Chapter 11
Synthetic Insecticides: The Backbone of Termite Management

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Abstract Termite management has been a challenge since time immemorial. In good old days, plant products have been used with limited success. With the discovery of organochlorine pesticides, the use of chemicals gained an impetus in management. Due to longer persistence and health hazards, the use of organochlorine pesticides was banned in most countries. However, for several decades, chlordane, heptachlor, lindane, etc. were mainly used for termite management. Subsequently organophosphates and pyrethroids replaced organochlorines in this scenario.

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Organophosphates and pyrethroids repel termites, but due to their highly toxic nature, ready availability, and relatively inexpensiveness, they are still being used in developing countries for management.

Termite management practices changed dramatically with the advent of newer molecules, viz., neonicotinoid (imidacloprid), phenylpyrazole (fipronil), pyrrole (chlorfenapyr), oxadiazine (indoxacarb), anthranilic diamide (chlorantraniliprole), etc. Majority of these compounds are of the slow-acting and non-repellent type. The termites fail to detect these insecticides and continue to forage in the treated soil for longer period and carry lethal amount of the toxicant to be later transferred to their nestmates. This behavior and the properties of the new molecules prompted research on bait technologies. Termite baiting has developed tremendously and has been commercialized over last three decades. Various bait matrices and bait stations have been developed successfully. The activity of termiticides varies widely depending on the soil characteristics and properties, as soil plays an important role in the success of management practices. With these new termiticides, fairly long-term barriers could be established around wooden structures and buildings. Optimal termite management still remains a challenge and depends widely on the type of termiticides available, soil type, cropping system, expertise available, type of structure/building, and economics of the procedure.

Keywords Termites • Termiticides • Termite baits

11.1 Introduction

Termites belong to one of the oldest groups of insects comprising of more than 3000 species and are reported to survive in all ecosystems except above snow line and the polar regions. The majority of the termite species are highly beneficial to mankind, and only a handful of species (Edwards and Mill 1986; Logan et al. 1990) are pests. Sustainability of life without termites is unimaginable. They are one of the most efficient organisms in food webs, helping in recycling nutrients in both agricultural and nonagricultural ecosystems. Though termites lack some of the very basic survival requirements, i.e., they are visually impaired, but their olfactory sense is extremely well developed, they are highly sensitive to changes in light, temperature, as well as humidity. With all these lacunae termites pose a formidable threat to agricultural crops. Their ability to withstand adverse environmental conditions is primarily due to their reproduction in large numbers at an astounding rate. Their social structure compliments in their ability to tide over adverse conditions. During last few decades as the demand for food production increased tremendously due to burgeoning population, damage caused to agricultural crops by termites has been realized resulting in a steady increase in the related literature (Vargo and Husseneder 2009). Even though damage control measures have been developed all over the world, including cultural practices, mechanical measures, and biological and chemical measures, management of termites is still in infancy, because very little is known about their biology.

Tremendous amount of data have been generated on termite management with synthetic insecticides. In the USA an estimated 77% of pest control market is represented by termite management using soil insecticides (Anonymous 2002). Various strategies have been developed to use different groups of insecticides, including botanical products (Verma et al. 2009). Investigations were carried out using natural enemies of termites, but their commercial viability is still lacking. Termites are known to thrive in conditions highly conducive for growth of microbes, leading to evaluation of several insect pathogens including bacteria, fungi, and viruses with limited success (Kramm et al. 1982; Rath 2000). In this chapter we shall discuss some of the most landmark studies carried out in termite management, with special reference to synthetic insecticides.

In subterranean termite management, mainly soil applicable formulations were used, and major strategies were followed for (a) prevention by soil treatment and (b) remedial control of active infestations, by applying insecticides directly into the infested soil. Both strategies have their own merits and demerits, the soil characteristics and insecticide properties playing a deciding role regarding the method to be used. For prophylactic treatment the insecticide must have a long residual life in order to repel or kill the termites rapidly. For remedial treatments the insecticide must be odorless/non-repellent and should be relatively slow acting so that the termites are able to carry it to their nests and galleries. The affected termites must be healthy enough so that no panic is created in the nest, whereas the other termites do not exclude the treated area for foraging.

Su et al. (1982) concluded that evaluation of insecticides against termites could not be based on mortality alone. The behavioral responses must be considered indeed, because termites could seal off or avoid treated areas and effectively protect themselves. These authors found that such behavior was due to repellency of insecticide itself or chemical factors associated with dead termites. They categorized tested insecticides into three groups, viz., Type I (including natural and synthetic pyrethroids), Type II (including commonly used insecticides, viz., diazinon, chlordane, and carbaryl), and Type III (including Amdro®). Type I insecticide exhibited repellent action which initially kills some termites, and subsequently the emanating source can be sealed off by the other termites. In Type II group, the termites continued to move around on the treated surface, and only when some individuals have died and decayed, the area was sealed off. This indicates that the insecticides were not as such repellent, the termites realized in a period of time to avoid the treated surface. In Type III group, the termites did not detect any chemical and continued visiting the treated area since the affected termites did not die at one place and the insecticide did not exhibit any repellent action.

The newer insecticides recommended for termite management are of two types, viz., fast-acting repellents, at lethal doses, and slow-acting non-repellents, at lower doses. The organophosphates used in termite management are quick acting with relatively short soil residual period, whereas the pyrethroids used in management have shown repellent properties which make the termites change their foraging area and persist in soil for longer period (Su et al. 1999a). Insecticides, viz., imidacloprid, fipronil, chlorfenapyr, indoxacarb, and chlorantraniliprole, belong to a novel group of insecticides that, when used at recommended concentrations, act as repellents (Osbrink et al. 2001; Ibrahim et al. 2003; Hu 2005; Rust and Saran 2006). These insecticides induce harmful behavioral changes/dysfunctions among termites, and their toxic effects are transmissible from poisoned termites to nonpoisoned individuals in the colony, leading to substantial deaths (Haynes 1988; Hu and Hickman 2006).

Investigations on termite poisoning with insecticides are multidimensional studies. Termite mechanisms for picking up insecticides are walking on treated surfaces, casual contacts, mutual grooming and antennation, trophallaxis (stomodeal or proctodeal), exchange of food and chemicals, coprophagy, necrophoresis, necrophagy, cannibalism, and contacting secondary contaminated surfaces (Smith and Rust 1990; Ibrahim et al. 2003; Kard 2003; Tomalski and Vargo 2004; Hu et al. 2005; Shelton et al. 2006; Song and Hu 2006; Tsunoda 2006; Spomer et al. 2008; Bagnères et al. 2009).

11.2 Termiticides

11.2.1 Repellent

All the organochlorine, organophosphate, carbamate, and pyrethroid insecticides are categorized as repellents. In the past, repellents were mainly used to protect wooden structures and buildings from attacks. One major advantage with a repellent termiticide is that it provides an effective barrier against termites and prevents any damage to structures and buildings. The use of inexpensive pyrethroid termiticides as a barrier was in vogue in the developed world for decades. The use of such barriers has a serious limitation, i.e., perfect barriers cannot be created under fully constructed houses or buildings. The termite workers can locate the gaps, and where the barrier is improper, they gain access to the structures, causing damage by recruiting more workers.

Synthetic pyrethroids, viz., permethrin, cypermethrin, deltamethrin, fenvalerate, cyfluthrin, tralomethrin, lambda-cyhalothrin, tefluthrin, bifenthrin, and flucythrinate, act on the sodium channels located in the insect nervous system. Their contact activity quickly kills termites when applied at the recommended doses or causes a directional change in tunneling, away from the treated area (Su and Scheffrahn 1990; Gahlhoff and Koehler 1999). Furthermore, repellents require rigorous application to all the possible entry points, if the application is meant to create a continuous chemical barrier (a full barrier) around and beneath the structure, and to all interior active infestations, in order to get an immediate control. To ensure that the structure is thoroughly treated, termite professionals need an in-depth understanding of the construction type, methods, and architectural materials and of the building features. Any untreated or poorly treated area or gap can be used by termites to invade and infest.

Efficacy of insecticides depends on toxicity, mode of action, susceptibility of termites to the test compound, soil properties, formulation, and application methods

(Osbrink et al. 2001). These authors further observed that fipronil was relatively slow acting on soldiers but quickly acting on workers. This slow action allows the soldiers to interact more with workers before death. The soldiers can identify the intoxicated individuals and separate or avoid contact with them (Osbrink et al. 2001). Su et al. (1997a) suggested elucidation of termite penetration ability in insecticide-treated soil is essential to evaluate efficacy. If a sufficient amount of insecticide is not acquired by the termites due to repellency, eventually reduced mortalities may be observed, in spite of toxicity (Smith and Rust 1990). Manzoor et al. (2012) observed bifenthrin to be repellent and fipronil repelling termites only above 25 ppm, whereas chlorfenapyr was non-repellent.

11.2.2 Non-repellent

The use of slow-acting insecticides has been reported to be in practice in the first few decades of the twentieth century (Table 11.1). Randall and Doody (1934) reviewed the use of slow-acting arsenic dust in termite control, citing earlier works by Van Zwaluwenberg (1916) and Wolcott (1924) on colonies of the arboreal termite *Nasutitermes costalis* (Holmgren) that were killed by applying powdered arsenic in their runways. Sodium arsenate, DDT, trichlorobenzene, creosote, ethylene dibromide, and pentachlorophenol were used for subterranean termite control in the early twentieth century (USDA 1951). The objectives of using slow-acting non-repellent toxicants for termite control are to impact colony populations, either by suppression or elimination.

In the 1980s imidacloprid (a neonicotinoid) was first studied for management and registered for termite treatment in Japan in 1993 (Potter 1997). With the introduction of new non-repellent termiticides in the 1990s, the application technologies changed drastically. Termites are unable to differentiate between treated and untreated soil when non-repellent insecticides are used. The unique properties of the newer molecules and formulations changed the termite management practices dramatically. The use of neonicotinoids rather than organophosphates is considered the choice for developing a new strategy to manage termites (Rust and Saran 2008; Smith et al. 2008; Ahmed et al. 2014; Ahmed and Saba 2014) as organophosphates are inherently more toxic than neonicotinoids for higher animals. Non-repellent insecticides often maintain the property of non-repellency even at high concentrations (up to 500 ppm in *Reticulitermes hesperus* Banks) (Saran and Rust 2007). Thorne and Breisch (2001) observed that non-repellent insecticide allows termites to enter treated soil, to be killed before the pest is able to cause any damage.

