Chapter 3
Termites and Indian Agriculture

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Abstract Termites are the most dominant arthropod decomposers in the tropical forests and show high diversity and abundance. Within tropical ecosystems, they play a key role in modifying the biotic and abiotic environment. The areas of higher altitudes and extreme temperatures have restricted the distribution of termite fauna in India. The species richness is more in the north-eastern regions, compared to rest of India. Out of 337 species of termites known so far from India, about 35 have been reported damaging agricultural crops and buildings. *Odontotermes* is the major mound-builder, whereas *Coptotermes*, *Heterotermes, Microtermes*, *Microcerotermes* and *Trinervitermes* are the major subterranean genera occurring in India.

The losses caused amount to several hundred million of rupees per year. Termites damage crops from sowing till harvest, and it is difficult to detect damage in the field. Usually it is too late when the symptoms are noticed. In general, termite damage is seen more (20–25%) in rain-fed crops than irrigated ones (10%). Perennial crops are usually attacked during dry seasons and annual crops towards harvest time. Termite infestations have been reported in fruit crops, sugarcane, cotton, paddy, maize, pearl millet, pulses, citrus, vegetables, spices, groundnut and potato in arid zones of India.

Indian agriculture depends on unpredictable rains and is dominated by small and marginal farmers, with meagre resource amounts for insect pest management. The majority of farmers follow the age old practices for management of insect pests. The crop and species diversity often makes the issue more complicated. India is divided into 15 agroclimatic zones. Technologies need to be developed for each zone separately, as no single technology would be effective for all of them. Termite control is a herculean task and is not an advisable option, and management in cropped areas should be our goal. Complete elimination or prevention of termites is neither feasible nor advisable, as their complex biology in many regards poses complications in devising management strategies. Optimistically, prospects for the development of new or improved technologies as well as public acceptance of alternative management appear good. Least toxic and nonchemical methods have been and will continue to be developed. In this chapter we discuss issues related to Indian agriculture and the contemporary practices, being followed by the majority of Indian farmers.

Keywords Termite management • India • Biodiversity • Damage • Agroecosystems

3.1 Introduction

Termites represent the most important fraction of soil fauna in the semiarid tropics (Lobry de Bruyns and Conacher 1990). They can be found in a wide range of terrestrial environments and are distributed throughout the tropical, subtropical and temperate regions of the world (Freise 1949; Krishna and Weesner 1970; Pearce 1997a). They are white, tan or black orthopteroid social insects that can cause severe destruction to crops, constructions and wooden structures. Termite castes, viz. workers, soldiers and reproductives, live in small to large colonies, sometimes a single colony containing a million or more individuals. They belong to the insect order Isoptera, an ancient group that dates back more than 100 M yrs ago. The Latin name Isoptera means "equal wing" and refers to the fact that the front set of wings on a reproductive termite is similar in size and shape to the hind set. By historical convention, all but 2% of termite genera end in the suffix *termes*, the Latin word for termite. The limits of survival are between latitudes 45 and 50° north and south, respectively. The farthest north that termites are known to have reached is Hamburg (Germany), where they were found in a number of warehouses. The order Isoptera is divided into seven families. The most devastating species are distributed among four families, viz. Rhinotermitidae, Kalotermitidae, Hodotermitidae and Termitidae (UNEP Report 2000). Out of 300 species of termites known so far from India, about 35 have been reported damaging agricultural crops and buildings. The major mound-building species in India are *Odontotermes obesus* (Rambur), *Odontotermes redemanni* (Wasmann) and *Odontotermes wallonensis* (Wasmann), and the subterranean species are *Heterotermes indicola* (Wasmann), *Coptotermes ceylonicus* Holmgren, *Coptotermes heimi* (Wasmann), *Odontotermes horni* (Wasmann), *Microtermes obesi* Holmgren, *Trinervitermes biformis* (Wasmann) and *Microcerotermes beesoni* Snyder (Rajagopal 2002).

Termites are a serious threat to agriculture in tropical areas with high relative humidity. Depending on the habits and habitats, termites can be broadly classified into wood dwellers and ground dwellers. The wood dwellers are comprised of species inhabiting damp wood and dry wood. The ground dwellers are categorized into subterranean, carton-nest builders and mound-builders (Pearce 1997b). Subterranean termites, including mound-building and arboreal species, account for 80% (or 147 species) of the economically important species. The genus *Coptotermes* (Rhinotermitidae) contains the largest number of economically important subterranean termites (28 species). Unlike drywood termites that are easily transported from region to region, most subterranean species have a restricted distribution. Of the 147 economically important subterranean termite species, only two, *Coptotermes formosanus* Shiraki and *Coptotermes havilandi* Holmgren, have been introduced in more than five regions worldwide (Edwards and Mill 1986).

Termites are the most abundant soil invertebrate (Table 3.1). Their abundance in any ecosystem drastically changes the below ground biodiversity. They build nests in dead tree trunks/stumps and some build mounds. The subterranean nests are not detectable easily on the soil surface. They also construct mud galleries for movement and transport to the food sources, as workers may travel long distances in search of dead decaying wood.

As termites are primary consumers, they promote the mineralization of nutrients rich in cellulose (Cunha and Orlando 2011). They are most dominant arthropod decomposers in the tropical forests (Collins 1983) and show high diversity and abundance (Bignell and Eggleton 2000). Within tropical ecosystems, termites play a key role in modifying the biotic and abiotic environment. Their diversity and distribution are greatly influenced by factors such as vegetation type (Pardeshi et al. 2010), habitat disturbance (DeBlauwe et al. 2008) and habitat fragmentation (Davies et al. 2003).

The termites have evolved as eusocial organisms. The life-history traits of termites might have predisposed them for development of eusocial society. The factors leading to development of eusociality are slow development; overlapping

Table 3.1 Abundance of common soil invertebrates in different ecosystems (Rahman et al. 2012)

	Number of individuals per m^2							
Ecosystem	Earthworm	Ant	Termite	Beetles	Millipede	Centipede	Orthoptera	Spiders
Natural forests	97.6	115.2	1542.4	24.0	6.4	16.0	6.4	9.6
Agroforestry	83.2	75.2	40.0	3.2	9.6	4.8	3.2	1.6
Plantations	116.8	52.8	70.4	4.8	4.8	3.2	1.6	3.2
Annual crops	24.0	40.0	16.0	3.2	1.6	8.0	0.0	1.6
χ^2	13.8	18.4	81.9	7.8	9.3	29.3	16.8	24.1
Probability[a]	0.003	<0.001	<0.001	0.003	0.026	<0.001	<0.001	<0.001

[a]Probability of significant χ^2 assuming negative binomial error distribution of the counts

generations; monogamy; familial associations in cloistered, food-rich habitats; iteroparity; high-risk dispersal of individuals; opportunities for nest inheritance by offspring remaining in their natal nest; and advantage of group defence. These factors create a selection pressure on the organism and the evolutionary outcome is eusociality. Among the eusocial society, a limited number of individuals are fertile and fecund; others have reduced reproductive capacities or sometimes are completely sterile. The most important aspect of such group is rearing of the progenies of primary reproductives, by worker caste (Thorne 1997).

3.2 Taxonomic Diversity of Termites in India

All the known nine families of Isoptera exist since the late Mesozoic period. There are four monogeneric families of termites, viz. Mastotermitidae (holotype *Masotermes darwinensis* (Froggatt) in Australia), Serritermitidae (holotype *Serritermes serrifer* (Bates) in Brazil), Stylotermitidae (holotype *Stylotermes* containing eight species from Indian sub-continent) and Indotermitidae (holotype *Indotermes* containing seven species from Oriental region). The most diverse family of termites is Termitidae, comprising of 4 subfamilies and 145 genera (Roonwal and Chhotani 1989).

The diversity in termite fauna of India is restricted to only 337 species and subspecies under 54 genera belonging to seven families. The areas of higher altitudes and extreme temperatures have restricted the distribution of termite fauna in India (Fig. 3.1). The species richness is more in the north-eastern regions of India compared to rest of the country. Biodiversity of termites in north-western and central region is relatively poor. Table 3.2 represents the taxonomic diversity of termites in different forest ecosystems in India.

In humid plains of India, *Odontotermes* species is the most widely distributed mound-building termite, and *Odontotermes distans* Holmgren is reported to occur in higher altitudes, i.e. Kumaon hills. *Heterotermes* species is the common household termite in temperate areas, whereas *Reticulitermes* and *Archotermopsis* occur in the wild areas of these regions. In western arid areas, *Psammotermes* and *Anacanthotermes* are known to occur. *Calcaritermes* and *Rhynchotermes* are known to occur exclusively in Nicobar Islands and Manipur, respectively. *Prorhinotermes flavus* (Bugnion and Popoff) has been found to occur in the coastal areas of Mangalore, Andaman and Nicobar islands. Some of the termite species are endemic to different regions of India, viz. Himalayan 34, Gangetic 20, peninsular 73, North East borderland 19 and insular 19, with 16 species common to several divisions. Out of 253 termite species reported from India till date (1989), 73 are found in tropical rain forests of Western Ghats. From the Indian sub-continent, Roonwal and Chhotani (1989) listed and described 337 species of termites belonging to 59 genera, and Bose (1984) recorded 95 species comprised of 5 families from southern India. Chhotani (1997) listed 92 species of soil inhabiting or mound-building termites damaging agricultural crops, timbers and buildings.

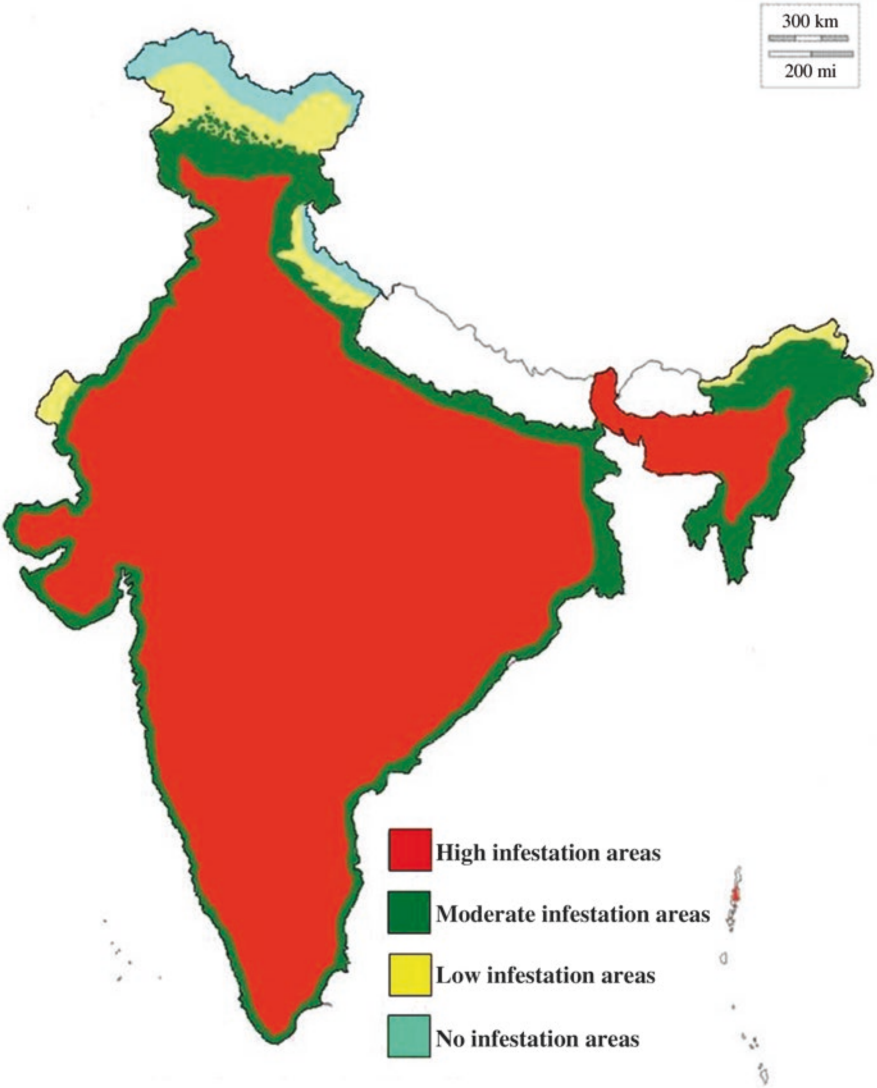

Fig. 3.1 Infestation of termites in India

3.3 Economic Importance

Termites cause extensive damage to agricultural and horticultural crops, agroforestry, stored timbers, books and records, woodworks in buildings and stored products containing cellulose (Rashmi and Sundararaj 2013). The losses caused in India alone run into several hundred million rupees per year, and the world loss must be more than $10,000 M. Howse (1970) observed that termites can damage man-made fabrics, plastics and some metal foils. A classical case of termite damage was reported from a Northern India town where termites damaged currency notes worth

