STUDIES ON FORAGING AND EVALUATIONS OF IMIDACLOPRID TREATMENTS FOR CONTROLLING SUBTERRANEAN TERMITES IN SELECTED PREMISES (ISOPTERA : RHINOTERMITIDAE)

ABDUL HAFIZ AB MAJID

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ABSTRACT

A survey was conducted in Penang to determine the main termite infestation in buildings. From the survey, it was discovered that *Coptotermes* was the main genus of termites found inside and outside building structures and they caused serious destructions. Other species like *Odontotermes* sp, *Macrotermes gilvus, Macrotermes carbonarious, Globitermes sulphureus* and *Microtermes pakistanicus* were also found in the surrounding structures. The genus *Coptotermes* was found infesting 13 out of 25 premises. From the foraging study, the population of *C. gestroi* was estimated to be around 56,127±11,925 up to 4,185,000±2127328. *Coptotermes curvignathus* was found only in one site. The population was estimated around 2,871,694±1,683,98 . Additionally, the foraging territory of *C. gestroi* was within 0.6 m^2 up to 300 m^2 and 324.4 m^2 for *C. curvignathus*. The mean feeding consumption of *C. gestroi* was within 1.0464 ±0.853 up to 130.320 ± 26.486 gram for every two weeks. For *C. curvignathus,* the mean feeding consumption was 89. 7500 ±16.154 gram for every two weeks. The non-repellent termiticide (Premise 200SC) containing 18% w/w imidacloprid was applied as minimum as possible around the exterior building perimeter plus the limited interior, especially at the termite infestation area. The delayed mode of action of Premise 200SC permits the transfer of this toxicant from exposed termites to the unexposed nest mates through social interactions including mutual grooming. This cause secondary mortality in subterranean termite population. Therefore, to minimize pesticide use and intrusion to homes, the efficacy of an innovative limited interior perimeter plus the external perimeter application of imidacloprid (Premise® 200SC) as an IPM option in post-construction termite control was evaluated. Seven private houses were chosen for the minimum application of imidacloprid. The study showed some very promising results. All the structures that were treated with minimum interior drilling showed full control of the foraging termite population inside the structures within a period of 2 to 12 weeks. However, one site was given a full perimeter treatment of internal and external perimeter drilling for the purpose of comparison to show that the termite population can be successfully controlled within the period of 6 weeks only

ABSTRAK

Satu tinjauan telah dijalankan di negeri Pulau Pinang untuk menentukan spesies anai-anai perosak utama bangunan. Genus *Coptotermes* merupakan genus utama yang dijumpai di dalam dan di luar bangunan dan ia menyebabkan kerosakan yang serius. Species lain seperti *Odontoterme* sp, *Macrotermes gilvus, Macrotermes carbonarious, Globitermes sulphureus* dan *Microtermes pakistanicus* turut dijumpai dipersekitaran bangunan. Genus *Coptotermes* telah dijumpai di dalam 13 darpada 25 premis yang ditinjau. Daripada kajian perilaku mencari makanan, anggaran populasi *C. gestroi* adalah 56,127±11,925 hingga 4,185,0026±2127328. Walau bagaimanapun, *C. curvignathus* hanya dijumpai pada satu lokasi kajian sahaja. Populasinya dianggarkan sebanyak 2,871,694±1,683,98. Di samping itu, luas kawasan untuk mencari makanan bagi *C. gestroi* adalah dalam lingkungan 0.6 m^2 hingga 300 m^2 dan bagi *C. curvignathus* adalah 324.4 m^2. Selain itu, kadar purata pemakanan *C. gestroi* adalah dalam lingkungan 1.0464 ±0.852 hingga 130.3200 ± 26.486 gram untuk setiap 2 minggu. Sementara itu, kadar purata pemakanan bagi *C. curvignathus* adalah 89. 7500 ±16.154 gram untuk setiap 2 minggu. Sifat tidak menolak bagi racun anai-anai (Premise 200SC) yang mengandungi 18% w/w imidacloprid diaplikasikan seminima yang mungkin disekitar bahagian perimeter luar bangunan dan ditambah sedikit diperimeter dalaman bangunan, terutama di kawasan serangan anai-anai. Tindak balas Premise 200SC secara perlahan membolehkan pemindahan toksik racun ini daripada anai-anai yang terdedah itu kepada ahli-ahli koloni yang lain melalui interaksi social anai-anai, termasuk proses pembersihan badan antara satu sama lain. Ini seterusnya menyebabkan kematian sekunder di kalangan populasi anai-anai tanah. Oleh itu, untuk tujuan mengurangkan penggunaan racun dan kerosakan terhadap bangunan, keberkesanan aplikasi rawatan dengan cara penggunaan imidacloprid (Premise 200SC) yang secara terhad di inovatif perimeter dalaman dan luaran bangunan sebagai satu daripada kaedah pilihan IPM untuk mengawal anai-anai adalah ditafsirkan. Tujuh rumah persendirian telah dipilih untuk dirawat melalui kaedah ini dengan menggunakan racun imidacloprid (Premise 200SC). Kajian ini mendapti beberapa hasil yang menggalakan. Kesemua bangunan yang dirawat dengan cara penggerudian minima menunjukkan pencegahan sepenuhnya populasi anai-anai dalam tempoh antara 2 hingga ke 12 minggu. Walau bagaimanapun, sebuah bangunan dirawat dengan cara penggerudian sepenuhnya disetiap perimeter dalaman dan luaran bangunan sebagai perbandingan untuk menunjukan bahawa populasi anai-anai berjaya dikawal dalam tempoh 6 minggu sahaja.

CHAPTER ONE
GENERAL INTRODUCTION

1.0 Introduction

Termites are social insects with a dual economic and ecological significance. They are beneficial insects in nature because they disintegrate fallen wood and recycle nutrients as humus, thereby contributing to soil genesis, fertility, stability, and hydrology (Gold *et al*., 1999). However, these similar insects can become pests when they attack the structures. The invasions by subterranean termites into structures have been a problem for centuries, since they cause destruction. The cryptic, soil-dwelling nature of these termites has been such that they are rarely discovered until there is evidence of a reproductive swarm or damage to the structure (Thorne, 1999). Subterranean termites are considered as one of the most economically important pests in the world. In the United States, the pest control industry profits billion of dollars annually by controlling infested termite population. The subterranean termites account for approximately 80% of the total amount spent on termite control annually (Su 1991).