Fipronil (a phenylpyrazole) was first investigated for termites in France in the late 1970s and was registered as a termiticide by BASF in 1999. This termiticide has a relatively low vapor pressure (3.7×10^{-4} mm Hg) and water solubility (1.9–2.4 mg/l at 25 °C) but a soil adsorption coefficient value (K_{oc}) as high as 825 (Gunasekara et al. 2007). Chlorfenapyr (a pyrrole) interferes with an insect's ability to produce energy by disrupting proton shuttles across the mitochondrial inner membrane

Table 11.1 History of termite control

Landmark achievements	References
The first report of the presence of parasitic "head-inhabiting" nematodes in *Reticulitermes lucifugus* (Rossi)	Merrill and Ford (1916)
Slow-acting toxicants such as arsenic dust applied into foraging tubes in an attempt to impact on colony populations	Van Zwaluwenberg (1916) and Wolcott (1924)
Nematodes could not kill *Coptotermes formosanus* Shiraki under soil conditions	Pemberton (1928)
Soil termiticides widely used for control of subterranean termites since the early 1900s	Randall and Doody (1934)
Runway of *Coptotermes formosanus* may extend up to 50 m in length and 0.3–3.0 m in depth	Erhorn (1934)
The presence of the fungus *Conidiobolus* sp. on *Nasutitermes* sp.	Kevorkian (1937)
Two bacterial species, *Bacterium* sp. and *Serratia marcescens* Bizio, killing laboratory colonies of *Zootermopsis angusticollis* Hagen	DeBach and McOmie (1939)
The presence of the fungus *Conidiobolus* sp. on *Coptotermes* sp.	Altson (1947)
Juvenile hormone-regulated soldier formation in termites	LuÈscher (1958)
Serratia marcescens could kill termites with "low vigor." This report marked the debut of termite biological control research	Toumanoff and Toumanoff (1959)
Aspergillus flavus Link as a fungal pathogen of *Reticulitermes* sp.	Beal and Kais (1962)
Serratia sp. and *Aspergillus* sp. used for termite control	Lund (1962)
First field study using *Serratia marcescens* against *Reticulitermes flavipes (Kollar)*	Lund (1965)
Susceptibility of *Reticulitermes flavipes* to a formulation of *Bacillus thuringiensis Berliner*	Smythe and Coppel (1965)
Metarhizium anisopliae (Metsch.) Sorokin and *Beauveria bassiana* (Balsamo) Vuill. as the two most virulent entomopathogenic microorganisms against *Reticulitermes flavipes*	Toumanoff and Rombau (1965)
Isaria sp. (syn. *Paecilomyces* sp.) shown to be pathogenic to *Reticulitermes flavipes*	Smythe and Coppel (1966)
Entomophthora virulenta Hall & Dunn, in association with *B. thuringiensis*, used to control *Coptotermes formosanus* in Hawaii	Page (1966)
The first patented formulations of *Aspergillus flavus* and *Serratia marcescens* against termites	Lund (1966)
Patent of a combination of *Entomophthora virulenta* Hall et Dunn and *Bacillus thuringiensis* as biological control agents against termites	Page (1967)
Proposal to the US Navy to investigate the effect of various pathogens against *Coptotermes formosanus*, including nematodes (*Steinernema* spp.) and fungi (*Metarhizium anisopliae* and *Beauveria bassiana*)	Tamashiro (1968)
Dechlorane (Mirex®), a slow-acting toxicant, proposed to eliminate isolated populations of *Reticulitermes flavipes* in Canada	Esenther and Gray (1968)
Development of biopesticides to control *Anacanthotermes ahngerianus* Jacobs	Stadykov (1970)

(continued)

Table 11.1 (continued)

Landmark achievements	References
Conclusion that field studies with various pathogens demonstrated sufficient pathogenicity to termites	Lund (1971)
Evaluation of various species of fungi against *Reticulitermes lucifugus* Rossi under laboratory conditions	Krejzová (1971)
Studies using Mirex™ bait blocks indicated that the continuous placement of toxic baits suppressed foraging activity of *Reticulitermes* spp.	Beard (1974) and Esenther and Beal (1974)
Field trials using juvenile hormone analogs such as methoprene and hydroprene against *Prorhinotermes simplex* (Hagen)	Lenz (1976)
The use of *Bacillus thuringiensis*, in an effort to develop a biopesticide against two termite species	Khan et al. (1977)
The first use of the mark-recapture method to estimate the cryptic foraging populations of subterranean termites. Importance of defining colony foraging territory using entomopathogenic fungi against *Coptotermes formosanus*	Lai (1977)
Ecdysis inhibition by diflubenzuron (Dimilin®) against *Heterotermes indicola* (Wasmann) and *Reticulitermes flavipes* demonstrated	Doppelreiter and Korioth (1981)
Termites exhibited behavioral mechanisms that reduced the possibility of epizootics	Kramm et al. (1982)
Organophosphates and pyrethroids used in termiticide barrier treatments	Mix (1988)
Surface treatment of borate solution, even at the label rate, did not protect wood beneath the treated surface from field populations of *Coptotermes formosanus*	Grace and Yamamoto (1994)
Using the trap + treat + release approach with sulfluramid, colony populations of *Reticulitermes flavipes* were significantly suppressed in city blocks of Toronto (Canada)	Myles (1996)
The first fipronil product in termite control in the USA (Termidor®) approved by the EPA in 1999	PANNA (2009)

(Silver and Soderlund 2005). Indoxacarb (an oxadiazine proinsecticide) perturbs voltage-gated Na^+ channels in the insect nervous system by binding receptors at a site different from that affected by pyrethroids (Wing et al. 2000; Nauen and Bretschneider 2001). Indoxacarb was initially registered with the Environmental Protection Agency (EPA) in the year 2000 as a "reduced-risk" insecticide for use on vegetable and other crops against Lepidopteran and sucking insect pests (McCann et al. 2001; Tillman et al. 2002). Chlorantraniliprole (anthranilic diamide) targets the ryanodine receptor and causes impaired muscle regulation, paralysis, and eventual death of insects (Cordova et al. 2006). The intoxicated termites become uncoordinated or convulsive, which interferes with the normal colony activities such as foraging, grooming, feeding, and trophallaxis (Glenn and Gold 2003). Chlorantraniliprole binds to soil with an average K_{oc} value of 328, which means it has less potential for leaching (McCall et al. 1979). Ecotoxicological profile of chlorantraniliprole based on its persistence in different soil types makes it an invaluable termiticide (Spomer and Kamble 2011; Wagner et al. 2011; Shelton et al. 2014). Shelton et al. (2014) found that in USDA Forest Service field plot trials, chlorantraniliprole when applied at 0.05% provided 8 years of protection from termites.

11.3 Soil Properties

Soil treatment has been used for termite control since 1920 (Su and Scheffrahn 1998; Peterson 2010). Su et al. (1982) found that soil properties, viz., texture, pH, moisture, temperature, particle size, organic matter content and microorganism diversity and content, and compactness, are important factors that determine the application rate, persistence, and movement of a termiticide in soil. Migration of termiticides is slower in soils with high clay and organic matter, compared to sandy soils. Groundwater contamination by termiticides is restricted in high-clay-content soils. Forschler and Townsend (1996) and Spomer et al. (2009) observed that a higher amount of termiticide is required in soils to attain desired result in general perimeter treatment in soils high in organic matter content. The pH affects the biodiversity of soil flora and their activities leading to degradation of applied termiticides. Gold et al. (1996) reported that in slightly acidic soils, low organic matter content, coupled with low soil temperature and moisture, helps in persistence of termiticides for a relatively longer period.

Non-repellent compounds are preferred for soil treatment because they do not seem to disrupt termite foraging in the treated soil zone and have a delayed mode of action that may contribute to movement of the active ingredient in the colony, through trophallaxis and social grooming (Kard 2003). Today, non-repellent liquid insecticides such as fipronil, imidacloprid, chlorfenapyr, and indoxacarb are gaining popularity, which have a delayed mode of action. The foraging termites fail to detect these insecticides and continue to forage on the treated soils. The termite foragers exposed to these insecticides are not killed immediately; rather they transfer the toxicants in lethal amounts to unexposed nestmates before death. In due course of time, the entire colony is seriously affected (Quarcoo et al. 2010). However, such effects are variable depending on physicochemical properties of soils, inherent toxicity of the insecticides, and termite behavior.

Temperature and other natural conditions in the field affect the uptake and transfer of toxicants. At higher temperatures more intense tunneling, foraging, and feeding activity have been noticed by Spomer et al. (2008), leading to higher uptakes of termiticides. Higher temperatures promote microbial degradation of termiticides leading to shorter residual effects in tropical climates (Reid et al. 2002). Osbrink and Lax (2002) found fipronil-treated sand had significantly greater and faster mortality of the Formosan subterranean termite workers, from susceptible or unsusceptible colonies, than treated soil or clay. This intense substrate effect also was observed by other researchers with other insecticides (Smith and Rust 1990; Forschler and Townsend 1996; Gold et al. 1996; Osbrink and Lax 2002). High-clay-content soils have high colloidal fraction which increases surface area, thus increasing the number of chemical-binding sites that promote hydrogen bonding and hydrophobic binding of hydrophobic insecticides (Saltzman and Yaron 1986). Sand particles retain more of the toxicant on the surface than other substrates (Harris 1972) and may increase pesticide performance. Manzoor and Pervez (2014) found that biflex and fipronil were effective against *Heterotermes indicola* (Wassman) in sandy loam soil compared to sandy clay loam soil. They observed concentration and time both are inversely related to each other, relative to efficacy and biflex was more bioavailable than fipronil. Several workers have reported the use of organic matter to prevent termite damage to crops (Mando et al. 1999; Mando and Stroosnijder 1999; Gould et al. 2001; Bokhtiar and Sakurai 2005).

Saran et al. (2014) reported *Reticulitermes flavipes* (Kollar) workers exposed to sand and soils treated with chlorantraniliprole at 50 ppm exhibited delayed mortality (it took >5 days to observe 90–100% mortality in termite workers). They also observed that exposure to chlorantraniliprole-treated sand (50 ppm) for as little as 1 min stopped feeding and killed 90–100% of workers. Tunneling (~2 h) was observed in different soil types treated with chlorantraniliprole at 50 ppm, even those with high organic matter (6.3%) and clay content by (30%) caused immediate feeding cessation in worker termites and mortality in the next 7–14 days. Worker termites exposed for 1 and 60 min to sand treated with chlorantraniliprole (50 ppm) were able to walk normally for 4 h after exposure. Delayed toxicity, increased aggregation, and grooming were observed in exposed termites leading to horizontal transfer effects within colonies. Yeoh and Lee (2007) demonstrated non-repellency of chlorantraniliprole in tunneling assays. Ramakrishnan et al. (2000) suggested that soil type affected termite worker mortality even after 7 days of continuous exposure to imidacloprid-treated sand or soil.

11.4 Baiting

Research on baiting technology developed during mid-twentieth century in Indonesia (Kalshoven 1955), Canada (Esenther and Gray 1968), the USA (Esenther and Beal 1974, 1978), and Australia (Paton and Miller 1980; Lenz and Evans 2002) especially for protection of timber trees, where barrier treatments were unsuccessful. Before the development of the baiting technology, subterranean termite management was performed by application of slow-acting toxicants such as arsenic dust, directly into the foraging galleries (Randall and Doody 1934). French (1991) reported the use of bait blocks containing dechlorane directly into the active galleries of subterranean termites in Australia. He further reported that termite control professionals would drill a hole in the trunk of the infested tree and connect a conduit box bait container. Dechlorane was the most commonly used bait during these years, but the use of organochlorines was then discontinued by national regulations or as the result of the Stockholm Convention on Persistent Organic Pollutants in 2004.

