Review Article

# Studies on Damage of Constructions Caused by Subterranean Termites and Its Control in Thailand*[1]

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## Introduction

Since wood is one of the oldest, most important and most versatile building materials and still widely utilized by us, particularly in less well-developed countries, it might continue to be only one available material in the future. Termites have long been a serious pest of wooden constructions, timber products and any other lignocellulosic materials, and they are still causing an important problem in most of tropical regions. Among more than 2,200 species of termites in the world, about 150 are known to damage wooden structures[1)] and divided into the three groups according to their habit, nature of damage and moisture requirement[2)]. They are drywood termites (live entirely within drywood and do not need to access to an external moisture source and soil), dampwood termites (live in old tree stumps, rotting logs and pieces of buried timbers, and can also invade into sound wood in buildings), and subterranean termites (build shelter tubes and nest in the soil or on the sides of trees or building constructions and rely principally on soil for moisture).

Current termite control of buildings has been carried out in two distinct time phases[2,3)]. First one is a pre-construction treatment, where environment is processed to confer a protection against termite attack before any wood damage. Second one is a post-construction treatment or remedial treatment for wooden structures damaged by termites.

Early pre-construction treatment was the synonyms of good buildings practices which offered the construction with adequate ventilation or consisted of durable timbers. Proper sanitation, removing all stumps and wooden debris from a building site before and after construction, was also requested. Adequate ventilation was controlling the water sources to minimize moisture uptake and retention by wood. Incomplete compacting of concrete or mortar should be avoided, because it causes flaws-holes and cracks and they permit easy penetration of termites. Some physical barriers as metal shields or other impenetrable materials are devised to force termites into the open and make them detectable. However, they were not always satisfactory in any case. In later stage, chemical barriers consisting of wood treatment and/or soil treatment with an appropriate chemicals was established as both pre-construction and post-construction treatments, and it has been widely employed at present. Chemical pretreatment is a very effective procedure because it provides a toxic barrier against termite movement into wooden constructions. Post-construction treatment, is often more expensive and more difficult to apply to the buildings once infested with termites. Post-construction is usually conducted by drilling holes in floors, walls or other structural parts to inject termiticidal fluid or dust or bait into the infested parts, if the nest is unable to take away. Early chemical treatment methods and chemicals used had been reviewed by Beal[4,5)]. Since 1960, organochlorine insecticides such as *p*, *p′*-dichloro-diphenyl-trichloroethane (DDT), aldrin, dieldrin, chlordane and heptachlor have been proved sufficiently effective for soil treatment[6–10)], and wood treatment[11,12)].

Due to the long-term persistence of these insecticides[13], it led the increasing public concern on environmental contamination and the risk to human health, particularly in cases of organochlorine insecticides[14]. Many chlorinated hydrocarbon termiticides have now been banned in many developed countries and thus they are almost totally banned in the other developing countries in the near future. All countries are now seeking for the safer chemicals or the more effective methods for termite control.

Organophosphates and synthetic pyrethroids insecticides have been the promising alternative compounds as termite control agents, because most of them have exceptionally high insecticidal activity, low mammalian toxicity and low environmental pollution[15]. Evaluation of their termiticidal efficacy have been carried out in laboratory and long-term field test in the United States, Europe, Australia and Japan against the destructive subterranean termites, *Coptotermes* and *Reticulitermes* spp. either in wood treatment[16–23], or in soil treatment[6–10,24–28].

Meanwhile, many researchers have paid attention to non-chemical methods for prevention of subterranean termites. A number of different physical barrier systems is going in various stages of development in the United States and Australia, and some have already been marketed and others are still under experiment. Basaltic barrier [29,30] and granitgard[31,32] are commercialized in United States and Australia, and coral[33], glass spinnerets[34] and sand barrier of the particular sizes of 1.6–2.5 mm[35] and 2.0–2.4 mm[36] are considered promising. Recently, new type of physical barrier, a fine mesh of high grade stainless steel was approved in Australia for prevention of subterranean termites from the ground[37].

Baiting methods have been adopted to estimate the field population of subterranean termites and to monitor their foraging territory[38–43]. Moreover, these methods had been reviewed by delivering some slow-acting chemicals to termite nest as an alternative termite control measure[44–47]. For the future termite control strategies, French[48,49] considered to combine physical barrier, bait and dust toxicants. As briefly reviewed here, the basic studies for the future termite control has been promoted in worldwide. It is well known that, termite biology, ecology and physiological activity of different termite species either living in the same area or in the various environmental conditions might be the important factors to establish the procedures and chemicals used for prevention and control measure. The control measure can be successfully implemented, after an infested buildings are carefully examined for which structural parts were damaged and how termites invaded into buildings. Also much knowledge or experience in termite control should be needed for the pest control operators.

Since many years ago, wood has been used mainly for building materials and also for furniture making or many other purposes in Thailand. High resistant timbers such as teak (*Tectona grandis* Linn. f.), daeng (*Xylia xylocarpa* Roxb.) and takhian-thong (*Hopea odorata*

Roxb.) have been popularly used for construction. However, the rapid growth of human population and demands for utilizing wood is steadily increasing. Natural durable timbers become very scare and expensive, therefore many fast-growing trees and other exotic timbers which are mostly non-durable have been introduced to the country. When non-durable wood are being used without any protective treatment, they are easily degraded by various biodegrading agents such as decay fungi and other organisms, especially termites.

As described before, subterranean termite is the most destructive pest of wooden constructions in Thailand, which is estimated over 90% of the overall losses caused by termites in the whole country. Termites in genus *Coptotermes* are mostly damaging in buildings and the economic losses caused by these termites has been roughly estimated as high as 2,200,000 US dollars annually, regardless of the cost of reconstruction and replacement of damage structural parts[50].

Chemical treatment is the principle termite control measure widely used in Thailand. The main termiticidal chemicals used have been a group of chlorinated hydrocarbons such as DDT, aldrin, dieldrin, chlordane or heptachlor, which are applied mostly as soil-poisoning. The solution is sprayed or injected into soil beneath foundation or concrete slabs after and before building construction and sometimes applied to the surface of timbers by spraying, dipping or brushing. Earlier prevention methods of wood in Thailand was a simple coating with natural resins from trees of Dipterocarpaceae, latex and lacquer or varnish for furniture. Ground contact timbers were coated with used lubricant oil or oil type preservatives, such as tar or creosote mixture. Modern wood preservation began in the wood treatment by vacuum pressure impregnation with CCA (copper/chrome/arsenic), sodium pentachlorophenoxide, and CCB (copper/chrome/boron) *etc.*[51]. They are also currently used for protecting wood from various biodegrading agents such as decay fungi and other wood destroying-insects including termites.

Since 1988, some organic chlorine insecticides have been banned in the country due to the awareness of the risks to human health and environmental hazard but aldrin and chlordane are now still popularly used for the long-term efficacy in termite control. However, these chemicals also might be almost banned in the country in the near future. Recently, organophosphorous chemicals such as chlorpyrifos and fenitrothion and synthetic pyrethroids such as permethrin, cypermethrin, fenvalerate, alpha-cypermethrin are introduced into the country as the alternative termiticides that are considered safer to human health and environmentally non-hazard. These products have not ever been used in Thailand and any other tropical countries for termite control. Therefore these new termiticides should be tested for their potential effectiveness in laboratory and for their long-term persistence in various environmental conditions against the important termite species in the particular area. In addition, application techniques of these chemicals combined with other non-chemical control measures should be developed together for the safer and effective termite control strategies in Thailand.

In consideration of the background described here, in this review article is targeted mainly for pre-construction treatment against the subterranean termite *Coptotermes gestroi* Wasmann, the most serious pest damage in buildings or wooden constructions in Thailand. Chapter 1 deals with the damage of constructions caused by subterranean termites in Thailand, that provides information of more frequently encountered termite species responsible for economic damage (Section 1.1). Mode of infestation of subterranean termite in three typical Thai's building constructions are demonstrated with illustrations and pictures (Section 1.2). Due to the effective and economic consideration in termite control, knowledges on ecology and biology of the target termite species are essential element, therefore Chapter 2 deals with the fundamental biological information of the economically important termite species, *C. gestroi*, that will be benefical for future design on the prevention and control measures, based on their behavior or habit in foraging territory (Section 2.1) and its estimated foraging population (Section 2.2). Moreover, feeding activity against commercial timbes is described in Section 2.3. Chapter 3 deals with the response of *C. gestroi* to chemical and physical control measures. Investigations on degradation of chemicals in wood and its effect on termiticidal performance after exposures in various environmental conditions, soil burial (Section 3.1) and above ground contact situation (Section 3.2) were discussed by chemical analyses and bioassays because weathering properties must be the most important factor for selecting the alternative chemicals in the tropical regions. In addition, longevity of soil termiticides after field exposure in Thailand was determined in Section 3.3. In the final section (Section 3.4), an application of physical barrier for termite control is tested in laboratory and in the field. In "Conclusion" results are summarized and some ideas of effective termite control in Thailand are proposed based on the present results. A series of these investigations will facilitate to define the whole image of termite control and to develop the new environmentally safer methods in the country.

## Chapter 1 Damage of Constructions Caused by Subterranean Termites

### 1.1 Survey and observation on damaged houses and causal termite species

#### 1.1.1 Introduction

In spite of the economical importance, damage of constructions by termites has been seldom investigated in Thailand. In earlier, Ahmad[52] published an excellent termite monograph on the entomological aspects, in which 74 species in 27 genera were listed. Later, Morimoto[53] listed 90 species of termites distributing in Thailand. However, up to now, research activity on termite control has not been much promoted yet. In consideration of the awakening of public concern, the author surveyed the damage of constructions by subterranean termites and attempted to make clear the current termite problem in Thailand. Results of survey are summarized on the most important destructive termite species in various part of the country, classification of damage in house structures and parts, and current countermeasures against termite infestation[54].

### 1.1.2 Methods of survey

**Procedure of postal survey**

Postal survey was conducted in 1992 in five regions of the country; northern (N), northeastern (NE), eastern (E), central (C) and southern (S) regions, five provinces were randomly selected from each region.

Following 8 questionnaires were sent to total 2,000 persons who are working as the government officials, each 400 in five regions:

1. Location of house for survey; Indicated by address.
2. Age of house (years after construction); a. Less than 5 years b. Over 5 years
3. Type of house classified by structural materials;
   a. Wooden house b. Masonry or concrete house
   c. Mix type of wooden and concrete parts
4. Treatment for termite prevention before construction; a. Yes b. No
5. Termite infestation in houses; a. Found b. Not found

For persons who answered "a. Found"

6. Time elapsed of the first infestation (years after construction); --------- years
7. Parts with frequent infestation in house; Indicated in series
   1. ----------- 2. ------------ 3. ------------
8. Countermeasures against the infestation;
   a. Destruction of termite nest and reconstruction of damaged parts
   b. Spraying of insecticides
   c. Dusting with Paris green
   d. Surface topping with used lubricant
   e. Others

For reference, some data on climate conditions and soil type in five regions were shown in Table 1.1.

**Personal survey to identify the causal species**

Termites were collected from 200 infested homes, each 100 in urban and rural areas, in 20 provinces from five regions of the country. Species of collected termites were identified based on their morphological key index using stereo-microscope. The results were used to make the distribution map of building-damaging subterranean termites in Thailand.

### 1.1.3 Results and discussion

**Infestation of termites in house**

Questionnaires were responded by 1,060 persons (53.0%) among the 2,000. The

Table 1.1. Average annual rainfall, temperature and relative humidity in five regions of Thailand during 1988–1993, and soil type in each region.

| Region | Temperature* (°C) | Relative humidity* (%) | Rainfall* (mm) | Soil type** |
|---|---|---|---|---|
| Northern | 26.2±0.3 | 73.3±1.0 | 1,127.7±121.2 | sandy loam |
| North-eastern | 26.9±0.5 | 72.2±1.2 | 1,314.8±135.1 | sandy clay |
| Eastern | 27.9±0.2 | 75.5±0.6 | 1,710.2±375.6 | sandy loam |
| Central | 28.0±0.2 | 71.8±1.5 | 1,262.5±269.4 | clay |
| Southern | 27.4±0.2 | 79.7±0.8 | 2,088.9±297.2 | sandy loam |

* : Data (mean±SD), average from six years, 1988 to 1993, which obtained from Data Processing Subdivision, Climatology Division, Meteorological Department, Bangkok.

** : Data from Soil Survey Division, Department of Land Development, Bangkok.

response rate was not high but considered available for this investigation. Of 1,060 houses were classified into some categories as follow : 435 (41.0%) were aged for less than 5 years and 625 (59%) were for over 5 years after their construction. Termite prevention treatment was made only in 181 (17.1%) houses and 664 (62.6%) houses were not treated before construction. Concerning the house type, it was counted 24% for masonry or concrete, 37% for wood and 39% for their mixture, respectively on the average, although some variances existed among the regions.

The infestation rate of houses are shown in Table 1.2. The lower infestation rate in new houses was expectedly anticipated but its value was much higher than our anticipation. Particularly, those of Northern and Northeastern regions were over 65%. Of older houses (over 5 years after construction), infestation rate exceeded 70% in Northeastern, Eastern and Central regions. For the infestation rate of each house type, wooden house was the highest almost in every region and in less-aged house, followed by mixture type and masonry or concrete type. Infestation rate of the concrete (masonry) house was the lowest in the three types but its value was not so low and increased with the aging of house. The values of longer aged wooden houses came down on the whole due to rising of those of other types. The results suggest that even the concrete (masonry) house is not necessarily highly resistant against the attack by subterranean termites. The relationship between infestation rate and region was not clear but the values of Northeastern and Central regions seemed considerably higher than those of Eastern and Southern regions. The reason might be much related to the soil type than climatic factors, since soils of the former two regions are rich in clay which many subterranean termites prefer to other soil components.

Table 1.3 shows the effectiveness of prevention treatment before construction. Among 181 pre-treatment houses throughout the country, 157 (86.7%) were effective to protect houses from termite attack. For the effectiveness of prevention rate, it was not much different among five regions (81.4%, 91.3%, 90.9%, 81.6% and 95.5% for northern, north-

Table 1.2. Infested houses classified by type and years after construction in Thailand.

| Region (No. of respondent) | House type* | No. of infested house (infestation rate in %) | | |
|---|---|---|---|---|
| | | Total | <5 yr | >5 yr |
| Northern (221) | T | 139 (62.9) | 48 (67.6) | 91 (60.7) |
| | M/C | 15 (27.8) | 4 (26.7) | 11 (28.2) |
| | W | 67 (76.1) | 22 (88.0) | 45 (71.4) |
| | W+M/C | 57 (72.2) | 22 (71.0) | 35 (72.9) |
| Northeastern (200) | T | 142 (71.0) | 53 (66.3) | 89 (74.2) |
| | M/C | 15 (27.8) | 4 (26.7) | 6 (26.1) |
| | W | 59 (72.0) | 22 (88.0) | 37 (86.0) |
| | W+M/C | 68 (85.0) | 22 (71.0) | 46 (85.2) |
| Eastern (254) | T | 144 (56.7) | 60 (44.8) | 84 (70.0) |
| | M/C | 18 (30.0) | 7 (15.6) | 11 (73.3) |
| | W | 61 (65.6) | 30 (68.2) | 31 (63.3) |
| | W+M/C | 65 (64.4) | 23 (51.1) | 42 (75.0) |
| Central (200) | T | 132 (66.0) | 47 (58.8) | 85 (70.8) |
| | M/C | 21 (36.8) | 9 (30.0) | 12 (44.4) |
| | W | 58 (79.4) | 20 (76.9) | 38 (80.8) |
| | W+M/C | 53 (75.7) | 18 (75.0) | 35 (76.1) |
| Southern (185) | T | 95 (51.4) | 36 (51.4) | 59 (51.3) |
| | M/C | 15 (27.3) | 6 (27.3) | 9 (27.3) |
| | W | 36 (72.0) | 14 (77.8) | 22 (68.8) |
| | W+M/C | 44 (55.0) | 16 (53.3) | 28 (56.0) |
| Total (1,060) | T | 652 (61.5) | 224 (56.1) | 408 (65.3) |
| | M/C | 84 (33.1) | 4 (26.7) | 11 (28.2) |
| | W | 281 (71.3) | 22 (88.0) | 45 (71.4) |
| | W+M/C | 287 (69.7) | 22 (71.0) | 35 (72.9) |

*: T: Total, M/C: Masonry or concrete, W: Wood, W+M/C: Wood+masonry or concrete.

eastern, eastern, central and southern region, respectively), but its value in masonry (95.8%) seemed a little bit higher than those of mixture type (85.3%) and wooden house (81.0%) and also more effective in less-aged houses (90.8%) than longer-aged houses (84.5%).