Approximately 2700 living and fossil species of termites have been described and 175 species occur in Peninsular Malaysia (Tho, 1992). The vast majorities are found within the tropics and occur in most warm habitats. Termites are well known both for their destruction of human property and for their construction of huge mounds that allow them to have a great degree of control over temperature and humidity of the environment where they live in. Termites inhabit approximately 70% of the world, mainly in the tropical and subtropical regions, extending to some areas in temperate latitudes (Lee *et al*., 1999). The distribution of termites has dramatically increased in the last 20 years and the current distribution of this pest now includes China, Taiwan, Japan, Guam, Midway, Hawaii, Sri Lanka, South Africa and the continental United States. Lee *et al*. (1999) grouped termites as dampwood termites, drywood termites and subterranean termites. In Malaysia, termite controls were focused on the latter group. The most destructive genus in Malaysia is *Coptotermes*. *Coptotermes* have now invaded many sites in the southern United States where they occur symmetrically with many *Reticulitermes* spp. In Peninsular Malaysia, species of *Coptotermes* are widespread in lowland forests, up to an altitude of approximately 1350 meters (Tho, 1992).

Providing a consistent control of subterranean termite population has been a complex and active process. This requires knowledge on a variety of topics including termite biology, the different control tactics available, the assortment of tools required to deliver appropriate treatment options, the landscaping and hydrology surrounding a structure, and building construction (Forschler, 1999). Three most important factors allowing subterranean termites to succefully infest a structure consist of locating adequate food sources, securing necessary moisture levels, and encountering suitable soil temperature to forage (Suiter *et al*., 2002). Today, two different approaches are used for the control of subterranean termite infestation, the first being the application of liquid termiticide and the second is the use of termite bait.

Control strategies against subterranean termites in the urban environment in Malaysia rely heavily on the use of soil termiticides (Chung and Lee 1999). Basically, the usage of soil termiticide can be divided into pre and post construction treatment. The survey conducted by Lee (2002a) on 10 major pest control companies in the country indicated that 50% of the total post-construction treatment jobs comprise dusting and corrective soil treatment, followed by 30% using dusting only, and 20 % using dusting and trenching. Arsenic trioxide is still heavily used for dusting, despite being an unregistered item in Malaysia (Lee, 2002b). Since the banning of Chlordane usage in 1998, chlorpyrifos based products have dominated the termiticide market (80%). Other insecticides used include cypermethrin (5%), chlordane (remaining stock) and other pyrethroids (15%).

The use of chemical applications as some means of eliminating subterranean termites from structures was suggested as early as the late 1800s. However, the actual evaluation of potential chemicals did not get underway until the 1940s (Aventis 2003).

At this time, several compounds were available for use against subterranean termites, including calcium cyanide, sodium cyanide, and carbon disulfide. Termite control by using liquid termiticides was greatly improved with the discovery of more effective chemicals. For instance, the chlorinated hydrocarbons (i.e. chlordane, heptachlor, endrin, aldrin, and dieldrin) were found to be very effective against termites and were relatively stable in the environment. Chlorinated hydrocarbons were used as a liquid barrier around structures for several decades. However, their use as termiticides was terminated by the EPA in 1988 due to their environmental persistence and/or high volatility. For the next following 30 years, organophosphate and pyrethroid chemicals were commonly used as liquid termiticides. Organophosphates, like chlorpyrifos (Dursban TC®), were less persistent in the environment and were widely accepted, although they were more toxic to vertebrates compared to chlorinated hydrocarbons. However, the organophosphate termiticides were also banned by the EPA in 2000. Pyrethroid termiticides are some of the most widely used liquid termiticide treatments today. These chemicals have a relatively long residual life, are effective at low concentrations, and have low acute mammalian toxicity. Pyrethroids are repellent compounds by nature and are used to repel foraging workers away from a treated structure (Su *et al.,* 1982). Pyrethroids products in use today are Tribute® (A.I.fenvalerate), Demon TC® (Cypermethrin), Dragnet® (permethrin), Prelude® (permethrin), Prevail® (cypermethrin), Talstar® (bifenthrin), and Torpedo® (permethrin). Non-repellent termiticides are not detectable by termites. As termites tunnel into treated soil, theyl come into contact with the insecticide and are either killed quickly or pick up a sublethal dose and become intoxicated. The intoxicated termites could not feed or groom themselves and, therefore, can die due to indirect effects of exposure. Products in use today include Premise® (imidacloprid) and Termidor® (fipronil). Imidacloprid is categorized as chloroniotinyls, whereas fipronil is a pyrazole insecticide.

Premise 200SC containins imidacloprid and is a non-repellent termiticide which provides a treated zone in the soil. Termites then will get affected when they pass through the treated zone. It also produces a transfer effect among the members of a termite colony through grooming and incidental contact. Previous research shows that the active ingredient of Premise®, imidacloprid, are transferred between individual termites (Thorne and Breisch,2001; Shelton and Grace,2003; Tomalski and Vargo,2004; Abdul Hafiz and Abu Hassan, 2006; Abdul Hafiz *et al.,* 2007) and that effect can be far reaching beyond the treatment area (Obsrink and Lax,2003,).

Termites has ever since become an alarming problem in Malaysia. This research was carried out to prove that the minimum usage of termiticide of imidacloprid (Premise 200SC) with limited interior perimeter treatments, plus limited external perimeter treatment as an Integrated Pest Management (IPM) option for subterranean termite management, can successfully control termite population in infested buildings. Thus it minimizes pesticide use and intrusion to homeowners as claimed by the manufacture. Furthermore, the minimum usage of termiticide can save time, labor and money

The objectives of this research are

1. To determine the important termite species infesting buildings in Penang
2. To determine the foraging activity and the territory of the subterranean termite
3. To observe and monitor food consumption of subterranean termites.
4. To investigate the efficacy of Premise 200SC (imidacloprid) with limited interior perimeter treatments plus limited external perimeter treatment as an IPM option for subterranean termite management which is considered to minimize pesticide use and intrusion to homeowners (minimum treatment).