Baits are an effective method of subterranean termite management, since only a small amount of insecticide is required (Su 1994) and, ideally, is in contact with a relatively small proportion of the foraging population, who then proceeds to transfer the toxicant to other colony members. Baits are typically made of organochlorine/organophosphorus/carbamate insecticides (Rust 1986). Baiting is mainly successful against the lower termite family Rhinotermitidae and is not effective against higher termites (Ngee et al. 2004). Baiting is a long-term approach to termite management because the impact is not visible immediately. The time taken by bait to show desired effect depends upon the type of insecticide used, inherent toxicity of the insecticide, the attractant used, the season when baiting is done, atmospheric temperature, and relative humidity. In this system it is expected that the foraging termites would carry the insecticide and pass it on to unexposed workers in lethal doses. The desired results are hence noticed some days or weeks after treatment. The most important aspect of a baiting program is the proper monitoring and maintenance of the bait stations till the goal is achieved. Baiting research took an impetus with the availability of newer molecules by the end of 1980s. Now the research focuses on the development of baiting active ingredients (Prestwich et al. 1983; Jones 1984; Su et al. 1987) and food matrices (Su et al. 1985; Su and Scheffrahn 1986) that would attract more termites toward the bait stations, eventually leading to commercialization of these technologies (Su et al. 1995, 2001).

In baiting systems, routine monitoring is essential to achieve the desired success. Monitoring devices are placed in the affected areas and left for the termites to visit. Once the presence of termites is established, then the untreated baits are replaced with those containing a small amount of insecticide such as hexaflumuron or noviflumuron. A successful bait trial is assumed when activity is reduced or eliminated at all locations identified as being visited by the targeted termites (Su and Scheffrahn 1996; Thorne and Forschler 2000). Some termite species that are sensitive to disturbance start avoiding the bait stations (Swoboda et al. 2004). Su (2007) evaluated cellulose baits containing 0.5% hexaflumuron in a hermetically sealed closed-cell polyethylene sheet envelope and placed in soil to test their durability and efficacy against field colonies of *Coptotermes formosanus* Shiraki and *R. flavipes*. He suggested that the sealed baits may be placed in soil for months or years without the need of monitoring, would save labor costs by bypassing the monitoring phase, circumvent the station avoidance by some termite species, and enable the use of baiting technologies in large areas such as agricultural fields in which the manual monitoring is impractical.

Ripa et al. (2007) evaluated four different termite control strategies consisting of two soil treatments with cypermethrin and fipronil and two bait treatments with hexaflumuron and sulfluramid for their efficacy and potential for controlling *R. flavipes*, in Quillota and Valparaiso, Chile. They reported that soils treated with fipronil and cypermethrin prevented termite access in 75% of homes. Sekamatte et al. (2003) used baits made of dead animals, meat bones, and sugarcane husks to poison *Macrotermes* mounds. They observed that ants were more attracted to protein-based baits resulting in more number of ant nests near maize plants leading to decrease in damage by termites and increase in maize yields. They suggested use of protein-based baits for integrated management of termites in maize in Uganda.

Su (1994) and Su et al. (1995) showed that colonies of subterranean termites can be eliminated by using hexaflumuron bait matrix. However the same delivery system cannot be used for managing arboreal termites (Su et al. 1989). For managing *Mastotermes* in Australian tropics, higher quantities of termiticides are required (Lenz 2002). Mound excavation is essential for control of *Coptotermes* spp. along the perimeter of baited homes in Malaysia, Thailand, and Singapore (Lee et al. 2007). Su and Scheffrahn (1990) screened and identified several toxicants as candidates to be incorporated into subterranean termite baits under laboratory conditions. Henderson and Forschler (1997) reported that fipronil could be effectively used as baits against the Formosan subterranean termite, at levels 100 times lower than hexaflumuron.

Baiting technology seems to have achieved its aims, i.e., small quantity of toxicant could suppress or eliminate termite colonies. However there was wide variation on the length of time taken to achieve the desired result, i.e., 24–80 weeks approximately (Pawson and Gold 1996; Haagsma and Rust 2005; Austin et al. 2008). Many workers have carried out studies on different bait technologies under laboratory and field conditions with highly encouraging results. However, the matter of concern is that majority of studies do not have untreated controls. These studies only include observations on termite activity either in monitoring or bait stations (Grace et al. 1996; Su et al. 1997b; Tsunoda et al. 1998; Su et al. 2001). The major advantage of the baiting system approach is the capability of reducing populations of subterranean termites, with the possibility of suppressing or eliminating colonies (Lax and Osbrink 2003). Ahmed Shiday and French (2013) showed flufenoxuron as a potential termite bait toxicant, particularly against *Coptotermes* species. There are some drawbacks in baiting systems, viz., initial treatment costs are higher, and it is a highly labor-intensive method and is based mainly on the treatment location area, with regular monitoring and maintenance hassles. However, the cost becomes negligible when weighed against the environmental safety, viz., no soil or ground pollution is reported because very little amount of toxicant is used.

11.5 Capture, Treat, and Release

"Trap and treat" is a method wherein termites are first lured into a trap using a food as bait and then treated with a poison. Dusting with Paris Green was the first documented example (early twentieth century) of trap and treat in tropical Asia, Australia, Hawaii, and California (Froggatt 1905; Fullaway 1920; Keuchenius et al. 1922; Jepson 1930; Kofoid et al. 1934; Cleghorn 1861; Hickin 1971; Roonwal 1979; Watson 1988).

Over the last two decades, many workers investigated transfer of termiticides among nestmates (Thorne and Breisch 2001; Valles and Woodson 2002; Ibrahim et al. 2003). Tomalski and Vargo (2004) proposed a theory stating that pesticides adhering to the integument of exposed termites (donors) are transferred to unexposed nestmates (recipients) through interaction with the donors. Haagsma and

Rust (2007) observed that in termites with sealed mouthparts, transfer of imidacloprid was through body contact, not trophallaxis. However, laboratory studies indicated that toxicant transfer occurs among termites (Hu et al. 2005; Rust and Saran 2006, 2008; Shelton et al. 2006; Song and Hu 2006; Saran and Rust 2007; Bagneres et al. 2009). Transfer of termiticide is a function of simple association among termites, i.e., common occurrence that happens is crowding during termite assays (Peterson et al. 2004). Had it been a simple correlation, then the increase in the number of donors would certainly increase the number of receivers leading to quicker spread of the toxicants. Valles et al. (2000) found a twofold difference in LC_{50} between a pair of colonies of *R. flavipes* to permethrin.

The transfer of fipronil and imidacloprid among workers as well as between workers and soldiers has been studied (Thorne and Breisch 2001; Ibrahim et al. 2003; Saran and Rust 2007). Saran and Rust (2007) observed that body contact including grooming plays a major role in horizontal transmission of a lethal dose of termiticide compared to transmission by trophallaxis. A linear relationship was found between dose uptake and insecticide contact time, in subterranean termites. Ibrahim et al. (2003) observed the transfer of termiticides from soldiers to workers was significantly higher than from workers to soldiers. A study on distance of horizontal transfer in the field showed that the lethal effects in Formosan subterranean termites may be limited (Su 2005).

Rust and Saran (2006) and Saran and Rust (2007) worked with *R. hesperus* and argued that a single donor carries very little amount of termiticide and only the termites directly interacting with it are killed. The receiving individuals in turn do not act as donors. The intoxicated termites are unable to travel long distances limiting the potential of spread of termiticide (Su 2005; Ripa et al. 2007; Quarcoo et al. 2010). Myles (1996) indicated that termites coated in sulfluramid were groomed by other nestmates, passing the toxicant through the colony by trophallaxis. None of the traditional repellent termiticides have been shown to transfer by contact among termites in the laboratory (Shelton et al. 2005). Schoknecht et al. (1994) used microencapsulated permethrin as a bait toxicant, which was transferred among nestmates by trophallaxis. Similarly, Iwata et al. (1989) argued that transmission of microencapsulated fenitrothion among *C. formosanus* individuals was accomplished by grooming. As on date only delayed-action, non-repellent termiticides are known to transfer among termites by bodily contact; however, the speed of lethality varies (Mao et al. 2011). To develop an effective bait technology, various workers have evaluated different ratios and proportions of different termiticides (Hu et al. 2005; Song and Hu 2006; Tsunoda 2006; Rust and Saran 2008; Bagneres et al. 2009).

11.6 Exclusion Barriers

During the 1940s the use of chemical soil barriers was in vogue and considered to be safer and more persistent, replacing the practice of dusting chemicals for termite control. Initially organochlorines (e.g., dieldrin and chlordane) dominated the termite control scenario for more than a decade, followed by organophosphates (e.g., chlorpyrifos) and synthetic pyrethroids (e.g., deltamethrin and bifenthrin). Chemical soil barriers were the most commonly used method of termite management for the next five decades. The decline in the use of chemical soil barriers started in the early 1990s due to environmental concerns (Carson 1962; Cropper et al. 1992).

The application of chemical pesticides against termites is generally aimed at creating a barrier to prevent access to plants. Effective chemicals are those with a degree of persistence or are able to penetrate into the soil profile to provide control. Therefore, insoluble compounds, or those that are not readily adsorbed onto clay particles, would be of no use unless they were thoroughly mixed into the soil. Soil termiticides have been widely used for control of subterranean termites since the early 1900s (Randall and Doody 1934). The major objective of barrier treatments is to exclude soil-inhabiting subterranean termites from structures in ground contact. Termiticides applied to establish soil barriers can be repellent, toxic, or both (Forschler 1994). A wide range of insecticides have been investigated, and their effects varied with environmental factors or soil conditions, which affect the residual activity and longevity of biocides (Smith and Rust 1993; Forschler and Townsend 1996).

Chlorpyrifos is one of the most common insecticides used worldwide against termites since late 1980s, till date (Mix 1988). In 1996, Bayer Corporation (Kansas City, MO) introduced a new termiticide, imidacloprid (Premise® 75), that belongs to chloronicotinyls (Potter 1997). Boucias et al. (1996) reported that imidacloprid-treated termites become sluggish, inhibited or reduced grooming and tunneling activity, eventually followed by death. Premise 75® when applied at the rate of 0.1% in concrete-slab tests in Arizona, Florida, and South Carolina provided 100% control for 5 years (Kard 1998). Kard et al. (1989) observed that 100% prevention of subterranean termite attack resulted when Dursban® TC was applied at the rate of 1% solution in tests carried out in Mississippi for 21 years by the US Department of Agriculture (USDA) Forest Service, based on concrete slabs. Su et al. (1999b) suggested that longevity of termiticides applied underneath and around structures could be underestimated in the USDA Forest Service trials because Dursban TC degraded faster in small plots such as those of the USDA Forest Service field trials compared with that of larger plots (40,000 cm^2). Beal and Carter (1968) observed that 1 day after applying heptachlor (0.47 liter/0.093 m^2) to Florida soils, 95% of active ingredient (a.i.) penetrated down to a depth of 1.9 cm. In another study, Davis and Kamble (1992) found that subslab termiticide concentrations decreased depending on horizontal and vertical distance from the termiticide injection point. Depth of termiticide penetration in soil is a function of soil moisture at application time and presence of rocks, duff, and organic matter (Beal and Carter 1968).