**Countermeasure conducted against termite infestation**

Summarized data of frequently attacked parts are shown in Table 1.4. Data were collected from 652 infested house but were not divided in house type. The order of

Table 1.3. The effectiveness of preventive treatment before construction clascified by type and years after construction in Thailand.

| Region (No. of respondent) | House type* | No. of pre-treatment houses/No. of non-infested houses (effectiveness of prevention in %) | | |
|---|---|---|---|---|
| | | Total | <5 yr | >5 yr |
| Northern (221) | T | 43/ 35 ( 81.4) | 13/11 ( 84.6) | 30/24 ( 80.0) |
| | M/C | 10/ 9 ( 90.0) | 1/ 1 (100.0) | 9/ 8 ( 88.9) |
| | W | 15/ 11 ( 73.3) | 4/ 2 ( 50.0) | 11/ 9 ( 81.8) |
| | W+M/C | 18/ 15 ( 83.3) | 8/ 8 (100.0) | 10/ 7 ( 70.0) |
| Northeastern (200) | T | 23/ 21 ( 91.3) | 6/ 6 (100.0) | 17/15 ( 88.2) |
| | M/C | 7/ 7 (100.0) | 2/ 2 (100.0) | 5/ 5 (100.0) |
| | W | 7/ 6 ( 85.7) | 2/ 2 (100.0) | 5/ 4 ( 80.0) |
| | W+M/C | 9/ 8 ( 88.9) | 2/ 2 (100.0) | 7/ 6 ( 85.7) |
| Eastern (254) | T | 44/ 40 ( 90.9) | 21/21 ( 44.8) | 23/19 ( 82.6) |
| | M/C | 14/ 13 ( 92.9) | 9/ 9 (100.0) | 5/ 4 ( 80.0) |
| | W | 10/ 9 ( 90.0) | 4/ 4 (100.0) | 6/ 5 ( 63.3) |
| | W+M/C | 20/ 18 ( 90.0) | 8/ 8 (100.0) | 12/10 ( 83.3) |
| Central (200) | T | 49/ 40 ( 81.6) | 20/16 ( 80.0) | 29/24 ( 82.8) |
| | M/C | 14/ 13 ( 92.9) | 9/ 9 (100.0) | 5/ 4 ( 80.0) |
| | W | 10/ 9 ( 90.0) | 4/ 4 (100.0) | 6/ 5 ( 83.3) |
| | W+M/C | 20/ 18 ( 90.0) | 8/ 8 (100.0) | 12/10 ( 83.3) |
| Southern (185) | T | 22/ 21 ( 95.5) | 5/ 5 (100.0) | 17/16 ( 94.1) |
| | M/C | 6/ 6 (100.0) | 2/ 2 (100.0) | 4/ 4 (100.0) |
| | W | 9/ 8 ( 88.9) | 2/ 2 (100.0) | 7/ 6 ( 85.7) |
| | W+M/C | 7/ 7 (100.0) | 1/ 1 (100.0) | 6/ 6 (100.0) |
| Total (1,060) | T | 181/157 ( 86.7) | 65/59 ( 90.8) | 116/98 ( 84.5) |
| | M/C | 48/ 46 ( 95.8) | 19/19 (100.0) | 29/27 ( 93.1) |
| | W | 58/ 47 ( 81.0) | 19/15 ( 78.9) | 39/32 ( 82.0) |
| | W+M/C | 75/ 64 ( 85.3) | 27/25 ( 92.6) | 48/39 ( 81.2) |

*: For legend see Table 1.2.

frequency might not be much different in the attack by any subterranean termite species and in any termite-infested country. The order showed that the parts of houses such as floor, beam, joist and sills that should be more carefully inspected and provided adequate treatment.

The survey results on the conventional prevention and control measures in Thailand are summarized in Table 1.5. The most common practice (39%) was the house owner's application of some toxic substance such as dusting with paris green or by spraying with chlorinated hydrocarbon insecticides. The next (36%) was the prevention and control

Table 1.4. Wood structural parts in houses which are frequently attacked by subterranean termites.*

| Parts attacked | Number of frequency answered |
|---|---|
| 1 Floor, beam, joists, sills | 362 |
| 2 Window, door frames and panels | 169 |
| 3 Wall and wall frames | 168 |
| 4 Furniture and other wood products | 81 |
| 5 Pole | 43 |
| 6 Roof trim, roof rafters | 38 |
| 7 Stairs | 10 |

* : Data collected on 652 infested houses from postal questionnaire survey in 1992.

Table 1.5. Prevention and control measure which have been used in Thailand (survey from 652 infested houses).

| Control measure | No. of control measure were used (%) | Chemicals or materials used |
|---|---|---|
| 1 Application of some toxic substance directly to kill termites | 244 (39) | - spraying with chlorinated hydrocarbon* insecticides<br>- dusting with Paris green or arsenic trioxide<br>- pouring with used lubricant |
| 2 Prevention and control by the PCO (applied chemicals as wood treatment and soil treatment under or around building construction | 225 (36) | - injection, spraying or brushing with chlorinated hydrocarbon* and some synthetic pyrethroid** insecticides |
| 3 Destruction of termite colony or their tunnels | 81 (13) | - using mechanical tools |
| 4 Replacing heavy damaged structures | 50 ( 8) | - using adequate durable timbers such as Tectona grandis Linn. f. *Hopea odorata* (Roxb) or wood preservative timbers |
| 5 Designed house construction | 25 ( 4) | - using a concrete high pole or concrete houses |

* : Aldrin, dieldrin, chlordane, heptachlor and DDT.
** : Deltamethrin and cypermethrin.

treatment by pest control operators.

**Termite species infesting in house**

Thirteen termite species were found infesting in houses in urban and rural areas (Table 1.6). Five species were belonging to Family, Rhinotermitidae, and eight to Family, Termitidae. The highest infestation in urban area was caused exclusively by the subterranean termite *Coptotermes gestroi* (90.0%) (Fig.1.1). In rural area, *Microcerotermes creassus* was a predominant species (42%) but *C. gestroi* was common also in this area. Other 11 species were minor as the house-infesting termites in Thailand.

From frequent observations during this survey, *C. gestroi* was recognized as the most

Table 1.6. Termite species found in 200 infested houses inspected in rural and urban area.

| Termite species | Number of houses found termite infestation | |
|---|---|---|
| | Urban area*** | Rural area*** |
| 1 *Coptotermes gestroi* Wasmann* | 90 | 22 |
| 2 *Coptotermes kalshoveni* Kemner* | 3 | — |
| 3 *Coptotermes premrasmii*, new species* | 1 | 1 |
| 4 *Coptotermes havilandi* (Holmgren)* | 4 | — |
| 5 *Schedorhinotermes medioobscurus* (Holmgren)* | 2 | 1 |
| 6 *Globitermes sulphureus* (Hagen)** | — | 7 |
| 7 *Macrotermes gilvus* (Hagen)** | — | 4 |
| 8 *Microtermes pakistanicus* Ahmad** | — | 2 |
| 9 *Microtermes anandi* Holmgren** | — | 2 |
| 10 *Microcerotermes creassus* Synder** | — | 42 |
| 11 *Odontotermes proformosanus*, New species** | — | 8 |
| 12 *Odontotermes longignathus* Holmgren** | — | 6 |
| 13 *Odontotermes feae* (Wasmann)** | — | 5 |

*: Family Rhinotermitidae, **: Family Termitidae, ***: 100 infested houses were inspected.

important house-damaging termite in urban areas. Wood-attacking activity of *C. gestroi* was very high compared to any other species and this species was considered most important in rural area, too. Distribution of *C. gestroi* was shown in Fig. 1.2. This species is distributing in Thailand in every part of the country, and any climate or soil condition might not much affect its distribution.

## 1.2 Mode of infestation of subterranean termites

### 1.2.1 Introduction

In Section 1.1, current status of termite problem in Thailand was reported. *Coptotermes gestroi* Wasmann is the most important termite species attacking wooden constructions not only in urban but also in rural areas and is widely distributing throughout the country.

To minimize the risk from termite attack, it is necessary to clearly understand termite habits and how they enter into buildings. In this section, infestation of termites into buildings is inspected in model and real houses of the three typical building constructions in Thailand. Mode of termite infestation into each construction was shown by illustrations, pictures, tables and discussed in relation to the termite behaviors.

### 1.2.2 Materials and methods

**Observation of infestation in model and real houses**

Three types of model houses, slab on ground (SG), crawl space (CS) and high pole (HP), were made as the typical Thai building constructions (Fig.1.3). The susceptible timber, Dipterocarpus alatus Roxb. and rubber wood (*Heves brasiliensis* Muell. Arg) particleboard were used as materials for construction. Each model house was measured

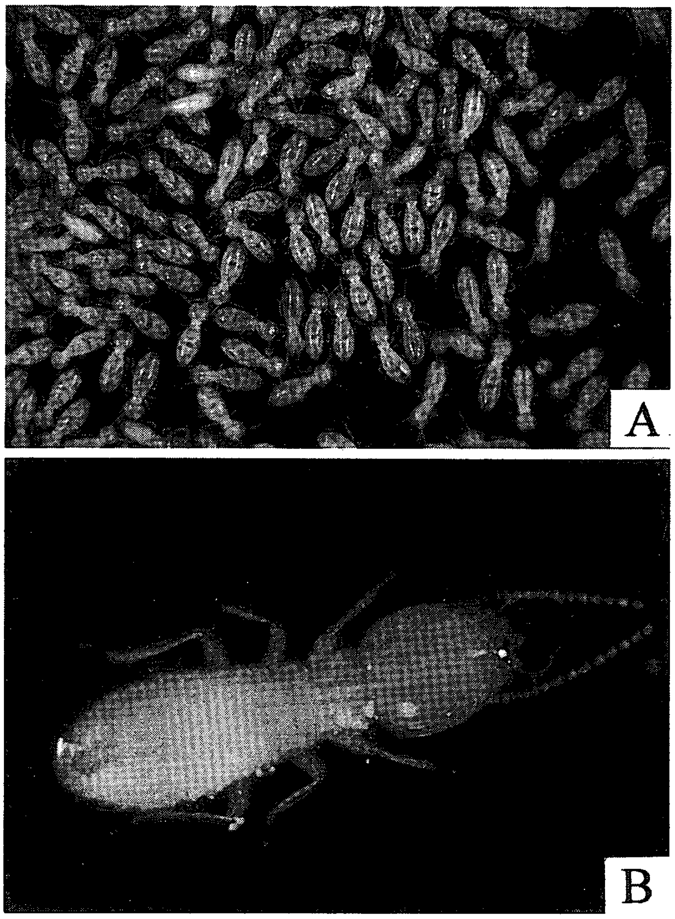


Fig. 1.1. Workers (White-headed individuals in A) and soldiers (Brown-headed individuals in A and B) of subterranean termite, *Coptotermes gestroi* Wasmann which is the most important species attacking in building constructions in Thailand.

750 (W)×900 (L)×800 (H) (mm) and established in May, 1992 at Saraburi field test site where by several termite species such as *Coptotermes gestroi, Odontotermes longignathus, Microcerotermes creassus* and *Hypotermes* sp. were found.

Real houses or buildings that are commonly seen in Thailand were also inspected to determine the extent of termite infestation in different regions of the country. Total seventy infested buildings were inspected in both urban and rural areas. Among them, 30, 20 and 20 cases were for SG, CS and HP types, respectively.

**Procedure for inspection of infestation**

Visual examination of termite infestation was made mainly by presence of shelter tubes. However, termite entry points were often hidden and were not directly observed. Therefore, infestation was determined also by the presence of damaged structures or by depressing the surface of wooden members to detect inner destructions. The inspection started at the basement of buildings which was close to or in contact with ground and other

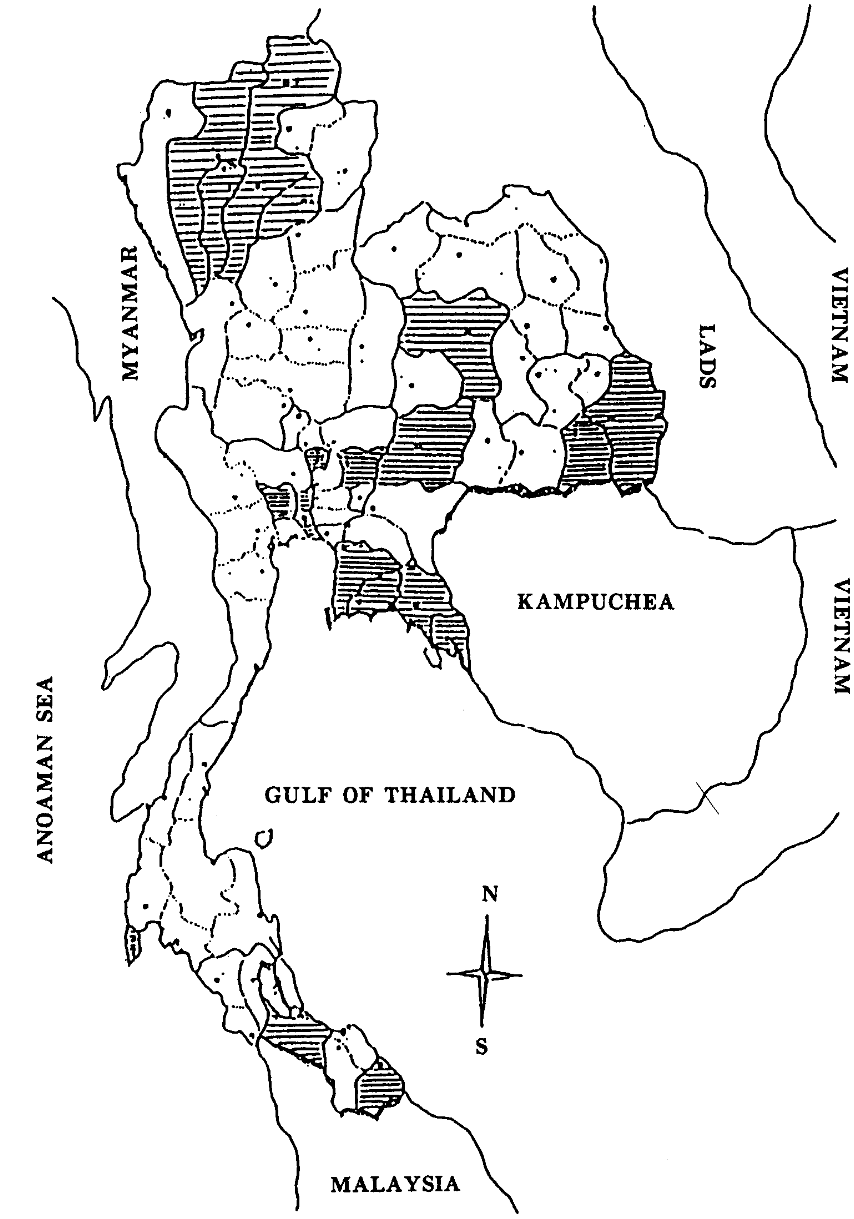



Fig. 1.2. The distribution map of subterranean termite, *Coptotermes gestroi* Wasmann.

appendages. Next inspection was conducted on wooden structural parts in both interior and exterior, particularly at the location where was normally in damp or humid condition to facilitate the termite infestation. Later, surroundings of building was examined to detect any other defects relevant to the infestation of subterranean termites.

### 1.2.3 Results and discussion

#### Mode of infestation

Results showing on the entry points of termite into the three types of construction from model house test are summarized in Table 1.7 and in Fig. 1.4 of illustrated diagram, and


Fig. 1.3. Three types of model house for observation on mode of infestation of subterranean termite at Saraburi field test site. A: Slab on ground type, B: Crawl space type, C: High pole type.

results from case inspections of real houses are shown in Fig. 1.5 of the illustrated diagram.

These results clearly indicated that foraging termites mostly came from the underground colonies and invaded into buildings through wood or other structural parts close to or in contact with ground, especially at basement construction, slab floor, base board, step, pole and wall (* remark in Fig. 1.5). Termites could enter into buildings through narrow cracks or voids in concrete slab and foundation, or through those in wall in

Table 1.7. Mode of the infestation of subterranean termite into buildings in model house test.

| Case No. | Type of construction | Initiation of infestation | Condition might cause infestation |
|---|---|---|---|
| 1 | Slab on ground (SG) | damaged on flooring, shelter tube on wall and wall beam | -- wood in contact with ground<br>-- infested tree branches close to the building |
| 2 | Crawl space (CS) | shelter tube running up from ground along house pole, behind step and wall | -- wooden step in contact with ground<br>-- moist air and insufficient ventilation |
| 3 | High pole (HP) | shelter tube running up from ground along house pole, beam and wall | -- wooden pole and step in contact with ground<br>-- termite mound close to the building |

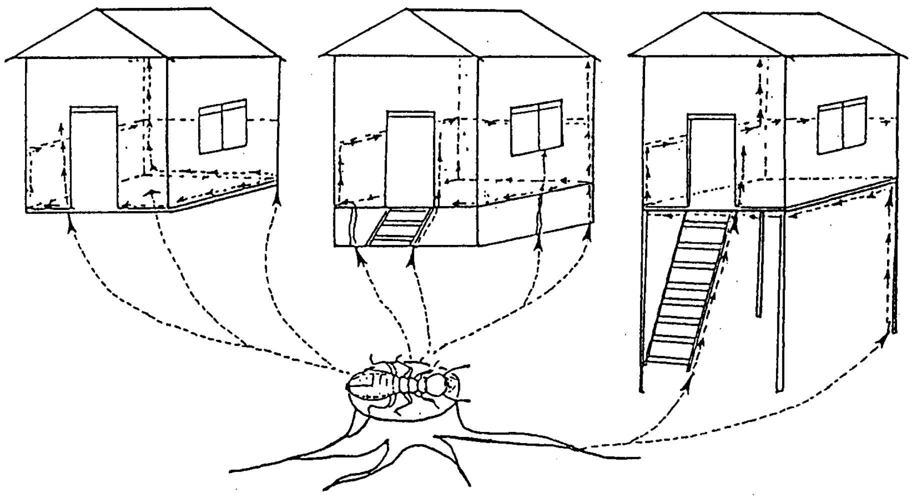



Fig. 1.4. Illustrated diagram to show the point of entry of subterranean termite into three typical Thai building construction in model house test. A (SG) : Termites entered mainly at an improper basement construction or directly attacked wooden part is in contact with ground, B (CS) : Termites made hidden way through interior pole or improper concrete foundation under crawl space or some time built their way along the exposure barriers in contact with ground, C (HP) : Termite entered through the shelter tubes along poles or other structural parts in contact with ground.