CHAPTER TWO

LITERATURE REVIEW

2.1 Subterranean termites in historical perspective

The fossilised remains of termites were documented 120 million years ago during rock formations (Krishna, 1992). Termites are of ancient lineage, having evolved approximately 200 million years ago (Krishna, 1992) from cockroach like insects (Prestwick, 1983). Unlike their close relatives, the scavenging cockroaches, termites lead a secretive life (Kofoid, 1934). The *Reticulitermes* and *Coptotermes* or subterranean termites spend their entire life in complex nests hidden below the surface of the soil or encased in wood (Wood, 1978b). Wood and other plant tissues comprised largely of cellulose are also the termites' primary source of food (Wood, 1978a; Potter, 1997). The common name, termite, derived from the Latin word terms, translated literally as woodworm (Potter, 1997). Old Chinese documents of two thousand years stated that termites were then, as now, an economically important pest of stored goods and wooden structures (Li *et al*., 1994). Presently, termites are believed to be the largest single cause of lumber decay in tropical areas (Mill, 1991). Thirty pest species of termites are reported to be found in North America (Su and Scheffrahn, 1990a) whereas two genera of termites, *Reticulitermes* and *Coptotermes*, are claimed to be a little of foreign affairs and forth responsible for most of the structural damages caused by termites in the United States (Su, 2002). Su (2002) reported that the economic impact of subterranean termites in the United States now exceeds $10 billion annually. In the southeastern U.S., the economic impact of termite damage is estimated to be 2-10 times greater than the impact of insect pests of any agricultural commodity (Su and Scheffrahn, 1990a).

Tthroughout history, humans have sought to protect their possessions from subterranean termites with various types of poisons. In the early part of the twentieth century, arsenic compounds were popular for the treatment of termite infestations (Randall and Doody, 1934 a, b, c). Physical barriers made of copper and lead were also used as a toxic subterranean termite preventative measure (Brown *et al.,* 1934; Potter, 1997). Later, soil treatments, including trichlorobenzene, were used to prevent subterranean termite attack (Hatfield, 1944; Beard, 1974; Williams, 1977; Su, 2002).

2.2 Termite ecology and biology

2.2.1 Social Insects

Termites, like other social insects, are characterized by their cooperation in the rearing of young, sharing of resources (i.e., food, water and shelter), overlapping of generations (i.e., eggs are laid year-round), and a division of labour, as characterised by the presence of one or more castes, or life forms.

Termites are insects that live in loosely associated societies called colonies. A colony is a collection of individuals that cooperate in the rearing of young and that share resources (e.g., food and shelter). Some scientists view the termite colony not as a collection of individuals but as a single living entity whose parts (i.e., individual termites) work together towards the survival and reproduction of the whole (i.e., the colony). Termite colonies are comprised of a few adults (the king and queen) while the majority of the population are immature forms that are represented by approximately equal number of males and females. The colony structure of subterranean termites does not likely reflect the model of other insect social organisations. In general, most social insects have a colony structure where the majority of members are females concentrated in a single, centralised, immobile nest from which the workers forage in search of food and water. Subterranean termite social groups are composed of both males and females and have a mobile nest site usually located near food, most often some form of dead wood that they excavate and inhabit (Pearce, 1997).

2.2.2 Termite Caste

Termites exhibit a caste system of organisation, wherein physically distinct individuals perform different tasks in the highly structured termite society. The proportion of each caste is regulated by a variety of environmental factors as well as the presence or absence of caste-regulating pheromones (chemicals) produced by the termites themselves. Generally there are three castes which are the worker caste, the soldier caste and the reproductive caste (Pearce, 1997).

2.2.1.1 The Worker Caste

Worker termites are physically and sexually immature males and females and are most numerous in the caste. These wingless, white insects are typically the first termites seen when an active shelter tube, infested log, or piece of infested structural wood is breached. Workers are blind and probably only perceive changes in light intensity. Workers destroy wood because they consume it. They are called workers because they perform most of the labour associated with colony maintenance. Worker termites are involved in numerous tasks such as locating and colonising food resources; excavating, repairing, and building galleries and shelter tubes; feeding, grooming, and caring for young termites (Pearce, 1997).

2.2.1.2 The Soldier Caste

Soldier termites are physically and sexually immature males and females whose primary function is to defend the colony. Soldiers are easily identified by their enlarged, yellowish to yellowish-brown head and long, hard black mandibles (mouthparts) that they use to ward off enemies, primarily ants and termites from other colonies. Soldier termites are wingless, blind, and otherwise soft-bodied (Pearce, 1997).

2.2.1.3 The Reproductive Caste

Adult winged termites, called alates or swarmers, have two pairs of long, narrow wings of equal size, thus describing the name of the Order of classification to which termites belong—Isoptera; *iso*, meaning equal, and *ptera*, meaning wing. Alate termites have fully functional wings and eyes, and their pigmented, dark skin can best tolerate water loss than the aforementioned immature forms. Unfortunately, alate termites are sometimes mistaken for flying (alate) ants. A winged termite can be easily distinguished from a winged ant by the presence of straight to slightly curved, beaded antennae while winged ant has distinctly elbowed antennae. A termite lacks of a "waist" while a winged ants have a distinct constriction between its body regions. Futhermore. A termite ha two pairs of equal size wings while the front pair of the ant's wing are larger than the hind pair.

The sudden, dramatic appearance of alate termites is commonly referred to as *swarming*, and when it occurs indoor it is often one of the first signs of a structural infestation. Subterranean termites swarm in an attempt to initiate new colonies. Fortunately for homeowners the success rate of colony establishment via swarming is extremely low because most alates die soon after swarming. Alates commonly succumb to desiccation, predation, and other environmental factors. Swarming occurs mainly when the outdoor temperatures are warm, and usually is carried out only by matured colonies (Pearce, 1997).