Traditionally, an amount of 0.5–5 kg of a.i. is required to exclude soilborne subterranean termites from a structure (NPCA 1985). A continuous horizontal barrier is created if the a.i. is applied correctly, which prevents entry of termites. However, the success rate depends on various factors, because in a termite colony, the gallery system may extend up to 50–100 m from an infested structure (King and Spink 1969; Su and Scheffrahn 1988; Grace et al. 1989) and soil treatments rarely impact the entire colony population, despite the large quantity of insecticide applied (Su and

Scheffrahn 1998). Soil insecticide treatment is, however, widely used for prevention of structural infestations (Grace et al. 1993; Gahlhoff and Koehler 2001). For several years, non-repellent soil insecticides, e.g., pyrethroids, have become popular alternatives to the use of more repellent materials, as barriers, to termite penetration. Higher mortalities are observed due to lack of repellence and delayed mode of action, the termites moving freely within the treated soil before death (Kard 2001).

Hu et al. (2006) demonstrated that soil-barrier application of fipronil can suppress and eventually eliminate termite colonies. They showed that workers readily tunneled and repeatedly moved in and out of the treated soil barriers, depending on the treatment concentrations. They observed intoxicated behaviors of termites, including erratic walking, body shaking, fluid excretion from the anus and mouth, impaired mobility, and lying on the back, while twitching and shivering. There was no avoiding of dead termites by the live ones, as shown by the increasing number of dead termites at the nest site and the decreasing number of termites in the foraging and treatment areas. Remmen and Su (2005) found that thiamethoxam and fipronil at ≥8 ppm and ≥1 ppm, respectively, provided an effective barrier against *C. formosanus* and *R. flavipes*. "Exterior-Only" and "Exterior Perimeter plus Localized Interior Treatment" (EP/LIT) strategy was proposed by Potter and Hillery (2002, 2003). EP/LIT is a two-phase strategy: (1) a full volume treatment of the soil outside the foundation wall, to establish a continuous barrier in soil on the structure's exterior, and (2) targeted applications to all known infested areas inside the structure by foaming, injection, or dust application. This strategy was more economic reducing labor, amount of insecticide, and intrusion into the structures.

Increasing public awareness concerns raised on the environmental fate of the insecticides applied led to development of physical barriers such as stainless steel mesh (Lenz and Runko 1994) and uniform-sized particle barriers (Tamashiro et al. 1987). Su et al. (2004) found that sufficient quantities of λ-cyhalothrin were released from the impregnated polyethylene film into adjacent sand, to prevent termite penetration. The impregnated film has less environmental impact than conventional liquid termiticides, because the a.i. is kept in the polymer.

11.7 Termite Management in Cropped Areas

References to plant protection are found in ancient Indian literature, the Vedas (viz., Rigveda ~3700 BC, Atharvaveda ~2000 BC), Kautilya's Arthashastra (~300 BC), Buddhist literature (~200 BC), Krishi Parashara (~100 BC), Sangam literature of Tamils (200 BC-100 AD), Agni Purana (~400 AD), Brihat Samhita of Varahamihira (~600 AD), Kashyapiyakrisukti (~800–900 AD), Surapala's Vrikshayurveda (~1000 AD, Someshwara Deva's Manasollasa (~ 1100A D), Lokopakara) by Chavundaraya (~1108 AD), Sarangadhara's Upavana Vinoda (~1300 AD), Vishwavallabha of Chakrapani Mishra (~1577 AD), and some documents of the medieval and premodern period. A detailed methodology of seed treatment and systematic strategies of plant protection and grain storage were presented by Surapala

(~1000 AD) in Vrikshayurveda. Therefore, this period may be considered as the starting point of systematic plant protection in Indian agricultural history. Surapala suggested watering the trees with cold water for a week to get rid of insects from branches and roots, smearing the roots with a mixture of white mustard, vaca (*Zingiber zerumbet* Rosc. Ex Smith.), kushta (*Saussurea lappa* C. B. Clarke), and ativisa (*Aconitum heterophyllum* Wall ex Royle). For termite control he suggested application of extract of *aak, Calotropis procera* (Aiton) (8–10 Kg of *aak* is soaked in water for about 24 h and filtered and applied in soil infested with termites). Details of termite control can be found in Agni Purana, an ancient Indian scripture, wherein the remedies mentioned to get rid of termites and fruit cracking consider the application of a paste (containing 200 g of turmeric powder and 1000 ml of mustard oil) on the tree trunks. The mustard oil would attract ants, and the turmeric powder acts as an antibiotic for healing the cracks. Suggestion includes the use of *aak* leaf-filled gunny bags in irrigation channels to kill termites. In a document of the early nineteenth century from the Mewar region of Rajasthan, the use of sesame oil for soil and foliar application to trees to protect from frost and termites is mentioned. In olden days Indian farmers used to keep asafoetida (an oleoresin dry gum obtained from *Ferula* spp.) in a pack of cotton cloth at two or three points in 10–15 m irrigation channels, for controlling termites in affected crops.

The use of chemical insecticides is roughly 100 years old, and their soil application for termite control in crops was developed relatively late. The earliest reference to soil-applied termiticides (called at the time "soil poisons" or, less commonly, "chemical insulation") was a 1928 test in California for protection of utility poles (St. George 1952). Although adopted rapidly for use in structures, soil applications were thought to be less desirable than the good building practices (which minimize susceptibility) and wood treatments (which protect the wood directly). In the early 1950s, chlorinated hydrocarbons, viz., aldrin, dieldrin, chlordane, and heptachlor, were used as soil termiticides and continued to dominate termite control scenario till the mid 1980s, when they were withdrawn from market due to public outcry for their long persistence in soil and other health hazards. In 1978 the US Environmental Protection Agency (EPA) canceled the use of chlordane on food crops and phased out other aboveground uses over the following 5 years. In 1988, all previously approved uses of chlordane in the USA were canceled by the EPA (http://www.epa.gov). With the advent of newer insecticides, the application methodology changed. Subsequently several organophosphates (isofenphos and chlorpyrifos) and pyrethroids (cypermethrin, permethrin, bifenthrin, and fenvalerate) were marketed for termite control in the USA.

In India, Roonwal and Chhotani (1961 and 1967) dealt with the Indian wood destroying termites, as described in the monograph by Sen-Sarma et al. (1975) on the Indian wood destroying termites. Other authors such as Beeson (1941), Harris (1961, 1971), Hickin (1971), Narayanan and Rattan (1952), Roonwal (1979), and Kapur and Bose (1972) provided some accounts on termites that are injurious to agriculture crops and their control. Thakur et al. (1956, 1957) suggested the use of aldrin and dieldrin for termite control in field crops. Gupta (1959) controlled termites with 5% BHC dust at 20 kg/ha, when applied in furrows in sugarcane.

Agarwala (1955) found that treatments of sugarcane setts with insecticides, viz., benzene hexachloride, aldrin, chlordane, dieldrin, etc., as dust or sprinkle were effective in termite control. Parihar (1985) reported that castor seed dressing with aldrin 30 E.C. at 10 ml/kg protected the crop against termites. He opined that pre-sowing soil application of 5% aldrin dust at 37.5 kg/ha also gave good results and the commonly used 10% HCH the least effective. Scheffrahn et al. (1997) suggested chemical toxicity, formulation, application method, drywood termite behavior, and gallery system architecture influenced the performance of local chemical treatments.

Singh and Singh (2001) reported sugarcane sett treatment with a 0.2% solution of imidacloprid 70 WS and soil treatment with phorate 10 G 2.50 kg a.i./ha, chlorpyrifos 15 G 2.50 kg a.i./ha, and chlorpyrifos 20 EC at 1 kg a.i./ha were the most performing in controlling the termite infestations. Rana et al. (2001) observed that plots where wheat seeds were treated with chlorpyrifos and endosulfan at 0.9 and 2.4 g a.i./kg respectively were least infested by termites. Delgarde and Rouland (2002) found the effective dose of thiamethoxam for *Trinervitermes trinervius* Rambur, *Odontotermes smeathmani* Fuller, and *Amitermes evuncifer* Silvestri to be 0.3 ppm, which resulted in 100% mortality within 2–8 days, depending on the species. They further observed that *O. smeathmani* consumed the product, and thiamethoxam could be transmitted in the colony from contaminated individuals to healthy individuals. Thiamethoxam acted as an antifeedant for *T. trinervius* and *A. evuncifer* and not as repellent. Sekamatte et al. (2003) observed that soybean and groundnut were more effective in suppressing termite attack than common beans in maize-legume cropping system and suggested an integrated management strategy for termites in smallholder cropping systems in East Africa.

Santos et al. (2004) observed the phenomenon of social facilitation among termites when poisoned with endosulfan and chlorpyrifos. They found that group size significantly affected the median time for death. This observation has important practical implications because density of individuals (population density) within the colony has significant role to play in time required to eliminate the colony and the doses are based on colony size and not on the population density reached inside the nest.

The sand termite, *Psammotermes hypostoma* Desneux, prefers to infest the places with a high moisture content and warm temperature (Hafez 1980; Moharram et al. 1992). Ahmed et al. (2015) found chlorpyrifos (48 EC) as the most potent, acetamiprid (20 SP) most toxic, and thiamethoxam (40 WG) most powerful insecticide for management of *P. hypostoma.* They further observed that the reduction percentages on palm fronds damage had a linear relationship with increase in exposure period (from 15–60 days).

Rust and Saran (2008) found acetamiprid very active against *R. hesperus* in topical applications. Moreover, they demonstrated that termites were quickly affected by short exposures to sand treated with acetamiprid (1 ppm) as within 1 h their locomotion was impaired. They also observed that acetamiprid was transferred from donors to recipients only when donors were held on deposits ≥50 ppm for 1 h. Deposits even as low as 1 ppm were repellent with termites failing to tunnel into the treated sand, without any significant mortality.

Ahmed et al. (2007) suggested the use of thiamethoxam and imidacloprid either as sett treatment or soil application in connection with irrigation could be a good alternative to chlorpyrifos and bifenthrin, in sugarcane crops in Pakistan, where insecticides are the usual approach to manage termites in this crop (Sattar and Salihah 2001; Ahmed et al. 2007). Singh and Singh (2002) suggested application of chlorpyrifos, imidacloprid, and fipronil as sett treatment in furrows before the first irrigation.

Iqbal and Saeed (2013) evaluated toxicities of insecticides against *Microtermes mycophagus* Desneux collected from four locations (tree plantation, untreated building, treated building, agriculture area) of Multan, Pakistan. They found that the population collected from agricultural area was more tolerant to all insecticides compared to those of other three locations. They ranked the insecticide order of average toxicity as follows: chlorfenapyr > spinosad > thiamethoxam > fipronil > indoxacarb > imidacloprid. Bhagawati et al. (2014) reported under field conditions sugarcane setts treated with clothianidin 50 WDG at concentration of 1 ml/liter registered the lowest infestation of termites and showed statistical parity with the combined application of acephate 50% + imidacloprid 1.8% at same concentration.