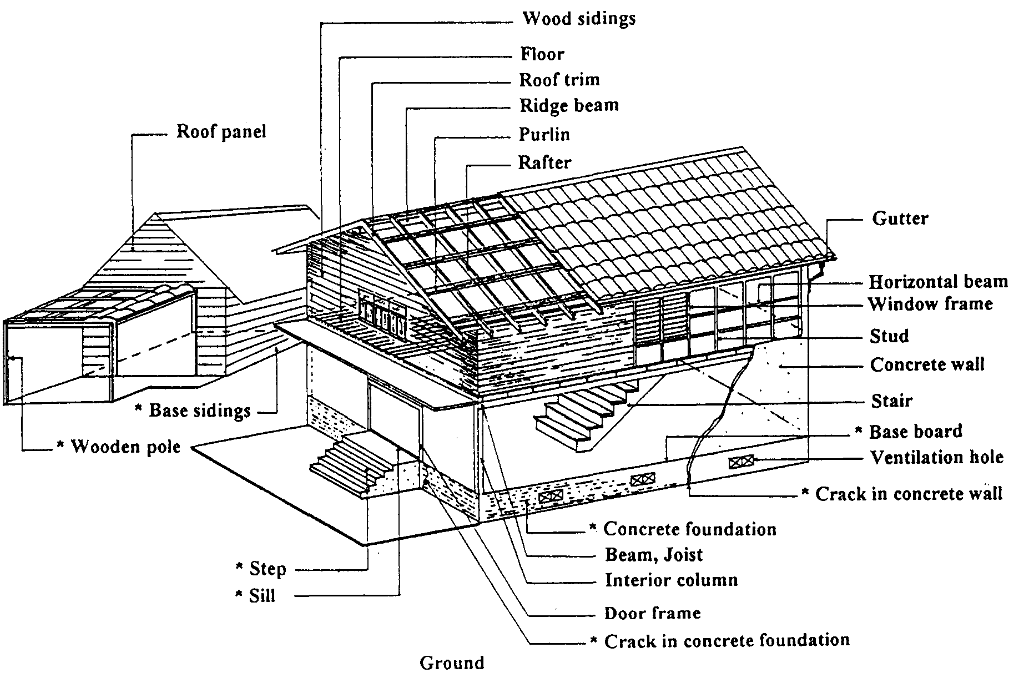



Fig. 1.5. Entry points of termite into the three types of building construction. The right building is exemplified for crawl space type, and the left is for slab on ground type but its front simulates high pole type.

SG and CS houses. Sometimes termites built their way over slab ridge to reach their food source. Also, they could easily enter through a small gap or cracks in step or between step and concrete foundation (Figs. 1.6, 1.7).

In every house type, termites could extend their way to reach upper wooden structures by extending tunnels or shelter tubes along the exposed concrete barriers or along the corner between inside column and wood sidings (Fig. 1.8). Furthermore, they were able to produce shelter tubes along the utility pipes in contact with ground and to attack the upper wood members (Fig. 1.9).

An interesting case was termite entry into high-storied buildings from aerial colonies or a pair of alates blown up by wind. Winged and dewinged alates of subterranean termites were found by the author in the terrace of six-storey hospital building in Nonthaburi province. It is recognized that swarming of subterranean termites in Bangkok normally occurs in the evening from 6.30–7.30 pm, especially on the day of high temperature and humidity or before rain during January to February. Some lucky alates pair might be blown up by wind to the roof or garden and might establish a new colony there. Also in other cases of high-storied buildings, any signs of infestation from underground colonies was not found. In some cases, mud-nest like structure was found on the ceiling of the 14$^{th}$ storey of the condominium in Bangkok City (Fig. 1.10). In addition, other signs of infestation, shelter tubes and damaged wood, were found on ceiling, ceiling betten, floor, wall and sidings in the utility room and lavatory. These infestations were probably caused from aerial colonies. According to the information from room owners and pest control operators, they found alates inside and outside of rooms at the 7$^{th}$ and the higher storey of the buildings. Another possible infestation into high-storied buildings is the transportation of termite-infested soil or shrubs and tress to the terrace for decorating landscape. For instance, infested tree stump was found on the garden at 9$^{th}$ storey.

Information from pest control operators suggest the re-infestation of surviving secondary nest that has been isolated from the primary nest after its eradication treatment. The secondary nest has the hard carton-like structure and is oftenly found inside of the wall. Termites in this nest escaped from the treatment could survive for longer time without contact in soil by receiving moisture from leaking pipes or cracked wall and damaged roof. They continue to attack the wooden structures and sometime they can increase the individuals by new supplemental reproductives.

**Infested parts of buildings**

Table 1.8 shows the frequency of termite infestation in various parts of the three types of building construction. In each type, inspected buildings were divided into their structural materials. In the SG type, basement part (porch, slab, floor, concrete foundation, base board, sill, floor beam and joist) and wall part (wood sidings, wall beam, wall plates, studs and interior finish) were the most infested parts showing 30% frequency. Roof (roof beam,

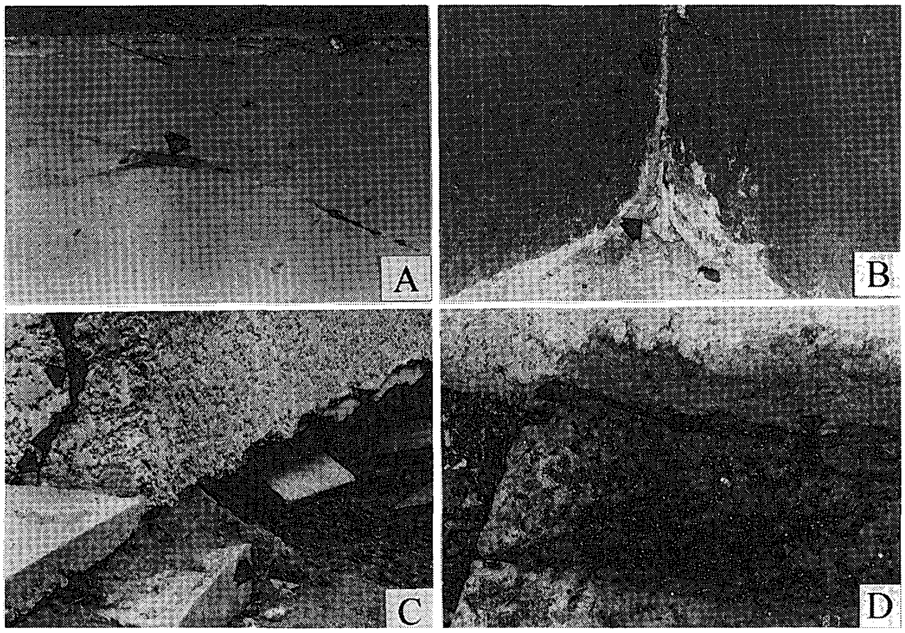



Fig. 1.6. Termite shelter tubes penetrated through cracks in concrete floor and wall due to an improper construction which observed from 4 cases inspection; slab on ground (A and B) and crawl space house (C and D).

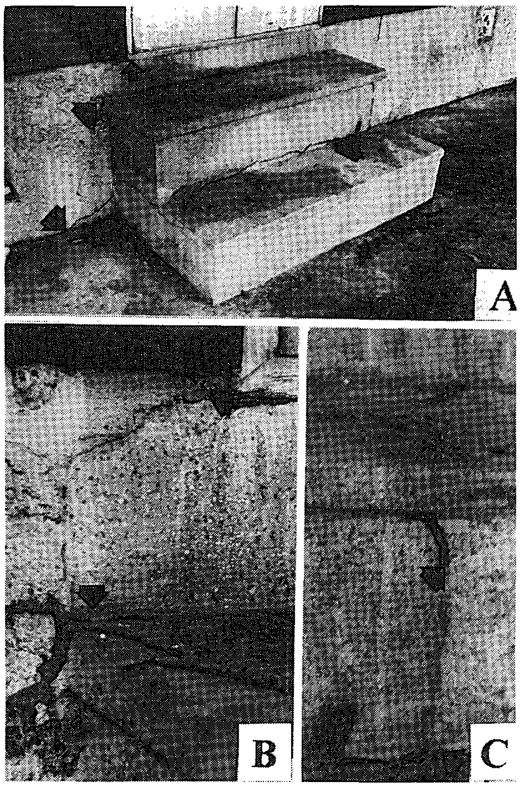



Fig. 1.7. Case inspection in crawl space house in Nonthaburi Province showing the point of termite entry to wood structure (A) by penetrating their shelter tube through cracks in step or small gap between concrete foundation and step (B, C).

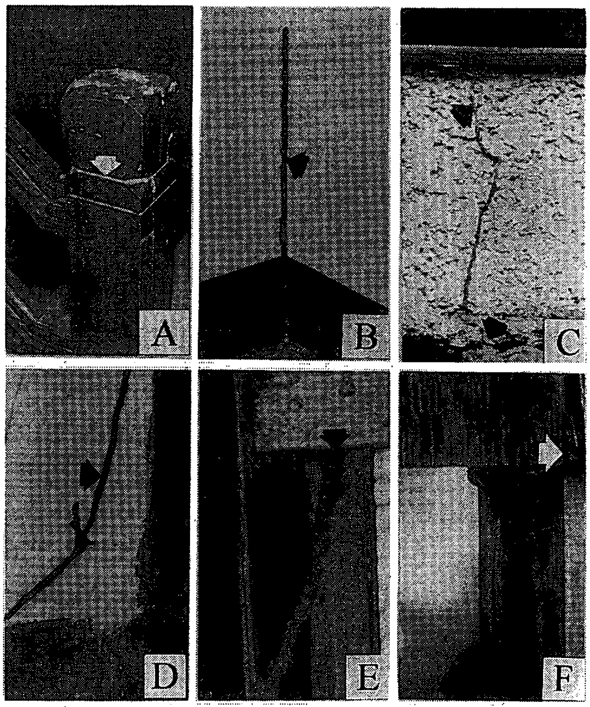



Fig. 1.8. The shelter tube is the typical signs of termite infestation in buildings. A-B : Shelter tube of *Coptotermes gestroi* along post and hand rail of stair (A), and concrete wall (B) in crawl space house type , Bangkok City, C : Shelter tube of *Microcerotermes* sp. exposed along stucco concrete foundation in crawl space house, Nonthaburi Province, D-E : Shelter tube of *C. gestroi* penetrated through cracks from slab floor to column and concrete wall (D) to reach their food source in the upper part (E) in slab on ground house, Rayong Province, F : Shelter tube of *Microcerotermes* sp. along house pole in high pole model house, Saraburi Province.

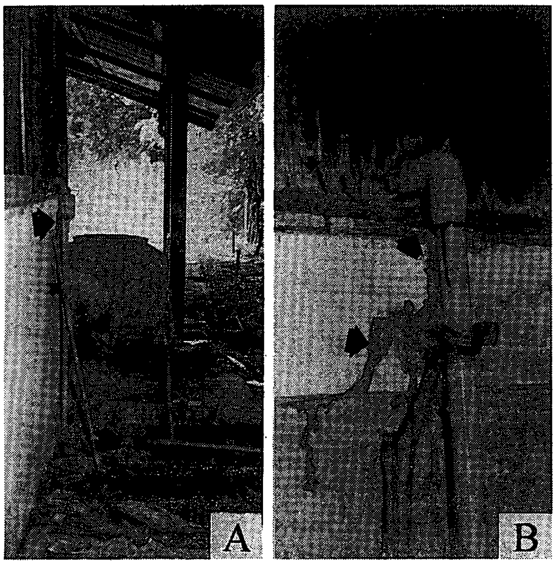



Fig. 1.9. Termites extended their way along stick or the utility pipe which is in contact with ground (A) and damaged on wooden structures in the upper part (B).

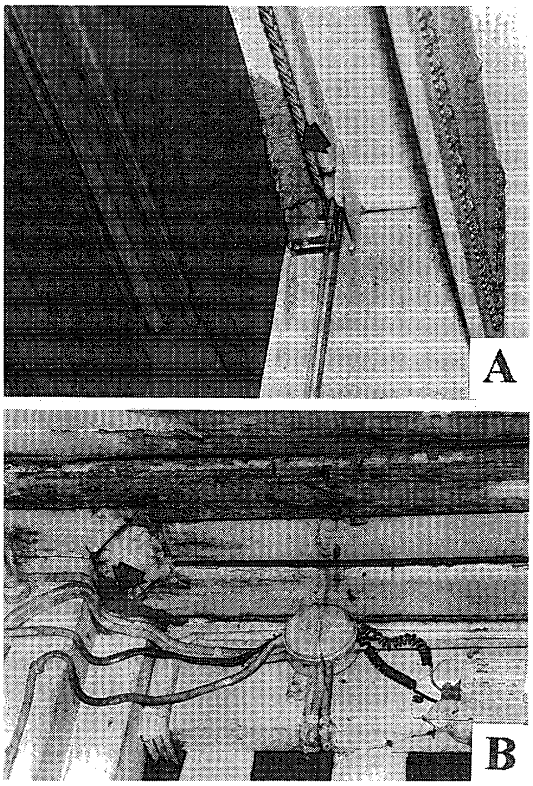



Fig. 1.10. Mud-nest like structure of subterranean termite found on ceiling of the 14th storey (A) and 10th storey (B) of the condominium, Bangkok City, that might assuming come from an aerial colony.

Table 1.8. Frequency of termite infestation in the parts of buildings.

| Parts in house | Number of infested houses in parts and in building materials | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slab on ground type No. of inspected house | | | | Crawl space type No. of inspected house | | | | High pole type No. of inspected house | | |
| | A 14 | B 10 | C 6 | Total (%) 30 | A 7 | B 10 | C 3 | Total (%) 20 | A 7 | B 13 | Total (%) 20 |
| Basement* | 3 | 5 | 1 | 9 (30.0%) | 2 | 5 | 2 | 9 (45.0%) | 2 | 1 | 3 (15.0%) |
| Wall** | 1 | 4 | 4 | 9 (30.0%) | 1 | 3 | 2 | 6 (30.0%) | 0 | 1 | 1 ( 5.0%) |
| Roof*** | 4 | 3 | 0 | 7 (23.3%) | 2 | 2 | 0 | 4 (20.0%) | 2 | 2 | 4 (20.0%) |
| Door and window frame | 2 | 0 | 0 | 2 ( 6.7%) | 1 | 1 | 1 | 3 (15.0%) | 1 | 1 | 2 (10.0%) |
| Other cellulosic materials | 4 | 0 | 0 | 4 (13.3%) | 1 | 1 | 0 | 2 (10.0%) | 0 | 3 | 3 (15.0%) |
| Step or stair cases | 1 | 1 | 0 | 2 ( 6.7%) | 0 | 0 | 0 | 0 ( 0 %) | 0 | 4 | 4 (20.0%) |
| Pole or column | 0 | 0 | 1 | 1 ( 3.3%) | 1 | 1 | 0 | 2 (10.0%) | 3 | 4 | 7 (35.0%) |

A : Masonry or concrete type, B : Wooden type, C : Mix type of masonry or concrete and wooden type, * : Porch, slab floor, concrete foundation, base board, sill, floor, beam and joist, ** : Wood sidings, wall beam, wall plate, stud and interior wall finish, *** : Roof beam, rafter, purlin, roof trim, roof panel, ceiling board, beam and joist.

roof rafter, purlin, roof trim, roof panel, ceiling beam, ceiling joist and ceiling board) was ranked next (23.3%) followed by other cellulosic materials (12.3%), door and window frames (6.7%), step or stair cases (6.7%) and pole or column (3.3%). Basement was the most infested part in CS type too, and followed by wall, roof and door and window frames. In HP type, pole or column, even when it was made by concrete, easily provided the termite entry to the upper wooden structures. In the susceptible parts of building should be frequently inspected and carefully given the adequate treatment.

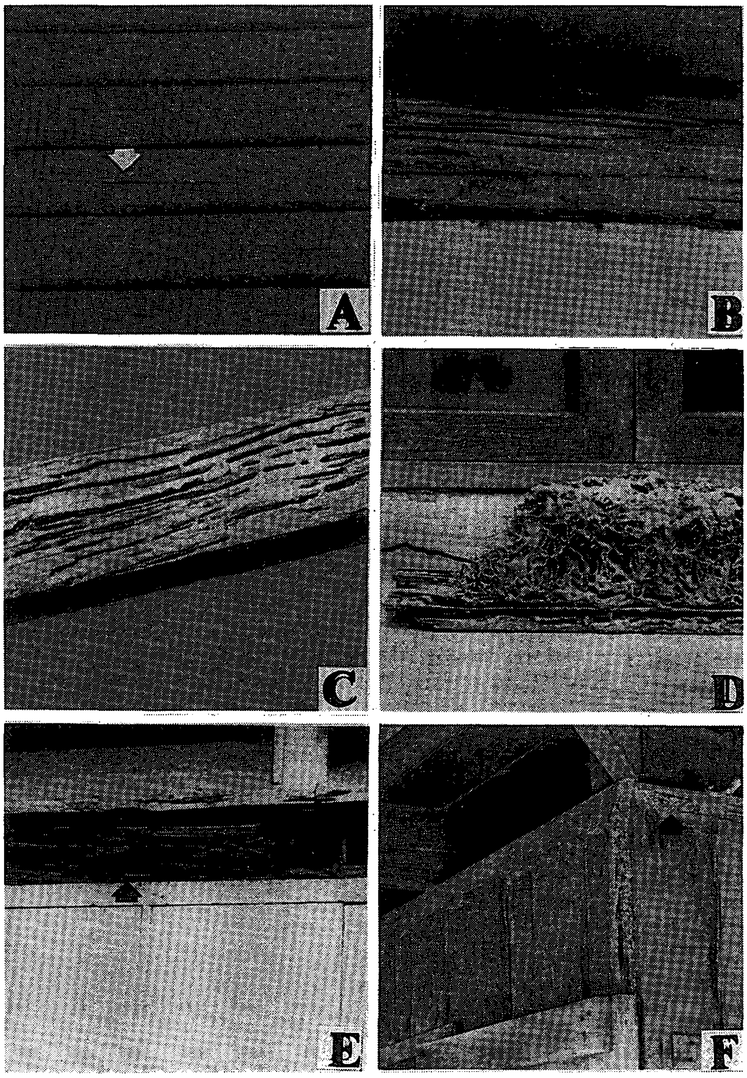



Fig. 1.11. Damaged wooden structures caused by *C. gestroi*. A: Wood siding was eaten inside scarcely showing surface opening, B: Inside of damaged wood siding, C: Infested wood showing the excavation of galleries that follow along the grain of wood, D-F: Heavy damage on wall, wall beam and window head board. After severe attack, space was filled with soil and saliva cement to form spongy like structure.

**Infesting termites and their characteristics**

As described in Section 1.1, *C. gestroi* is the most important building-attacking species in urban area. Figure 1.11 shows the characteristics of damaged structures caused by this species. The excavation of galleries followed the grain of wood. Inside of wooden members were eaten up without any surface opening. Resultant inside hollow was partially filled with soil and sponge-like structure or saliva cement. In later stage of infestation, termites reinforced the exhausted wooden structures by forming the carton nest (Fig. 1.12). Edward and Mill[2] described that the carton nest was a honey-combed mass and consisted of fecal and undigested wood residue fixed with saliva.