Table 3.2 Taxonomic diversity of termites in different forest ecosystems in India (Maiti and Maiti 2011)

Tropical wet evergreen forest (Nilgiri hills)	23/14
Tropical moist deciduous forest (Nicobar)	22/10
Tropical dry deciduous forest (Chotanagpur)	17/9
Subtropical pine forests (Kumaon hills)	20/13
Tropical thorn forest (Coimbatore)	23/11
Desert vegetation (Thar desert)	22/11
Swamp forest (Sundarbans)	11/6
Insular Andaman evergreen forest	23/11

Rs 10 M (US $ 222,000) kept in a steel chest inside the State Bank of India branch, housed in an old building, infested with termites (Sacks 2011). Dwarika Prasad, a trader from Patna, Bihar, lost his life savings after termites infested his bank's safety deposit locker (Tewary 2008). In an estimate it was found that in Australia, 20% of homes are infested by termites. In China 90% of homes in south of Yangtze river are affected by termites (GEI 2005; MRP 2010). Roonwal (1955) reported that an entire township in India was gradually destroyed by the termite *Heterotermes indicola* (Wasmann) and eventually resembled a bombed-out ghost town. Annual losses caused by termites in the USA and Japan are 1000 and 800 M US$. In India the losses have been estimated around 35.12 M US$ (Joshi et al. 2005). Globally, the estimated loss due to termite damage is about 50 billion US$ annually (Subekti et al. 2015), although estimates vary considerably by the cropping systems followed in different geographical regions.

Roonwal and Chhotani (1967) reported that 58 species of termites cause major damage to wood. Sixty-four species of wood-destroying termites were reported by Sen-Sarma et al. (1975), 11 being major wood-destroying termites. Seventy-two wood-destroying termite species from Southeast Asia have been reported by Roonwal (1979). About 270 termite species were identified as injurious to economic plants, in South Asia (Srivastava 1996).

The economic impact due to termite damage worldwide is estimated to be increased to US$40 billion (Rust and Su 2012). Although many people think termites have only negative impacts, in nature they make many positive contributions to the world's ecosystems. Their greatest contribution is the role they play in recycling of wood and plant material. Their tunnelling efforts also help to ensure that soils are porous, contain nutrients and are healthy enough to support plant growth.

Significant yield losses are recorded on annual and perennial crops by termites in semiarid and sub-humid tropics. Damage is more severe during droughts and dry season, compared to irrigated crops. In rain-fed crops the plants experience moisture stress which predisposes them to termite infestations. Exotic crops are more susceptible to damage than indigenous ones.

3.3.1 Nature of Damage

There are several ways in which the termites attack plants. Nair and Varma (1981) discussed the different aspects of primary and secondary termite attack to *Eucalyptus* species. The termite made tunnels on the tree surface and built earthen runways on the surface indicating that the tree had been infested. However, under such case the tree appeared normal and healthy, as most of the living parts were not damaged, whereas *Odontotermes* species fed directly on the roots and killed the plant (Harris 1971). The plants attacked by the termite wilted before dying: this may be due to root damage, making the proper intake of water, minerals and nutrients difficult for the plant. In some cases, *Odontotermes* species infest maximum part of the plant particularly with shrubs and small plants. The attack of Termitidae (particularly of *Odontotermes* spp.) usually occurred in the form of earthen sheets and runways on the bark. The termite worker and soldiers continue their activity under the earthen layer, which covered the dead barks of almost any tree attacked (Roonwal 1979). The workers remained in a thin surface layer of the bark. However, the damage so caused was negligible although occasionally it can become serious. In some cases the termites formed nests among tree branches or trunk. The attack in most cases began from the root level and spread to the upper part. In older stem, the bark under lying tissue was eaten up gradually, reaching the pith hollowing out of the stem, resulting in the ultimate death of plant.

The nature of damage by termites varies in the different trees. The damages of *O. wallonensis* (Wassman) were recorded in the form of nibbling on dead, as well as live, bark of both stem and root underneath the cover of earthen sheet and runways. The attack of *Odontotermes* sp. occurred usually at the basal part of the trunk. The damage, although not severe, was localized, resulting in the formation of irregular cavities or grooves of various sizes on the surface of the trunk, which reached up to about 2–3 m height. The infestation generally originates and spread internally in the plant, as the termite move from soil into the roots. The damages were more or less similar in *Azadirachta indica* Juss., *Cocos nucifera* L., *Mangifera indica* L. and *Eucalyptus* species. It extended runways from the ground up to 2 m on the barks of the trunk. In some trees such as *C. nucifera*, *M. indica* runways were constructed in and around underneath bark. Mostly, these runways extended towards the dead portion of the living trees, and the damage was observed on the dried portion of the living plant. In *Eucalyptus* trees, it ate up dead wood as well as tissues adjacent to the stem, thus hollowing the stem. However, the trees remained in a live condition, as other parts were not damaged. The termite damages the stem of *C. nucifera* and *Eucalyptus* either by entering the roots or wounds present on the stem or feeding up to their middle portion.

The damages caused by *O. wallonensis* in *Acacia arabica* (Lam.) trees and *Tamarindus indica* L. are produced by extended runways of the stem above the bark, up to the branches at about 6 m in height, and were also recorded at the basal portion of the trunk. This species partially hollowed out the trunk of *Tectona grandis* L.f. from the base filling the excavated portion with mud and the cavity up to 2 m in the stem from the surface of the ground.

Nair and Varma (1981) did not find any correlation between the seasonal distribution of rainfall and incidence of termite attack nor any relationship between annual rainfall and annual loss due to termite. They even found no support to the general belief that termite attacks are more common during dry periods. They further reported that most of the damage occurred before the onset of the dry season. The damage intensities of *O. wallonensis* on *Eucalyptus* sp. and *A. indica* reached the maximum during winter season in southern India. With a decrease in temperature there was no significant correlation between its damage and seasonal temperature variations. These authors found seasonality in infestation of various trees, viz. *Casuarina equisetifolia* L.*, C. nucifera* and *M. indica* with seasonal variations in temperature rainfall and relative humidity. In absence of relative humidity, temperature did not influence the damage intensity by *O. wallonensis*.

Predisposing Factors for Termite Attack in Crops
Man-made conditions that put crops under stress are the result of poor cultural practices. Some of the common practices inadvertently leading to termite attack are as follows:

- Unsuitable cropping site and climatic conditions; the crops would be stressed and weakened and are more liable to be attacked by termites.
- Accumulation of crop refuge, viz. stubbles, straw, uprooted dry weeds, etc., serves as additional food resources of termites.
- Unhealthy nursery raising practices in vegetables, horticultural and silvicultural plants, resulting in poor-quality crops.
- Non-removal of damaged bark would allow the termites to colonize the pruned dead ends.
- Root damage, due to intercultural operations in field/horticultural crops, attracts termites. The root exudates serve as attractants for termites.
- Root infection caused by soilborne diseases/nematodes weakens the plants and attracts termites.
- Any stress caused by drought, poorly drained soil, etc. favours termite attack

3.3.2 Symptoms of Damage

Wilting is the first sign of termite attacking roots on seedlings or older plants. Eventually some plants fall over or die. The presence of live termites is confirmed by pulling out the affected plants and examining the roots and lower stem. In some instances roots and stems may be completely hollowed out and soil-filled. Termites are often seen under the soil sheets prepared to escape biotic and abiotic agents. They move down deeper during the higher temperature by day and come back to the surface when the temperature becomes tolerable. In orchards, the termite damage often begins in an area of dead wood produced by pruning or any other damage. Termite attack on trees and bushes often begins with small cracks or tunnels made by other insects that may allow winged termites (reproductive stage) to enter. They may also travel up through the roots into the trunk and branches and eventually disrupt the movement of nutrients and water through the vascular system, resulting in the plant death.

3.4 Damages in Agroecosystem

Termite attacks on annual and perennial crops cause significant yield losses damaging the plants at all growth stages (Chhotani 1977). The attack usually begins on the roots and then spreads to upper parts. In older plants the bark and underlying tissue is eaten up, which are gradually exposed to attack by pathogenic microbes resulting ultimate death of the plant. Apart from crops, they also attack the crop leftover (root stubble), fallen leaves, twigs, bark, etc. So far there are no reports available on the losses caused, except a report of Rajagopal and Veeresh (1983). Termite damage has been recorded on the majority of crops grown in and around Bidar, Karnataka area. Plant may be partially or severely attacked at the base such as maize, soybean, groundnut, sugarcane, finger millet and mango trees. Information on the economic losses caused by termites is difficult to obtain because the damages are often patchy in nature. The damage to crops in general is expressed as plant attacked or plant mortality. Termites mainly feed on woody materials, but some species are known to collect green grasses and seeds and store them inside their nest as food reserves.

Bark-eating termites cover the tree trunks and stems with a sheet of mud or make mud galleries on a wide range of crops, rendering them locally important pests. The galleries and tunnels are usually built with mud and saliva, but sometimes plant fragments are also used. They gnaw away the bark and wood underneath their tunnels and galleries on the roots and underground stems. Often the collected materials are transported to their nests. Due to such a feeding damage to trees is low, but the tree becomes weak and fruit bearing is seriously affected. The tree trunks often break under moderate wind speed.

In field crops, viz. cotton and groundnut, taproots of young seedlings are eaten up by termites just below the soil surface. The central root portion is damaged and filled with soil. The damaged plants wilt overnight and die within few days. Sorghum, maize and bajra plants often topple down due to termite attack at the collar region. When the plant lodges, the grains touch the ground, and soil fungi such as *Aspergillus* spp. may invade them. Termites threaten major crops, which form the basis of household nutrition in many countries such as wheat, maize, groundnut, sugarcane, yams and cassava. The most common termite species in India are *Microtermes* and *Odontotermes.*

In this chapter we would discuss only some most important crops damaged by termites. Most of the field crops grown under rain-fed agriculture are severely affected by termites, and considerable losses are observed (Tables 3.3, 3.4 and 3.5).