Gao et al. (1985) reported successful control of termite infestations with dechlorane bait in fields. Actually, workers all around the globe are actively involved in developing new integrated termite management program which would be effective and sustainable.

11.8 Factors Deciding Management Methodology

It is very difficult to decide the best method for termite management because every situation is different. The major factors that determine the methodology are as follows:

(a) Whether termite management is to be done in field, wooden structures, or buildings.
(b) Termite species in question, whether mound forming or non-mound forming or subterranean or arboreal.
(c) Soil characteristics, viz., clay content, organic matter content, pH, moisture content, bulk density, cation exchange capacity, etc.
(d) The presence of previous crop residues, current crop present in the field, and cropping system followed by the farmer.
(e) Type of insecticide/termiticide available and availability of particular formulations in the local market.
(f) Proper knowledge of cultural practices and pest control measures being followed.
(g) Cost of protection, a very important factor. In less developed countries, small and marginal farmers dominate the farming community. The newer termiticides are expensive so they prefer to use cheaper organophosphate-based products.

(h) Whether a new structure is being constructed or termite management is to be done for an existing structure/building.
(i) Soil type and structure, viz., clay, loamy, sandy loam, or sandy soils.
(j) Depth of foundation and perimeter area.
(k) Availability of proper barrier materials, especially for physical barriers.
(l) Availability of termite management professionals, bait stations, and monitoring professionals.

11.9 Conclusion

Management of termites varies widely, depending on the situation and cost incurred in the procedure. Today numerous termiticides are available in the market, including organophosphates and pyrethroids, which are more economic to use and expensive non-repellent termiticides. Termites are highly organized and "intelligent" social insects; they reproduce at an alarming rate and are able to replenish any shortage in number of workers or soldiers quickly. Termite management science has progressed tremendously in the last two decades. Detailed studies related to their behavior and biology need to be carried out to achieve success in management.

Termite workers have generated voluminous amount of literature which has helped in developing new management technologies. Biological control is still in its infancy. However, some natural enemies have been reported, but literature indicating their successful use is limited. A number of plant products have been reported to have deleterious effect on termites, but economically and viable application technologies need to be developed. A thorough perusal of the literature shows that the use of synthetic chemical insecticides is the preferred way to manage termites. We believe, however, that an integrated approach represents the right path to follow. Insects have survived for more than 1.5 million years, and it is their adaptability that makes them stand against humans more firmly than any other species. Application of bait technology and liquid termiticides is used in different situations. These technologies have their own merits and demerits. We have to weigh the benefits against the demerits and decide which strategy to follow. No matter whatever strategy we may adopt, synthetic chemical insecticides still remain the backbone of termite management, and more experimental studies need to be carried out, to work out strategies to avoid their damage in a more pragmatic way.

References

Agarwala, S. B. D. (1955). Control of termites (1946–1953). *Journal of Economic Entomology, 48*, 533–537.

Ahmed, M. A. I., & Saba, R. M. (2014). Comparative toxicological evaluation between different formulations of two selected neonicotinoid pesticides on *Culex pipiens* (Diptera: Culicidae) mosquito. *Advances in Environmental Biology, 8*, 1169–1174.

Ahmed Shiday, B. M., & French, J. R. J. (2013). The efficacy of flufenoxuron as potential bait toxicant against termites. *African Journal of Agricultural Research, 8*, 3688–3694.

Ahmed, S., Riaz, M. A., & Hussain, A. (2007). Assessment of the damaged and population of termites (*Odontotermes* & *Unicolor*) under various methods of insecticide application. *International Journal of Agriculture and Biology, 9*, 125–128.

Ahmed, M. A. I., Eraky, S. A., Fakeer, M., & Soliman, A. S. (2014). Toxicity assessment of selected neonicotinoid pesticides against the sand termite, *Psammotermes hypostoma* Desneux workers (Isoptera: Rhinotermitidae) under laboratory conditions. *Australian Journal of Basic and Applied Sciences, 8*, 238–240.

Ahmed, M. A. I., Eraky, S. A., Mahmoud, F. M., & Soliman, A. S. (2015). Potential toxicity assessment of novel selected pesticides against sand termite, *Psammotermes hypostoma* Desneux workers (Isoptera: Rhinotermitidae) under field conditions in Egypt. *Journal of Plant Protection Research, 55*, 193–197.

Altson, R. A. (1947). A fungus parasitic on *Coptotermes curvignathus*, Holmgr. *Nature, 160*, 120.

Anonymous. (2002). *Pest Control, 70*, S1–S23.

Austin, J. W., Glenn, G. J., & Gold, R. E. (2008). Protecting urban infrastructure from Formosan termite (Isoptera: Rhinotermitidae) attack: A case study for United States Railroads. *Sociobiology, 51*, 231–247.

Bagnères, A. G., Pichon, A., Hope, J., Davis, R., & Clément, J. L. (2009). Contact versus feeding intoxication by fipronil in *Reticulitermes* termites (Isoptera: Rhinotermitidae): Laboratory evaluation of toxicity, uptake, clearance, and transfer among individuals. *Journal of Economic Entomology, 102*, 347–356.

Beal, R. H., & Carter, F. L. (1968). Initial soil penetration by insecticide emulsions used for subterranean termite control. *Journal of Economic Entomology, 61*, 380–383.

Beal, R. H., & Kais, V. (1962). Apparent infection of subterranean termites by *Aspergillus flavus*. *Insect Pathology, 4*, 488–489.

Beard, R. L. (1974). Termite biology and bait-block method of control. *Connecticut* Agr Esp Sta Bull 748.

Beeson, C. F. C. (1941). *The ecology and control of forest insects in India and the neighbouring countries*. Government of India, ii+ 1008 pp. Dehra Dun (Vasant Press).

Bhagawati, S., Bhattacharyya, B., Mishra, H., & Gogoi, D. (2014). Chemical management of termites (*Odontotermes obesus*) in preserved setts of sugarcane (*Saccharum officinarum*). *Journal of Entomology and Zoology Studies, 5*, 856–859.

Bokhtiar, S. M., & Sakurai, K. (2005). Integrated use of organic manure and chemical fertilizer on growth, yield and quality of sugarcane in high Ganges river floodplain soils of Bangladesh. *Communications in Soil Science and Plant Analysis, 36*, 1823–1837.

Boucias, D. G., Stokes, C., Storey, G., & Penland, J. C. (1996). The effects of imidacloprid on the termite *Reticulitermes flavipes* and its interactions with the mycopathogen *Beauveria bassiana*. *Pflanzenschutz-Nachr Bayer, 49*, 103–144.

Carson, R. (1962). *Silent Spring*. Boston: Houghton Mifflin.

Cleghorn, H. F. C. (1861). *The forests and gardens of South India*. London: WH Allen Co.

Cordova, D., Benner, E. A., Sacher, M. D., Rauh, J. J., Sopa, J. S., Lahm, G. P., Selby, T. P., Stevenson, T. M., Flexner, L., Gutteridge, S., Rhoades, D. F., Wu, L., Smith, R. M., & Tao, Y. (2006). Anthranilic diamides: A new class of insecticides with a novel mode of action, ryanodine receptor activation. *Pesticide Biochemistry and Physiology, 84*, 196–214.

Cropper, M. L., Evans, W. N., Berardi, S. J., Ducla-Soares, M. M., & Portney, P. R. (1992). The determinants of pesticide regulation: A statistical analysis of EPA decision making. *Journal of Political Economy, 100*, 175–197.

Davis, R. W., & Kamble, S. T. (1992). Distribution of subslab injected Dursban TC (chlorpyrifos) in a loamy sand soil when used for subterranean termite control. *Bulletin of Environmental Contamination and Toxicology, 48*, 585–591.

DeBach, P. H., & McOmie, W. A. (1939). New diseases of termites caused by bacteria. *Annals of the Entomological Society of America, 32*, 137–146.

Delgarde, S., & Rouland, L. C. (2002). Evaluation of the effects of thiamethoxam on three species of African termite (Isoptera: Termitidae) crop pests. *Journal of Economic Entomology, 95*, 531–536.

Doppelreiter, V. H., & Korioth, M. (1981). Entwicklungshemmung durch Diflubenzuron bei den Bodentermiten *Heterotermes indicola* und *Reticulitermes flavipes*. *Zeitschrift für Angewandte Entomologie, 91*, 131–137.

Edwards, R., & Mill, A. E. (1986). *Termites in buildings: Their biology and control*. East Grinstead: Rentokil Ltd.

Erhorn, E. M. (1934). The termites of Hawaii, their significance and control, and the distribution of termites by commerce. In C. A. Kofoid (Ed.), *Termites and termite control* (pp. 321–333). Berkeley: University of California Press.

Esenther, G. R., & Beal, R. H. (1974). Attractant-mirex bait suppresses activity of *Reticuliternes*. *Journal of Economic Entomology, 67*, 85–88.

Esenther, G. R., & Beal, R. H. (1978). Insecticidal baits on field plot perimeters suppress *Reticulitermes*. *Journal of Economic Entomology, 71*, 604–607.

Esenther, G. R., & Gray, D. E. (1968). Subterranean termite studies in southern Onrurio. *Canadian Entomology, 100*, 827–834.

Forschler, B. T. (1994). Survivorship and tunneling activity of *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) in response to termiticide soil barriers with and without gaps of untreated soil. *Journal of Entomological Science, 29*, 43–54.

Forschler, B. T., & Townsend, M. L. (1996). Mortality of eastern subterranean termites (Isoptera: Rhinotermitidae) exposed to four soils treated with termiticides. *Journal of Economic Entomology, 89*, 678–681.

French, J. R. J. (1991). Baiting techniques for control of *Coptotermes* species within existing buildings in Australia. In M. I. Haverty, & W.W. Wilmx (Eds.), *Proceedings of symposium of current research on wood-destroying organisms* (pp. 46–50). USDA forest service' general technical report PSW-128, Berkeley.

Froggatt, W. W. (1905). Economic entomology white ants (Termitidae) with suggestions for dealing with them in houses and orchards. *The Agricultural Gazette of New South Wales, 16*(632–656), 753–774.

Fullaway, D. T. (1920). Termites, or white ants, in Hawaii. *Hawaiian Agriculture, 17*, 294–301.

Gahlhoff, J., & Koehler, P. (1999). To kill or not to kill? *Pest Control Technology, 27*, 22–28.

Gahlhoff, J. E., & Koehler, P. G. (2001). Penetration of the eastern subterranean termite into soil treated at various thicknesses and concentrations of Dursban TC and Premise 75. *Journal of Economic Entomology, 94*, 486–491.

Gao, D., Zhu, B., Gan, H. S., & Yuan, S. (1985). A new toxic bait for the control of forest-infesting termites. *Journal of Nanjing Institute, 3*, 128–131.