In rural area, *C. gestroi* was still an active invader to buildings, but some mound-building termites, *Odontotermes* spp., *Microcerotermes* spp. and *Macrotermes* spp., were also

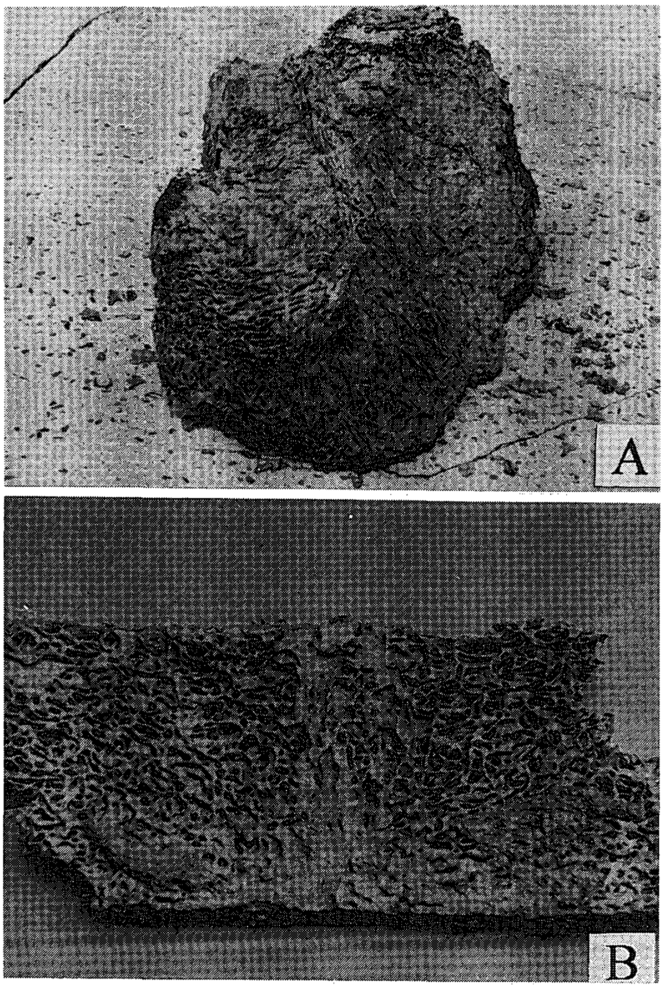


Fig. 1.12. Pictures A and B show the part of secondary carton nest of *C. gestroi*, found in the wall cavity of slab on ground house, Bangkok City.

attacking the buildings. Their damage on wood was easily differentiated from that by *C. gestroi*. The infestation by *Odontotermes* spp., stucco mud plaster or soil cover was formed on the surface of wood and expanded the area. Termites removed wood beneath the soil cover in wide area. *Macrotermes* spp. also formed similar cover on wood surface but it was thinner and flatter. Both species filled severely attacked parts with soil or mud. *Microcerotermes* spp. built the shelter tube to reach wooden structures like as *C. gestroi*. However, their tubes was harder and narrower than those of *C. gestroi*, and they attacked wood along and across the grain. Furthermore, after severe attacking wood to inside, honey-combed mass was not formed by *Microcerotermes* spp.

**Causes of infestation into buildings**

From the results described above, causes of termite infestation were summarized as follows;

*1. Woodworks direct to ground contact*

Wooden parts in ground contact were the easiest entry of subterranean termites (Fig. 1.13). They are very moisture-depending and usually establish their nest under the

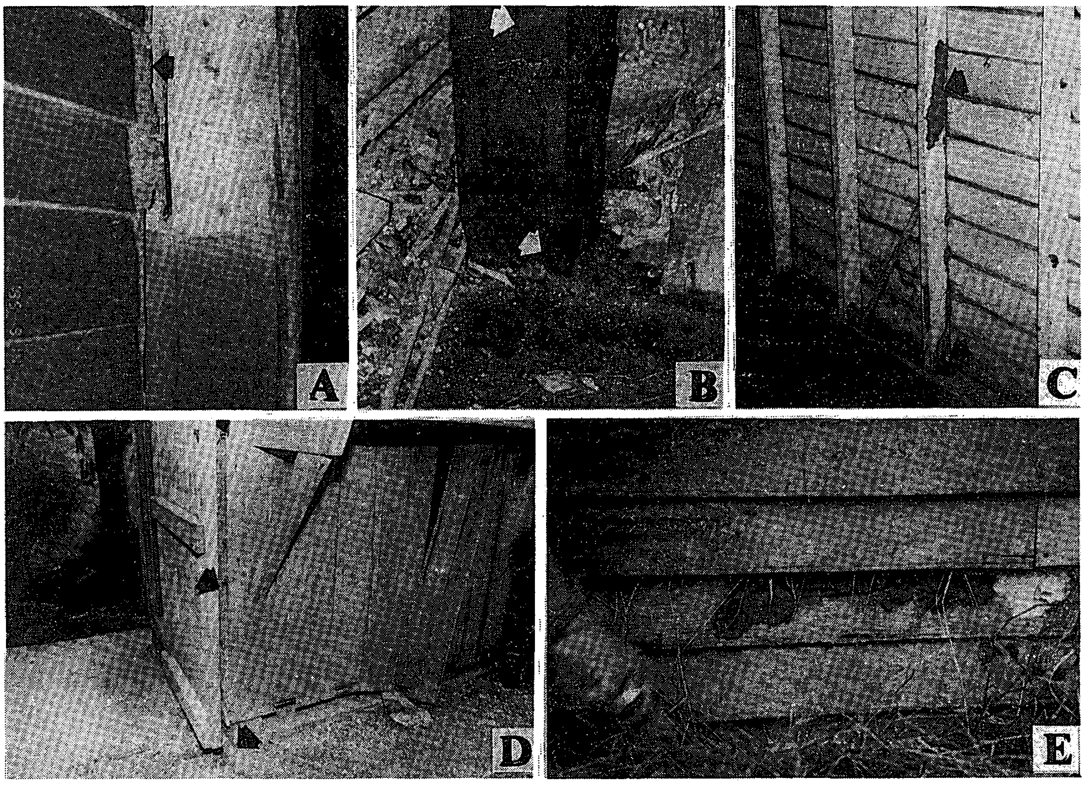



Fig. 1.13. Woodworks direct to ground contact inviting termite into building. A-B: Termite damage on wood sidings (A) and pole (B), from shelter tube through cracks in wooden pole in high pole house, Nakhon Sawan Province, C-E: Wood sidings, stud or interior column infested by subterranean termite, in slab on ground house, Nonthaburi (C, D) and Nakhon ratchasima Province (E).

ground. Dead tree stump and mass of wood debris close to or beneath buildings should be removed or treated, since they are favorable food sources of subterranean termites.

*2. Improper construction of foundation*

Termites could easily enter and extended their way into buildings by shelter tubes through cracks in concrete foundation or through the gaps or cavities between wall and basement, and any other opening in the structural parts. These defects are due to the improper construction.

*3. Improper drainage and humid condition*

Water leaking on the roof and watering plants in bed bank often caused a humid condition in some part of building constructions. Leakage from utility pipe or drain pipe should also be carefully inspected.

*4. Insurficient ventilation in crawl space*

Ventilation in crawl space should be carefully inspected, because humid condition is often produced due to small vent, improper drainage or interrupted ventilation by growth of dense shrub-berry or grass in front of vent openings.

*5. Insufficient clearance of termite food source in and around buildings*

Lumber and wood debris are often stored or left under or around buildings. Other cellulosic materials, including books, carton boxes and useless furnitures or decorations, were usually kept in store room. They are good food source for termites, when they are kept in dark and humid condition.

*6. Termite nest and infested timbers around buildings*

Termite-infested timbers and termite nest around buildings mean the coming infestation into buildings, even if they are not infested yet.

These facts should be utilized to develop the hygiene to minimize the risk of termite attack before application of termiticidal treatment.

# Chapter 2 Ecology and Biology of the Most Economically Important Subterranean Termite Species : *Coptotermes gestroi* Wasmann

## 2.1 Foraging territory of subterranean termites, *Coptotermes gestroi* Wasmann

### 2.1.1 Introduction

It is difficult to study the foraging behavior and territory of subterranean termites because all their activities occur underground. It is very true that in an urban environment excavation of termites' galleries[55] and application of radio-isotope tracer[56] are not suitable. In these areas, a mark-release-recapture method has been recognized as a practical alternative to the conventional methods for determining foraging territory and population of subterranean termites[40,57–62]. Previously, Sudan Red 7 B had been used as a marking material for studying Formosan subterranean termite[63–65] and eastern subterranean termite[66]. Following, Su *et al.*[67] practiced on twelve dye markers for foraging population study of subterranean termites, and reported that Neutral Red and Nile Blue A worked well for the required purpose. Recently, Haagsma and Rust[68] evaluated four dyes for histological use for population studies and indicated that Nile Blue A and Neutral Red were the most suitable dyes for marking the western subterranean termite, *Reticulitermes hesperus.*

Although *Coptotermes gestroi* Wasmann is the most economically important termite, its biology and ecology have not been extensively investigated. In this section, the proper concentration of Nile Blue A as a dye marker was evaluated, and foraging activity and territory of the species in an urban area was monitored by a triple mark-recapture system[69].

### 2.1.2 Materials and methods

#### Application of Nile blue A for marking *C. gestroi*

Nile Blue A (87%, Aldrich Chemical Company, Ltd.) was dissolved into distilled water to prepare dyeing solutions of concentrations of 0.25%, 0.05% and 0.01% (W/W). Filter papers (55 mm in diameter, Whatman No. 2, Whatman BioSystems Ltd.) were dipped into one of the dyeing solutions for 10 seconds. Stained filter papers were air-dried overnight and served for forced-feeding by termites. Approximately 100 termites (worker) were separated from a laboratory colony of *C. gestroi* maintained at the Forest Products Research Division, Royal Forest Department (RFD) Bangkok, and put into a Petri dish containing a moist dyed filter paper. Undyed filter papers were used as controls. After three or five days, twenty stained workers were randomly selected and transferred into another petri dish with two moist unstained filter papers. Five soldiers were added to the stained worker group and daily observation was made to record the number of stained termites and survivors after 3, 7, 10 and 15 days. Four replicates were prepared for each concentration and feeding period.

#### Monitor collection traps

A survey on termite activities of three field *C. gestroi* colonies was conducted in February 1994 in an urban area where the elevation was approximately 1–1.5 m above mean sea level with the average annual rainfall of 597.6 mm, 71.7% relative humidity and mean yearly temperature of 29.6°C. Two colonies (A and B) were located in the RFD, Bangkok, while colony C was in Pak Kret, Nonthaburi Province near the Choa Praya river, locating 20 km away from colony A and B.

Rubber wood stakes measuring 25 (R)×25 (T)×200 (L) mm were installed around the infested wood, stumps and the buildings at each colony site. After termite activity was observed, 40 collection traps (Fig. 2.1) were randomly set up in the ground area of colonies A and C, while there were 25 collection traps at the site of colony B. The collection trap unit was made of polyvinyl chloride (PVC) pipe (150 mm I.D. in various heights of 200, 250, 350, 500, 650, 950 and 1250 mm) with a roll of moistened 150 mm height corrugated paper and a rubber wood stake (25×25×200 mm) at the core of that. The top end of a PVC pipe was

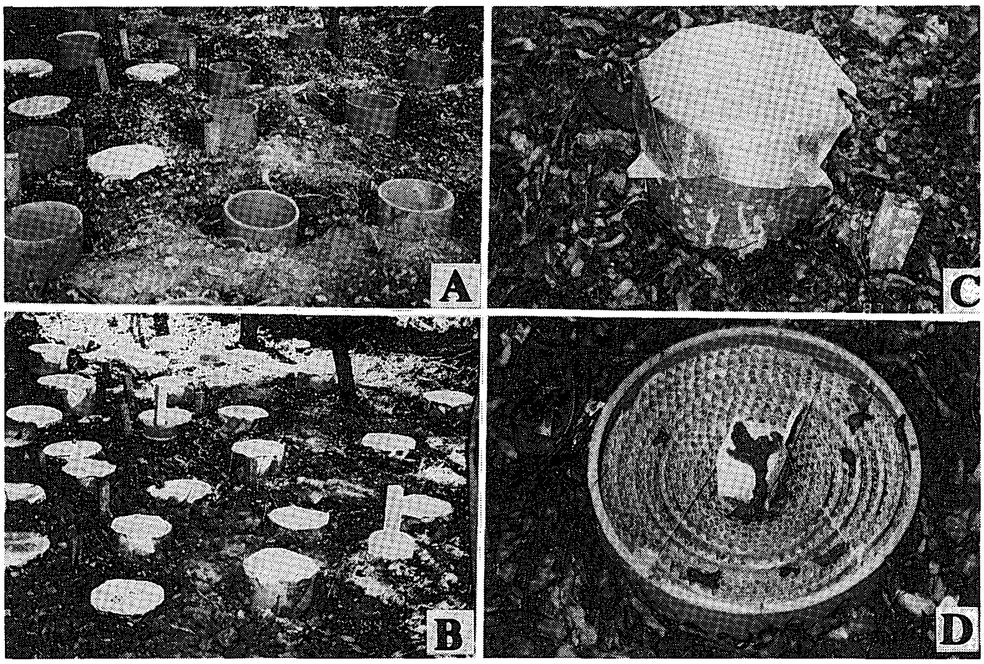



Fig. 2.1. Collection trap unit. A-B : Collection traps in various height are randomly set up in the ground area, C : Each trap is covered with aluminium lid, D : Roll of corrugated paper and rubber wood stake infested by subterranean termites.

covered with aluminium lid. The collection trap units were buried in ground at the depths of 50, 150, 300, 450, 600, 900 and 1,200 mm for determining the underground foraging depth. The collection traps were randomly set up at various distances (0.50 to 30.0 m) from the first station at which the first collection was conducted (Fig. 2.2a, 2.3a and 2.4a).

**Mark-release-recapture method**

After the traps were established, a triple mark-release-recapture procedure was carried out for three colonies during the beginning of rainy season, from March through May 1994. Following the first collection at a monitoring station (the first station in Figs), termites were forced to feed on filter papers stained with 0.05% (w/w) Nile Blue A solution for 3 days and released back to the same station. Traps in which termites were actively attacking were brought back to the laboratory two weeks later to determine the number of marked termites belonging to the first dyed and released group. All collected termites were counted, stained and released again to their respective original traps. A triple mark-release-recapture procedure was conducted for each colony. Numbers of workers and soldiers collected from the traps were determined by weighing of termites. Individual body weight of worker and soldier was calculated from the measurements of 100 termites four times at each recapture cycle. The results were subjected to analysis of variance (ANOVA). Mean body weight of termite was used for the determination of statistical significance difference among three colonies by Scheffe's test at $P<0.05$[70].

Foraging territory of a colony, the maximum foraging depth or the distance by termites was defined as the area encompassed by the stations containing marked termites during the three mark-release cycles.

### 2.1.3 Results and discussion

**Application of Nile Blue A to *C. gestroi***

Applicability of the dye to the termites is presented in Table 2.1. Three days' forced-feeding on treated filter papers with 0.05% Nine Blue A for 10 second was considered most suitable for marking *C. gestroi* because of high marking rate and negligible mortality. Marking was easily identified for at least 15 days in this case. Although the lowest concentration (0.01%) also produced 100% marking and low mortality, marking was not so clear as the case of 0.05%. The highest concentration (0.25%) resulted in significantly high mortality in comparison with that of control. When feeding period increased to 5 days, mortality seemed to become slightly higher at any concentration. At the lower concentrations of 0.01 and 0.05%, however, mortality remained the same level as that of control. Therefore, dyeing of the termites with 0.05% solution of Nile Blue A for three days was employed in later field survey.

**Foraging territory and foraging activity of three colonies**

During the three recapture cycles in colony A, marked termites were recovered from 6, 7 and 8 monitoring collection traps, respectively (Fig. 2.2b, c and d). The maximum travel distance was 5.0 m from the first released station, and the underground foraging activity was observed only in the trap at the depth of 50, 150 and 300 mm. Mean number of foragers collected from each depth indicated that the highest foraging activity (approximately 18,159) was recorded at the depth of 150 mm, and that the highest soldier proportion (13.4%) was observed at the depth of 50 mm (Table 2.2). Mean individual body weights of worker and soldier were $2.71 \pm 0.07$ mg and $2.38 \pm 0.09$ mg (mean $\pm$ SD), respectively

Table 2.1. Mortality of termites after feeding on filter paper treated with Nile Blue A at three concentrations.

| Feeding period (days) | Nile Blue A concentration (%) | Mortality of workers (%) | | | |
|---|---|---|---|---|---|
| | | 3 days | 7 days | 11 days | 15 days |
| 3 | 0.01 | 3.75* | 7.5 * | 13.75* | 18.75* |
| | 0.05 | 5.0 * | 8.75* | 15.0 * | 21.25* |
| | 0.25 | 10.0 * | 18.75* | 26.25* | 32.5 * |
| 5 | 0.01 | 5.0 * | 8.75* | 15.0 * | 21.25* |
| | 0.05 | 5.0 * | 11.02* | 16.25* | 23.75* |
| | 0.25 | 15.0 * | 23.75* | 32.5 * | 40.0 * |
| Control | | 1.0 | 8.75 | 16.25 | 23.75 |

*: Marking of all workers was visually recognized.

(Table 2.3).