2.3 Food consumption, foraging behavior, trail pheromones and population

2.3.1 Food and feeding habits

The main source of termite feed are cellulose-based materials (Pearce, 1997). Although termites are soft-bodied insects, their hard saw-toothed jaws work like shears and can bite off extremely small fragments of wood (Pearce, 1997). Chemically, their food can be characterized as lignocelluloses matter, which is the most abundant organic material in the biosphere. Preferences for food by termites and resistance of wood species to termite infestation depend on the hardness, lignin content and the chemical constituents of the material. These factors vary in various species to species of wood and during the life of a tree. Termites are able to digest cellulose. As for the lower termites, they depend on the protozoa flagella in the gut to digest the cellulose (Lewis & Foshler, 2006). According to Lewis and Foshler (2006), there were nine genera of protists found in the hindgut of *Reticulitermes flavipes, R. virginicus* and *R. hageni.* They were *Dinenympha, Holomastigotes, Microjoenia, Monocercomonas, Pyrsonympha, Spironympha, Spirotrichonympha, Trichomitus and Trichonympha.* Meanwhile, Sajap and Lardizabal (1998) reported that there were three genera of protists found in the hindgut of *Coptotermes curvignathus* which were *Pseudotrichonympha, Holomastigotoides* and *Spirotrichonympha.*

For termite consumption, trophallaxis involves the exchange of secretions/liquid food between individuals. Termites can pass partially digested semi-liquid food from the crop or secretions by mouth (stomodeal feeding), or receive secretions from the anus of another termite (proctodeal feeding) (Pearce, 1997). Nonetheless, several workers can be involved with the transfer of food at the same time. The degree of trophallaxis within a colony depends on its size and age, and the seasonal variation of food supply. Salivary glands of the termites may vary in size. In *Macrotermes bellicosus,* the nursery workers have the largest salivary glands for feeding the young. Meanwhile, the lower termites that have protozoan in their gut, will lose the salivary glands just before moult but regain them later through trophallaxis (Pearce, 1997).

2.3.2 Termite foraging behaviour

The gallery system of a single colony may exploit food sources over as much as one hectare, with individual galleries extending up to 100 m in length. Apart from grass-eating species that forage in the open at night, all subterranean termites remain within a completely closed system of galleries, devoid of light. In addition, all termite castes are mobile throughout their lives. Even the reproductives move freely from one feeding site to another. As a result of this mobility, there appears to be no permanent central nest area. On any given day the reproductives, eggs and or very young termites might be found in different sites occupied by a colony. Termites living within their food resources are free to move from one location to another within the network of galleries. They are connected to various food resources identified by their nest mates. The colony is thought to concentrate its activity in different locations at different times. Termite activity might be concentrated in one section of their feeding range at one point and just within days or weeks later might shift to yet another section.

When searching for food, termites follow chemical and moisture gradients in the soil, as well as physical guidelines such as roots, abandoned insects and earthworm tunnels, foundation elements, and cracks or crevices in the soil profile. Studies on the geometry of search show that gallery construction tends to minimize repeating the search in the same area (Long and Thorne 2006). According to the examples given by Long and Thorne (2006), when the subterranean termite *Reticulitermes flavipes* builds two galleries, they tend to be about 180 degrees apart. If three galleries are constructed, they are separated by about 120 degrees and four-branch galleries divide the ground to be searched into approximately 90 degrees sectors. Termite foraging activity in soil is usually is confined to areas of adequate moisture and moderate temperature. In addition, according to Kaib and Ziesmann (1992) and Reinhard *et al*. (1995), African termites *Schedorhinotermes lamanianus* and the French species *Reticulitermes santonensis* recently demonstrated that during communal food exploitation, the labial gland secretion is released onto the feeding workers. It contains a chemical signal that stimulates additional workers to feed at the same site, thereby initiating clusters of feeding termites, aiding in efficient food exploitation. The feeding stimulating signal was shown to be highly polar, heat- resistance, and nonvolatile as in both *S. lamanianus* and *R. santonensis* (Kaib and Ziesmann, 1992; Reinhard *el al*., 1997). Furthermore, both termite species belong to the same family, Rhinotermitidae, but they differ in many aspects of their biology, such as habits, nesting habits, and foraging and recruitment strategies. While *S. lamanianus* is an arboreal termite that lives in the humid forest of tropical Africa, *R. santonensis* occurs in a temperate zone of France in subterranean nests (Harris, 1968; Becker, 1970; Kaib and Brandl, 1992; Brandl *et al*.,1996). According to Schedel and Kaib (1987), in the case of *S. lamanianus,* foraging is initiated by soldiers. On the contrary, *R. santonensis's* foraging is initiated by the workers. Nevertheless, both species form distinctive feeding clusters on the food source induced by the release of a feeding stimulating signal. Therefore, this may indicate that feeding stimulation by the chemical signal from the labial gland is a general strategy for the organization of communal food exploitation in termites.

In addition, according to Theresa *et al*. (2000), termites may also encounter the tunnels of other termites that are still in use or have been abandoned. Entering the active tunnels of conspecificsor other species may lead to aggressive encounters. Although such confrontations may be costly, winners may reap the reward of access to a valuable resource at the end of the tunnel. However, some aspects of foraging or search behavior of several species of termites have been studied. An extensive examination of the underground gallery system of a *Macrotermes bellicosus* (Smeathman) colony in Africa revealed that the termites built many more foraging tunnels when the colony was in need of food (Lys and Leuthold, 1991). This is an example of how the needs of the colony may affect tunneling behavior. Additionally, Asian species of *Macrotermes*, *Longipeditermes*, and *Hospitalitermes* follow preexisting guidelines found in the open field land and respond to gravitationally forces as they forage above ground in the open air without the cover of shelter tubes (Jander and Daumer, 1974).