Glenn, G. J., & Gold, R. E. (2003). Evaluation of commercial termiticides and baiting systems for pest management of the Formosan subterranean termite, *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Sociobiology, 41*, 193–196.

Gold, R. E., Howell, H. N., Jr., Pawson, B. M., Wright, M. S., & Lutz, J. C. (1996). Persistence and bioavailability of termiticide to subterranean termites (Isoptera: Rhinotermitidae) from five soil types and locations in Texas. *Sociobiology, 28*, 337–363.

Gould, K. A., Herrick, J., & Lemma, H. (2001). Refuse to refuge: Dry season use and modification of cattle dung by subterranean termites in Guanacaste, Costa Rica. *Biotropica, 33*, 121–130.

Grace, J. K., & Yamamoto, R. T. (1994). Simulation of remedial borate treatments intended to reduce attack on Douglas-fir lumber by the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 87*, 1547–1554.

Grace, J. K., Abdallay, A., & Farr, K. R. (1989). Eastern subterranean termite (Isoptera: Rhinotermitidae) foraging territories and populations in Toronto. *Canadian Entomologist, 121*, 551–556.

Grace, J. K., Yates, J. R., Tamashiro, M., & Yamamoto, R. T. (1993). Persistence of organochlorine insecticides for Formosan subterranean termite (Isoptera: Rhinotermitidae) control in Hawaii. *Journal of Economic Entomology, 86*, 761–765.

Grace, J. K., Tome, C. H. M., Shelton, T. G., Oshiro, R. J., & Yates, J. R. (1996). Baiting studies and considerations with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Hawaii. *Sociobiology, 28*, 511–520.

Gunasekara, A. S., Truong, T., Goh, K. S., Spurlock, F., & Tjeerdema, R. S. (2007). Environmental fate and toxicology of fipronil. *Journal of Pesticide Science, 32*, 189–199.

Gupta, B. D. (1959). Studies on the control of termites in sugarcane. *Proceedings of International Society of Sugar Cane Technologists, 10*, 961–977.

Haagsma, K. A., & Rust, M. K. (2005). Effect of hexaflumuron on mortality of the western subterranean termite (Isoptera: Rhinotermitidae) during and following exposure and movement of hexaflumuron in termite groups. *Pest Management Science, 61*, 517–531.

Haagsma, K. A., & Rust, M. K. (2007). The effect of imidacloprid on mortality, activity, and horizontal transfer in the western subterranean termite (Isoptera: Rhinotermitidae). *Sociobiology, 50*, 1127–1148.

Hafez, M. (1980). Highlights of the termite problem in Egypt. *Sociology, 5*, 147–156.

Harris, W. V. (1961). *Termites, their recognition and control* (p. 187). London: Longmans Green and Co. Ltd.

Harris, W. V. (1971). *Termites: Their recognition and control* (2nd ed.p. 186). London: Longmans.

Harris, C. (1972). Factors influencing the effectiveness of soil insecticides. *Annual Review of Entomology, 17*, 177–198.

Haynes, K. F. (1988). Sublethal effects of neurotoxic insecticides on insect behavior. *Annual Review of Entomology, 33*, 149–168.

Henderson, G., & Forschler, B. T. (1997). Termite bait tests. *Louisiana Agriculture, 40*, 9–11.

Hickin, N. E. (1971). *Termites: A world problem* (1st ed.). London: Hutchinson and Co. Ltd.

Hu, X. P. (2005). Evaluation of efficacy and nonrepellency of indoxacarb and fipronil treated soil at various concentrations and thicknesses against two subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 98*, 509–517.

Hu, X. P., & Hickman, B. (2006). Exterior perimeter plus limited interior treatments with fipronil as an IPM option for subterranean termite management. *International Pest Control, 48*, 200–203.

Hu, X. P., Song, D., & Scheler, C. (2005). Transfer of indoxacarb among workers of *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae): Effects of dose, donor/recipient ratio, and post-exposure time. *Pest Management Science, 61*, 1209–1214.

Hu, X. P., Song, D., & Presley, W. (2006). Horizontal and vertical transfer of fipronil within functional colonies. In T. Sutphin, B. Cartwright, & R. Houseman (Eds.), *Proceedings of 2006 national conference on urban entomology, 21–24 May 2006* (pp. 39–44). North Carolina: Raleigh.

Ibrahim, S. A., Henderson, G., & Fei, H. (2003). Toxicity, repellency, and horizontal transmission of fipronil in the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 96*, 461–467.

Iqbal, N., & Saeed, S. (2013). Toxicity of six new chemical insecticides against the termite, *Microtermes mycophagus* D. (Isoptera: Termitidae: Macrotermitinae). *Pakistan Journal of Zoology, 45*, 709–713.

Iwata, R., Ito, T., & Shinjo, G. (1989). Efficacy of fenitrothion microcapsule against termites, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). II Transmissibility of fenitrothion through grooming. *Applied Entomology and Zoology (Japanese), 24*, 213–221.

Jepson, F. P. (1930). The control of tea termites. *Tropical Agriculture, 75*, 191–195.

Jones, S. C. (1984). Evaluation of two insect growth regulators for the bait-block method of subterranean termite (Isoptera: Rhinotermitidae) control. *Journal of Economic Entomology, 77*, 1086–1091.

Kalshoven, L. G. E. (1955). The ability of *Coptotermes* to locate exposed timber. *Idea, 10*, 43–49.

Kapur, A. P., & Bose, G. (1972). Termite problems in tropical ecology in India. In *Termite problems in India* (pp. 31–37). New Delhi: Biological Research Committee.

Kard, B. M. (1998). Premise termiticide field test results. *Pest Control, 66*, 64–65,105.

Kard, B. (2001). Gulfport studies stay the course. *Pest Control, 69*, 30–33.

Kard, B. M. (2003). Integrated pest management of subterranean termites (Isoptera). *Journal of Entomological Science, 38*, 200–224.

Kard, B. M., Mauldin, J. K., & Jones, S. C. (1989). Evaluation of soil termiticides for control of subterranean termites (Isoptera). *Sociobiology, 15*, 285–297.

Keuchenius, P. E., Corporaal, J. B., & vijanden van, D. (1922). *Hevea brasiliensis* (animal enemies of *Hevea brasiliensis*) In N. L. Swart, A. A. L. Rutgers, & J. H. de Bussy (Eds), *Handboek voor de rubber cultuur in Nederlandsch-Indie (Handbook for rubber culture in Netherlands-India)* (pp. 216–229).

Kevorkian, A. G. (1937). Studies in the entomophthoraceae. I. Observations on the genus *Conidiobolus*. *Journal of Agriculture of the University of Puerto Rico, 21*, 191–200.

Khan, K. I., Fazal, Q., & Jafri, R. H. (1977). Pathogenicity of locally discovered *Bacillus thuringiensis* strain to the termites: *Heterotermes indicola* (Wassman) and *Microcerotermes championi* (Snyder). *Pakistan Journal of Scientific Research, 29*, 12–13.

King, E. G., & Spink, W. T. (1969). Foraging galleries of the Formosan termite, *Coptotermes formosanus,* in Louisiana. *Annals of the Entomological Society of America, 62*, 537–542.

Kofoid, C. A., Light, S. F., Horner, A. C., Randall, M., Herms, W. B., & Bowe, E. E. (1934). *Termites and termite control*. Berkeley: University of California Press.

Kramm, K. R., West, D. F., & Rockenbach, P. G. (1982). Termite pathogens: Transfer of the entomopathogen *Metarhizium anisopliae* between *Reticulitermes* sp. termites. *Journal of Invertebrate Pathology, 40*, 1–6.

Krejzová, R. (1971). Infektionsversuche mit einigen Entomophthora-Arten bei den termiten Coptotermes formosanus (Shiraki) und Reticulitermes lucifugus (Rossi). *Entomophaga, 16*, 221–231. (in German).

Lai, P. Y. (1977). Biology and ecology of the Formosan subterranean termite, *Coptotermes formosanus*, and its susceptibility to the entomogenous fungi, *Beauveria bassiana* and *Metarrhizium anisopliae*. PhD dissertation, University of Hawaii, Honolulu

Lax, A. R., & Osbrink, W. L. A. (2003). United States Department of Agriculture—Agriculture Research Service research on targeted management of the Formosan subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). *Pest Management Science, 59*, 788–800.

Lee, C. Y., Vongkaluang, C., & Lenz, M. (2007). Challenges to subterranean termite management of multi-genera faunas in Southeast Asia and Australia. *Sociobiology, 50*, 213–221.

Lenz, M. (1976). The dependence of hormone effects in termite caste determination on external factors. In M. LuÈscher (Ed.), *Phase and caste determination in insects. Endocrine aspects* (pp. 73–89). Oxford: Pergamon Press.

Lenz, M. (2002). Termite problem species and management of termite problems in Australia. *Sociobiology, 40*, 11–12.

Lenz, M., & Evans, T. A. (2002). Termite bait technology: Perspectives from Australia. In S. C. Jones, J. Zhai, W. H. Robertson, & S. C. Charleston (Eds.), *Proceedings of the 4th international conference on urban pests* (pp. 27–36).

Lenz, M., & Runko, S. (1994). Protection of buildings, other structures and materials in ground contact from attack by subterranean termites (Isoptera) with a physical barrier – A fine mesh of high grade stainless steel. *Sociobiology, 24*, 1–16.

