odontotermes* was found to be the highest in cocoa system (0.75) and the least in cashew plantation (0.33) indicating a greater termite diversity in the cashew based systems as compared to less prone cocoa systems at Vellanikkara.

6. The termite colonisation map prepared and documented by depicting the distribution, spread and colonization density with the identified termite genera showed that there is high influence of the agro ecological and edaphic factors in the faunal distribution of the termites in the area which can be utilized for the agro ecosystem management along with GIS information map of the campus.

7. Small and medium sized termitarial mounds having sub cylindrical to sub conical shapes with 5- 7 buttresses around them were observed in mango, cashew and cocoa based systems and can be considered as an indication of the genus *Odontotermes*. The density of these *Odontotermes* mounds varied only slightly among the three systems. The mean height of the mounds varied marginally from 31- 35 cm while, the mean external volume of the mounds was found to be the highest in cocoa plantation (63663 cm^3) and the least in the cashew based system (5723 cm^3). The mounds in the cocoa plantation showed no significant difference

in relative per cent increase in external volume unlike that of the mounds in cashew and mango systems where significant difference in volume was noticed during certain periods indicating the change in termite activity by the microclimate and seasons as influenced by the tree types, canopy spread, litter fall and human intervention, etc.

8. The colour of both mound soil and adjacent soil when determined during wet season (October, 2010) and dry season (March, 2011) using the standard Munsell Soil Colour Chart was found to be dark reddish brown during wet season while, during the dry season the termitarial soil only changed to brown in colour when the adjacent soil remained dark reddish brown. The textural analysis of mound soil and surrounding soil by the standard hydrometer method and mechanical sieve analysis proved that the particle size distribution of the soil in different crop environments did not differ significantly except that of the per cent silt content in cashew system. However, it was found that the clay content of mound soil were 10- 12 per cent higher than that of the adjacent soil. At the same time, the sand content in mound soil decreased by about 10- 15 per cent when compared with that of the adjacent soil. There was no appreciable variation in silt content between mound soil and adjacent soil. Thus, the termitarial soil was found to have more of finer fractions than the adjacent soil as modified by the termite activity. Therefore, it could be observed that the termite activity can alter the texture of garden soil from sandy loam to sandy clay loam which may enhance the soil properties to suit plant growth and water holding capacity.

9. The weekly mean temperature and relative humidity inside and outside the mounds when measured and compared by standardised procedures by Temperature humidity meter (Model- HT- 3006HA) proved that the temperature and relative humidity inside the mounds were significantly higher than that of the external ambience highlighting the fact the termite activity can modify the soil microclimate to suit the microbial and macrobial population, enhancing the nutrient recycling and thereby soil and plant health.

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Appendices

APPENDIX I

Key to the families from Southern India (Bose, 1984)

1(4) Fontanelle and fontanelle gland absent; eyes present, large; mandibles with prominent marginal teeth.		
2(3) Antennae long, with 20-23 segments	.....	Hodotermitidae
3(2) Antennae short, with 10-18 segments	.....	Kalotermitidae
4(1) Fontanelle and fontanelle gland present; eyes absent, if present, small and dot-like; mandibles with or without marginal teeth.		
5(8) Pronotum flat		
6(7) Tarsi 4- jointed	.....	Rhinotermitidae
7(6) Tarsi 3- jointed	.....	Stylotermitidae
8(5) Pronotum saddle-shaped	.....	Termitidae

Key to the genera of family Rhinotermitidae

1(2) Head parallel sided; labrum with a thin, needle-like, hyaline tip	.....	*Heterotermes*
2(1) Head oval; labrum tongue-shaped, either with rounded anterior margin or a short pointed tip		
3(4) Fontanelle large, lying at the front end of head-capsule; labrum with a short pointed tip	.....	*Coptotermes*
4(3) Fontanlle small, lying on head dorsum; labrum with rounded anterior margin	.....	*Prorhinotermes*

Appendix I continued...