Marked termites were found at 6, 7 and 8 monitoring collection traps at each three

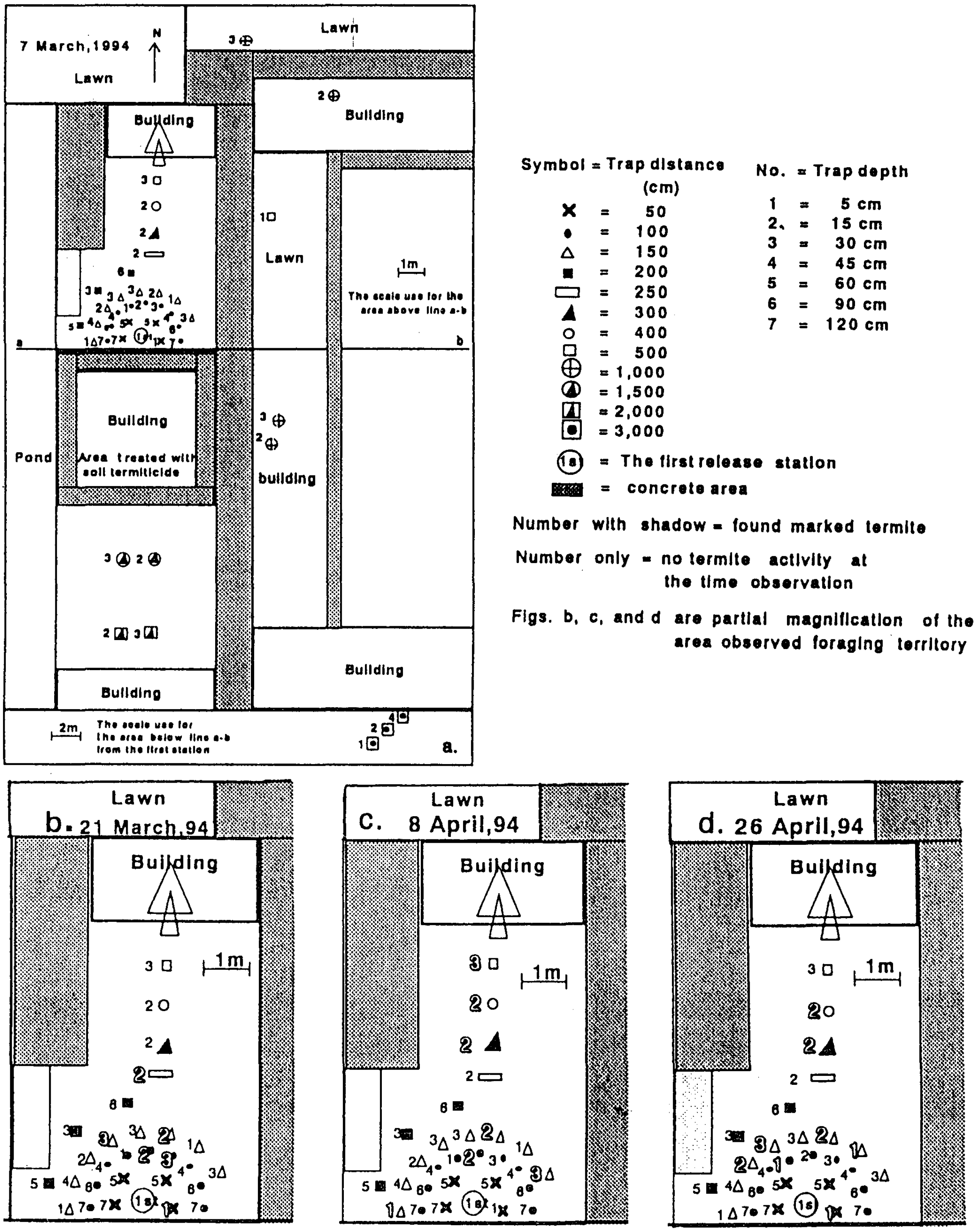



Fig. 2.2. Observation of foraging territory of *C. gestroi* (Colony A) at Forest Products Research Division (FPRD), Bangkok. a : Initial set up of 40 traps, b : First observation, c : Second observation, d : Third observation.

respective recapture cycles in colony B ( Fig. 2.3b, c and d). The maximum foraging distance and foraging depth were similar to those of colony A. The highest number of

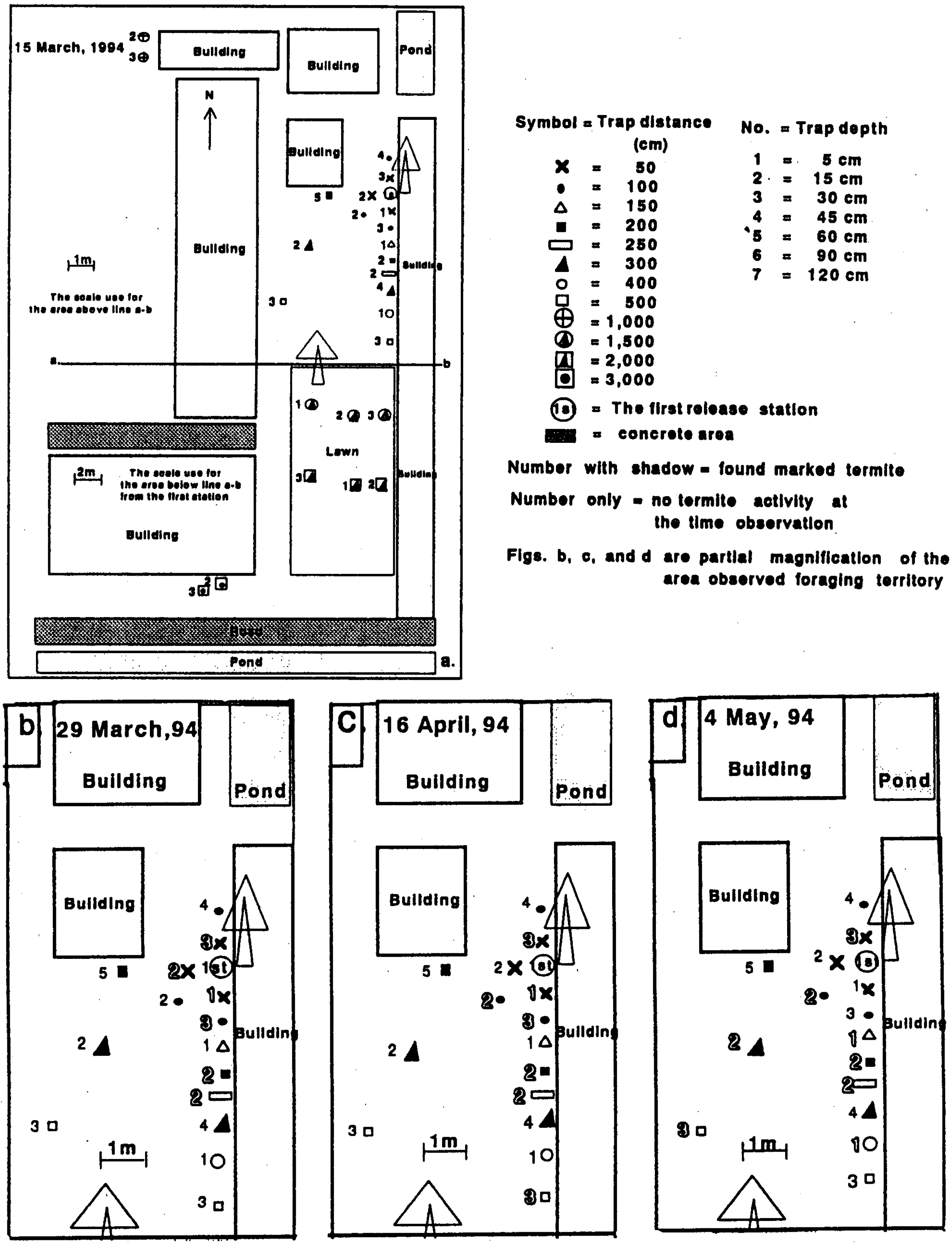



Fig. 2.3. Observation of foraging territory of *C. gestroi* (Colony B) at Forest Products Research Division (FPRD), Bangkok. a: Initial set up of 25 traps, b: First observation, c: Second observation, d: Third observation.
Note: Traps at the depth of 90 cm and 120 cm were not set up for this colony.

foragers (approximately 14,247) was collected from monitoring collection traps at the depth of 150 mm, and the highest percent soldier proportion (15.2%) was observed at the depth of 50 mm (Table 2.2). Mean individual body weights of worker and soldier were 2.73±0.11 mg and 2.43±0.07 mg (mean±SD), respectively (Table 2.3).

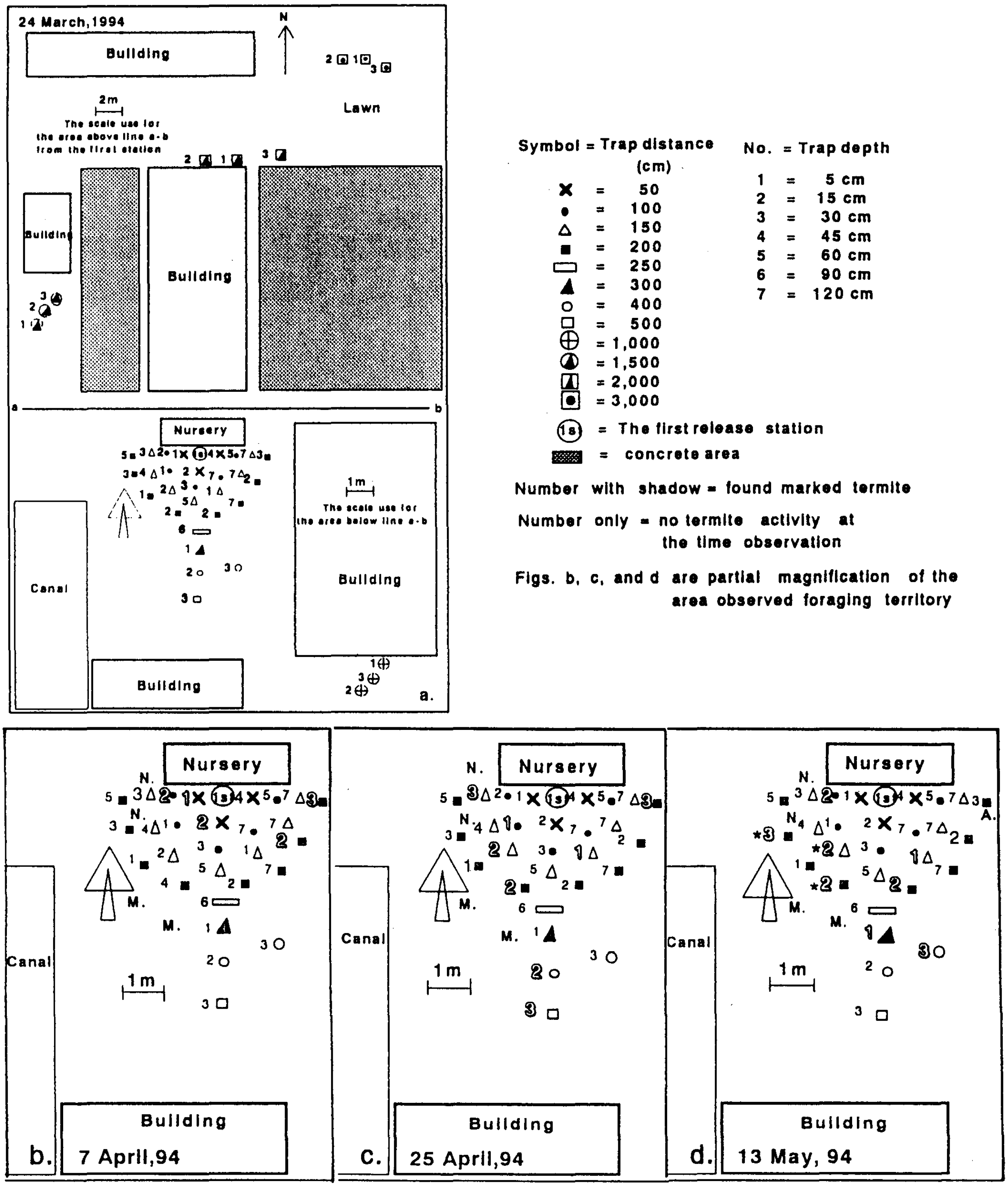



Fig. 2.4. Observation of foraging territory of *C. gestroi* (Colony C) at Pak-Kret, Nonthaburi Province. a: Initial 40 traps, b: First observation, c: Second observation, d: Third observation, M: *Microcerotermes* sp., N: *Nasutitermes* sp., O: *Odontotermes* sp., A: Ant.

Table 2.2. Termite activity of *C. gestroi* from three colonies in Bangkok Metropolitan and Nonthaburi Province during March through May 1994.

| Trap depth (cm) | Colony A | | Colony B | | Colony C | | Mean of 3 colonies | |
|---|---|---|---|---|---|---|---|---|
| | Number of worker | % soldier | Number of worker | % soldier | Number of worker | % soldier | Number of worker | % soldier |
| 5 | 2,469 | 13.4 | 2,082 | 15.2 | 3,578 | 11.0 | 2,710 | 13.2 |
| 15 | 18,159 | 7.8 | 14,247 | 2.6 | 14,930 | 5.4 | 15,779 | 5.3 |
| 30 | 3,089 | 7.6 | 5,364 | 3.6 | 5,856 | 5.5 | 4,770 | 5.6 |

Note: Mean numbers of workers and percent soldier proportion were obtained from three capture cycles.

Table 2.3. Mean individual body weight of worker and soldier of three colonies of subterranean termite *C. gestroi* during March through May 1994.

| Colony | Mean individual body weight (mg±SD)* | |
|---|---|---|
| | Worker | Soldier |
| A | 2.71±0.07 | 2.38±0.09 |
| B | 2.73±0.11 | 2.43±0.07 |
| C | 2.80±0.06 | 2.54±0.08 |

*: Mean individual weight was calculated from the four times measurements of 100 termites each at three capture cycles.

On the basis of observation during a triple mark-release-recapture program, marked termites were found in 5, 8 and 8 monitoring collection traps, respectively in colony C (Fig. 2.4b, c and d). Results indicated that foraging distance extended up to the maximum of 5.0 m with the highest number of foragers (14,930) at the depth of 150 mm and the highest soldier proportion (11%) at the depth of 50 mm (Table 2.2). Mean individual body weights of worker and soldier were $2.80 \pm 0.06$ mg and $2.54 \pm 0.08$ mg (mean ± SD), respectively (Table 2.3).

The present study demonstrated that foraging territory of *C. gestroi* was very small when compared with that of the other subterranean species. Formosan subterranean termite, *C. formosanus*, extended its galleries up to 100 and foraging territory of the termite ranged from about 126 to 3,571 2 per colony [61]. On the other hand, western subterranean termite, Reticulitermes flavipes (Kollar), extended foraging distance up to 41-79 m and covered an area of approximately 285–1,091 $m^2$ [40,62].

Mean individual worker weight of three colonies of *C. gestroi* was 2.7–2.8 mg (Table 2.3) which were smaller than those 2.9 to 6.0 mg of *C. formosanus*[38,58].

From the present result, it can be assumed that a depth of 150 mm below ground surface provides a suitable environmental condition for *C. gestroi* feeding activity. The similar result was obtained by La Fage *et al.*[71] with respect to the desert subterranean termite, *Gnanthamitermes perplexus*. Percent soldier proportion was relatively higher at the depth of 50 mm than that at the depth of 150 mm or 300 mm. The reason might relate to the termite behavior in defencing or protecting their colony from enemies, since more ants and other predators were found at the 50 mm depth than those at the deeper levels. Unfortunately, soil temperature and soil moisture in the trap at different foraging depths were not measured in this study. Further intensive study should be conducted using more colonies at different locations and under various environmental conditions and different seasons to conclude the suitable environmental conditions for foraging activity of *C. gestroi*.

## 2.2 Foraging population of *Coptotermes gestroi* Wasmann in an urban area

### 2.2.1 Introduction

Following the investigation on foraging territory (Section 2.1), foraging population must be estimated. Excavation of termite nests and tracing of radioisotope-labeled termites were conducted to estimate the population sizes of mound building termites[56,72] and subterranean termite[73]. Collection of infested wood[74–76] has been used to investigate subterranean termites in the past. However, these methods are not suitable for the estimation of foraging populations of subterranean termites in an urban area because of their colonies might be close together and their foraging territories are mostly occurred underground or under concrete slab in the building areas.

Wood-baiting or trapping techniques have been proposed and applied to subterranean termites[38,59,77–79] together with a mark-release-recapture system for the estimation of foraging populations[40,57,58,62]. In order to improve reliability of the results, multiple mark-recapture techniques have been extensively used in recent years[60,61]. In this section a triple mark-recapture program was conducted to estimate foraging populations of the Thai subterranean termite, *C. gestroi*, in an urban environment[80].

### 2.2.2 Materials and methods

A survey of the population sizes of the Thai subterranean termite, *C. gestroi* was conducted from May through June 1994 in an urban area using three field colonies described in the last section.

Approximately 30 rubber wood stakes measuring 25×25×200 mm were installed near infested wood, stumps or trees and around the buildings at each colony site. After termite activity was found, stakes were replaced by collection traps (with adjacent traps no closer than 500 mm). The collection trap unit was made of polyvinyl chloride (PVC) pipe (150 mm I.D. and 200 mm high) with a roll of corrugated paper and a rubber wood stake in it. The unit was buried up to 150 mm in the soil (Fig. 2.5). The corrugated paper in each collection trap was moistened with water. The top end of the PVC pipe was covered with an aluminium lid. Ten collection traps were used at each site.

A triple mark-release-recapture procedure[61] was carried out to estimate the foraging

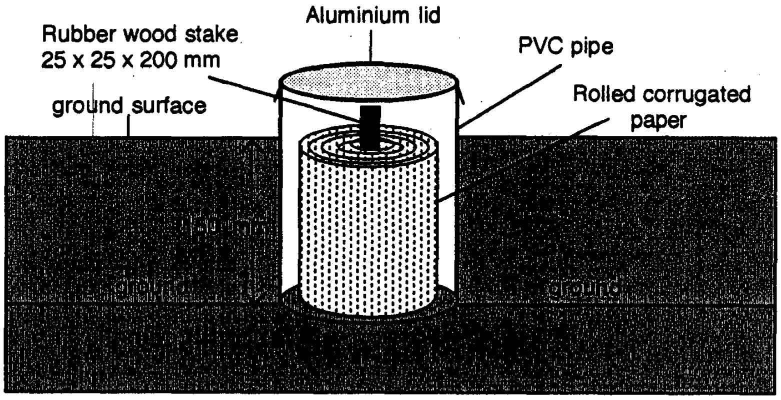



Fig. 2.5. Collection trap unit.

populations of *C. gestroi*. Following the first collection of termites from a monitoring station, they were force-fed on filter paper stained with 0.4% (w/w) Nile Blue A (Aldrich Chemical Company, Inc.) for 3 days and released back to the same station. Termites were collected from the monitoring stations every week after the release of stained termites. Termites collected from the stations containing marked termites were assumed to belong to the first released group were counted, stained and released back into their respective stations. Three mark-release-recapture cycles were conducted for each colony. Numbers of workers and soldiers collected from each monitoring station were estimated by weighing, and the foraging population of a colony ($N$) and associated SE were calculated from the following equations[47,81]

$$N=(\Sigma Mini)/[(\Sigma mi)+1]$$

$$\mathrm{SE}=N\sqrt{[1/(\Sigma mi+1)]+[2/(\Sigma mi+1)^2]+[6/(\Sigma mi+1)^3]}$$

where for each $i$ th cycle, $ni$ is the number captured, $mi$ is the number of marked individuals among captured termites, and $Mi$ is the total number of marked individuals up to the $i$ th cycle.