2.3.3 Foraging trail pheromones

The organization of the foraging and recruitment process in social insects as well as the underlying mechanisms have been investigated in many species within both Hymenoptera and Isoptera (Reinhard and Kaib, 2001). While many ants and bees also rely on optical cues, the search for food in termites is organized predominantly by chemical signals such as pheromone trails laid on the substrate for orientation and recruitment. According to a research conducted by Holldobler and Wilson in 1990, only two components have been identified with certainty. Behavioral evidence suggests that termite trail pheromone are multicomponent systems as shown by some ants. Several researchers suggested that additional compounds act for the species specifity (e.g., Moore, 1974; Howard *et al*., 1976; Oloo, 1981; Oloo and McDowell, 1982; Kaib *et al*. ,1982; Runcie, 1987; Grace, 1991; Laduguie *et al*. ,1994) and for the differentiation between foraging and recruitment trails (Traniello, 1982). Furthermore, qualitative or quantitative differences in pheromone trails laid by the different castes have been suggested as the cause for caste-specific polyethism during termite foraging and recruitement (Lys and Leuthold, 1991; Traniello and Busher, 1985; Schedel and Kaib, 1987; Kaib, 1990). Tokoro *et al.* (1991) and Tokoro et al (1989) had isolated the trail pheromone from two rhinotermitidae termites, *Reticulitermes seperatus* (Kolbe) and *Coptotermes formosanus* Shiraki. They identified it as DTE-OH which may be a trail pheromone common to the Rhinotermitidae family. Meanwhile, according to another research conducted by Reinhard and Kaib (2001) on *Reticulitermes santonensis*, like the other *Reticulitermes* species, they indicate that the pheromone isolated as only (Z,Z,E)-3,6,8-DODECATRIEN-1-OL and was shown to be a major compound of the trail pheromone of *R. santonensis*.

Caste- specific polyethism during foraging and recruitement has been observed in various termite species (e.g., Heidecker and Leuthold, 1984; Lys and Leuthold, 1991; Traniello and Busher, 1985). According to a research done by Reinhard and Kaib (2000), it demonstrates a caste specific difference in trail following, with workers having a lower threshold than the soldiers. This corresponds to the different roles of the two castes during the search for food (Reinhard *et al*., 1997). In addition, foraging in *R, santonensis* is initiated by the workers. They are the first to enter an unknown territory, relying on weak and incomplete trails for orientation. Therefore, they need to react to rather low quantities of the trail pheromone. Meanwhile, the soldiers of *R. santonensis*, in contrast, do not participate in foraging, but appear only after considerable reinforcement of the foraging trails or when wood is discovered and strong recruitment trails are laid (Reinhard and Kaib, 2001).

2.3.4 Studies on foraging population

According to Nutting and Jones (1990), ecological studies of termites include termite trapping, population estimation and foraging territory. For this matter, many shapes and patterns had been produced to trap termites above and under the ground. The earlier method for trapping termites above the ground was done by using the roll of tissue to trap *Heterotermes aureus* (Haverty *et al.,* 1974; Haverty and Nutting,1975). Furthermore, this method was later modified by substituiting corrugated fiberboard to trap eastern subterranean termites, *Reticulitermes flavipes* (Esenther,1980), the mound building species, *C. lacteus* (French and Robinson 1985), and to extract termites from wood in the laboratory (La Fage *et al*., 1973). According to Tamashiro *et al.* (1973), paper products such as toilet rolls or fibreboard, however, disintengrate rapidly under warm and humid conditions, thus they are not suitable for field baiting. Nevertheless, these paper products are easily and quickly consumed by termites. Therefore it is not suitable for long term research in the field. Eventually, to overcome this matter, the wooden trap developed by Tamashiro *et al.* (1973) for collecting and monitoring field activities of *C. formosanus* appears to be suitable for field studies of termites. The trapping method introduced by Tamashiro *et al.* (1973) is composed of a bundle of wood placed on the ground covered by a steel can (27 cm diameter by 36 cm high).

In addition, studies of the foraging activity and foraging population size have been studied on several species of termites, *Reticulitermes spp*. and *Coptotermes formosanus* Shiraki (Su and Scheffrahn, 1988; Su *et al*., 1984, Haagsma and Rust, 1993; Forschler and Townsend, 1996a). These studies employed wood filled inspection port or wooden stakes placed in urban areas in order to define foraging territory. On the other hand, one of the earliest mark recapture experiments conducted on termite field Colonies, Su *et al.* 1984 concluded that by depositing their nutritional payload at the main nest, *Coptotermes formosanus* (Shiraki) workers redeployed randomly among the colony's established feeding sites, thus a colony's entired population cycles through all of its feeding sites at random. However, Evans *et al.* (1998 and 1999) showed that marked subterranean nesting foragers consistently failed to remix uniformly with their unmarked nestmates. Similar patterns are evident in previous *Reticulitermes* work (Su *et al*. 1993a, Forschler and Townsend, 1996b).

The first single mark recapture method to estimate foraging population was introduced by Lai (1977) using Lincoln Index formula to estimate the foraging population of *C. formasanus*. Recently, Abdul Hafiz *et al*., (2007) also used single mark recapture to estimate the foraging population of *Globitermes sulphureus* in Penang, Malaysia. However, because the use of single mark recapture had been argued for its high standard error (Su & Scheffrahn 1988, 1996), therefore a triple mark recapture was introduced using Weighted Mean Model (Begon, 1979). This method is widely used nowadays by termite researchers to estimate the foraging population of *Coptotermes formasanus* and *Reticulitermes flavipes* (Su *et al.* 1991; Su 1994; and DeMArk *et al*. (1995). Meanwhile in Malaysia, the triple mark recapture was also used by Sajap *et al*. (2000), Abdul Hafiz and Abu Hassan (2006) to estimate the foraging population of *C . curvignathus,* Abdul Hafiz *et al.* (2006) to estimate foraging population *of C. gestroi.*

During the process of estimating a termite population and its foraging territories, a selection of suitable marker (dye) is very important (Begon, 1979). A dye, Sudan

Red 7B, was used as a marking material for the foraging population studies (Lai, 1979). Su *et al.* (1983) also used Sudan Red 7B as a candidate marking material to examine the foraging activity of *C. formasanus*. According to Su *et al.* (1983), the marking material used to trace the subterranean activity of *C. formosanus* must remain on the termite during the experimental period and ideally is measureable quantitatively. Ngee (2001), in his research on *Globitermes sulphureus* in the laboratory showed that Nile Blue A gave a long lasting stain of 60 days. In Malaysia, Sajap *et al* (2000), Lee (2001) , Lee *et al*.(2003b) and Abdul Hafiz *et al.* (2006) used Nile Blue A to estimate the termite foraging population of *C. gestroi* , *C. curvignathus* and *Globitermes sulphureus.*