Table 3.3 Termite species found in various crops in India

Crops	Termite species	States
Paddy	*Anacanthotermes viarum* (Koenig)	Tamil Nadu
	Microtermes sp.	Delhi and Maharashtra
Wheat	*Odontotermes bangalorensis* (Holm. and Holm.)	Madhya Pradesh
	Odontotermes gurudaspurensis (Holm. and Holm.)	Rajasthan and N.W. India
	Odontotermes obesus (Rambur)	Bihar, Delhi, Punjab, U.P., Haryana, M.P., Rajasthan, Gujarat, A.P., Maharashtra, Karnataka, Kerala and Tamil Nadu
	Microtermes obesi Holm.	A.P., Bihar, Delhi, Punjab, U.P., M.P. and Rajasthan
	Microtermes mycophagus (Desneux)	Rajasthan
	Microtermes tenuignathus (Holm.)	
	Eremotermes sp.	
	Nasutitermes sp.	
Barley	*Odontotermes gurudaspurensis* (Holm. and Holm.)	Haryana
	Odontotermes latigula Snyder	
	Odontotermes latiguloides (Roonwal and Verma)	
	Microtermes mycophagus (Desneux)	
	Microtermes obesi Holm.	
	Odontotermes obesus (Rambur)	Haryana, U.P. and Rajasthan
Oats	*Microtermes obesi* Holm.	Bihar
Maize	*Odontotermes gurudaspurensis* (Holm. and Holm.)	Rajasthan and N.W. India
	Odontotermes wallonensis (Wasmann)	Karnataka
	Odontotermes obesus (Rambur)	Rajasthan
	Microtermes obesi Holm.	Bihar and Rajasthan
Bajra	*Microtermes mycophagus* (Desneux)	Delhi, Punjab and Rajasthan
	Odontotermes obesus (Rambur)	
	Microtermes obesi Holm.	
	Odontotermes guptai Roonwal and Bose	Rajasthan

(continued)

Table 3.3 (continued)

Crops	Termite species	States
Jowar	*Microtermes obesi* Holm.	Delhi, Punjab and Rajasthan
	Odontotermes obesus (Rambur)	Delhi, Haryana, Punjab and Rajasthan
Sugarcane	*Coptotermes heimi (Wasmann)*	U.P. and Bihar
	Eremotermes paradoxi Holm.	Bihar, Delhi, Punjab, U.P., M.P., Karnataka and Tamil Nadu
	Microtermes beesoni Snyder	U.P.
	Odontotermes taprobanes (Walker)	
	Microtermes mycophagus (Desneux)	Assam and T.N.
	Microtermes obesi Holm.	Assam, Delhi, Punjab, U.P., Rajasthan, Karnataka, Bihar and T.N.
	Odontotermes assmuthi Holm.	U.P., Maharashtra, A.P., Bihar and T.N.
	Odontotermes bangalorensis Holm.	M.P., Karnataka and W.B.
	Odontotermes obesus (Rambur)	Punjab, W.B. Assam, Bihar, U.P., Rajasthan, Delhi, Karnataka, M.P., Maharashtra, A.P. and T.N.
	Odontotermes obesus (Wasmann)	Karnataka, A.P., Bihar, M.P., Orissa and T.N.
	Trinervitermes biformis (Wasmann)	Bihar, U.P., M.P., Maharashtra, Orissa and T.N.
Groundnut	*Microtermes mycophagus* (Desneux)	Rajasthan
	Microtermes obesi Holm.	Rajasthan, U.P. and Delhi
	Odontotermes obesus (Rambur)	Punjab, U.P., Kerala, Rajasthan, Delhi, Gujarat, Haryana, Karnataka, M.P., Maharashtra, A.P. and T.N.
	Odontotermes wallonensis (Wasmann)	Karnataka
	Trinervitermes biformis (Wasmann)	U.P. and Maharashtra
Tea	*Coptotermes ceylonicus* Holm.	S. India and N.E. India
	Microtermes obesi Holm.	
	Odontotermes obesus (Rambur)	

Groundnut (*Arachis hypogaea* L.)
In semiarid tropical countries of Africa and India, groundnut crops are seriously damaged by *Microtermes*, *Odontotermes* and *Amitermes* spp., resulting in yield losses between 10 to 30%. Very little attention has been paid indeed, to the losses caused by termites in groundnut. Harris (1969) listed 17 termite species known to damage groundnuts in moderate to low rainfall areas of Africa and Asia. They are known to attack groundnut in all stages of growth and during storage too. Seedlings,

Table 3.4 Major crops attacked by termites causing extensive damage in different countries

Crop	Country
Cereals	
Maize	Argentina, Benin, Brazil, Democratic Republic of Congo, Ethiopia, India, Kenya, Malawi, Nigeria, Paraguay, South Africa, Saudi Arabian Peninsula, Swaziland, Tanzania, Uganda, Uruguay, Zambia, Zimbabwe, Yemen
Sorghum	Ethiopia, India, Malawi
Barley	Argentina, Brazil, India, Paraguay, Uruguay
Millets	China, Ethiopia, India, Yemen
Wheat	India, Yemen
Pulse crops	
Beans	India, Malawi
Cowpea	India, Malawi
Chickpea	India, Malawi
Oil crops	
Groundnut	Australia, Botswana, Brazil, Burkina Faso, China, Ethiopia, Gambia, Guyana, India, Malawi, Mali, Niger, Nigeria, Senegal, Sudan, Zambia, Zimbabwe
Sunflower	India, Yemen
Soybean	India, Brazil, Guyana
Sugarcane	Argentina, Australia, Bolivia, Brazil, Caribbean, Central African Republic, China, Colombia, Cuba, Dominican Republic, Guyana, India, Jamaica, Kenya, Mexico, Nicaragua, Nigeria, Pakistan, Panama, Paraguay, Philippines, Uruguay, Somalia, South Africa, Sudan, Venezuela
Root crops	
Sweet potatoes	India, Jamaica
Potatoes	Australia, India
Yam	Ghana, Nigeria
Cassava	Brazil, Guyana, West Africa, Malawi
Vegetables	
Tomato	Saudi Arabian Peninsula, Yemen
Okra	Saudi Arabian Peninsula, Yemen
Pepper	Saudi Arabian Peninsula, Yemen
Eggplant	Saudi Arabian Peninsula
Cabbage	India
Fruit trees	
Guava	India, Saudi Arabian Peninsula
Tea	India, Malawi, Pakistan, Peru
Coffee	Argentina, Brazil, Bolivia, Kenya
Citrus	Afghanistan, Algeria, Australia, Egypt, India, Iran, Iraq, Israel
Cocoa	Ghana
Passion fruit	Colombia, Trinidad, Venezuela
Banana	Malawi
Mango	Australia, India, Saudi Arabian Peninsula
Papaya	Saudi Arabian Peninsula

(continued)

Table 3.4 (continued)

Crop	Country
Grapes	Australia, India
Palm trees	
Oil palm	Ghana, Nigeria, South Asia, Pacific Island
Date palm	Afghanistan, Algeria, Egypt, Iran, Iraq, Israel, Jordan, Libya, Morocco, Sudan, Tunisia
Coconut	India, Malaysia, Nigeria, some South Pacific Islands
Field crops	
Pineapple	Argentina, Australia, Brazil, Kenya, Paraguay, Uruguay
Cotton	Central African Republic, India, Malawi, Sudan, Tanzania, Uganda, Yemen
Forestry plantations	
Rubber trees	Southeast Asia
Pine plantations	Australia, Southeast Asia
Hardwood plantations	Mahogany in South Pacific islands, eucalyptus in South America, street trees in France,

Table 3.5 Termite infestation (%) at different crop stages (Pardeshi et al. 2010)

		Crops			
Species	Stages	Castor	Cotton	Sugarcane	Wheat
Coptotermes heimi	Seedling	0.0	0.0	100.0	0.0
	Maturing	0.0	0.0	0.0	100.0
Odontotermes obesus	Seedling	58.6	44.2	82.4	40.5
	Maturing	4104	55.8	17.6	59.5
Odontotermes redemanni	Seedling	0.0	0.0	0.0	40.2
	Maturing	0.0	0.0	100.0	59.8
Microtermes obesi	Seedling	0.0	0.0	78.3	28.6
	Maturing	0.0	100.0	21.7	71.4
Microtermes mycophagus	Seedling	84.8	62.9	100.0	0.0
	Maturing	15.2	37.1	0.0	0.0

growing and mature plants are attacked by termites (Sands 1960; Kaushal and Deshpande 1967; Feakin 1973). Yield losses are direct and also indirect, reducing the quality of seed both for planting and human and animal consumption. The recommended management practices include use of resistant or tolerant varieties, cultural practices, botanical insecticides and minimum application of synthetic insecticides.

Chhotani (1980) observed that groundnut plants attacked by *O. wallenensis* show typical symptoms of stems covered with earthen sheet up to 5 cm high from the ground surface. Termites bored into the main stem just close to the ground level and then tunnelled down into the taproot or up to the stem. They damage pegs as well as mature pods, occasionally penetrating into their shells. The damage to pegs leads to their breaking during harvesting, thus leaving the pods in the ground. Termites remove the soft non-fibrous layer of the shell, leaving the veins exposed and causing scarification of the pods, which may become mouldy at the time of harvesting. More plants were attacked in the field area with low soil moisture content. However, there was no direct information on the relationship between field soil moisture content and the termite damage to groundnut plants. A significant relationship has been recorded between rainfall and *Microtermes* sp. infestation to the groundnut (Johnson et al. 1981). Termite damage may be serious in low rainfall area. The pods scarified are weaker and liable to crack, and scarification of pods is the most common type of damage caused by termites nearing maturity. *Aspergillus flavus* Link invades and colonizes the scarified pods and produces aflatoxin, a carcinogen that poses serious health hazards to farmers and consumers (McDonald 1970).

In India groundnut yields are low, rarely exceeding 700 kg/ha, and this is mainly due to suboptimal plant populations resulting from poor seedling emergence. Seed treatment with synthetic insecticides reduces the losses incurred in germination. In severely infested fields, the termites devour the seed sown, so substantial losses have been observed. As the crop matures the damage caused by termite increases. In general, seedling loss is relatively low, but sporadic cases with higher levels of damage have been recorded. Usually, under moisture-stressed conditions, the attacked plants die within a few days. However, upon irrigation they recover quickly, if the vascular tissues are not damaged.

Rawat et al. (1970) reported that in Madhya Pradesh (India), *O. obesus* attacks the crop more severely, leading to 35% plant mortality. Kaushal and Deshpande (1967) estimated direct pod losses to be more than 25%. Repeated mechanical cultivations reduce termite populations. Timely harvesting the crop as soon as they are mature and early removal of produce from the field also reduce termite damage.

Maize (*Zea mays* L.)

In the tropics, maize is often damaged by termites. Species of *Odontotermes* can defoliate maize seedlings or consume the entire plant. Field observations on *O. wallonensis* showed damage to seeds and seedlings. However, the termite attacked the stem of the maize plant at the ground level, covering with earthen sheet up to a 10 cm height from the base. When the earthen sheet was removed to examine the damage, a hole was found at the base which was completely eaten a few cm upward and downward and filled with soil. However, the outer covering of the stem remained intact. Some of plants were found covered with earthen sheet; these are severely damaged plants lodged on the ground even by a slight wind.

Odontotermes wallonensis caused severe damage to young maize crops. It doesn't attack the root until plants reach maturity. They may either remain standing or lodge, due to termite attacks resulting in the total destruction of cobs. In India it is observed that the *Microtermes* sp. attack on maize plants is maximum, as compared to other termites. Harvesting of lodged plants in commercial agriculture where the crop is mechanically harvested leads to high yield losses. In southern India, however, when harvesting is undertaken by hand, losses are considerably lower.