Individual body weight of worker and soldier was measured for 4 groups of 100 termites from each recapture cycle, then subjected to an analysis of variance (ANOVA). Mean body weight of termites was analyzed for statistical significance among the three colonies by Scheffe's test[70] at $P<0.05$.

### 2.2.3 Results and discussion

**Foraging population of the Thai subterranean termite *C. gestroi***

A triple mark-release-recapture program conducted at three field colonies (A, B and C) during May–June 1994 were illustrated in Figs. 2.6–2.8. At each colony site, a monitoring station with the highest termite activity was designed to the first collection trap (denoted by 1st in a circle), which was initially collected termites and released of stained termites back into this single station. Monitoring stations with termite activity were denoted by solid circles with identification number, but open circles denote monitoring stations without termite activity at the time of observation (Figs. 2.6–2.8b, c and d). The number of stained termites released, termites recaptured including stained individuals at each recapture cycles are summarized in Table 2.4.

The foraging population of colony A was estimated at $(2{,}610 \pm 82) \times 10^3$ (mean ± SE). Body weight of an individual worker and soldier was (mean ± SE) $2.73 \pm 0.01$ mg and $2.43 \pm 0.01$ mg, respectively (Table 2.5).

Colony B was considered independent of colony A, as the trial site was approximately 600 m away from the area of colony A. Foraging population of colony B was estimated at

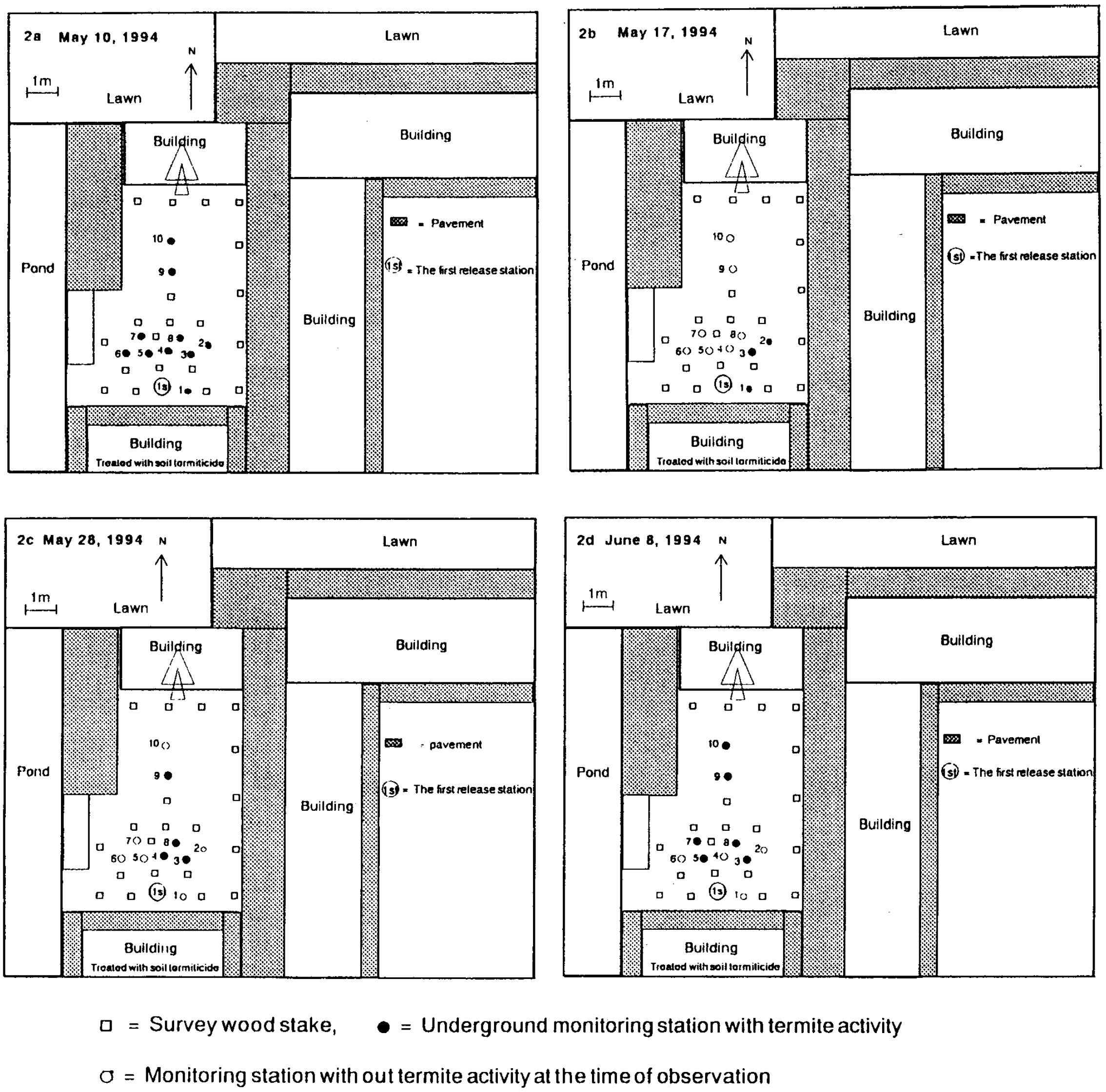
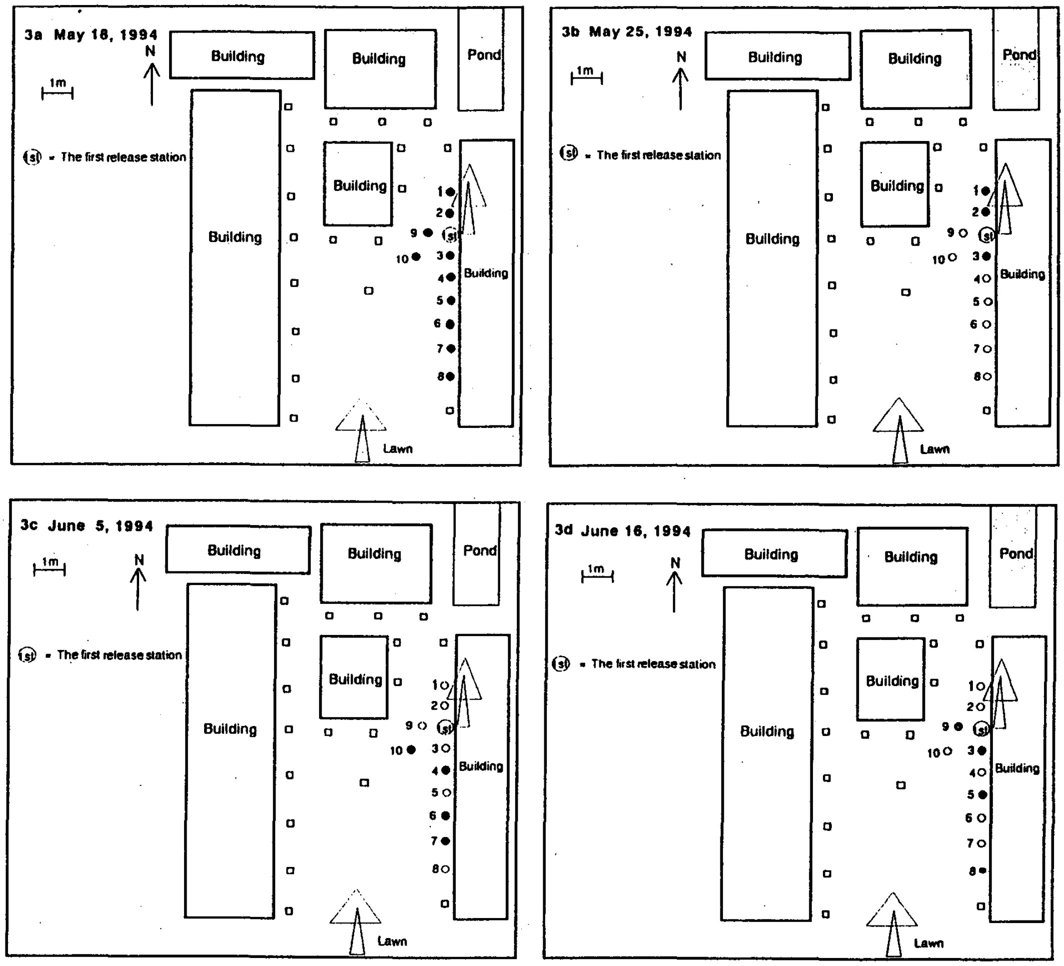



Fig. 2.6. Triple mark-recapture procedure for the estimation of foraging population of a field colony of *C. gestroi* (Colony A at Forest Products Research Division, Royal Forest Department, Bangkok).




□ = Survey wood stake, ● = Underground monitoring station with termite activity

○ = Monitoring station without termite activity at the time of observation

Fig. 2.7 Triple mark-recapture procedure for the estimation of foraging population of a field colony of *C. gestroi* (Colony B at Royal Forest Department, Bangkok).

$(2{,}750 \pm 100) \times 10^3$. Body weight of an individual worker and soldier was $2.74 \pm 0.01$ mg and $2.44 \pm 0.01$ mg, respectively (Table 2.5).

Estimated foraging population of colony C was about $(1{,}127 \pm 26) \times 10^3$ termites per colony that seem to be smaller number of foragers comparable to colony A and B. Mean individual body weight of worker and soldier was $2.88 \pm 0.03$ mg and $2.49 \pm 0.01$ mg, respectively (Table 2.5).

**Factors causing variation in foraging populations.**

Since the present field survey was carried out at the beginning of the rainy season, we suspected that environmental factors might play an important role in influencing termite foraging population size, as pointed out earlier[71,82,83]. From observation in the sites of colonies A and B, environmental conditions such as high moisture, low air ventilation and

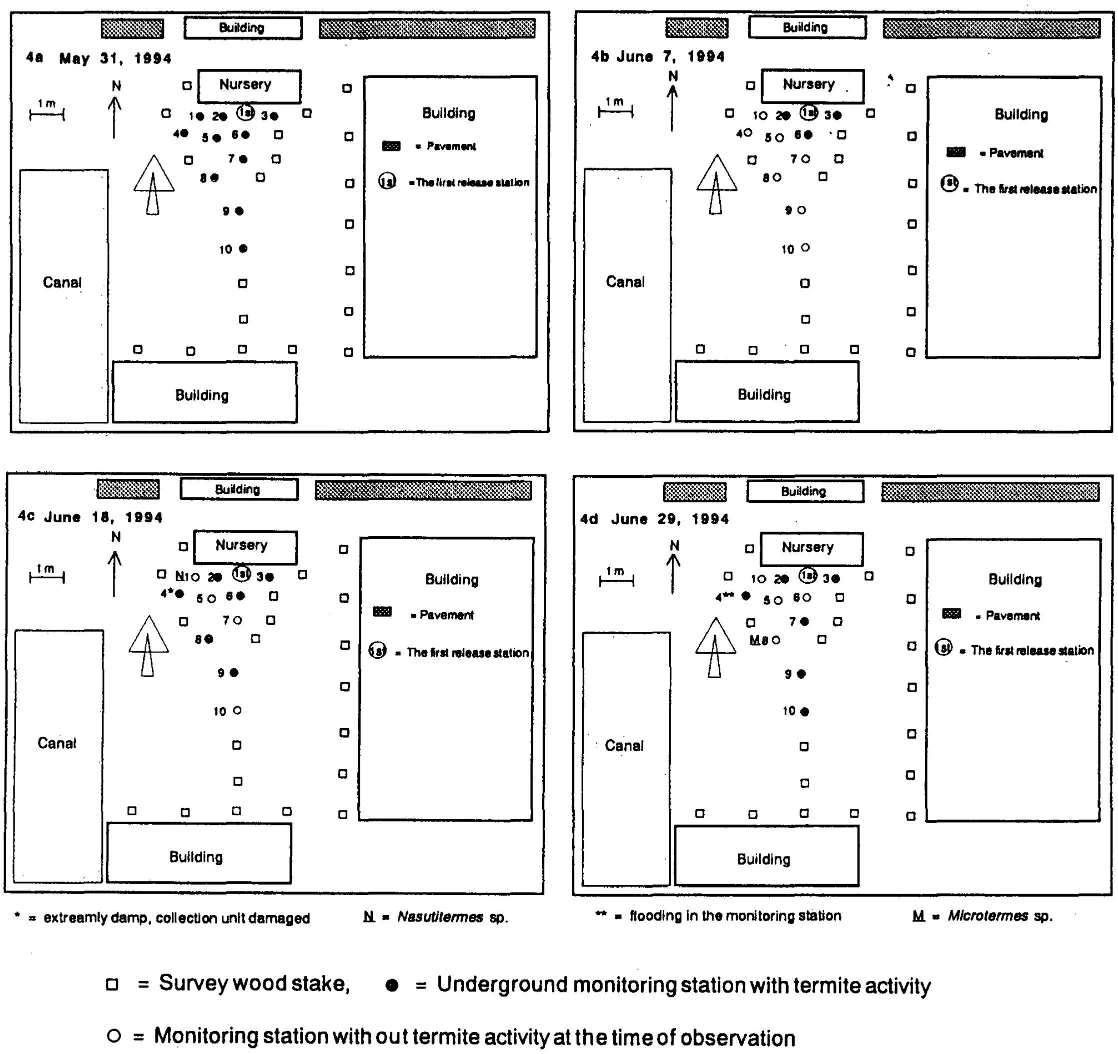



Fig. 2.8 Triple mark-recapture procedure for the estimation of foraging population of a field colony of *C. gestroi* (Colony C at Pak-Kret, Nonthaburi Province).

more shading area might increase site suitability *C. gestroi.*

On the other hand, colony C was located on a low land area near the Choaw-phaya river which was subjected to occasional flooding. Competition with other termite species was evident from the presences of *Nasutitermes* sp. and *Microtermes* sp. in traps previously occupied by *C. gestroi* (Figs. 2.8c and d). Thus, natural competition and disturbance (flooding) might suppress termite foraging activity and result in the smaller foraging population. Heavy rainfall often brought about flooding, and some termites were found dead in the traps. Trap collection units were also damaged under extremely damp condition. These factors appeared to decrease the number of termite collected.

It is also important to note that termite colonies are not static and unchanging, one would expect that colony foraging population change with the age of the colony as recently

Table 2.4. Number of marked termites released *(ri)*, number of termites captured *(ni)*, and number of marked termites among those captured *(mi)* during a triple mark-recapture program

| Colony | *i* th Mark-recapture | *ri* | *ni* | *mi* |
|---|---|---|---|---|
| A | 1 | 21,814 (1st) | 18,409 (1, 2, 3) | 166 |
| | 2 | 16,900 (1, 2, 3) | 27,168 (3, 4, 8, 9) | 384 |
| | 3 | 23,609 (3, 4, 8, 9) | 19,558 (3, 5, 7, 8, 9, 10) | 473 |
| B | 1 | 26,150 (1st) | 19,411 (1, 2, 3) | 250 |
| | 2 | 15,528 (1, 2, 3) | 24,247 (4, 6, 7, 10) | 237 |
| | 3 | 20,000 (4, 6, 7, 10) | 9,446 (3, 5, 8, 9) | 276 |
| C | 1 | 26,400 (1st) | 37,207 (2, 3, 6) | 350 |
| | 2 | 35,000 (2, 3, 6) | 11,237 (2, 3, 4, 6, 8, 9) | 1,112 |
| | 3 | 10,000 (2, 3, 4, 6, 8, 9) | 6,009 (2, 3, 4, 7, 9, 10) | 402 |

Identification number of monitoring stations (see Figs. 2.6−2.8 for location) from which marked termites were captured and released are listed in parentheses.

Table 2.5. Foraging populations and mean individual worker and soldier body weight of *C. gestroi* from 3 field colonies in an urban area during May −June 1994.

| Colony | Foraging population ($\times 10^3$, mean$\pm$SE) | Mean individual body weight* (mg, mean$\pm$SE) | |
|---|---|---|---|
| | | Workers | Soldiers |
| A | 2,610± 82 | 2.73±0.01 | 2.43±0.01 |
| B | 2,750±100 | 2.74±0.01 | 2.44±0.01 |
| C | 1,127± 26 | 2.88±0.03 | 2.49±0.01 |

*: Mean of 4 groups of 100 termites from three capture.

described by Grace *et al.*[84].

Statistical analysis (ANOVA) showed that weight of termites of colony C were bigger than those of colonies A and B (worker, $F=17.2$; df=2,33; $MS=0.08$; $P<.0001$ and soldier, $F=5.24$; df=2,33; $MS=0.011$; $P=0.0106$)

Foraging population sizes of *C. gestroi* estimated in our study fell within the range of the two important termite species, Formosan subterranean termite *Coptotermes formosanus* Shiraki (1–7 million) and Eastern subterranean termite *Reticulitermes flavipes* (Kollar) (0.1–5 million) in the United State and Canada[40,60,61]. Thus, the results actually will show a great deal of similarity among these three species, when sample size increases. Further investigations should be conducted in different seasons and under various ecological conditions to estimate a realistic population size of *C. gestroi* in Thailand.

## 2.3 Feeding activity of *Coptotermes gestroi* Wasmann against commercial and fast growing timbers of Thailand

### 2.3.1 Introduction

In Sections 2.1 and 2.2, foraging characteristics of *C. gestroi* have been investigated. For many years, typical Thai houses have been made of wood. Constructional timbers should not be perishable in the short term due to economic considerations. Durable timbers, such as *Tectona grandis* Linn. f., *Xylis xylocarpa* (Roxb.) and *Hopea odordta* Roxb. *et al.*, have been popularly used for building constructions in this country. However, the rapid growth of the human population has led to a drastic increase of wood demands in the tropical countries, and this causes a severe shortage of durable timbers for building construction. Other species, such as *Dipterocarpus* spp. and some fast growing timbers have been used for many purposes other than building constructions in Thailand, but these are now popularly used for construction.