2.4 Economic importance of termites

The genus *Coptotermes* is a worldwide pest. It has a more economic impact than all the other termite species found in the world (Edwards and Mill, 1986; Su and Scheffrahn, 1998) and in Australia (Gay and Calaby 1970; French *et al.,* 1986). All the *Coptotermes* listed in the family of Rhinotermitidae, are subterranean or above ground wood eaters, and are widely distributed across the world. At present, the taxonomic status of several species of *Coptotermes* is less than certain (Su and Tamashiro, 1987). It is hoped that deoxyribonucleic acid (DNA) or cuticular hydrocarbon analysis will assist in clarifying accurately the various *Coptotermes* species (Watson & Abbey, 1990).

In Australia, the most economically important termite species in relation to timber-in-service is *Coptotermes acinaciformis* (Froggatt) (Gay and Calaby, 1970). The worldwide cost to control termite damage has been estimated to be at approximately US $2 billion (Edwards and Mill, 1986). About 5% of the 2500 termite species cause significant damages to timber-in-service; to name a few, *Coptotermes* species (Asia, Australia, China, Japan, South Africa, Thailand and USA,), *Reticulitermes* species (China, Japan, Southern Europe, and USA), *Mastotermes darwiniensis* (Papua New Guinea and Northern Australia), *Heterotermes* species (Asia, Australia, and Southern

USA) and *Nasutitermes* species (Australia and South America), *Psammotermes* and *Anacanthotermes* species (Africa and Middle East) and some *Macrotermitinae* (Africa and Asia) (Harris 1968; La Fage *et al*., 1973). *Coptotermes acinaciformis* are found in every major capital city on the mainland of Australia, except Canberra.

The economic importance of *Coptotermes* in Peninsular Malaysia has been reviewed by Tho and Kirton (1990). In some exotic plantations of *Araucaria* and *Pinus* in Malaysia, up to 100% of trees can be attacked by *Coptotermes* species (especially C. elisae) and can become a major limitation to re-afforestation schemes (Dhanarajan, 1969). In urban areas and rural settlements, *Coptotermes* are the main cause of damage to wood-based building materials in Malaysia (Lee, 2002b).

Under natural conditions in the Malaysian rain forest, *Coptotermes* may be rare. When the trees are cleared, other species of termites are killed and waste vegetation becomes an ideal food for *Coptotermes*. However, newly planted crops or tree seedlings will not be attacked until this food supply runs out. Termite attacks can often reduce the value of timber not only because of the direct effect of the termites themselves, but also because of the allowance of entry of other pests and pathogens.

Although *Coptotermes* mainly attack trees, they sometimes damage crops as well. For example, *C. formosanus* has been reported to damage groundnuts and other food crops in China and Japan (Sands, 1969). Seasonal changes in foraging groups can affect the amount of damage that occurs. Attacks on healthy young rubber trees in Malaysia by *C. curvignathus* can occur within 3-4 weeks.

In some trees (e.g. oil palm) termites can feed just under the bark or under leaf bases, as in coconuts. Large cavities can be also eaten out of trees. In Indonesia, *C. curvignathus* enter wounds and damages tend to be greater in older plantations. In Malaysia, *Coptotermes* spp. are more abundant in outlying habitats, particularly in *Avicinia mangrove* swamps. These places act as reservoirs for re-infestation (Tho, 1992).

2.5 Controls of Subterranean Termite

Subterranean termites can cause extensive damage when they forage into wooden structures, and considerable effort has been put to discover methods of control. Today, two very different approaches are used for the control of subterranean termite infestations: the application of liquid termiticides and the use of termite bait systems. Liquid termiticides are applied to the soil beneath a structure and are intended to provide a defensive barrier between the termites in the soil and the structure above. Liquid termiticides are applied by drenching or injecting the soil along the perimeter outside and inside of foundations where feasible, especially around the supporting piers, chimney bases, and pipes, under filled porches and terraces, and under driveways (Rambo, 1985). If necessary, the concrete slab is drilled so that the soil underneath may also be treated. Liquid termiticides are applied around the foundation at a rate of 4 gallons per 10 linear feet, per foot of depth to the footer (Rambo, 1985).

The bait systems have a more direct approach to termite control. The baits target the termites themselves and are designed for colony elimination. Bait systems do not utilise a permanent liquid barrier in the soil. Instead, they are used to monitor for termite infestations with multiple in-ground stations containing pieces of untreated wood. A pest control operator places these in-ground stations around the perimeter of the foundation, and the stations are checked periodically (monthly, bimonthly, or quarterly). When a termite infestation is discovered, a toxicant formulated in a cellulose matrix is inserted into the bait station. Termites foraging at the station carry the toxic materials back to the colony. Thus, the bait systems are designed as a stand alone treatment and are normally not combined with conventional liquid applications. Although liquid termiticides are still the primary method of subterranean termite control, bait systems are becoming more widely used. Both approaches differ greatly in terms of their methodology, yet their ultimate goals are the same, protecting the structures from being attacked by termites (Su *et al*., 1982).

2.6 The development of commercial termiticides

During the 1920s and 1930s, the first long-term surveys of possible preventive termiticides were initiated by a private industry in the United States (Randall and Doody 1934c; Hatfield, 1944). The earliest research into possible soil barrier treatments met with little success. The only compounds identified as effective termiticides were too expensive to be of practical use (Randall and Doody, 1934c). It was not until after World War II that the cyclodienes, a class of chemical compounds identified as highly effective termiticides, became commercially available (Ware, 1999). Soil barrier treatments created by saturating building sites with cyclodienes prior to construction were the standard weapon against structural infestation used from the late 1940s until 1988 (Lewis, 1980; Su and Scheffrahn, 1990b Jitunari *et al*., 1995). The cyclodienes, particularly chlordane, were extremely efficacious and stable in the soil, in some cases protecting structures from subterranean termite infestation for several decades (Lenz *et al*., 1990; Su and Scheffrahn, 1990b; Grace *et al*., 1993).