Preharvesting loss in maize due to termite is enormous. Agarwala (1955) noticed a gradual increase in the intensity of termite attacks from November, when rains were ceased. *Microtermes* sp. attacks maturing and mature maize plants, while *Macrotermes* sp. causes damage to seedlings. Maize plants attacked early in the season can compensate damage with new tiller growth. The management options include sowing at a higher seed rate and seed dressing with insecticides. Logan et al. (1990) listed measures to reduce termite damage to crop plants. They suggested attempts made to (1) initially prevent termite access to plants, (2) reduce termite numbers in the vicinity of plants and (3) reduce the susceptibility or increase resistance of the plants themselves.

For subsistence farmers, the use of intercropping to improve yields in low-input agriculture was proposed by Ofori and Stern (1987). In general intercropping is known to reduce damage caused by insect pests to the principal crop (Trenbath 1993).

Maize-legume intercropping system is the most widely recommended system in endemic areas of termite damage. Different legumes differ in their ability to influence the termite damage. In India soybean and groundnut intercropped with maize allow better yields of maize compared to intercropping with common beans. Subsistence and marginal farmers often include forage legumes as an intercrop. However, the socio-economic status of the farmer mainly decides whether he adopts intercropping or not.

Sugarcane (*Saccharum officinarum* L.)

Sugarcane is mainly damaged by termites belonging to five genera, viz. *Coptotermes*, *Macrotermes, Odontotermes, Microtermes* and *Eremotermes.* Their damage potential is very high in India, whereas in other countries such as Sudan and Central Africa, usually the losses are around 18% and 5–10%, respectively. The most common damage to sugarcane is the destruction of the planting material (setts).

Agarwala (1955) estimated 2.5% loss in sugarcane tonnage and 4.47% in sugar production in Bihar. Roonwal (1981) noticed that the most important termite species attacking wheat and cotton were *M. obesi* and *O. obesus*. He observed that intensity of damage to wheat by *M. obesi* was lower when the crop received two or three irrigations, vs nil or only one. Pardeshi et al. (2010) conducted investigations and recorded 15 species of termites belonging to two families and seven genera from Vadodra and Gujarat, during 2002–2005. They observed that sugarcane was attacked by maximum 5 species, followed by wheat (5), cotton (3) and castor (2). The incidence and attack of *C. heimi* was maximum (76%) and minimum (24%) in sugarcane and wheat, respectively. This particular species was found attacking the planting stalks of sugarcane but in wheat crop damage was mainly noticed in maturing stage.

In Gujarat, India, only a single species, *O. redemanni*, was recorded to damage the sugarcane at mature stage, while *M. obesi* and *O. obesus* were found to infest seedling and maturing stages. Sugarcane provides maximum shade and is more susceptible to termite attack. Shade, high sugar content and faster growth rate are some of the major reasons for the preference of this crop by a wide variety of termites. Food and habitat also greatly influence the termite activity. Termite-infested organic manure, when applied to field, also increased the intensity of the attack. Due to high evaporation rate and low water-holding capacity, the incidence of termite attack is lower in sandy loam soil. High evaporation rates of sandy loam soil pose in fact a desiccation threat to the soft-bodied termites, which probably restrict their distribution in those areas. Shady areas provide a good moisture level favouring termites, a factor that justifies the higher intensity of attacks in shady places than in open areas. In addition to shade and plant cover, objects like big boulders, manure heaps, wooden logs, tree stumps, etc. also provide shelter and moisture to the termites. Because of their affinity to shady and moist places, the termites make galleries in and around these objects. Thick vegetation provides the ground shade which in turn supplies more moisture and humidity to soil, one of the major factors promoting termite activity.

Attack by *O. wallonensis* after plantation prevents germination, resulting in a poor stand. Termite attacks the crop as it begins to mature. Secondary attacks also occur when termites gain access to soft pith through site damaged by rodent and stem borers. It also attacks the cane stalks in the year of scanty rainfall. The most common damage to crops occurs when setts are first planted in the field. The attack at this stage prevents germination, resulting in a poor stand. Termite also attacks crops as it begins to mature; further secondary attack also occurs when termite gains access to soft pith. They enter the cane laterally through one or more holes in the stalk (shoot) and bore downward as well as upward killing the growing points. Thus it cuts upward of the central leaf causing heavy yield losses as it affects the plant area which will be poor in juice with less cane weight. It damages the crops soon after internode formation, and its activity continues till harvest. The usual method of prevention is to dip the setts in various formulations of chlorinated hydrocarbons before planting or to spray them in the furrows before filling in.

Pardeshi et al. (2010) observed that *O. obesus* acted as pest to all crops, irrespective of the plant stages. However, attack was more prominent in sugarcane (43%) than in cotton (27%), wheat (19%) and castor (10%). This species caused more damage during sugarcane seedling stage (82%), as compared to maturing stage (18%). Such difference in occurrence between the seedling and the maturing of crop is only noticed in sugarcane. Wheat was mostly (73%) liked as food rather than sugarcane (27%) by *O. redemanni.* Attack severity was higher in maturing sugarcane. However, another subterranean species, *Microtermes mycophagus* (Desneux), showed preference for castor (53%) rather than cotton (29%) and sugarcane (18%). *Microtermes mycophagus* attacked the young plants of sugarcane, castor and cotton, and matured crops appeared less vulnerable. However, *M. mycophagus* was not recorded from wheat.

Microtermes obesi is a serious pest of sugarcane (58%), particularly at seedling stage, as well as of wheat (37%), whereas cotton (6%) was less preferred. However, matured wheat crops were more susceptible to the attacks of this species. Cotton was damaged only at its maturing stage. In terms of occurrence, *O. obesus* occupies the highest position (28%), followed by *M. obesi* (25%) and *M. mycophagus* (17%). *Odontotermes redemanni* and *C. heimi* are very rare, and a very few specimens were collected. Termite damage in sugarcane occurs both at seedling (setts) and maturing stage. In wheat, the infestation is seen more in the seedling than the maturing stage. Thakur (1996) recorded *O. obesus* and *M. obesi* as a major pest of sugarcane in India and Pakistan. *O. obesus*, *M. obesi* and *M. mycophagus* were found to be the most versatile species in this study, and besides their occurrence in the crop field, they also showed a marked presence in a number of other microhabitats.

Wheat (*Triticum aestivum* L.)
Among cereals, wheat is one of the most susceptible cultivated crops to termite attack at all stage of its growth, throughout the rain-fed and irrigated regions. *Odontotermes wallonensis* attacks all stages of wheat plants and has been reported as the most important termite species (Hussain 1935). The average annual losses of wheat in India were estimated to vary from 6 to 40%, at different places.

Other important species of termites attacking wheat crop are *O. obesus*, *M. obesi* and *Microcerotermes tenuignathus* Holmgren. Loss of wheat crop has been reported to be 7.15% by Parihar (1978). In western Rajasthan, on the whole, infestation is more severe in the rain-fed light soils than in irrigated, heavy soils. The infested plants wither and dry up, losing their anchorage and getting dislodged. Sometimes the attacks also occur in the earhead stage, resulting in chaffy earheads with little or no grain.

Soybean (*Glycine max* (L.) Merr.)
Under field conditions, *O. wallonensis* severely damages soybean plants below ground level and removes the internal tissue causing weakened plants. In addition, the termite also attacks roots, with maximum losses noticed on soybean root stubble.

Pearl Millet (*Pennisetum typhoides* (Burm) Stapf & Hubb.)
In Rajasthan, *bajra* or pearl millet (*Pennisetum typhoides* (Burm) Stapf & Hubb.) is subjected to attacks by termites such as *M. obesi.* This pest initially attacks roots, and later on the stem, resulting in wilting and ultimate drying of plants.

Cluster Beans (Guar) (*Cyamopsis tetragonoloba* (L.) Taub.)
The termite species responsible for damaging guar crops are *Microcerotermes baluchistanicus* (Ahmad), *Odontotermes guptai* (Roonwal and Bose) and *M. obesi*. They attack the crop at germination, flowering and fruiting stages in August and September (Parihar 1978). At the germination stage, they nibble the roots, while at the flowering and fruiting stages, they also enter the stem base by making a hole in it. They completely devour the inner portions, leaving only the rind, thus depriving the stem of its nutritional supply. The termite infestation ranges from 12.3 to 16.3% of plants.

Castor (*Ricinus communis* L.)
This crop is attacked by *M. mycophagus* both at the seedling and the growth stages. In the seedling stage, the attack is more prominent on roots, while the stem remains unaffected. In young plants the termites nibble the taproot. In grown-up plants the termites can be seen around the root zone and in certain cases up to 3 ft on the stem (Parihar 1977). The root bark, in each case, was found to be quite intact, while the hard cores were mostly tunnelled through. The fine roots (more than 2–4 mm in diameter) showed more damage. When severely damaged, the roots show galleries which were rather irregular and ran almost parallel to their length. The larger

galleries are occasionally filled with earth and excreted wood. Owing to unique phyllotactic arrangement, castor leaves are mainly restricted to the apical region for which termites get very little shade around them. Since the termites are soft-bodied animals and are very much prone to desiccation, for obvious reasons they either stay away from the somewhat drier areas around castor plants or penetrate deep into the soil.

Primarily the termites attack young plants, immediately after planting or when they are very young, devouring the taproot. The injured plants become weak, and leaves turn yellowish. Young plants exhibit signs of drooping of tender leaves, followed by withering and death. Plants already weak due to drought, abnormally high and low moisture conditions, nutritional stress or pest attack became easily vulnerable to the termite attacks. Occasionally, soft plant parts, exposed because of mechanical injuries (strong wind, cattle grazing, several anthropogenic activities, etc.), become susceptible to termite attack (Wardle 1987; Thakur 1996).

Chillies (*Capsicum annuum* L.)

In Rajasthan, chillies in various growth stages are attacked by termites. The plants, both at and below ground level, are attacked, with a loss of 10–45% recorded at Mathania (Jodhpur). The damaging species were *O. obesus* and *M. obesi.* The attack is at the transplanting stage of the crop, when the termites nibble the growing root regions. At the flowering stage, they also enter the base of the stem and devour its inner portion by filling it with earth and excreted saliva.

Pulse Crops

Important crops like moong (*Phaseolus radiatus* L.), moth (*Phaseolus aconitifolius* Jacq.) and cowpea (*Vigna sinensis* L.) are sometimes attacked, at various stages of growth, by *O. obesus* and *Odontotermes parvidens* Holmgren and Holmgren. Losses between 25–30% (cowpea), 10–15% (moth) and 5–17% (moong) have been observed at Jodhpur.

Coconut Trees (*Cocos nucifera* L.)

Odontotermes wallonensis causes serious damage to coconut seedlings in nurseries and, particularly, on transplanted seedling in the earlier stages. More serious losses are caused when they nibble at the tender growing point. This species also damages coconut plants in nursery by constructing mud galleries. Trunk wilting of central shoot, stunted growth and presence of mud galleries are also seen on the trunk. The tender shoots of coconut seedlings have been observed to be cut off by termites, which also cause damages to roots and shoots of seedlings, as well as on young coconut trees. The attacked plants dry gradually and finally become wilted.