Key to the genera of the family Termitidae

1(30) Head not nasutiform; mandibles large, well developed

2(19) Mandibles symmetrical, curved inwards at tips

3(4) Dimorphic; size very large; labrum with a hyaline tip ..... *Macrotermes*

4(3) Monomorphic; size moderate; labrum without hyaline tip

5(10) Postmentum broad; arched convexically in middle

6(9) Mandibles robust; moderately to fairly large species

7(8) Left mandible with a prominent tooth on inner margin ..... *Odontotermes*

8(7) Left mandible with crenulations on basal part of inner margin ..... *Hypotermes*

9(6) Mandibles thin and delicate; small and delicate species ..... *Microtermes*

10(5) Postmentum narrow, not arched in middle

11(12) Inner margin of mandibles not serrated; both or left mandible with a prominent tooth

13(14) Head with a frontal projection; mandibles long, slender, weakly to appreciably

Appendix I continued...

incurved near about middle on outer margin and slightly incurved apically ..... *Eremotermes*

14(13) Head without frontal projection; mandibles thick, stout, weakly incurved near base on on outer margin and strongly incurved apically

15(16) Head rectangular with sides convex, only a little longer than broad; mandibles incurved to a long thin tip ..... *Speculitermes*

16(15) Head rectangular with sides nearly straight, much longer than broad; mandibles incurved to a thickly pointed tip

17(18) Mandibles very broad basally ..... *Euhamitermes*

18(17) Mandibles comparatively much less broad basally ..... *Euritermes*

19(2) Mandibles asymmetrical, twisted

20(21) Mandibles slightly asymmetrical, long, slender and rod-like, flattened apically at inner margins ..... *Angulitermes*

21(20) Mandibles distinctly asymmetrical, right mandible straight, blade-like, left weakly to strongly twisted

22(23) Antero-lateral corners of head produced into tubercle-like projections in front of and below antennal sockets ..... *Dicuspiditermes*

Appendix I continued...

23(22) Antero-lateral corners of head not
produced into projections

24(25) Labrum greatly swollen and enlarged ..... *Labiocapritermes*

25(24) Labrum not swollen and enlarged

26(27) Labrum with anterior margin substraight
or faintly convex, with very short antero-
lateral points ..... *Pericapritermes*

27(26) Labrum with anterior margin concave,
with very long antero-lateral points

28(29) Mandibles thin, left slender and
moderately bent in middle; antennae
with 13 segments ..... *Homallotermes*

29(28) Mandibles thick, left faintly to deeply
bent in middle; antennae with 14 segments ..... *Procapritermes*

30(1) Head nasutiform; mandibles small,
degenerate

31(32) Dimorphic ..... *Trinervitermes*

32(31) Monomorphic

33(40) Mandibles without or with small, lateral,
Spine-like processes; antennae short;
nasute comparatively long

34(35) Nasute very long and slender; mandibles
without any lateral spine-like processes;
head delicate, round, bulb-like ..... *Emersonitermes*

35(34) Nasute comparatively short, cylindrical
or conical; mandibles without or with

Appendix I continued...

short lateral spine-like processes; head round or pear-shaped or ampular

36(37) Head slender, ampula shaped; mandibles with blunt apical processes ..... *Ampoulitermes*

37(36) Head round or pear-shaped, mandibles with or without a small spine

38(39) Head large; mandibles with or without spines ..... *Nasutitermes*

39(38) Head small; mandibles with no spines or processes ..... *Alstonitermes*

40(33) Mandibles with a well developed long, lateral spine-like process; antennae fairly long; nasute short

4(42) Head not constricted behind antennae; nasus short and broad ..... *Grallatotermes*

42(41) Head strongly constricted behind antennae; nasus short but slender

43(44) Larger species; head length including Rostrum1.75-2.00; rostrum length 0.65; head-width 1.20-1.32 ..... *Hospitalitermes*

44(43) Smaller species; head length including Rostrum 1.15-1.23; rostrum length 0.37-0.43; head width 0.53-0.60 ..... *Ceylonitermes*

APPENDIX II

Key to the genera in Assam region (Roonwal and Chhotani, 1961)

1(2) Soldier caste absent ..... 1. *Anoplotermes*

2. *Speculitermes*

2(1) Soldier caste present

3(12) Pronotum flat (not saddle-shaped)

4(5) Head truncated in front ..... 3. *Oryplotermes*

5(4) Head not truncated in front

6(7) Left mandible with four marginal teeth. Fontanelle absent ..... 4. *Neotermes*

7(6) Left mandible without, or with only two, marginal teeth. Fontanelle present

8(9) Head sub-rectangular, with sub parallel sides. Marginal teeth of left mandible wanting. Fontanelle lying a little in front of middle of head-dorsum ..... 5. *Reticulitermes*

9(8) Head oval, with sides converging in front. Marginal teeth of left mandible either present or wanting. Fontanelle lying much in front of middle.