Logan, J. W. M., Cowie, R. H., & Wood, T. G. (1990). Termite (Isoptera) control in agriculture and forestry by non-chemical methods: A review. *Bulletin of Entomological Research, 80*, 309–330.
LuÈscher, M. (1958). Ueber die Entstehung der Soldaten bei Termiten. *Revue Suisse de Zoologie, 65*, 372–376.
Lund, A. E. (1962). Subterraneans and their environment – New concepts of termite ecology. *Pest Control, 30*, 60–61.
Lund, A. E. (1965). Piggyback bacteria can kill termite colony. *Pest Control, 33*, 22–24.
Lund, A. E. (1966). US Patents 3249,492; 3249,439; 3249,494; 3249,500; 3249,501
Lund, A. E. (1971). Microbial control of termites. In H. D. Burges & N. W. Hussey (Eds.), *Microbial control of insects and mites* (pp. 385–386). London: Academic.
Mando, A., & Stroosnijder, L. (1999). The biological and physical role of mulch in the system wide program on integrated pest management. *IPM Research Briefs, 2*, 11–26.
Mando, A., Brussaard, L., & Stroosnijder, L. (1999). Termites and mulch mediated rehabilitation of vegetation on crusted soil in West Africa. *Restoration Ecology, 7*, 33–41.
Manzoor, F., & Pervez, M. (2014). Efficacy of Biflex and Fipronil in controlling subterranean termites (Isoptera: Rhinotermitidae) in different soils types in Pakistan. In B. T. Forschler (Ed.), *10th Pacific-termite research group conference held at Kuala Lumpur, Malaysia*, February 26–28, 2014.
Manzoor, F., Sayyed, A. H., Rafique, T., & Malik, S. A. (2012). Toxicity and repellency of different insecticides against *Heterotermes indicola* (Isoptera: Rhinotermitidae). *The Journal of Animal and Plant Sciences, 22*, 65–71.
Mao, L., Henderson, G., & Scherer, C. W. (2011). Toxicity of seven termiticides on the Formosan and eastern subterranean termites. *Journal of Economic Entomology, 104*, 1002–1008.
McCall, P. J., Swann, R. L., Laskowski, D. A., Vrona, S. A., Unger, S. M., & Dishburger, H. J. (1979). Prediction of chemical mobility in soil from sorption coefficients. In *Proceedings of aquatic toxic hazard* (pp. 49–58). Philadelphia: ASTM.
McCann, S. F., Annis, G. D., Shapiro, R., Piotrowski, D. W., Lahm, G. P., Long, J. K., Lee, K. C., Hughes, M. M., Myers, B. J., & Griswold, S. M. (2001). The discovery of indoxacarb: Oxadiazines as a new class of pyrazoline-type insecticides. *Pest Management Science, 57*, 53–164.
Merrill, J. H., & Ford, A. L. (1916). Life history and habits of two new nematodes parasitic on insects. *Journal of Agricultural Research, 6*, 115–127.
Mix, J. (1988). King of the hill. *Pest Control, 56*, 34–35.
Moharram, A. M., Bagy, M. M. K., & Abdel-Galil, F. A. (1992). Fungi associated with the sand termite *Psammotermes hypostoma* in Assiut, Egypt. *Mycologia, 84*, 930–935.
Myles, T. G. (1996). Development and evaluation of a transmissible coating for control of subterranean termites. *Sociobiology, 28*, 373–457.
Narayanan, E. S., & Rattan, L. (1952). A short review of recorded information on the control of termites damaging crops in India, along with results of recent control experiments at Delhi. *Indian Journal of Entomology, 14*, 21–50.
Nauen, R., & Bretschneider, T. (2001). New modes of action of insecticides. *Pesticide Outlook, 13*, 241–245.
Ngee, P. S., Yoshimura, T., & Lee, C. Y. (2004). Foraging populations and control strategies of subterranean termites in the urban environment, with special reference to baiting. *Japanese Journal of Environmental Entomology and Zoology, 15*, 197–215.
NPCA (National Pest Control Association). (1985). *Approved reference procedures for subterranean termite control*. Dunn Loring: NPCA Inc.
Osbrink, W. L. A., & Lax, A. R. (2002). Effect of tolerance to insecticides on substrate penetration by Formosan subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 95*, 989–1000.
Osbrink, W. L. A., Lax, A. R., & Brenner, R. J. (2001). Insecticide susceptibility in *Coptotermes formosanus* and *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 94*, 1217–1228.

Page, R. Z. (1966). Affidavit submitted to the US Navy, Hawaii (p. 46)

Page, R. Z. (1967). Termite control by induced epizootics of entomophagous microorganisms. US patent #3337,395.

PANNA. (2009). PAN pesticides database – Pesticide products. Pesticide action network, North America. http://www.pesticideinfo.org/Detail_Product.jsp?REG_NR=00796900210&DIST_NR=007969

Parihar, D. R. (1985). Crop termite damage in Indian desert and its control in castor. *Zeitschrift furAngewandte Zoologie, 72*, 309–315.

Paton, R., & Miller, L. R. (1980). Control of *Mastotermes darwiniensis* Froggatt (Isoptera: Mastrotermitidae) with mirex baits. *Australian Forestry Research, 10*, 249–258.

Pawson, B. M., & Gold, R. E. (1996). Evaluation of baits for termites (Isoptera: Rhinotermitidae) in Texas. *Sociobiology, 28*, 485–510.

Pemberton, C. E. (1928). Nematodes associated with termites in Hawaii, Borneo and Celebes. *Proceedings of the Hawaiian Entomological Society, 7*, 148–150.

Peterson, C. (2010). Considerations of soil-applied insecticides for termite control. *Outlooks on Pest Management, 21*, 89–93.

Peterson, C. J., Gerard, P. D., & Ems-Wilson, J. (2004). Recommendations for treated-area choice assays with termites (Isoptera). *Sociobiology, 44*, 171–185.

Potter, M. F. (1997). Termites. In D. Moreland (Ed.), *Handbook of pest control* (pp. 233–332). Cleveland: Mallis Handbook and Technical Training Co.

Potter, M. F., & Hillery, A. E. (2002). Exterior-targeted liquid termiticides: an alternative approach to managing subterranean termites (Isoptera: Rhinotermitidae) in buildings. *Sociobiology, 39*, 373–405.

Potter, M. F., & Hillery, A. E. (2003). Trench warfare. *Pest Control Technology, 31*, 28–32.

Prestwich, G. D., Mauldin, J. K., Engstrom, J. B., Carvalho, J. F., & Cupo, D. Y. (1983). Comparative toxicity of fluorinated lipids and their evaluation as bait-block toxicants for the control of *Reticulitermes* spp. (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 76*, 690–695.

Quarcoo, F. Y., Appel, A. G., & XP, H. (2010). Effects of indoxacarb concentration and exposure time on onset of abnormal behaviors, morbundity, and death in eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 103*, 762–769.

Ramakrishnan, R., Suiter, D. R., Nakatsu, C. H., & Bennett, G. W. (2000). Feeding inhibition and mortality in *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) after exposure to imidacloprid-treated soils. *Journal of Economic Entomology, 93*, 422–428.

Rana, J. S., Ombir, & Dahiya, K. K. (2001). Management of termite, *Microtermes obesi* (Holmgren) in wheat, *Triticum aestivum* through seed treatment. *Annales Biologiques, 17*, 207–209.

Randall, M., & Doody, T. C. (1934). Poison dusts. I. Treatments with poisonous dusts. In C. A. Kofoid (Ed.), *Termites and termite control* (pp. 463–476). Berkeley: University of California Press.

Rath, A. C. (2000). The use of entomopathogenic fungi for control of termites. *Biocontrol Science and Technology, 10*, 563–581.

Reid, B. L., Brinkmann, R., Smith, G., Ishizaka, K., Palis, B., & DeVilliers, V. (2002). Imidacloprid use in termite control operations globally and changing use patterns in the United States. In S. C. Jones, J. Zhai, & W. H. Robertson (Eds.), *Proceedings of the 4th international conference on urban pests, 7–10 July 2002, Charleston, South Carolina* (pp. 355–368). Blacksburg: Pocahontas Press.

Remmen, L. N., & Su, N. Y. (2005). Tunneling and mortality of eastern and Formosan subterranean termites (Isoptera: Rhinotermitidae) in sand treated with thiamethoxam or fipronil. *Journal of Economic Entomology, 98*, 906–910.

Ripa, R., Paola Luppichini, S. N. Y., & Michael, K. R. (2007). Field evaluation of potential control strategies against the invasive eastern subterranean termite (Isoptera: Rhinotermitidae) in Chile. *Journal of Economic Entomology, 100*, 1391–1399.

Roonwal, M. L. (1979). *Termite life and termite control in tropical South Asia* (p. 177). Jodhpur: Scientific Publishers.

Roonwal, M. L., & Chhotani, O. B. (1961). *Termite fauna of Assam region, Eastern India* (p. 406). Monograph, Zoological Survey of India.

Roonwal, M. L., & Chhotani, O. B. (1967). Indian wood-destroying termites. *Journal of the Bombay Natural History Society, 63*, 354–364.

Rust, M. K. (1986). Managing household pests. In G. W. Bennett & J. M. Owens (Eds.), *Advances in urban pest management* (pp. 335–368). New York: Van Nostrand Reihald Co.

Rust, M. K., & Saran, R. K. (2006). Toxicity, repellency, and transfer of chlorfenapyr against western subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 99*, 864–872.

Rust, M. K., & Saran, R. K. (2008). Toxicity, repellency, and effects of acetamiprid on western subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 101*, 1360–1366.

Saltzman, S., & Yaron, B. (1986). *Pesticides in soil*. New York: Van Nostrand Reinhold Company.

Santos, C. A., DeSouza, O., & Guedes, R. N. C. (2004). Social facilitation attenuating insecticide-driven stress in termites (Isoptera: Nasutitermitinae). *Sociobiology, 44*, 1–7.

Saran, R. K., & Rust, M. K. (2007). Toxicity, uptake, and transfer efficiency of fipronil in western subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 100*, 495–508.

Saran, R. K., Ziegler, M., Kudlie, S., Harrison, D., Leva, D. M., Scherer, C., & Mark, A. C. (2014). Behavioral effects and tunneling responses of eastern subterranean termites (Isoptera: Rhinotermitidae) exposed to chlorantraniliprole-treated soils. *Journal of Economic Entomology, 107*, 1878–1889.

Sattar, A., & Salihah, Z. (2001, September 24–26). Detection and control of subterranean termites. In *Technologies for sustainable agriculture. Proceedings of national workshop* (pp. 195–198). NIAB, Faisalabad.

Scheffrahn, R. H., Su, N. Y., & Busey, A. (1997). Laboratory and field evaluations of selected chemical treatments for control of drywood termites (Isoptera: Kalotermitidae). *Journal of Economic Entomology, 90*, 492–502.

Schoknecht, U., Rudolph, D., & Hertel, H. (1994). Termite control with microencapsulated permethrin. *Pesticide Science, 40*, 49–55.

Sekamatte, M. B., Ogenga-Latigo, M., & Russell-Smith, A. (2003). Effects of maize-legume intercrops on termite damage to maize, activity of predatory ants and maize yields in Uganda. *Crop Protection, 22*, 87–93.

Sen-Sarma, P. K., Thakur, M. L., Mishra, S. C., & Gupta, B. K. (1975). *Wood destroying termites in India* (p. 187). Dehradun: Forest Research Institute.

Shelton, T. G., Bell, C. D., & Wagner, T. L. (2005). Lack of transfer of permethrin among nestmates of *Reticulitermes flavipes* in laboratory trials (Isoptera: Rhinotermitidae). *Sociobiology, 45*, 69–75.

Shelton, T. G., Mulrooney, J. E., & Wagner, T. L. (2006). Transfer of chlorfenapyr among workers of *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) in the laboratory. *Journal of Economic Entomology, 99*, 886–892.

Shelton, T. G., Fye, D., & Ulyshen, M. (2014). U.S. Department of Agriculture-Forest Service Termiticide Report for 2013. *Pest Management Professional, 82*, 42–52.

Silver, K. S., & Soderlund, D. M. (2005). Action of pyrazoline-type insecticides at neuronal target sites. *Pesticide Biochemistry and Physiology, 81*, 136–143.

Singh, M., & Singh, N. B. (2001). Application of insecticide for termite control and its effect on yield contributing characters in sugarcane. *Sugar Tech, 3*, 146–153.

Singh, M., & Singh, N. B. (2002). Bud damage due to termites in sugarcane. *Cooperative Sugar, 33*, 655–658.

Smith, J. L., & Rust, M. K. (1990). Tunneling response and mortality of the western subterranean termite (Isoptera: Rhinotermitidae) to soil treated with termiticides. *Journal of Economic Entomology, 83*, 1395–1401.