Yams and Cassava

Amitermes sp., a predominantly root-feeding termite, is known to attack the elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) and cassava (*Manihot esculenta* Crantz.), which are grown from tubers and stem cuttings in Africa and India. Mature crops are attacked at the stems by other termites belonging to *Macrotermes*, *Odontotermes* and *Microtermes* sp. At present, the best known management strategy involves treatment of tuber setts with synthetic insecticides, viz. chlorpyrifos.

Cotton (*Gossypium* sp.)

Cotton is grown in black clay soils in India, where a large area is grown under rain-fed agriculture. In India, the termite damage in cotton crop has been observed in states of Rajasthan, Gujarat, Haryana, Punjab and Madhya Pradesh. The crop is attacked mainly by species of three genera, viz. *Trinervitermes*, *Microtermes* and *Odontotermes*. The termites feed on the roots and make tunnels in them. The plants show symptoms of wilting because the root tissues are replaced with soil by the termites, eventually leading to the plant's death. Well-developed root systems of older plants help them to survive the attack. The most common management strategy consists of application of broad-scale insecticides or seed dressings and baiting with dry grass mulch, treated with insecticides.

Horticultural and Tree Crops

Eaten-bark symptom is the most common sight in orchards in tropical, arid and semiarid regions in India. In orchards, trees plastered with mud layer are very common. On removal of the mud plaster, live termites can be seen. Bark-eating termites are of local importance. The damage they cause is often negligible, but in severe infestations hollowed-out cavities are seen on the main trunk and branches, filled with soil, as well as on roots, filled with soil. Termites collect plant materials and transport them to their nests for their fungus gardens. Those feeding on dead bark gather no significance on established trees. It has been observed that sometimes the termites gain entry into the trees through pruned dead ends of branches and stumps. In the orchard, initiation stage termites have been reported to kill the saplings, damaging roots and stems.

Tea (*Camellia sinensis* (L.) Kuntze)

Tea, as a perennial crop, is attacked by 1031 species of arthropod pests across the world, of which only 300 species are recorded in India with about 190 fungi, reported from North East India (Das 1965; Rattan 1992; Sivapalan 1999). Among the tea pests, termites have a distinct niche by attacking plants from under soil or at collar region of a bush. They are important subterranean pests in tea, by limiting the establishment of newly planted young seedlings and by reducing the mature tea, by attacking their frame and killing bushes. These pests cause 11–55% losses in yield (Gurusubramanian et al. 2008).

3.5 Management of Termites

Occurrence of some species in a number of diverse microhabitats confers them an added advantage allowing survival in dry, arid or harsh environments, an important factor for a species to be considered as a pest. Most termite pests are subterranean, and their management primarily relies on soil treatment with termiticides at the site of attack. As a result of the adverse effects of the organochlorines on the environment, research trends shifted towards third- and fourth-generation insecticides such as carbamates, organophosphates and synthetic pyrethroids. Due to the well-understood and proven ill effects of synthetic pesticides on the environment, research trends have also shifted towards use of more environment-friendly techniques. Today farmers are looking for low impact measures of insect pest management.

While developing a strategy, the usefulness of termites must be kept in mind. They are the best decomposers and nutrient recyclers of dead plant material and an indispensable member of the food chain. However, a large number of termite species have an economic importance as pests. Effective foolproof management strategy against termites is not really available due to a fragmentary understanding of their biology. Moreover, the patchiness of infestations under field condition often makes the management strategies more complicated.

Various strategies have been developed over the last few decades to manage termites under field conditions in different field and horticultural crops. We would limit ourselves to the various practices that are being recommended and practised in India. There are several methods to manage termites. None of them is efficient and suitable enough to eradicate established colonies. There are typical shortcomings related to the development of chemical and biological control strategies that need to be solved. Termites are always hidden in galleries and nests. Any method to exterminate them needs to reach them, but usually these niches are inaccessible. Moreover, termites are known to cordon off or block the contaminated/treated area. They are known to bury the diseased individuals or carry them out of their nests or sometimes to eat away the dead ones. Termites are also known to produce certain antibiotics which allow only their beneficial fungi to grow in their colonies. The only effective remedy to the termite problem is hence to prevent their attacks. In orchards, termites are known to attack the weakened trees, so our aim should be to maintain the trees in healthy conditions and remove/destroy the dead or decaying ones.

3.5.1 Physical and Mechanical Methods

- Burning of crop residues on top of termite mounds is a common practice in Indian villages to suffocate these pests. However, neither heat nor smoke penetrates deep enough in the mounds so that the primary reproductives are killed.
- Destruction of mud galleries or tunnels by tillage or flooding gives only temporary solution to the problem. The termites eventually reinfest these areas.
- Destruction of mounds and killing the primary and secondary reproductives also give a temporary solution. This is due to the fact that the nests are often located deep inside the ground and are difficult to reach. Moreover, this method is highly labour intensive. Chances for some brood and workers to escape along with soldiers are very high, which would eventually develop into large colonies again, after a given time.
- Coconut nurseries are protected from foraging workers by covering a layer of sand over the nursery area rather than with soil (Kashyap et al. 1984). Digging deep trenches around the tree nurseries helps to protect the saplings from surface foraging workers of *Macrotermes* sp. which will not be able to construct galleries, (Beeson 1941).

Protection of Traditional Granaries

- Avoid construction of granaries in places infested with termites or with a close proximity to termite mounds. Before construction of granary, ensure removal of all organic matter and crop residues.
- Use termite-resistant timbers (e.g. teak) as poles for granaries. If termite-resistant wood is not available, apply a coating of engine oil on the poles and other wooden structures.
- Preferably use concrete or stone platforms resting on poles.
- Use pure mud walls instead of walls made up of mud and chopped straw.
- Underground pits and bunkers are easily invaded by termites. To avoid this situation, use thin galvanized metal sheets to line the pits and bunkers or line with clay or soil from termite mounds, which is then fired to harden.
- Always apply a layer of ash to the base of the granary or plant materials with insecticidal or repellent properties. This would not only prevent termite entry but also prevent common storage insect pests.

Cultural Practices

Preventive measures are a long-term exercise to avoid termite attacks, but cannot provide a suitable cure for any existing problem. Termites mostly attack diseased and stressed plants and rarely healthy plants (Sen-Sarma 1986). Removal of crop debris and residues will reduce termite food supplies, thereby leading to less foraging activity by workers and reduction in termite numbers and attacks (Brown 1962). Higher seed densities are recommended in areas where a termite attack is expected, so that even when attacked seedlings are thinned out some amount of economic losses are avoided (Wood and Cowie 1988). Deep summer ploughing is recommended before the onset of monsoon, in order to destroy the foraging tunnels and the workers present in the subterranean region (Kumar 1991). Only well-decomposed farmyard manure (FYM) has to be applied to the field. If partially decomposed FYM is applied, it will act as an attractant to foraging workers. Singh and Brar (1988) reported that optimum fertilizer application increases plant vigour, thereby reducing the crop susceptibility to attacks.

In plantations, debris and dead woods must be removed. Pruning has to be applied carefully, with clean cuts to minimize the area of exposure. The pruned areas and wounds should be painted with copper oxychloride to avoid termite attacks and dieback (Harris 1971; Sivapalan et al. 1977). Application of vetiver grass leaf mulch at the tree base has shown to prevent termite attack. Destruction of termite-infested trees and dead trees before the next rainy season helps to prevent release of swarmers from infested trees, also eliminating considerable amount of termite population in the infested area (Srivastava and Butani 1987). Sivapalan et al. (1977) reported that excessive use of nitrogenous fertilizer in tea encouraged growing soft tissues which are highly susceptible to attacks by *Glyptotermes dilatatus* Bugnion & Popoff. Care should be taken while establishing the orchard, avoid growing in sandy/red sandy loam soil. The pits must be also treated with soil insecticides before transplanting seedlings, removing the mud galleries in infested tree trunks and then swabbing the area with kerosene oil.

Clean Cultivation
The field or orchards must be maintained clean to avoid infestations, irrigating the cropped area regularly and removing all the dead and decaying plant/trees/weeds from the cropped areas and near vicinity. Removal of diseased and mechanically injured or damaged plants should also be done. Weeds surrounding the fields compete with crops for nutrients, light and water and may lead to stress and hence increased susceptibility to termite attacks. Inorganic fertilizers may be used to enhance plant vigour and eventually withstand pest damage. Timely proper application of nitrogen, phosphorus and potassium in wheat reduces termite incidence. Crop rotation results in better soil fertility and plant vigour and breaks continuous attack cycle of termites. Deep ploughing exposes the termites to desiccation and predators and thus helps in reducing their numbers. Harvesting the crop at the right time, without leaving the harvested plant material in the field, represents a useful practice.

Crop Rotation and Intercropping
Farmers should follow crop rotation especially including non-preferred crops, following a cropping system with a fallow period. This helps the soil to regain its fertility and also sustains the subsequent crop healthy growth, thereby developing some tolerance towards attacks. Intercropping maize with soybean or groundnut has reduced the termite activity and increased the predatory ant activity (Sekamatte et al. 2003).

Soil Management
Regular intercultural operations and pre-planting tillage destroy the tunnels and galleries built by termites. These operations restrict their foraging activities and also reduce damage to crops. In vertisols termite is not a problem due to frequent occurrence of small cracks and crevices that prevent maintenance of runways, galleries and mounds.

Water Stress
The healthy plant growth must be sustained to avoid termite damage, as these pests more often attack sickly or water-stressed plants than healthy ones. Frequent irrigation reduced attack by *M. obesi* in field crops, viz. maize, wheat, sugarcane and groundnut (Verma et al. 1980; Kumar and Veeresh 1990). On groundnut, Jayanthi et al. (1993) reported that the activity of termites recorded in drip-irrigated plots was higher than in surface-irrigated plots.

3.5.2 Biological Control Strategies

Biodiversity of natural enemies can be increased by applying less persistent insecticides and planting large trees around the agricultural fields. Efforts should be made to increase the presence of natural enemies preying on swarms of termites.

Predation

Wood and Sands (1978) reported that there are two different types of predation on termites, viz. on swarming alates and on foraging workers. In the former predation type, the antagonists are classified as arthropod predators (which include scorpions, spiders, centipedes, dragonflies, cockroaches, mantids, crickets, beetles, flies, ants and wasps) and vertebrate predators (including reptiles, amphibians, birds and mammals, sloth bear, echidna, ant-eaters, etc.). Sheppe (1970) reported that foraging termite workers are predated by ants such as *Myrmicaria cumenoides* Gerst and *Pheidole megacephala* (Fab.). Birds (drongo, bush lark, swallow, green bee eater, hoopoe, Indian roller) predate on termites during swarming. Reptiles such as lizards commonly feed on termites. Frogs are also an important predator of termites during swarming. Mammals such as the five-striped squirrel *Funambulus pennantii* (Wroughton) and mongoose *Herpestes edwardsi* (Geoffroy Saint-Hilaire) were recorded to feed upon a swarm of *Microtermes* sp. Predatory ants like *Pheidole* sp. and *Dorylus* sp. were observed feeding on *O. obesus*. Beeson (1941) noticed that termites were controlled when *Solenopsis* sp. was transplanted in nurseries of tree seedlings in India. The predatory ants attacking termites belong to family Ponerinae and Myrmicinae. Some of the predatory ant species recorded in India are *Leptogenys processionalis* (Jerdon), *Camponotus sericeus* (Fab.), *Anoplolepis longipes* (Jerdon) and *Oecophylla smaragdina* (Fab.) (Rajagopal 1979; Kumar 1991).