10(11) Mandibles with inner margin not serrated at base; left mandible with only a few crenulations in basal half of inner margin. fontanelle prominent, lying more forward, just behind clypeus ..... 6. *Coptotermes*

11(10) Mandibles with inner margin serrated at

Appendix II continued...

at base; left mandible with two marginal teeth. Fontanelle minute, lying less forward, clearly separated from clypeus ..... 7. *Parrhinotermea*

12(3) Pronotum saddle-shaped

13(14) Head projected in front into a nasute or rostrum; mandibles rudimentary ..... 8. *Nasutitermes*

14(13) Head not projected in front into a nasute; mandibles well developed

15(18) Mandibles asymmetrical

16(17) Tip of left mandible hooked ..... 9. *Pseudocapritermes*

17(16) Tip of left mandible not hooked ..... 10. *Capritermes*

18(15) Mandibles symmetrical

19(20) Mandibles with inner margins serrate ..... 11. *Microcerotermes*

20(19) Mandibles with inner margins not serrate

21(22) Mandibles strongly incurved in front, each with a prominent triangular tooth a little behind the middle ..... 12. *Synhamitermes*

APPENDIX III

Key to the genera of termite of Thailand (Sornnuwat *et al.*, 2004)

1.	Head without fontanelle	2
-	Head with fontanelle	6
2.	Antennae more than 22 segments	*Archotermopsis*
-	Antennae less than 20 segments	3
3.	Head long or weakly phragmotic	4
-	Head short and strongly phragmotic	*Cryptotermes*
4.	Third segment of antennae elongated like club shape; Antero-lateral margin of pronotum deeply concave	*Incisitermes*
-	Third segment of antennae not elongate like club shape	5
5.	Forehead steeply sloping, with antero-lateral lobes; antennae with less than 15 segments	*Glyptotermes*
6.	Pronotum flat	7
-	Pronotum saddle shaped	11
7.	Mandibles sabre-shaped, without any marginal teeth	8
-	Mandibles with prominent marginal teeth	10
8.	Fontanelle very wide and close to clypeus	*Coptotermes*
9.	Head elongate oval with a groove running forward from the fontanelle	*Prorhinotermes*
-	Head rectangular, parallel sided	*Reticulitermes*
10.	Soldiers monomorphic; labrum prominent; mandibles with leaf shape marginal teeth	*Parrhinotermes*
-	Soldier dimorphic	*Schedorhinotermes*
11.	Mandibles well developed, functional; head not produced into a nasutus	12
-	Mandibles degenerate, non-functional; head produced into a nasutus (nasutiforms)	31
12.	Mandibles symmetrical, curved at tips, used for biting	13
-	Mandibles slightly to strongly asymmetrical, used for snapping or for both snapping and biting	25
13.	Left mandible without teeth but cutting edge crenulated basally	14
-	Left mandible with one or two teeth or cutting edge serrated	19
14.	Labrum with hyaline tip; meso and metanotum greatly expanded laterally; soldiers distinctly dimorphic	*Macrotermes*
-	Labrum without hyaline tip; meso and metanotum not greatly expanded laterally; soldiers monomorphic	15
15.	Head rectangular	*Microcerotermes*
-	Head round	16
16.	Mandibles with crenulation	17
-	Mandible without crenulation	18

17.	Mandibles long, strongly curved	*Prohamitermes*
-	Mandibles short, weakly curve	*Hypotermes*
18.	Mandibles weakly curved apically; head oval	*Microtermes*
-	Mandibles strongly curved apically; head as nearly broad as long	*Ancistrotermes*
19.	Right mandible with distinct teeth	20
-	Right mandible with minute or without teeth	*Odontotermes*
20.	Clypeus distinctly bilobed; head longer than wide; tooth of left mandible laterally directed	*Amitermes*
-	Clypeus not bilobed	21
21.	Head round or globular; mandibles long, strongly curved downward	*Globitermes*
-	Head short parallel sided	22
22.	Mandibles long, sabre-shaped, slightly curved apically	*Synhamitermes*
-	Mandibles short; stoutly built, not very strongly curved apically	23
23.	Pronotum very strongly saddle-shaped, anterior lobe longer than posterior lobe; head hypognathous, covered with dense coat of thin short hairs; tarsi three segmented	*Indotermes*
-	Pronotum not very strongly saddle-shaped, anterior lobe not longer than posterior lobe	24
24.	Mandibles with large broad tooth	*Speculitermes*
-	Mandibles with small, pointed tooth	*Euhamitermes*
25.	Head with frontal projection	26
-	Head without frontal projection	28
26.	Mandibles slightly asymmetrical	27
-	Mandibles strongly asymmetrical, left mandible twisted; right mandibles blade-like	*Microcapritermes*
27.	Labrum shallowly cut; lateral sides almost straight; base of the antenna with a ridge; mandibles long and slender, rod-like, bent downward	*Termes*
-	Labrum deeply cut; lateral sides convex; base of the antenna without ridge; mandibles anteriorly directed	*Angulitermes*
28.	Antennae with 13 segments; head distinctly narrowed anteriorly; mandibles with tip not bent in form of hook	*Homallotermes*
-	Antennae with 14 segments; mandibles slightly to strongly asymmetrical	29
29.	Antero-lateral corners of head rounded without projections	30
-	Antero-lateral corners of head with pointed projections below antennal sockets with its lateral corners produced into long needle-like projections;	*Dicuspiditermes*