Unfortunately, improper application frequently resulted in the volatilisation of chlordane into the structures built on treated sites (Midwest Research Institute, 1994; Jitinari *et al*., 1995; Kilburn and Thornton, 1995; Sim *et al*., 1998; Environmental Protection Agency, 2003; Australian Department of Environment and Heritage, 2001). In addition, the manufacturing practices of Velsicol, the sole licensed producer of chlordane, led to chlordane's widespread intrusion into both the atmosphere and groundwater (Midwest Research Institute, 1994; US Geological Survey, 1997; Environmental Protection Agency (EPA), 2003).

Because of cyclodiene residual longevity, questions were raised about the environmental impact of these chemicals (Lewis, 1980; Su and Scheffrahn, 1990a; Mill, 1991; Wood and Pierce, 1991 & Singh *et al*., 1992). The research carried out by (EPA, 1998) demonstrated that long term exposure to organochlorines, like the cyclodienes, resulted in biomagnification and accretion in the fatty tissues of humans (Lewis, 1980;

Jitunari *et al*., 1995; Kilburn and Thornton, 1995; EPA, 1998; Nasir *et al*., 1998; Sim *et al*., 1998) and other organisms (Lewis, 1980; EPA, 1998; Walker and Newton, 1998). In 1973, Velsicol Chemical Corporation, the licensed producer of chlordane, funded a study performed by the International Research and Development Corporation (IRDC) to determine chlordane's mammalian toxicity. IRDC reported that mice were given oral doses of 25- and 50-ppm of technical chlordane daily for 18 months and they showed a decreased rate of survival, relative to controls. EPA-sponsored examination of mouse liver histological slides found a statistically significant increase of carcinomas in groups of mice exposed to 25- and 50-ppm doses of technical chlordane (EPA, 1998). As a result of this study, most agricultural uses of cyclodienes in the U.S. were canceled in1980 (Ware, 1991; EPA, 1998). In 1988, the use of chlordane and heptachlor, as termiticides, was canceled through mutual agreement of the EPA and Velsicol Corporation (Robertson and Su, 1995 and EPA, 1998).

For the next decade, the only termiticides available for use as soil barrier treatments were chlorpyrifos (an organophosphate) and several pyrethroids. The residual activity of chlorpyrifos was significantly shorter than that of the cyclodienes (Lenz *et al*., 1990; Grace *et al*., 1993). In addition, the toxicity of chlorpyrifos to subterranean termites was significantly affected by the variations in the clay and cellulose content of treated soil (Smith and Rust, 1993). As a result of the Food Quality Protection Act of 1996, EPA revised its risk assessment of chlorpyrifos and, in the year 2000, a joint agreement of the EPA and the registered manufacturers of chlorpyrifos canceled the chlorpyrifos' use as a soil barrier treatment against subterranean termites (EPA, 2000).

Pyrethroids are more durable than chlorpyrifos, but less stable in the soil than the cyclodienes (Lenz *et al*., 1990; Su and Scheffrahn, 1990b; Pawson and Gold, 1996). Soil barriers composed of pyrethroids are more likely to fail than barriers composed of cyclodienes or chlorpyrifos (Lenz *et al*., 1990; Su and Scheffrahn, 1990b;

Su *et al*., 1993b; Forschler, 1994; Kard, 1999) because pyrethroids are repellent to subterranean termites (Su and Scheffrahn, 1990b; Rust and Smith, 1993; Su *et al*., 1993b). Subterranean termite foragers are able to detect and avoid repellant termiticides. So areas treated with pyrethroids are rarely contacted. The subterranean termites' ability to detect chemical barriers allows termite foragers to follow the edge of the pyrethroid treated area until they find a gap in the treatment (Su *et al*., 1982; Su and Scheffrahn, 1990b; Rust and Smith, 1993; Forschler, 1994). Thus, gaps in pyrethroid applications may actually funnel foragers towards the structures intended to be protected (Forschler, 1994; Kuriachan and Gold, 1998).

The inevitability of gaps in soil termiticide barriers is a major limitation to the efficacy of repellant liquid termiticides (Forschler, 1994; Kuriachan and Gold, 1998). Gaps may exist in a soil termiticide treatment for a number of reasons. Firstly, pre-construction treatments often contain gaps due to imperfect initial application or physical disturbance of soil after the application (Su and Scheffrahn, 1990a, 1998). So when an existing structure becomes infested and requires a remedial termiticide application, it is difficult to create a continuous horizontal barrier of liquid termiticide beneath the structure (Su and Scheffrahn, 1990a, 1998). Next, all termiticides degrade over time. An ageing soil treatment, applied below the foundation before a structure was built, is inaccessible after construction and cannot be reapplied (Su and Scheffrahn, 1990a).

At the beginning of year 2000, several new nonrepellent soil termiticides had appeared on the market such as fipronil, imidacloprid, and chlorfenapyr. These are all considered to be non-repellent, and to have a delayed mode of action that ultimately kills large numbers of termites (Potter and Hillery, 2000). These termiticides have generated interest as soil barrier treatments as they have achieved a level of performance not seen since the days of chlordane (Potter and Hillery, 2003). It is believed that these non-repellent termiticides cannot be detected by foraging termites in a treated area because of its non repellent and odorless characteristics (Thorne and Breisch, 2001). Nevertheless, it has been hypothesised that the population of termites could be exposed to and killed by the termiticide instead of termites avoiding the treated soil much in the same manner as was the case for chlordane (Kard, 2003).

There is a new evidence which shows that there could be an additional advantage of using these new products, especially due to their delayed mode of action. It has been suggested that the toxicant is transferred to the nest mates in the field. This is known as the “transfer effect”. When the second termite picks up a lethal dose of chemical in this manner, it is called “secondary mortality”. Laboratory studies have qualitatively shown that secondary mortality is caused by fipronil in subterranean termites (*Reticulitermes spp*. and *C. Formosanus*) and in German cockroach, *Blattella germanica* (L.) (Shelton and Grace, 2003; Ibrahim *et al*., 2003; Buczkowski and Schal, 2001; Durier and Rivault, 2000; Clement, 1998). However, only little information, is available concerning the magnitude and mechanism of the transfer effect (Shelton and Grace 2003).