Microbial Control

For some past decades organochlorines have been used for termite management worldwide. Owing to their persistence, these pesticides were banned or withdrawn from the market for human health and environmental reasons in an increasing number of countries since the last two decades. The United Nations Environment Programme (UNEP) and the Food and Agriculture Organization (FAO) jointly made efforts to eliminate production and use of persistent organic pollutants including organochlorine pesticides. As a result, the focus on use of "greener" technologies increased tremendously.

In the recent decades, many researchers investigated the potential use of entomopathogens as microbial control agents for insects (Tanada and Kaya 1993). Much of this research focused on the use of *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metsch.) Sorokin. To date, the majority of work include evaluation of *M. anisopliae* for biological control of insects has focused on pests important for agriculture (Zimmerman 1993). Grace (1997) provided a review of biological control of termites and concluded that microbes, primarily entomopathogenic fungi, have some potential in the biological control of Isoptera. Termite pathogenic viruses have not been reported so far. However, some workers have published their findings in this respect, but the results do not indicate their possible use in biological control programmes. A potential candidate for development of microbial pesticides must have the capability to complete its life cycle and spread before the death of host (Chouvenc and Su 2010).

Before 1960, few reports noted the pathogenic effect of microorganisms on termites. Merrill and Ford (1916) and Pemberton (1928) first reported the presence of parasitic "head-inhabiting" nematodes in *Reticulitermes lucifugus* (Rossi) and *C. for-*

mosanus, respectively, but concluded that such nematodes could not kill termites in soil conditions. DeBach and McOmie (1939) later reported the existence of two bacterial species killing laboratory colonies of *Zootermopsis angusticollis* Hagen and identified them as *Bacterium* sp. and *Serratia marcescens* Bizio. A thorough perusal of the available literature indicated that plenty of research is being carried out using microbial agents for the management of termites. However, very few pathogens have shown promising results. Most of the experiments were conducted in Petri dishes only, and their results may not be applicable under field conditions. The most important reason for this uncertainty is the susceptibility of termites to light and humidity, as most of the workers die when exposed to fluorescent light for more than 30 min.

Myles (2002a) listed 2 viruses, 5 bacteria, 17 fungi, 5 nematodes and 4 mites as natural enemies of termites. Under natural conditions, diseased termite colonies are rarely encountered, as they maintain a very strict sanitary regimen, with absolute cleanliness, by removing the diseased and dead individuals from the colony. They may also produce selective antibiotics and ensure that only members of *Termitomyces* grow in their fungal gardens. When the colony is weakened by any other means, epizootics can be expected. Some of the present-day termiticides act synergistically with soil microbes and predispose termites to attacks by pathogenic microbes. High rate of fungal infection was observed in imidacloprid (sublethal dose)-treated insects. The stressed insects are also more susceptible to pathogen invasions (Neves and Alves 1999).

1. Nematodes

Entomopathogenic nematodes (EPNs) have been known to kill termites since decades. Under laboratory conditions, they are very effective against termites, but under field conditions their efficacy was not proved. Termites can recognize and wall off infected individuals, hence limiting the spread of nematodes throughout the colony. Furthermore, soil moisture and soil type appear to limit the nematode's ability to move in the soil and locate termites.With time and new frontiers in research, termite management using nematodes has increased. Reese (1971) studied the effectiveness of *Steinernema feltiae* (Filipjev) against large field colonies of *C. formosanus*. He opined that direct physical contact between termite and nematode species is required for colony control. Poinar (1979) noticed mortality among workers of *Coptotermes* and *Nasutitermes* when challenged with *Neoaplectana carpocapsae* (Breton strain) (=*Steinernema feltiae*) in laboratory experiments. Similarly, Georgis et al. (1982) recorded 96–98% mortality among *Zootermopsis* and *Reticulitermes* with 2000 infective stage of *N. carpocapsae* as well as *Heterorhabditis heliothidis* (Khan, Brooks & Hirschmann), respectively, 3 days after the treatment. The EPNs invade different body structures of termites, such as nervous and muscle tissue, fat body and salivary and sternal glands. Parasitism of termites was highly perceptible in Egyptian laboratories and field by *Heterorhabditis baujardi* Phan, Subbotin, Nguyen & Moens and *Heterorhabditis indica* Poinar, Karunakar & David (El-Bassiouny and El-Rahman 2011).

In Sri Lanka, Danthanarayana and Vitarana (1987) could successfully manage populations of the dampwood termite, *Glyptotermes dilatatus* (Bugnion & Popoff) (with colonies of several thousand members) applying *Heterorhabditis* sp. in tea plantations. Similarly, Lenz and Runko (1992) and Lenz et al. (2000) reported that in the South Pacific islands, nematodes have a potential to manage infestations of *Neotermes* sp. in the unbranched trunks of coconut palms. On the other hand, susceptibility of *Neotermes* sp. was reduced in branched trees of citrus, cocoa or American mahogany (*Swietenia macrophylla* King). Weeks and Baker (2004) recorded significant differences in survivability, detectability and ability to kill *Heterotermes aureus* (Snyder), when challenged with *Steinernema carpocapsae* (Weiser) and *Heterorhabditis bacteriophora* Poinar. Rich et al. (2006) indicated that efficacy of nematodes can be increased if they are applied in combination with some insecticide. In laboratory experiments, they observed that four EPNs were capable of killing termites. *Steinernema riobrave* (Cabanillas, Poinar and Raulston) caused more than 80% mortality of *H. aureus* and *Gnathamitermes perplexus* (Banks) on sand assays. However, *R. flavipes* was less susceptible to all nematodes (Yu et al. 2006). In Indian Agricultural Research Institute (IARI), the Division of Nematology has developed a nematode formulation against termite named as Nemagel. This formulation, tested in maize, gave an effective control of termites. The nematode used in this formulation is *Heterorhabditis thermophilum* Ganguly and Singh which harbours the symbiotic bacterium *Xenorhabdus indica.* The nematode releases the bacteria into the insect haemocoel causing a septicaemia that kills the termite within 24–48 h. Nemagel has to be dissolved in 20 l of water which has to be applied over an acre.

Till date there are 83 EPN species, which were able to parasitize insect pests during 2001 all over the world (Grewal et al. 2001). It was observed that the focus on the application of nematodes has increased progressively, and up to now 26 EPN species, along with more than 30 different isolates, have been recorded from all over the world. A list of nematode species parasitic on termites is presented below (Table 3.6).

2. Fungi

Fungi have been used all over the world in the management of insect pests (Glare and Milner 1991). More than 700 species of fungal pathogens of insects have been listed by Milner (2000). To cause infection, a fungus has to penetrate through the host cuticle, as infection would not occur only by ingestion of the spores/conidia. Milner et al. (1998) and Sun et al. (2003) isolated termite pathogenic fungi from attacked wood and mud galleries. The most common pathogenic fungi used in research are *B. bassiana*, *M. anisopliae* and *Paecilomyces fumosoroseus* (Wright 2005). *Metarhizium anisopliae* is the most widely used fungus for field evaluation against termites. A list of common fungal species pathogenic to termites is given below (Table 3.7).

Shortcomings in Utilization of Fungal Pathogens for Termite Management

Termites are highly sensitive to light, humidity and temperature. Their olfactory sense is also very well developed, to compensate for their blindness. Termites were capable to identify conidia of virulent strains of *M. anisopliae* and keep away by triggering alarm and aggregate around spore-dusted individuals (Staples and Milner 2000; Myles 2002b). The identified individual would be groomed by nest mates and then bitten and defecated upon. The dead termites are buried (Myles 2002b). Rosengaus et al. (1998) and Rosengaus and Traniello (2001) studied the

Table 3.6 Nematodes species parasitic to termites

Species	Reference
Heterorhabditis sonorensis, Stock, Rivera-Orduño & Flores-Lara, *H. indica* Poinar, Karunakar & David	Zadji et al. (2014a, c)
Steinernema sp.	Zadji et al. (2014b)
Steinernema carpocapsae (Weiser)	Divya and Sankar (2009)
Steinernema glaseri Konza	Murugan and Vasugi (2011)
Steinernema feltiae Filipjev	Mauldin and Beal (1989)
Steinernema longicadam	Zhu (2002)
Heterorhabditis bacteriophora (Poinar)	Yu et al. (2006)
Neosteinernema longicurvicauda Nguyen & Smart	Nguyen and Smart (1994)
Chroniodiplogaster aerivora (Cobb)	Merrill and Ford (1916); Poinar Jr (1990)
Diplogaster labiates (Pemberton)	Pemberton (1928)
Heterorhabditis baujardi Phan, Subbotin, Nguyen & Moens	El-Bassiouny and El-Rahman (2011)
Pseudaphelenchus yukiae Kanzaki & Giblin-Davis	Kanzaki et al. (2009b)
Pseudaphelenchus vindai Kanzaki, Giblin-Davis, Herre, Scheffrahn & Center	Kanzaki et al. (2010)
Pseudaphelenchus sui n. sp	Kanzaki et al. (2014)
Termirhabditis fastidiosus Massey	Massey (1971)
Rhabditis rainai n. sp.	Carta and Osbrink (2005)
Oigolaimella attenuata von Lieven & Sudhaus	von Lieven and Sudhaus (2008)
Poikilolaimus carsiops n. sp.	Kanzaki et al. (2011)
Poikilolaimus floridensis Kanzaki & Giblin-Davis	Kanzaki et al. (2009a)
Poikilolaimus ernstmayri Sudhaus & Koch	Sudhaus and Koch (2004)
Pelodera scrofulata sp. nov.	Tahseen et al. (2014)
Pelodera termitis sp. n.	Carta et al. (2010)
Pristionchus aerivorus (Cobb)	Christie (1941)
Hartertia gallinarum (Theiler)	Watson and Stenlake (1965)
Caenorhabditis sp.	Handoo et al. (2005)

behavioural defence mechanism and concluded that allogrooming among termites could make fungal spore/conidia treatments ineffective. They also observed that social grooming in bigger colonies would dislodge all the fungal spore/conidia from the spore-dusted individuals. The bigger the colony, the higher the number of individuals so that more grooming individuals would make fungal spore dusting ineffective. Milner (2003) observed that less virulent *M. anisopliae* strains are less repellant to termites. Rath and Tidbury (1996) noticed that when repellent conidia of *M. anisopliae* were formulated with attapulgite clay and surfactants, the challenged termites could not detect them. Milner (2003) suggested addition of attractants or reduction in spore dose to overcome the bottleneck of conidia detection.