	anterior margin of labrum deeply concave	
30.	Labrum with anterior margin straight; antero- lateral corners very short; tip of left mandible broad, not strongly bent	*Pericapritermes*
-	Labrum with anterior margin concave; its antero-lateral corners long; tip of left mandible narrow, bent in the form of hook	*Procapritermes*
31.	Head constricted behind antennal sockets	32
-	Head not constricted behind antennal sockets	35
32.	Legs and antennae greatly elongated; hind femura as long as or longer than abdomen	33
-	Legs and antennae not usually long; head not produced behind, not depressed at base of nasus	*Bulbitermes*
33.	Third antennae segment moderately long and shorter than or sub equal to fourth; soldiers generally with distinct colour forms	*Lacessititermes*
-	Third antennae segment very long much longer than fourth	34
34.	Soldier monomorphic; head not greatly produced behind	*Hospitalitermes*
-	Head triangular, greatly produced behind; soldiers distinct dimorphism; legs paler than the body	*Longipeditermes*
35.	Nasutus with minute projection at base on each side; head covered with minute hairs; mandibles without apical projection	*Aciculitermes*
-	Nasutus without projection at base	36
36.	Antennal articles long, apical projection of mandible with minute tooth; dorsal profile of head weakly concave; rostrum long	*Havilanditermes*
-	Antennal articles short, apical projection of mandible without tooth; dorsal profile of head straight	*Nasutitermes*

BIODIVERSITY OF THE TERMITE (ISOPTERA) FAUNA IN CROP ENVIRONMENTS

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Termites (Insecta: Isoptera) are eusocial insects living in a highly organised and small to large extent of communities in different ecosystems. A termite colony has morphologically and functionally distinct caste system which includes functional reproductives / 'royal pair' of king and queen, sterile soldier and worker castes and the immature stages or nymphs along with other inquiline species of organisms.

The present investigation on the 'Biodiversity of the termite (Isoptera) fauna in crop environments' was undertaken in a few selected crop environments in the instructional farm area of the College of Horticulture at Vellanikkara during 2010-11. The main objectives of the study were to identify the composition of the termite fauna up to the family/ genus level in mango, cashew, cocoa and coconut crop environments, elucidation of their feeding nature, behaviour, association and their mound forming characteristics and to prepare a primary termite colonisation map in the selected plantation and orchard systems in this tract.

A preliminary survey was conducted by transect walk throughout the instructional farm area of the campus to select the termite prone plantation and orchard systems for the study. The soldier castes of termites were sampled from a unit area of 200 sq. m each from different crop environments and kept under preservation. The soldier castes from earthen mounds were collected by a special "Glue trap technique" designed and standardised for the purpose by the author through 20 numbers of encounter samplings per unit area of observation. The soldier castes were identified based on the standard keys (Bose, 1984; Roonwal and Chhotani, 1961 and Sornnuwat *et al.*, 2004) with reference to their characteristics of head capsule, mandibles and pronotum. The diversity pattern of termite genera in different agro ecosystems in Vellanikkara were assessed by using various diversity indices. Based on these information, a preliminary termite

colonisation map was prepared by depicting the distribution, spread and colonisation density of the identified termite genera in the selected crop environments. The morphometry of the aerial mounds along with some of the physical properties of the termitarial soils were also determined. The influence of temperature and humidity on the termite colonisation process was also observed.