Due to the aim of this study, feeding activity of *C. gestroi* against some commercial and fast growing timbers which are now popularly used for building constructions is evaluated in this section[85].

### 2.3.2 Materials and methods

**Timber species**

The seven commercial timbers used in this study were *Anogeissus acuminata* Wall., *Chukrasia tabularis* Wight & Arn., *Lagerstroemia floribunda* Jack., *Dipterocarpus alatus* Roxb., *D. tuberculatus* Roxb., *D. baudii* Korth. and *D. obtusifolius* Jeijsm. *Hevea brasiliensis* Muell. Arg. (rubber wood) and *Pinus densiflora* Sieb. et Zucc. (Japanese red pine) were also used as control susceptible timbers.

Eleven species of fast growing timber were *Swietenia macrophylla* King, *Melia azedarach* Linn., *Peltoporum dasyrachis* Kurz, *Leucaena leucocephala* de Wit, *Anthocephalus cadamba* Miq, *Tetrameles nudiflora* R. Br., *Pinus oocarpa*, *P. caribeae* Morelet, *P. merkusii* Junch, *P. kesiya* Royle and *Ochroma lagopus* Sw. Three control susceptible timbers were *Hevea brasiliensis* Muell. Arg. (rubber wood) *D. baudii* Korth and *D. alatus* Roxb.

**Termites**

*C. gestroi* maintained in concrete tub, measuring 60 cm (W)×90 cm (L)×80 cm (H) for six months at the laboratory of Wood Products Research Division, Royal Forest Department, Bangkok prior was used for bioassay.

**Preparation of wood blocks**

The seven timber species and two control species were cut into small blocks, measuring 10 mm (R)×10 mm (T)×20 mm (L), but for the fast growing timbers and three control species, measuring 50 mm (R)×25 mm (T)×100 mm (L), without any consideration whether those were from sapwood or heartwood or a combination of both. Ten replicates were prepared for each species of seven timbers, and each half of them was tested by two bioassay methods (A and B) described below. Before termite bioassay, all blocks were dried at 105°C to measure their oven-dried weight before test (W1). Three replicates were prepared for each species of fast growing timbers and tested by Method C.

**Bioassays**

From the results of preliminary experiments[86], a modified wood block test in bottle (Method A or MWBT-test) was employed for a no-choice test (Fig. 2.9). The glass bottle

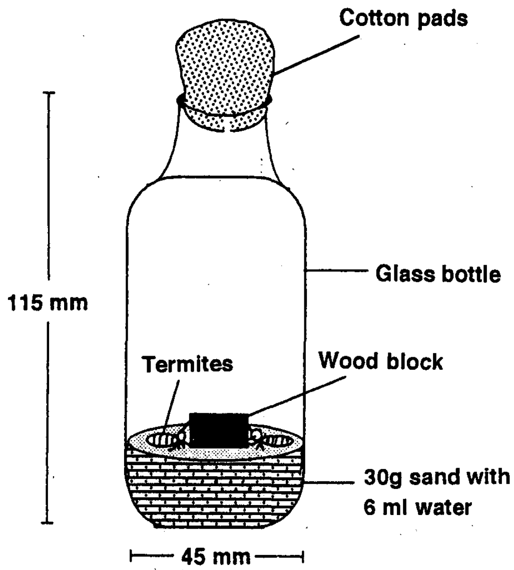



Fig. 2.9 An glass bottle container for modified wood block test (MWBT).

with volume of 180 ml, 45 mm in diameter and 115 mm in height, was used as a container. It has been used for laboratory tests with *Reticulitermes* spp.[87] and *Nasutitermes* spp.[88]. Thirty grams of sand sieved through 20 mesh was filled in the bottle and moistened with 6 ml of distilled water. Test wood blocks were put onto the soil surface of the bottle with 250 workers and 25 soldiers of *C. gestroi*. Each bottle was plugged with cotton wool and kept in the dark under ambient condition for 21 days.

Method B is a choice test, using a whole laboratory colony of *C. gestroi* maintained for 6 months. Wood blocks were randomly placed onto a wire sieve set on the termite nest in a concrete tub. After 4 months all blocks were recovered, water-washed, dried and re-weighed to obtain weight after termite attack (W2). Percent mass loss of wood blocks was calculated by the following equation $[(W_1-W_2)/W_2]\times 100$ (%) in Section 2.3. From percent mass loss of test wood blocks of the seven timbers were classified into five levels of resistance as follows:

| Percent mass loss | | Level of resistance |
|---|---|---|
| No-choice test (Method A) | Choice test (Method B) | |
| 0 | 0 | Highly resistant |
| 1–3 | 1–15 | Resistant |
| 4–8 | 16–40 | Moderately resistant |
| 9–15 | 41–75 | Non-resistant |
| >15 | >75 | Susceptible |

Method C is a current laboratory testing method normally used in Thailand for evaluating either the natural resistance of timbers or the efficacy of chemicals as wood treatment. One replicate of each wood species was randomly placed in a row and bundled together. Each bundle was installed in the nest of *C. gestroi*. After six months, all blocks were recovered, water washed and dried. Results examined by visual rating. Timbers were classified into five levels of durability according to the rate as shown below.

| Degree of damage | Termite attack on wood | Classified to natural durability | |
|---|---|---|---|
| 0 | No damage | Very durable | (VD) |
| 1 | Hardly visible damage | Durable | (D) |
| 2 | Superficial and slightly inner damage | Moderately durable | (MD) |
| 3 | Moderately inner damage | Non durable | (ND) |
| 4 | Heavy inner damage | Perishable | (P) |

### 2.3.3 Results and discussion

**Natural durability of some timbers commonly used for building construction**

Table 2.6 shows average percent mass loss of wood blocks after 3 weeks in no-choice test (Method A). *C. tabularis* had the highest resistance against *C. gestroi*, appearing less than 3% mass loss, and was classified as "Resistant". Following this, *A. acuminata* and *L. floribunda* were classified as "Moderately resistant" as the test blocks sustained 4.6 and 3.8% mass loss, respectively. No significant difference was observed among these three species at $p=0.01$. In addition, 100% termite mortality was observed within 15–17 days for these timbers. As several researchers pointed out[1,89,90], extractives in heartwood may contribute to the higher resistance of these species against *C. gestroi* in no-choice test. But in the study, no data has been obtained with respect to extractives from these species yet.

Four *Dipterocarpus* species, which showed from 9.4 to 12.9% mass loss, were classified as

Table 2.6. Percent mass loss of seven commercial timbers and their level of resistance against *C. gestroi* in no-choice test (Method A).

| Timber species | Mass loss (%)* | Level of resistance |
|---|---|---|
| *Anogeissus acuminata* Wall. | 4.6 a±1.2** | Moderately resistant |
| *Chukrasia tabularis* Wight & Arn. | 2.7 a±0.4** | Resistant |
| *Lagerstroemia floribunda* Jack. | 3.8 a±1.4** | Moderately resistant |
| *Dipterocarpus alatus* Roxb. | 10.6bc±1.4 | Non-resistant |
| *D. tuberculatus* Roxb. | 9.4bc±2.3 | Non-resistant |
| *D. baudii* Korth | 10.2bc±2.2 | Non-resistant |
| *D. obtusifolius* Jeijsm. | 12.9 c±1.8 | Non-resistant |
| *Hevea blasiliensis* Muell. Arg. | 16.5 c±2.9 | Susceptible |
| *Pinus densiflora* Sieb. et Zucc. | 15.9 c±3.0 | Susceptible |

*: Values are means±SE for 5 replicates, **: 100% mortality was observed within 15−17 days.

Note: Values in the same column followed by the same letter are not significantly different at $P<0.01$ according to Duncan's New Multiple Range Test.

"Non-resistant", and no significant difference was observed among these species (Table 2.6). Wood blocks of control timbers, *H. brasiliensis* and *P. densiflora*, had more than 15% mass loss after the 3 weeks' attacks of *C. gestroi*.

As shown in Table 2.7 the higher mass loss was obtained when wood blocks were exposed to *C. gestroi* laboratory colony directly (Method B) in comparison with Method A. It has been reported that feeding activity of termites is enhanced with the higher group sizes or density[1,88,91]. The results obtained here well supports this idea.

From the percent mass loss, *A. acuminata*, *C. tabularis* and *L. floribunda* were classified as "Resistant", showing 7.9, 11.6 and 14.8% mass loss, respectively (Table 2.7). Four *Dipterocarpus* spp. were classified as "Non-resistant" because of their relatively high mass loss (41.7–72.6%). Two control species showed more than 85% mass loss after 4 months' attacks of *C. gestroi*.

In the present investigation, *Dipterocarpus* spp. were classified as "Non-resistant" in both test methods against the most economically important subterranean termite, *C. gestroi*. As well known that *D. alatus* is the most popularly used for building constructions in Thailand. As from the earlier studied, Vongkaluang and Sornnuwat[92,93] had been reported that this timber is non-resistant against *C. gestroi* and three species of *Globitermes sulphureus*, *Macrotermes gilvus* and *Microcerotermes creassus* from pine plantation. Further it was indicated that wood attacking ability of *C. gestroi* to this timber is as destructive as *G. sulphureus*. On the other hand, wood attacking ability of *Macrotermes gilves* was considered as destructive as *Microcerotermes creassus* and seemed to be less destructive than either *C. gestroi* or *G. sulphureus*.

Since classification of seven timbers was generally identical between both test methods,

Table 2.7. Percent mass loss of seven commercial timbers and their level of resistance against *C. gestroi* in choice test (Method B).

| Timber species | Mass loss (%)* | Level of resistance |
|---|---|---|
| *A. acuminata* | 7.9 a±3.8 | Resistant |
| *C. tabularis* | 11.6 a±7.1 | Resistant |
| *L. floribunda* | 14.8 a±5.1 | Resistant |
| *D. alatus* | 41.7 b±3.1 | Non-resistant |
| *D. tuberculatus* | 54.1bc±9.6 | Non-resistant |
| *D. baudii* | 63.2bc±7.0 | Non-resistant |
| *D. obtusifolius* | 72.6cd±7.6 | Non-resistant |
| *H. brasiliensis* | 87.0de±3.9 | Susceptible |
| *P. densiflora* | 96.6 e±0.9 | Susceptible |

*: Values are means±SE for 5 replicates.
Note: See Note in Table 2.8.

it seemed that the glass bottle method was applicable for evaluating natural resistance of timbers as a simplified test method with the smaller group size of test insects and the shorter test period. By use of this laboratory method, performance of treated timbers against termite attacks can be also evaluated with the smaller efforts.

**Natural durability of some fast growing timbers**

Table 2.8 shows mean degree of damage of wood blocks after 6 months in current testing method (Method C). Seven species of fast growing timber, *Anthocephalus cadamba*,

Table 2.8. Degree of damage from visual rating and their level of durability of twelve species of fast growing timber against *C. gestroi* in choice test (Method C).

| Timber species | Mean degree of damage | Level of durability |
|---|---|---|
| *Swietenia macrophylla* King. | $0.7^{+}$ | VD/D |
| *Dipterocarpus baudii* Korth. | $0.7^{+\circ *}$ | VD/D |
| *Melia azedarach* Linn. | $1.0^{+}$ | D |
| *Peltophorum dasyrachis* Kurz. | $1.0^{+}$ | D |
| *Hevea brasiliensis* Muell. Arg. | $1.0^{+\circ *}$ | D |
| *Leucaena leucocephala* de. Wet. | $1.3^{+\circ *}$ | D/MD |
| *Anthocephalus cadamba* Miq. | 2.7* | MD/ND |
| *Tetrameles nudiflora* R. Br. | 3.0 | ND |
| *Dipterocarpus alatus* Roxb. | 3.0 | ND |
| *Pinus oocarpa* | 3.3* | ND/P |
| *P. caribeae* Morelet. | 3.3* | ND/P |
| *P. merkusii* Jungh. | 3.7* | ND/P |
| *P. kesiya* Royle. | 3.7* | ND/P |
| *Ochroma lagopus* Sw. | 3.7 | ND/P |

$^{+}$: White rot, $^{\circ}$: Mold, *: Stain.

*Tetrameles nudiflora*, *Pinus oocarpa*, *P. caribeae*, *P. merkusii*, *P. kesiya* and *Ochroma lagopus* were classified as non-durable timber as well as control species (*D. alatus*), showing the higher mean degree of damage (2.7–3.7). Another four fast growing species, *Swietenia macrophylla*, *Melia azedarach*, *Peltophorum dasyrachis* and *Leucaena leucocephala* show the lower degree of damage (0.7–1.3), and were classified as durable timber as well as another two susceptible control species, *D. baudii* and *Hevea brasiliensis*. Results in the present section is in contrast with previous reported by Vongkaluang and Jitkeaw[94], who have indicated that either *Swietenia macrophylla* or *Leucaena leucocephala* or *D. baudii* and *Hevea brasiliensis*. are classified as non-durable against *C. gestroi*. This difference might be due to the effect from fungi and mold attacks on wood specimens as described in Table 2.8. Some researchers[1,95] have point out that white rot and mold, especially *Aspergillus flavas*, could provide the toxic substance that affecting wood attacking ability of termite.

**Factors affecting the natural resistance of timbers against termite attack**

Physical and chemical properties of wood[96,97] or some extractive in heartwood of the particular timber species are also supposed to be the important factors affecting on wood attacking ability of termite[98,99]. The results shown in Table 2.8 could support this assumption. As described above, the smaller mass loss and termite mortality was observed in the three resistant timbers. On the other hand, the higher mass loss and no toxic effect was obtained in some timbers that classified as non-resistant.

Some biological factors such as wood-attacking microorganisms are considered to suppress wood attacking ability of termite as described above. Termite species is also considered to another biological factors affecting the resistance to termite attack of wood species as earlier pointed out by Ruyooka and Gorves[100]. In addition, testing and evaluating methods could be determined as factors that might cause some variation on the resistance of timbers.

# Chapter 3 Response of the Important Termite Species to Chemical and Physical Control Measures

## 3.1 Termiticidal performance of treated wood after exposure to soil burial in laboratory

### 3.1.1 Introduction

It has been previously agreed that the basic requirement for any insecticides to be used for the preventive treatment against subterranean termite is effectiveness and long term persistence[101]. Chlorinated hydrocarbon termiticides such as dieldrin chlordane and heptachlor were used worldwide for decades due to the long residual life which was advantageous especially in the tropics region[13]. But as public concern about the toxicity and detrimental environmental impact of chemicals was increasing in recent years, the application of those conventional termiticides were banned in many countries. To search for alternative termiticides, experiments on some organophosphates and synthetic pyrethroids have been evaluated as wood treatment in laboratory for termite control in Thailand, Sornnuwat *et al.*[102] indicated that organophosphate and synthetic pyrethroid show a high potential as alternative termiticides used in the country. However, these chemicals also have some disadvantageous features, they are unstable under severe weathering conditions, especially in the soil. Experiments on these chemicals showed that they deteriorated and become ineffective after soil burial, and also their effectiveness decreased conspicuously with the period of soil burial[17,22,103,104].

At present the organophosphate and synthetic pyrethroid termiticides are still not widely used in Thailand, either for soil or wood treatment[50]. As a result of public environmental concern, many products which were for termiticides have recently been introduced into the country for laboratory and long-term efficacy testing. In this section, degradation of chemicals and changes of termiticidal effectiveness are discussed when wood blocks treated with five alternative termiticidal chemicals are evaluated after soil burial in Thailand[105].

### 3.1.2 Materials and methods

**Termiticides**

Three synthetic pyrethroids (cypermethrin, fenvalerate, permethrin), the silane (silafluofen) and the organophosphate (chlorpyrifos) were used as termiticidal chemicals. These were diluted by ethanol to give concentrations of 0.5, 1.0 and 2.0% (w/w)

**Preparation of wood blocks**

Wood blocks (10 mm (R)×10 mm (T)×20 mm (L)) were prepared from sapwood of *P. densiflora* and brush treated with solutions of each termiticide at the rate of 110±10 g/m$^2$. Six replicates were prepared for each aging period. All treated wood blocks were air-dried under room conditions for 3 weeks prior to soil burial.

**Procedure of soil burial**

Treated wood blocks from each treatment were kept separate in humic unsterilized soil with the pH of 6 (a commercial horticultural soil ) in a plastic box in the dark at room temperature for 1, 3, 6 and 12 months. Soil was kept moist for the optimum growth of microorganisms throughout the test period. Untreated wood blocks were similarly subjected to determine mass loss during soil burial.

**Chemical analyses**

After 1, 3, 6 and 12 months' soil burial, three wood blocks were recovered, cut into chips, and the remaining chemicals were extracted with acetone for three hours by soxhlet apparatus. The extract solutions were evaporated to near dryness and re-dissolved in 1 ml acetone to obtain the samples for GC analysis.

GC analyses were performed by Shimadzu GC-15 A gas chromatography fitted with

FID-detector. Analyzing conditions were as follows: Column: CBP-1-W-12-300 for synthetic pyrethroids and the silane; CBP-10-W-25-100 for chlorpyrifos, Carrier gas: He 60 ml/min, Column temp: 190°C (Chlorpyrifos); 230°C (permethrin and fenvalerate); 250°C (cypermethrin and silafluofen); Detector temp.: 230°C (chlorpyrifos); 260°C (permethrin, fenvalerate and silafluofen); 280°C (cypermethrin).

**Termite bioassays**

The remaining of three replicates of treated wood blocks were also recovered from soil after 1, 3, 6 and 12 months, and were cleaned, oven-dried and weighed to measure their oven-dried masses. After that the wood blocks were subjected to attack by the subterranean termite, *C. gestroi*, in a laboratory bioassay. MWBT-test descibed in Section 2.3 was employed as the laboratory bioassay method.