Milner (2003) observed that foragers of *Nasutitermes exitiosus* (Hill), dusted with repellent spores at a feeding site, were denied entry in the nest, whereas individuals dusted with conidia of a less repellent strain mixed with masking agents were allowed to enter. Five fungal pathogens (*B. bassiana*, *M. anisopliae*,

Table 3.7 Fungal species pathogenic to termites

Species	References
Aspergillus sp.	Pandey et al. (2013)
Aspergillus flavus Link	Henderson (2007)
Aspergillus fumigatus Fresenius	Chai (1995)
Beauveria bassiana (Bals.-Criv.) Vuill.	Neves and Alves (1999a)
Conidiobolus sp.	Altson (1947)
Conidiobolus coronatus (Costantin) Batko	Sajap et al. (1997)
Cordycepioideus bisporus Stifler	Ochiel et al. (1996)
Entomophthora coronata Costantin , *E. Virulent* Hall and Dunn	Yendol and Paschke (1965)
Gliocladium virens (Miller, Giddens, and Foster)	Kramm and West (1982)
Gloeophyllum trabeum (Pers.) Murrill	Grace et al. (1992)
Hirsutella thompsonii F52 Fisher	James (2009)
Isaria fumosorosea Wize	Wright and Lax (2013)
Metarhizium anisopliae (Metchnikoff) Sorokin	Neves and Alves (1999)
Metarhizium anisopliae var. anisopliae (Metschn.) Sorokin	Khan et al. (1993)
Metarhizium anisopliae var. acridum (Driver & Milner) Bisch., Rehner & Humber	Jarrold et al. (2007)
Metarhizium anisopliae var. dcjhyium Dong, Jia M. Zhang, W.G. Chen & Y.Y. Hu	Dong et al. (2009)
Metarhizium flavoviride Gams & Rozsypal	Wells et al. (1995)
Metarhizium flavoviride var. Minus Rombach, Humber & Roberts	Khan et al. (1993)
Paecilomyces lilacinus (Thom) Samson	Khan et al. (1993)
Paecilomyces cicadae (Miq.) Samson	Chai (1995)

Metarhizium flavoviride, *Paecilomyces lilacinus* and *P. fumosoroseus*) were tested against *O. obesus*, showing that the termites were very susceptible to all fungi (Khan et al. 1993; Chouvenc et al. 2009a, b). *Aspergillus* sp. (Pandey et al. 2013) and *Isaria fumosorosea* (Wright and Lax 2013) caused prompt mortality by growing on the termite colony, and the worker caste became more susceptible due to an extensive exposure, as compared to other individuals. Coghlan (2004) developed a strategy to deliver pre-sporolytic phase mycelium in termite nests. His suggestion was to offer the termites a pre-sporolytic mycelium which is highly attractive to them. The termites need to carry the fungus and deposit it in their gardens, where it would sporulate and cause mycosis. This methodology would work and be effective only if the termites carry the mycelia and deposit them in their garden, rather consuming it.

Milner (2003) developed bait bioformulations containing *Metarhizium* conidia, for management of termites. In bait, the termite would consume the spores and pass it out encased in faecal matter. The encased spores are viable but lose the opportunity to germinate because termite faeces are known to have antifungal properties (Rosengaus et al. 1998). The ability of the spores to move out of the matrix and get attached to the termite body would only be able to cause infection. This process, however, took a fairly long time before the population in mounds of *N. exitiosus* were significantly reduced (Milner 2003). The infected workers and soldiers moved throughout the colony and get dispersed without any restriction, eventually planting small amount of inocula throughout the nest. The healthy workers would gather them and encase them with faecal matter and other building material, thus reducing the chances of disease spread in the colony.

Rosengaus et al. (1999) carried out studies and indicated development of resistance to various pathogens among *Zootermopsis angusticollis* (Hagen). However, *Reticulitermes flavipes* (Kollar) was effectively controlled (92%) by using commercial formulation of *M. anisopliae*, Bio-Blast™ (Quarles 1999). Maniania et al. (2002) reported that application of *M. anisopliae* at the seedling stage of maize effectively controlled termite attacks in Kenya.

3. Bacteria

The first candidates evaluated for use in termite biological control were some bacteria (Toumanoff and Toumanoff 1959; Smythe and Coppel 1965), although they never received serious consideration for field applications. They have been used for management of termites since the mid-1950s. Khan et al. (1977) isolated a strain of *Bacillus thuringiensis* Berliner from the termite species *Bifiditermes beesoni* (Gardener). Efficiency of bacterial pathogens may be accelerated by the warm, humid environment of the colony, trophallaxis as well as by their grooming contact with nest mates (Grace 1994). Fifteen bacterial species have been used to control *C. formosanus*, including *Serratia marcescens* Bizio which caused 100% mortality of hosts (Osbrink et al. 2001). Bacteria were shown to cause mortality of termite though inhibition of their respiration. *Pseudomonas fluorescens* (Flügge) Migula, when evaluated against termites, blocked their respiratory system by producing hydrogen cyanide (Devi and Kothamasi 2009). The pathogenicity of bacterial strains such as *B. thuringiensis* subsp. *israelensis* was assessed against *M. beesoni*, causing higher mortality at low concentrations, although under laboratory conditions (Singha et al. 2010).

Bacteria isolated from termites have also been recorded in previous research studies and include *Pseudomonas aeruginosa* (Schröter) Migula (Tsunoda et al. 1993), *S. marcescens* (Osbrink et al. 2001) and *Citrobacter* sp. (Harazono et al. 2003). A list of bacterial species pathogenic to termites is provided in Table 3.8.

3.5.3 Botanicals

Different plants contain some biologically active compounds that can be used in termite management (Table 3.9). Beeson (1941) reported the efficacy of two botanical mixtures (gambir mixture and gondal fluid) against termite attack. The gambir mixture is prepared by mixing the aqueous extract leaves of *Uncaria gambir*/*Acacia catechu* (L.) Willd., Oliv. along with *Canarium strictum* Roxb. oil. This mixture, when painted on wounds, provides effective protection against termites. The gondal fluid is prepared by mixing the castor oil cake with extracts of *Gardenia gummifera* L.f., *Ferula jaeschkeana* L. and *Aloe vera* (L.) Burm.f. This mixture, when painted around the base of a tree, offers protection against termites for 8 months. *Calotropis* latex is used to protect wooden pegs, offering protection up to 4 months (Giridhar et al. 1988). Singh et al. (2002a) suggested that sugarcane sett dipping in 15 or 20%

Table 3.8 Bacterial species pathogenic to termites

Species	Reference
Acinetobacter calcoaceticus Beijerinck	Osbrink et al. (2001)
Aeromonas caviae Popoff	Devi et al. (2007)
Bacillus cereus Frankland & Frankland	Khucharoenphaisan et al. (2012)
Bacillus licheniformis (Weigmann) Chester	Natsir and Dali (2014)
Bacillus subtilis (Ehrenberg) Cohn	Omoya and Kelly (2014)
Bacillus sphaericus Meyer and Neide	Toumanoff (1966)
Bacillus thuringiensis subsp. *israelensis*	Wang and Henderson (2013)
Burkholderia cepacia (Palleroni and Holmes) Yabuuchi et al.	Devi (2013)
Candida utilis (Henneberg)	Khucharoenphaisan et al. (2012)
Citrobacter sp.	Harazono et al. (2003)
Citrobacter freundii (Braak) Werkman and Gillen	Omoya and Kelly (2014)
Corynebacterium urealyticum Pitcher et al.	Osbrink et al. (2001a)
Enterobacter cloacae (Jordan) Hormaeche and Edwards	Husseneder and Grace (2005)
Enterobacter gergoviae Brenner et al.	Osbrink et al. (2001a)
Escherichia coli Throop	Khucharoenphaisan et al. (2012)
Photorhabdus luminescens (Thomas and Poinar) Boemare et al.	Shahina et al. (2011)
Pseudomonas aeruginosa (Schröter) Migula	Khucharoenphaisan et al. (2012)
Pseudomonas fluorescens (Flügge) Migula	Devi and Kothamasi (2009)
Rhizobium leguminosarum (Frank) Frank	Devi (2013)
Rhizobium radiobacter (Beijerinck and van Delden) Young et al.	Devi et al. (2007)
Serratia marcescens Bizio	Osbrink et al. (2001a)
Staphylococcus aureus Rosenbach	Khucharoenphaisan et al. (2012)
Xenorhabdus nematophila (Poinar and Thomas) Thomas and Poinar	Hiranwrongwera et al. (2007)

solution of *Calotropis procera* (Aiton) W.T.Aiton extract or soil treatment with 2% solution is effective in controlling termites in sugarcane.

Nakashima and Shimizu (1972) reported insecticidal activity of essential oils, known to have insect repellent activity along with contact and fumigant action against certain pests (Isman 2000). Vetiver oil was found to have long-lasting effects against *C. formosanus* (Zhu et al. 2001a). Zhu et al. (2001b) reported nootkatone (a sesquiterpene ketone), a component of vetiver grass oil, as a strong repellent and toxicant to *C. formosanus*. They act as arrestants, repellents and feeding deterrents. Nootkatone negatively affected termites for 12 months and appears more long-lasting then vetiver oil (Maistrello et al. 2003). It causes complete loss of *Pseudotrichonympha grassii koidzumi*, the most important flagellate required for cellulose digestion in *C. formasanus* (Maistrello et al. 2001). Mao et al. (2006) suggested use of vetiver oil and nootkatone into potting media for surface treatments to restrict the spread of *C. formasanus*. Nix et al. (2006) observed that vetiver grass-root mulch treatment decreased the tunnelling activity and wood consumption of *C. formosanus* and increased their mortality.

Table 3.9 Plants with antitermite properties

Plant species	Common name	Activity/active principle	Plant part
Acacia catechu (L.) Willd., Oliv.	Catechu, khair	Aqueous extract of tannins	Leaves and twigs
Acacia mearnsii De Wild.	Wattle tree	Ethyl acetate extract and water-soluble extract	Bark waste
Acacia crassicarpa Benth.	Red wattle	Ethyl acetate extract and water-soluble extract	Bark waste
Acacia modesta Wall.	Palosa	Methanol extract	Aerial parts
Acacia nilotica (L.) Hurter & Mabb.	Egyptian thorn	Anti-insect	Wood/pulp
Acacia polyacantha Willd.	Hook thorn	Insect repellent tanins	Roots
Afrormosia laxiflora (Benth. ex Baker) Harms	English satin wood		Wood/pulp
Afzelia cuanzensis Welw.	Pod mahogany		Seed oil
Agave americana L.	American aloe	Repellent, insecticidal	Whole plant
Albizia odoratissima (L.f.) Benth.	Tes shade tree		Wood/pulp
Albizia saman Muell.	Saman	Repellent	Wood/pulp
Albizia zygia (DC.) Macbr.	Nongo	Termite durable but not resistant	Wood
Allium sativum L.	Garlic	Anti-feedant, fungicidal, repellent	Bulbs
Anacardium occidentale L.	Cashew	Anti-insect, repellent	Seeds, oil
Argemone Mexicana L.	Mexican poppy	Insecticidal, repellent	Whole plant
Artemisia douglasiana Besser ex Besser	California mugwort	Insect repellent	Leaves
Azadirachta indica Juss	Neem	Termiticidal, anti-feedant	Leaves, seeds
Bidens pilosa L.	Blackjack	Anti-feedant, insecticidal, repellent	Whole plant, mature seeds
Borassus aethiopum Mart	African fan palm		The fibrous wood is highly resistant
Boswellia dalzielii Hutch.	English frankincense tree	Repellent	Gum/resin
Brachylaena hutchinsii Hutch. (Muhuhu)	Muhugu oil tree	Highly resistant, almost impenetrable to termites	Wood
Brugmansia candida Pers. (pro. sp.)	Angel's trumpet	Termiticidal activity in n-hexane, ethyl acetate and aquadest	leaves
Calotropis gigantea (L.) W. T. Aiton	Giant Milkweed	Anti-insect	Leaves, sap/latex/juice

(continued)

Table 3.9 (continued)