In the case of carton-forming termites like *C. formosanus,* Su *et al*. (1982) had proposed another control strategy. Non-repellent and slow-acting termiticides could be introduced into a portion of the colony and this will be distributed to its entire population through social interaction. One hypothesis is that secondary mortality could occur through the social phenomenon of trophallaxis, which Suarez and Thorne (2000) defined as “the direct transfer of alimentary liquids, including suspended particulates and derivatives, from one nest mate to another via regurgitation or anal feeding”. Trophallaxis is a mechanism for the transfer of nutrients, symbionts, pheromones, and information within social insect colonies. In *R. flavipes* and *R. virginicus,* >20% of the alimentary fluid in a donor is transferred to a recipient group and it is distributed in a “trophallactic cascade”. The donor termite it turn transfers the fluid to a recipient termite and that recipient termite will in turn transfer it to another recipient until all have about the same volume (Suarez and Thorne, 2000). Both the amount of alimentary fluid passed on from a foraging termite to the nest mates, and the method in which it is done, has made trophallaxis a feasible method for the transfer of fipronil in termite population. Other possible mechanisms for horizontal transmission include cannibalism, necrophagy (consumption of dead termites), corprophagy (consumption of termite faeces), and social grooming.

In a recent survey in the United State, it was discovered that 93 percent of householders expressed concern about the application of termite control chemicals inside their homes (Potter and Bessin, 2000). This has been a definite problem when a houseowner has had to choose between the use of liquid termiticide barrier treatments and the stand-alone baits that are placed only on the exterior of a structure. A newer research has suggested that subterranean termite infestations can be eliminated by applying fipronil and imidacloprid solely around the exterior perimeter of buildings because the "effects of the termiticide extend inwards and well beyond the exterior site of application" (Potter and Hillery, 2002; Potter and Hillery, 2003; Abdul Hafiz and Abu Hassan, 2006). It has been reported that only minimum usage of imidacloprid will work effectively because of its "transfer effect" (Abdul Hafiz and Abu Hassan, 2006). Therefore this has been a very attractive idea to pest control operators because it means that they could theoretically treat a termite infection by just using a minimum application of termiticide either through minimum drilling or small residue spraying, just like with baits. At the same time, it can save time, labour, and money. This would be especially important, considering that the new termiticides are considered to be less persistent. Thus, structures treated with them may need to be treated more often.

2.7 Minimum usage of termiticide and benefit to customer

Traditional application technology associated with soil barrier treatment is destructive to property owners. Therefore there is a need for the use of a high amount of finished product because it specifies a thorough application to the interior by drilling holes through the foundation, and treating with a uniform application to the exterior perimeter (Potter and Hillery, 2003; Hu and Hickman, 2006 ; Kamble and Davis, 2005). According to Potter and Hillery (2003) it is believed that the application of non- repellent liquid termiticides can be destructive to property owners due to the traditional application. Recent reports suggested that subterranean termite infestation can be eliminated by applying fipronil solely around the exterior building perimeter plus limited interior (Potter and Hillery, 2002; Potter and Hillery 2003; Kamble and Davis 2005; Hu and Hickman 2006). According to Hu (2005), this application was practiced in the field because of the termiticide's unique character. Its delayed mode of action permits the transfer of its toxicant from exposed termites to unexposed nest mates through social interactions, including mutual grooming, thus causing secondary mortality in subterranean termite population. Meanwhile, a research conducted by Waite *et al*.,(2004), supports this new method of application. He found that although a barrier of treatment had been applied outside the house perimeter, there was still a possibility that an interior population of termites will not be controlled due to the inaccessible entry points that were not treated. In addition, according to (Hu, 2005) the present study demonstrates that the new method of applying a minimum usage of termiticides can be an effective option in termite IPM programmes, including multiple tactics such as moisture management, inspection, monitoring, education, and collaboration of all termite-affected parties.

2.8 PREMISE 200SC (Imidacloprid)

Imidacloprid is a relatively new insecticide. It was first registered for use as a pesticide in the U.S. in 1994, and was the first insecticide in its chemical class to be developed for commercial use. Imidacloprid is a systemic insecticide. It moves through plants from the place where it is applied and kills insects when they feed on these plants. Its major manufacturer is Bayer Corporation that markets imidacloprid products with the brand names of Merit, Admire, Premise, Pre-Empt, and Advantage, among others. It is a relatively new, systemic insecticide chemically related to tobacco toxin nicotine. Like nicotine, it acts on the nervous system. Worldwide, it is considered to be one of the insecticides used in largest volume. It has a wide diversity of uses in agriculture, on turf, on pets, and for household pests**.** The development of imidacloprid for termite control began in the late 1980s (Reid, 2001), and culminated in the registration of Hachikusan® in Japan in 1993. Imidacloprid soil treatments have been evaluated for termite control efficacy in more than 25 distinct trial locations in four continents (Reid, 2001). These trials have challenged the effectiveness of imidacloprid treated soils by exposure to more than 20 species of termites including *Allodontermes, Amitermes, Coptotermes, Heterotermes, Macrotermes, Mastotermes, Microcerotermes, Microtermes, Nasutitermes, Reticulitermes, and Schedorhinotermes* (Reid, 2001).

Imidacloprid works differently compared to other insecticides presently being marketed (i.e. carbamates, organophosphates and pyrethroids). The mode of action is based on interference of the transmission of impulses in the nerve system of insects. Similar to the naturally occurring signal-transmitting acetylcholine, imidacloprid stimulates certain nerve cells by acting on a receptor protein. In contrast to acetylcholine, which is quickly degraded by the enzyme acetylcholine-esterase, imidacloprid is inactivated either very slowly or not at all. It has both contact and ingestion activity. The target pest’s feeding activity ceases within minutes to hours,