A total of nine termite genera under two families were identified in Vellanikkara. Out of this, seven termite genera *viz*., *Odontotermes*, *Procapritermes*, *Dicuspiditermes*, *Homallotermes*, *Microtermes*, *Microcerotermes* and *Nasutitermes* were under the family Termitidae, while, *Heterotermes* and *Coptotermes* were coming under the family Rhinotermitidae. *Odontotermes* was found to be the most dominant genus in all the selected crop environments accounting for about 62.03 per cent of the total genera identified from the Vellanikkara tract. The least present genus was *Coptotermes* which constituted only 1.27 per cent among all the identified genera. Based on the distribution, spread and colonisation density, a primary termite faunal distribution map was prepared in selected systems.

The genera *viz., Odontotermes, Microcerotermes, Nasutitermes, Heterotermes* and *Coptotermes* were identified as wood feeders while, *Procapritermes, Dicuspiditermes, Homallotermes* and *Microtermes* were observed as soil/ humus feeders.

Various diversity indices were worked out for the faunal distribution of the termites in this tract to find out their relative dominance, spread and evenness in its distribution. The genus richness of the termite genera at Vellanikkara tract was found to be 9 and the value of Simpson- Yule diversity Index (D) was found to be 2.44 and that of the Shannon- Weiner Diversity Index (H) was found to be 1.38. The Evenness Index (E) when worked out was found to be 0.63 and the Berger Parker Dominance Index (d) for the genus *Odontotermes* was found to be 0.62.

When different systems were compared, the genus richness was found to be the highest in cashew plantation with a value of 6 while, the mango, cocoa and coconut systems were having a value of 3 only. The D value of 4.65, H value of 1.64 and the E value of 0.92 was found to be highest in cashew plantation, which indicated that the cashew system was supporting maximum generic diversity of the termites with a more evenness in its distribution. The values of these indices were found to be the lowest in cocoa which indicated that the cocoa based systems was having the lowest diversity and very low evenness in the distribution of various genera. The mango and coconut based systems were having intermediate values with these indices. The "d" value indicating the dominance of the particular termite genus *viz.*, *Odontotermes* was found to be the highest in the cocoa based system with a value of 0.75 and the least in cashew with a value of 0.33.

The mean density of the mounds in mango, cashew and cocoa based systems varied only slightly indicating their relative uniform distribution. The mean number of buttresses or young mounds ranged from 5- 7 per mound formation. The mean height of the mounds present in all the three systems showed only very slight variation, but there was difference in the mean basal circumference of the mounds in the three systems. Accordingly, the mean external volume (above ground) of the mounds in cubic centimetres was found to be the highest in cocoa and least in mango based systems. Statistical analysis of the data revealed that there was no significant difference in the relative per cent increase in the external volume of the mounds in cocoa plantation, while, there was significant difference in the change of volume as observed in July'10- Aug'10 and Jan'11- Feb'11 in mango and cashew based systems implicating the degree and period of termite activity within the termitaria.

Regarding the physical properties, the soil colour of the mounds and of the adjacent soil during the wet season was found to be dark reddish brown as per the visual comparison through the standard Munsell colour chart. However, the colour of the mound soil and of the adjacent soil during the dry season was found to be brown and dark reddish brown, respectively. Particle size distribution in the soil samples of the termitarial mounds from the three crop environments *viz.*, mango, cashew and cocoa based systems showed no significant difference among them. But within the same crop systems, the clay content of the mound soil was observed to be increasing by 10-12 per cent while, the sand content was decreasing by about 10-15 per cent. There was not much variation in silt content between the mound soil and adjacent soil. However, gravel was found to be totally absent in the mound soil as compared to the adjacent soils.

When the temperature and relative humidity were recorded and compared between inside and outside of the mounds, it was found out that both temperature and relative humidity inside the mounds were significantly higher than that of the external environment which prove that the termites have to essentially maintain their homoeostasis with respect to the internal ambience for their survival and other activities irrespective of the external ambience.

To conclude, the study reveals that the Vellanikkara tract is diverse in the faunal distribution of termites with nine genera under two families and five subfamilies with a dominant mound dwelling genus *viz., Odontotermes* in all the crop environments of mango, cashew, cocoa and coconut systems. The identification of the termite genera can very well be undertaken based on head capsule and mandibular characteristics of the soldier caste by collecting them easily by the newly designed method of "glue trap technique" by the author. The termites colonize these systems without any major environmental or resource degradation and thereby their role may be further investigated for the eco restoration and conservation activities.