Plant species	Common name	Activity/active principle	Plant part
Calotropis procera (Aiton) W. T. Aiton	Rubber bush	Termiticidal	Latex
Camellia sinensis (L.) Kuntze	Tea	Anti-feedant, insectidical	Leaves and fruit
Capparis aphylla (Karien)	Bare Caper	Termite resistant shrub	Wood/pulp
Carica papaya L.	Pawpaw	Insecticidal	Fruit, fresh leaves and roots
Carya ovate (Mill.) K. Koch.	Shagbark hickory	Termiticidal	Bark
Cassia siamea Lam.	Yellow cassia, kassof tree	Repellent	Used as a leaf mulch
Catalpa bignonioides Walter	Common catawpa		Resistant to *Reticulitermes flavipes*
Cedrela odorata L.	West Indian cedar	Termiticidal	Wood
Chenopodium ambrosioides L.	Wormseed	Anti-feedant, insecticidal, repellant	Whole plant
Cleistanthus collinus (Roxb.) Benth. ex Hook.f.	Garari	Repellent	Bark
Commiphora africana (A.Rich.) Endl.	African myrrh	Termiticidal, repellent	Gum/resin
Consolida regalis Gray	Blue cloud	Termiticidal	Seeds
Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson	lemon-scented gum	Anti-termite property	crude volatile leaf oil and its methanol- and hexane fractions
Daniellia oliveri (Rolfe) Hutch. & Dalziel	African copaiba balsam tree	Anti-termite property	Gum/resin
Detarium senegalense J.F.Gmel.	Sweet detar	Oral poison	Wood/pulp
Diospyros ebenum J.Koenig ex Retz.	Ebony	Anti-insect	Roots
Dodonaea viscosea Jacq.	Purple hop bush	Termite resistant shrub	Wood/pulp
Erythropleum suaveolens (Guill. & Perr.) Brenan	Forest ordeal tree	Oral poison	Wood/pulp
Eucalyptus microcorys F. Muell.	Tallowwood	More resistant than other Eucalyptus	Wood
Grevillea robusta A.Cunn. ex R.Br.	Silky oak, silver oak	Termite tolerant in Tanzania	Wood
Hardwickia mannii (Harms) Oliv.	Indian black wood	Termiticidal	Stem/branches
Hyptis spicigera Lam. marubio	Black Sesame	Repellent	Aerial parts

(continued)

Table 3.9 (continued)

Plant species	Common name	Activity/active principle	Plant part
Intsia bijuga (Colebr.) Kuntze ifil. *or I. palembanica* Miq.	Merbau	Resistant	Wood
Juniperus procera Hochst. ex Endl.	E. African pencil cedar	Highly resistant	Wood
Juniperus virginiana L.	Eastern red cedar	Anti-insect	Wood
Leucaena leucocephala (Lam.) de Wit	Ipil ipil	Repellent	Used as a leaf mulch
Margaritaria discoidea (Baill.) G.L.Webster	*Common* pheasant-berry	Feeding deterrents	Bark and wood
Melia azedarach L.	Chinaberry, persian lilac	Oral poison, anti-feedant, contact poison, repellant	Bark, branches, leaves, fruit, oil
Mesua ferrea L.	Indian rose chestnut	Anti-insect	Wood
Ocimum basilicum L.	Sweet basil	Insecticidal, repellent	Whole plant
Ocimum canum L.	Wild basil	Insecticidal, repellent	Whole plant
Ocimum urticifolium Benth.	Basil		Water-based extracts
Pinus strobus (L.)	*Eastern white pine*	Termiticidal	Bark
Prosopis africana (Guill. & Perr.) Taub.	African *mesquite*	Anti-insect	Roots
Quassia indica (Gaertn.) Noot.	Bitter wood	Termiticidal	Leaves
Quercus prinus L.	Chestnut oak	Termiticidal	Bark
Samadera indica Gaertn.	Niepa Bark Tree	Termiticidal	Leaves
Santalum album L.	Sandalwood	Anti-insect	
Sassafras albidum (Nutt.) Nees.	Sassafras	Termiticidal	Bark
Semecarpus anacardium L.f.	Marking nut	Anti-insect	Seeds
Strychnos nux-vomica L.	Poison nut	Oral poison	Leaves
Swartzia madagascariensis Desv.	Snake bean	Repellent	Fruit
Tabebuia spp.	Ipe	Resistant	Wood
Tagetes minuta L.	Mexican marigold		Water-based extracts
Tectona grandis L. f.	Teak	Repellent	Wood/pulp
Terminalia chebula (Gaertn.) Retz.	Mirabolans	Antibacterial	Fruits
Uncaria gambier (Hunter) Roxb.	Gambier	Antifungal and antibacterial	Leaves
Zanthoxylum zanthoxyloides (Lam.)	Senegal prickly-ash		Wood/pulp

Essential oil extracted from leaves of *Tagetes erecta* L. rich in (Z)-β-ocimene caused mortality of *O. Obesus* after 24 h exposure (Singh et al. 2002b). *Calocedrus formosana* (Florin) Florin leaf essential oil and its main constituent, T-muurolol, caused 100% mortality of *C. formosanus* at the dosage of 5 mg g^{-1} (Cheng et al. 2004). Cheng et al. (2007) reported antitermitic activity of 11 essential oils from three species of coniferous tree against *C. formosanus*. Among all, heartwood of *Calocedrus macrolepis* var. *formosana* exhibited the strongest termiticidal property. Sakasegawa et al. (2003) indicated superiority of gelam oils over cajuput oils against termites. Park and Shin (2005) observed that garlic oil was more toxic than clove bud oil against termites.

Doolittle et al. (2007) reported that the number of microbes present in the hindgut of *C. formosanus* was reduced by treatments with neem extract, capsaicin and gleditschia. Neem extracts could significantly reduce the population of spirochaetes, leading to 100% mortality among termites. Rudman and Gay (1963) observed that anthracenes, anthrones, anthraquinones and xanthones act as deterrents against termites, whereas Cornelius et al. (1997) indicated the toxicity of monoterpenoids, alkaloids and hydrocarbons. Similarly, flavonoids and related compounds were found to be toxic and possess antifeedant properties (Boue and Raina 2003).

Grace and Yates (1992) found Margosan-O™, a neem-based formulation, containing 0.3% azadirachtin and 14% neem oil, to be toxic against the *C. formosanus*. Sharma et al. (1999) investigated and observed that *Acorus calamus* L., rhizomes, and aerial parts of *T. erecta*, were most toxic against *O. obesus.* Thambidurai (2002) observed that the fermented extract of *Musa paradisiaca* L. leaves at 100% concentration prevented termite attack for 50 days. Fokialakis et al. (2006) reported that four *Echinops* species had antitermite properties against *C. formosanus.* Verma and Verma (2006) studied termiticidal effects of 5% chloroform extract of *Lantana camara* var. *aculeata* L. leaves. Similarly Ganapaty et al. (2004) isolated plumbagin, isodiospyrin and microphyllone from the roots of *Diospyros sylvatica* L. and found them to be toxic against *O. obesus*.

The continued interest in search of greener pesticides led to the evaluation of different plant products all over the world. Workers around the globe are reporting activities of new compounds isolated from various plant parts. Under laboratory conditions, the plant products show promising results. However, often these results cannot be reproduced under field conditions. The reasons are plant products are an expensive option, the concentration of the active principle per unit varies from location to location and the avoidance behaviour of termites from the treated surface/substrate renders the treatments useless, under field conditions.

3.5.4 Chemical Methods

Because the termites remain hidden in the tree or under the soil surface/tree barks, chemical control is also not suitable in most of the cases. Practically, the insecticides fail to reach the target. Earlier, chlorinated hydrocarbons and cyclodienes were used for control, but with limited success. Today these insecticides are banned in most of the countries owing to their long persistence in soil. Management of subterranean termites primarily relies on soil treatment with termiticides at the site of active infestation. In India the most commonly used insecticide for termite management is chlorpyrifos. Farmers all over the country use chlorpyrifos with irrigation water irrespective of the crop grown. Scientists from different regions of India evaluated a plethora of synthetic insecticides with little or no effect. However, in some evaluations, a limited success was achieved for a short period of time. We presented a list of most commonly used insecticide (Table 3.10) for termite management in agricultural crops in India.

Table 3.10 Insecticides used in termite management in India

Crop	Insecticide	References
Sugarcane sett dipping	Imidacloprid 70 WS @ 0.1–0.2% solution	Singh and Singh (2002), Singh et al. (2003), and Jaipal and Singh (2003)
Spraying on sugarcane setts	Imidacloprid 200 SL @ 250 to 375 ml/ha	Santharam et al. (2002)
	Imidacloprid (17.8% SL) @ 375 ml/ha	Jaipal and Chaudhary (2010)
Soil application	Carbofuran @ 1 kg a.i./ha	Gangwar et al. (2003)
	Chlorpyrifos 20 EC @ 1.25 kg a.i./ha	Singh et al. (2001)
	Endosulfan 35 EC @ 1.25 kg a.i./ha	
	Phorate 10 G @ 2.5 kg a.i./ha	Singh and Singh (2002)
	Chlorpyrifos 20 EC @ 1 kg a.i./ha	Singh et al. (2003)
	Chlorpyrifos 15 G @ 2.5 kg a.i./ha	
	Chlorpyrifos 20 EC @ 1.25 kg a.i./ha	Madan et al. (1998)
		Sharma et al. (2002)
	Methyl parathion 2% dust @ 25 kg/ha	Kumawat (2001)
	Endosulfan 4% dust	
	Quinalphos 1.5% dust	
	Chlorpyrifos 10 G @ 1 kg a.i./ha	Mohapatra et al. (1995)
Wheat seed treatment	Chlorpyrifos 20 EC @ 4.5 ml/kg seed	Kumawat (2001)
	Endosulfan 35 EC @ 7.3 ml/kg seed	
	Lindane 20 EC at 0.5 ml/kg seed	
	Chlorpyrifos 20 EC @ 0.9 g a.i/kg seed	Rana et al. (2001)
	Endosulfan 35EC @ 2.4 g a.i/kg seed	
	Fipronil 5 SC @ 5 ml/kg seed	Gadhiya and Borad (2013)
	Imidacloprid 600 FS @ 3 ml/kg seed	
	Bifenthrin 10 EC @ 2 ml/kg seed	
Maize seed treatment	Endosulfan 35 EC @ 3 g per kg	Sharma et al. (2003)
Groundnut seed treatment	Chlorpyrifos 20 EC @ 12.5 ml/kg	
Side dressing of maize	Fipronil granules	Sharma et al. (2003)
	Chlorpyrifos granules	

3.6 Conclusion

Termite control is a herculean task, and their complete elimination or prevention in cropped areas is neither feasible nor advisable. Indian agriculture is a gamble with rains and is dominated by small and marginal farmers, with meagre amount of resources for insect pest management. The majority of the farmers follow the age old practices for management of insect pests. A good number of indigenous traditional practices are indeed available, but they result locally specific, with a limited general success. The biggest challenge for an Indian farmer is the availability of quality seeds and fertilizers, followed by availability of water, whenever needed. The pest management takes a back seat in their list of priorities; hence the allocation of resources for pest management is also minimal.

Scientists have generated a huge amount of data and recommended several practices for insect pest management, for all the crops grown in India. Several cutting-edge technologies have been developed for this purpose, but farmers are often unaware of these new technologies. There is a big extension gap between the laboratories and farms, and the crop and species diversity often makes this issue more complicated. India is a large country divided into 15 agroclimatic zones. Technologies need to be developed for each agroclimatic zone, separately. No single technology would be effective for all the agroclimatic zones. Optimistically, prospects for the development of new and improvements of existing technologies, as well as public acceptance of alternative termite management, appear positive and feasible. Least toxic and nonchemical methods have been, and will continue to be, developed. In India, termite baits are not available in the market, so there is a need and goal for development of termite bait technology, in particular for subterranean species, for which baits will play a major role in control. However, products increasing bait appeal and retention at application stations are still needed.

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