Smith, J. L., & Rust, M. K. (1993). Cellulose and clay in sand affects termiticide treatments. *Journal of Economic Entomology, 86*, 53–60.

Smith, J. A., Pereira, R. M., & Koehler, P. G. (2008). Relative repellency and lethality of the neonicotinoids thiamethoxam and acetamiprid and an acetamiprid/bifenthrin combination to *Reticulitermes flavipes* termites. *Journal of Economic Entomology, 101*, 1881–1887.

Smythe, R. V., & Coppel, H. C. (1965). The susceptibility of *Reticulitermes flavipes* (Kollar) and other termite species to an experimental preparation of *Bacillus thuringiensis* Berliner. *Journal of Invertebrate Pathology, 7*, 423–426.

Smythe, R. V., & Coppel, H. C. (1966). Pathogenicity of externally occurring fungi to *Reticulitermes flavipes*. *Journal of Invertebrate Pathology, 8*, 266–267.

Song, D., & Hu, X. P. (2006). Effects of dose, donor–recipient interaction time and ratio on fipronil transmission among the Formosan subterranean termite nestmates (Isoptera: Rhinotermitidae). *Sociobiology, 48*, 237–246.

Spomer, N. A., & Kamble, S. T. (2011). Temporal changes in chlorantraniliprole and indoxacarb in four midwestern soils and bioefficacy against the eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 104*, 990–1001.

Spomer, N. A., Kamble, S. T., Warriner, R. A., & Davis, R. W. (2008). Influence of temperature on rate of uptake and subsequent horizontal transfer of [14C] fipronil by eastern subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 101*, 902–908.

Spomer, N. A., Kamble, S. T., & Siegfried, B. D. (2009). Bioavailability of chlorantraniliprole and indoxacarb to eastern subterranean termites (Isoptera: Rhinotermitidae) in various soils. *Journal of Economic Entomology, 102*, 1922–1927.

St. George, R. A. (1952). Tests with new insecticides for termite control. *Pest Control, 20*, 20.

Stadykov, S. I. (1970). The use of entomopathogenic bacteria for the control of termites. *Journal of Economic Entomology, 49*, 1144–1149.

Su, N. Y. (1994). Field evaluation of hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 87*, 389–397.

Su, N. Y. (2005). Response of the Formosan subterranean termites (Isoptera: Rhinotermitidae) to baits or nonrepellent termiticides in extended foraging arenas. *Journal of Economic Entomology, 98*, 2143–2152.

Su, N. Y. (2007). Hermetically sealed baits for subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 100*, 475–482.

Su, N. Y., & Scheffrahn, R. H. (1986). A method to access, trap, and monitor field populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the urban environment. *Sociobiology, 12*, 299–304.

Su, N. Y., & Scheffrahn, R. H. (1988). Foraging population and territory of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in an urban environment. *Sociobiology, 14*, 353–359.

Su, N. Y., & Scheffrahn, R. H. (1990). Comparison of eleven soil termiticides against the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 83*, 1918–1924.

Su, N. Y., & Scheffrahn, R. H. (1996). A review of the evaluation criteria for bait-toxicant efficacy against field colonies of subterranean termites (Isoptera). *Sociobiology, 28*, 521–530.

Su, N. Y., & Scheffrahn, R. H. (1998). A review of subterranean termite control practices and prospects for integrated pest management programmes. *Integrated Pest Management Reviews, 3*, 1–13.

Su, N. Y., Tamashiro, M., Yates, J. R., & Haverty, H. I. (1982). Effect of behaviour on the evaluation of insecticides for prevention of or remedial control of the formosan subterranean termite. *Journal of Economic Entomology, 75*, 188–193.

Su, N. Y., Tamashiro, M., & Haverty, M. I. (1985). Effects of three insect growth regulators, feeding substrates, and colony origin on survival and presoldier production of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 78*, 1259–1263.

Su, N. Y., Tamashiro, M., & Haverty, M. I. (1987). Characterization of slow-acting insecticides for the remedial control of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 80*, 1–4.

Su, N. Y., Scheffrahn, R. H., & Ban, P. M. (1989). Method to monitor initiation of aerial infestations by alates of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in high-rise buildings. *Journal of Economic Entomology, 82*, 1643–1645.

Su, N. Y., Thoms, E. M., Ban, P. M., & Scheffrahn, R. H. (1995). Monitoring/baiting station to detect and eliminate foraging populations of subterranean termites (Isoptera: Rhinotermitidae) near structures. *Journal of Economic Entomology, 88*, 932–936.

Su, N. Y., Ban, P. M., & Scheffrahn, R. H. (1997a). Remedial baiting with hexaflumuron in above-ground stations to control structure-infesting population of Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 90*, 809–817.

Su, N. Y., Chew, V., Wheeler, G., & Scheffrahn, R. H. (1997b). Comparison of tunneling responses into insecticide treated soil by field populations and laboratory groups of subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 90*, 503–509.

Su, N. Y., Ban, P. M., Chew, V., & Scheffrahn, R. H. (1999a). Size and edge effects of concrete plots on chlorpyrifos degradation in sub-slab sand. *Journal of Economic Entomology, 92*, 409–415.

Su, N. Y., Ban, P. M., & Scheffrahn, R. H. (1999b). Longevity and efficacy of pyrethroid and organophosphate termiticides in field degradation studies using miniature slabs. *Journal of Economic Entomology, 92*, 890–898.

Su, N. Y., Ban, P. M., & Scheffrahn, R. H. (2001). Control of subterranean termites (Isoptera: Rhinotermitidae) using commercial prototype above ground stations and hexaflumuron baits. *Sociobiology, 37*, 111–120.

Su, N. Y., Ban, P., & Scheffrahn, R. H. (2004). Polyethylene barrier impregnated with Lambda-cyhalothrin for exclusion of subterranean termites (Isoptera: Rhinotermitidae) from structures. *Journal of Economic Entomology, 97*, 570–574.

Swoboda, L. E., Miller, D. M., Fell, R. J., & Mullins, D. E. (2004). The effects of nutrient compounds (sugars andamino-acids) on bait consumption by *Reticulitermes* spp. (Isoptera: Rhinotermitidae). *Sociobiology, 44*, 547–563.

Tamashiro, M. (1968). *Susceptibility of termites to microbes* (p. 7). A research proposal submitted to the office of Naval Research, Department of entomology, University of Hawaii, Honolulu.

Tamashiro, M., Yates, J. R., & Ebesu, R. H. (1987). The Formosan subterranean termite in Hawaii: Problems and control. In M. Tamashiro & N. Y. Su (Eds.), *Biology and control of the Formosan subterranean termite* (pp. 15–22). Honolulu: College of Tropical Agriculture and Human Resources, University of Hawaii.

Thakur, C., Prasad, A. R., & Singh, R. P. (1956). The use of different doses and formulations of aldrin and dieldrin against termites and their effect on soil fertility. *Indian Journal of Sugarcane Research and Development, 1*, 50–55.

Thakur, C., Butani Dhamo, K., & Prasad, A. R. (1957). Pests of sugarcane. *Eekh Samachar, 4*, 8.

Thorne, B. L., & Breisch, N. L. (2001). Effects of sublethal exposure to imidacloprid on subsequent behavior of subterranean termite *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 94*, 492–498.

Thorne, B. L., & Forschler, B. T. (2000). Criteria for assessing efficacy of stand-alone termite bait treatments at structures. *Sociobiology, 36*, 245–255.

Tillman, P. G., Hammes, G. G., Sacher, M., Connair, M., Brady, E. A., & Wing, K. D. (2002). Toxicity of a formulation of the insecticide indoxacarb to the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae) and the big-eyed bug, *Geocoris punctipes* (Hemiptera: Lygaeidae). *Pest Management Science, 58*, 92–100.

Tomalski, M. D., & Vargo, E. L. (2004). Chain reaction. *Pest Control, 72*, 51–53.

Toumanoff, C., & Rombau, J. (1965). Action de certains champignons entomophages, cultivés sur les milieux appropriés attractifs, sur le termite de Saintonge Reticulitermes santonensis (de Feytaud). *Annales Parasitologie Humaine et Comparee, 40*, 605–609. (in French).

Toumanoff, C., & Toumanoff, C. (1959). Les épizooties dues à Serratia marcescens Bizio chez un termite (*Reticulitermes santonensis* de Feytaud). *Comptes Rendus Hébdomadaires de l'Academie Agricole Française, 45*, 216–218. (in French).

Tsunoda, K. (2006). Transfer of fipronil, a nonrepellent termiticide, from exposed workers of *Coptotermes formosanus* (Isoptera: Rhinotermitidae) to unexposed workers. *Sociobiology, 47*, 563–575.

Tsunoda, K., Matsuoka, H., & Yoshimura, T. (1998). Colony elimination of *Reticulitermes speratus* (Isoptera: Rhinotermitidae) by bait application and the effect on foraging territory. *Journal of Economic Entomology, 91*, 1383–1386.

USDA (US Department of Agriculture). (1951). *Decay and termite damage in houses*. US Department of Agriculture Farmer's Bull 1993.

Valles, S. M., & Woodson, W. D. (2002). Group effects on insecticide toxicity in workers of Formosan subterranean termite, *Coptotermes formosanus* Shiraki. *Pest Management Science, 58*, 769–774.

Valles, S. M., Oi, F. M., Wagner, T., & Brenner, R. J. (2000). Toxicity and in vitro metabolism of t-permethrin in eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 93*, 1259–1264.

Van Zwaluwenberg, R. H. (1916). *Report of entomologist*. Annuul Report Porto Rico Agr Esp Sra 1915: 4245.

Vargo, E. L., & Husseneder, C. (2009). Biology of subterranean termite: Insights from molecular studies of *Reticulitermes* and *Coptotermes*. *Annual Review of Entomology, 54*, 379–403.

Verma, M., Sharma, S., & Prasad, R. (2009). Biological alternative for termite control: A review. *International Biodeterioration and Biodegradation, 63*, 959–972.

Wagner, T., Peterson, C., & Shelton, T. (2011). Termiticide efficacy reports 2010. *Pest Management Professional, 2011*, 28–34.

Watson, J. A. L. (1988). *Termites in the Canberra region* (2nd ed.). Canberra: CSIRO Publishing.

Wing, K. D., Sacher, M., Kagaya, Y., Tsuruvuchi, Y., Mulderig, L., Connair, M., & Schnee, M. (2000). Bioactivation and mode of action of the oxadiazine indoxacarb in insects. *Crop Protection, 19*, 537–545.

Wolcott, G. N. (1924). The comparative resistance of woods to the attack of the termite *Cryprotermes brevis* Walker. *Porro Rico lnsulur Exp Stu BUN, 33*, 3–15.

Yeoh, B. H., & Lee, C. Y. (2007). Tunneling responses of the Asian subterranean termite, *Coptotermes gestroi* in termiticide-treated sand (Isoptera: Rhinotermitidae). *Sociobiology, 50*, 457–478.