### 3.1.3 Results and Discussion

**Biodegradation of untreated wood blocks**

Severity of biodegradation during soil burial period was determined by mass loss of the untreated wood blocks. As shown in Fig. 3.1, mass losses of untreated wood blocks gradually increased for approximately 2.5% to 53.6% after 1 and 12 month' soil burial. The results of Tsunoda *et al.*[104], who observed the degree of biodegradation activity after 12 weeks' soil exposure, were approximately 50% less than the result obtained in the present experiment. It, thus, seems that soil conditions greatly affect the biodegradation of wood, and the test conditions employed here were severe to termiticidal chemicals.

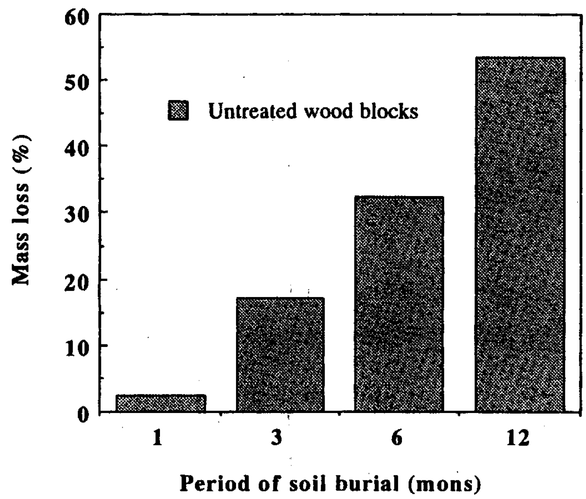



Fig. 3.1. Mean % mass loss of untreated wood blocks after 1, 3, 6 and 12 months' soil burial.

**Degradation of termiticides by soil burial**

Recovery rates of five chemicals after soil burial are shown in Figs. 3.2–3.4. The higher recovery rates were basically obtained from wood blocks treated with higher

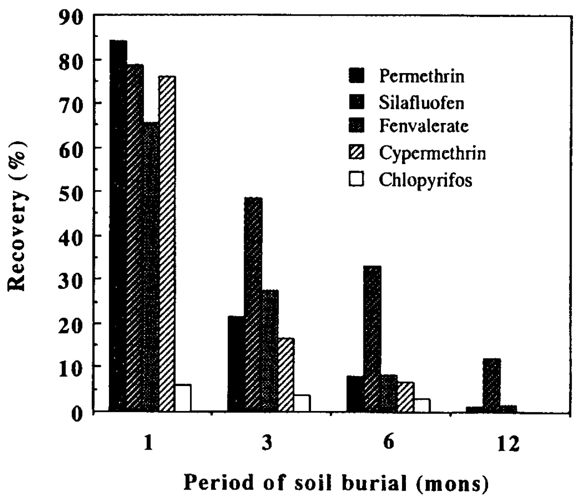



Fig. 3.2. Recovery rates of termiticides at 0.5% treatment after 1, 3, 6 and 12 months' soil burial.

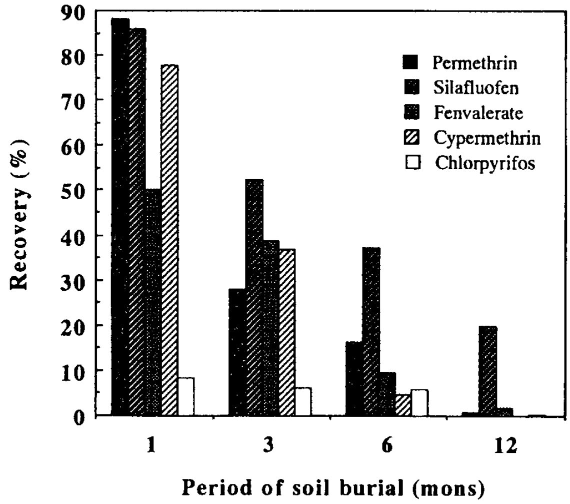



Fig. 3.3. Recovery rates of termiticides at 1.0% treatment after 1, 3, 6 and 12 months' soil burial.

concentrations in all chemicals as shown in previous works[22,108,109]. Chlorpyrifos showed the lowest resistance to degradation compared to the other termiticides. Even after only one month soil burial, recovery rates were greatly reduced (6.2, 8.5 and 11.9% for treatment with chlorpyrifos at the concentration of 0.5, 1.0 and 2.0%, respectively).

Recovery rates of the three synthetic pyrethroids and the silane after one month's soil burial even at the lowest concentration of 0.5% were approximately over 50%. Silafluofen, at every concentrations, showed the highest recovery rate compared to the other three pyrethroids. Approximately 12–20% of initial silafluofen still remained after 12 months' soil burial at any concentrations. It was followed by permethrin, fenvalerate and cypermethrin, showing about 7% and 0–1% recovery rates at 2.0% and the lower concentration, respectively, after 12 months' soil burial.

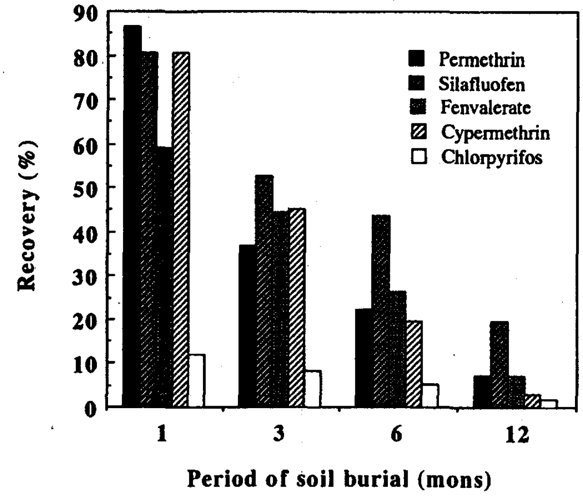



Fig. 3.4. Recovery rates of termiticides at 2.0% treatment after 1, 3, 6 and 12 months' soil burial.

These results evidently show that chlorpyrifos degrades more rapidly than the other termiticides when in contact with soil having rich microflora. It is well known that organophosphates are easily broken down when applied to alkaline soils[106]. The value of pH of the soil used in the present experiment is slightly acidic (6.0), therefore, it might be concluded that chlorpyrifos degrades at the highest rate among test chemicals regardless of soil conditions. Among the termiticides tested, silafluofen is the most resistance to soil burial, followed by the three synthetic pyrethroids.

**Effect of soil burial on termiticidal performance**

Data from termite bioassays (summarized in Figs. 3.5–3.7) demonstrated that all chemicals maintained a good performance after 1 month's soil burial regardless of

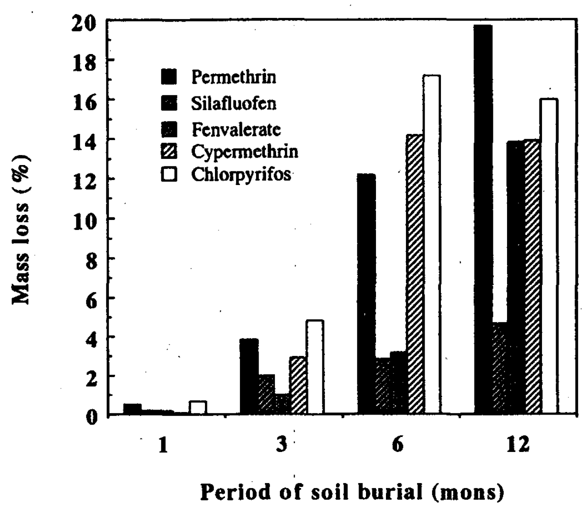



Fig. 3.5. Termiticidal efficacy at 0.5% treatment after 1, 3, 6 and 12 months' soil burial.

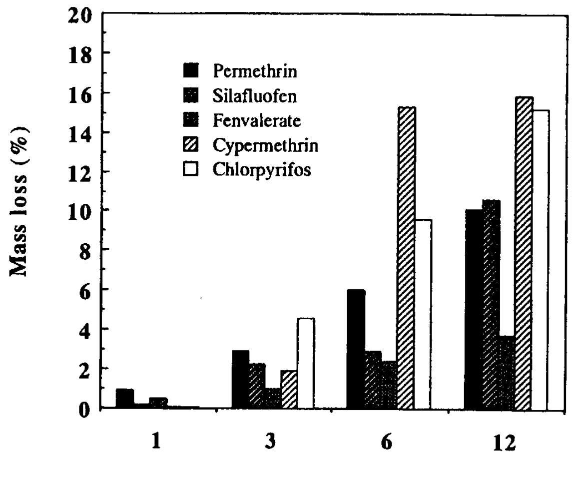



Fig. 3.6. Termiticidal efficacy at 1.0% treatment after 1, 3, 6 and 12 months' soil burial.

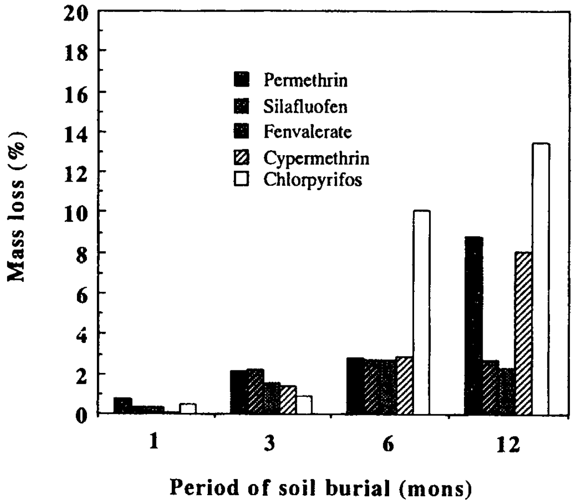



Fig. 3.7. Termiticidal efficacy at 2.0% treatment after 1, 3, 6 and 12 months' soil burial.

concentration. Their termiticidal activity decreased with the period of soil burial. Permethrin 0.5% and chlorpyrifos 0.5% and 1.0% failed to produce satisfactorily efficacy within 3 months. When the period of soil burial increased to 6 months, silafluofen at every concentration, fenvalerate at 1.0% and 2.0%, and permethrin and cypermethrin at 2.0% showed good termiticidal performance. However, after 12 months' soil burial, only silafluofen and fenvalerate at the highest concentration were found to be effective to protect the tested wood blocks from the termite attack. Less than 3% wood consumption and 100% termite mortality were observed at the end of bioassay in these cases.

The results of bioassays coincided well with the chemical analyses. Silafluofen was the most resistance to soil burial treatment, and treated wood blocks were the most effective in bioassays after prolonged period of soil burial. The order of effectiveness of treated wood blocks after long-time soil burial against *C. gestroi* among four termiticides other than chlorpyrifos was silafluofen ≥ fenvalerate > permethrin > cypermethrin. Although more than 90% of chlorpyrifos degraded by 3 months' soil burial, the moderate termiticidal effectiveness was observed because of the high toxicity of the chemical.

The present results indicate the possibility of all test chemicals as potential alternatives termiticides in Thailand.

## 3.2 Termiticidal performance of treated wood after indoor and outdoor exposures in above ground situation

### 3.2.1 Introduction

In the last section, it was described that synthetic pyrethroids (cypermethrin, fenvalerate and permethrin), the silane (silafluofen) and the organophosphate (chlorpyrifos) had a potential as alternative termiticides when used as wood treatments against Thailand's most economically important subterranean termite, *Coptotermes gestroi* Wasmann. But for a long term protection of more than 12 months, only silafluofen and fenvalerate at 2% treatment were effective for protecting wood from termite attack in ground contact situation. On the basis of published data[16,18,107,108], termiticidal performance of some organophosphates tended to decrease over time with heat exposure especially at lower concentrations, and an adverse effect on their performance was produced by ultraviolet (UV) irradiation. In this section, degradation of termiticides and changes of termiticidal performance in the tropical weathering, outdoor and indoor exposures in above ground situation were investigated by chemical analyses and bioassays for further consideration on selecting the suitable alternative termiticides used in certain environmental condition[109].

### 3.2.2 Materials and methods

**Treatment of wood blocks with test chemicals**

The test chemicals and treating method of wood blocks were the same as in Section 3.1. Treatment concentrations were 0.5%, 1.0% and 2.0% for all chemicals.

**Procedure of natural weathering for above ground situation**

After measuring the oven-dried masses, treated wood blocks were separated into two groups. One group was set on an uncovered table and exposed to natural indoor weathering for 12 and 24 months in a room that diurly lit and not exposed to direct sunlight, with an average temperature of 28°C and relative humidity of 74%. Another group was placed horizontally on a plastic sieve, and exposed to natural outdoor weathering for the periods of 1, 3, 6 and 12 months. The average annual rainfall was 1,543.6 mm. After exposure, the wood blocks were recovered, and oven dried at 105°C to calculate mass losses caused during the exposure period. Due to a limited numbers of samples, chemical analyses were not conducted on the samples after 24 months' indoor exposure and 12 months' outdoor exposure.

**Chemical analyses and bioassays**

Chemical analyses and bioassays were carried out by the same methods as described in Section 3.1.

### 3.2.3 Results and discussion

**Effect of natural weathering on untreated wood block**

The severity of natural weathering of above ground situation was determined by mass losses of untreated wood blocks. As expected natural weathering in above ground situation caused significantly less mass losses than those of soil burial (Section 3.1). Mass losses of untreated wood blocks were approximately 1.6, 2.9, 4.4 and 6.1% after 1, 3, 6 and 12 months' outdoor exposure, respectively, while mass losses of untreated wood blocks after indoor weathering were only 0.7 and 1.0% after 12 and 24 months, respectively.

Natural weathering in outdoor condition is more severe than indoor situation, especially at the longer period of weathering. In natural weathering above ground situation, various environmental factors, such as light or UV irradiation, temperature or heat, rain, strong wind, and other unspecified factors, are assumed to be a combination of factors which affects chemical degradation of the treated wood blocks. Previous results indicated that UV irradiation was considered to be the most important factor having an influence to chemical degradation on treated wood blocks[16,18,107,108]. This is supported by the following observation: The chemical analyses of the standard samples of chlorpyrifos after direct exposure to sunlight, in a shaded room, under refrigeration, and in an oven at $60 \pm 2°C$ for 3 hrs were compared. Results indicated that the lowest recovery rate derived from the sample exposed to direct sunlight, followed by that of shade condition, but for others samples recovery rates were as high as that of the control.

In addition, wind and heavy rainfall in outdoor exposure might also accelerate the chemical degradation of treated wood blocks. It, thus, seems that degradation starts with a preferential breakdown of wood consumption by photo-oxidative radicals, and degradation products are leached away from the surface cell layers. When the cell walls collapse, total degradation occurs at the surface of wood specimen. After that, wood decaying fungi play an important role for chemical degradation[110].

**Degradation of termiticides by natural weathering in above ground situation**

Recovery rates of five chemicals after indoor and outdoor exposures in above ground situation are shown in Figs. 3.8–3.11. As shown in Fig. 3.8 the recovery rates of chemicals did not show any relationship to treating concentration when wood blocks were exposed to indoor weathering for 12 months. Chlorpyrifos showed the lowest resistance to indoor exposure compared to the other termiticides, with rates of approximately 37% after 12 months at all three concentrations. On the other hand, approximately 80% of the three synthetic pyrethroids and the silane remained after 12 months.

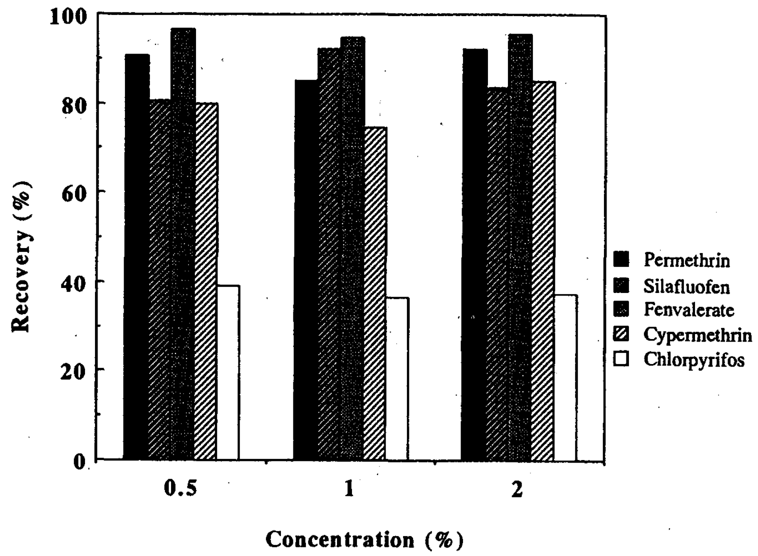



Fig. 3.8. Recovery rate of termiticides after 12 months' indoor exposure.

Figs. 3.9–3.11 show the degradation of test chemicals by outdoor exposure in above ground situation. Similar to the indoor exposure, chlorpyrifos degraded more rapidly than any of the termiticides tested. Even after one month's exposure, less than 30% of chlorpyrifos was recovered at any concentration, whereas more than 50% of other termiticides were detected after 6 months. As well shown in Figs. 3.9–3.11, recovery rates in all chemicals treated to decrease with longer period of exposure.

These data indicate that the synthetic pyrethroids and the silane, silafluofen, are

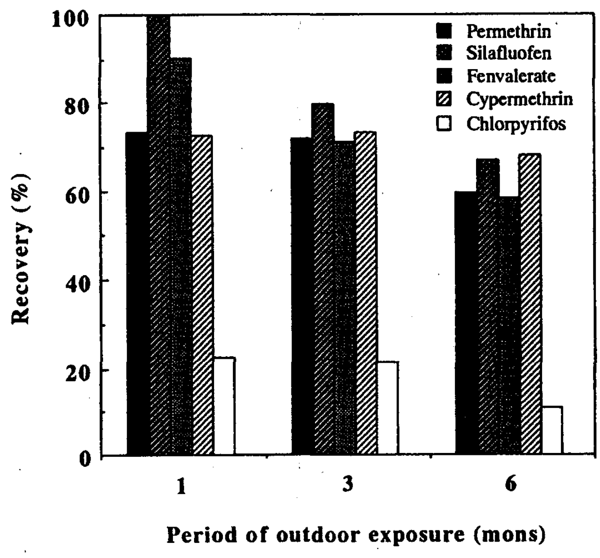



Fig. 3.9. Recovery rate of termiticides at 0.5% treatment after 1, 3 and 6 months' outdoor exposure in above ground situation.

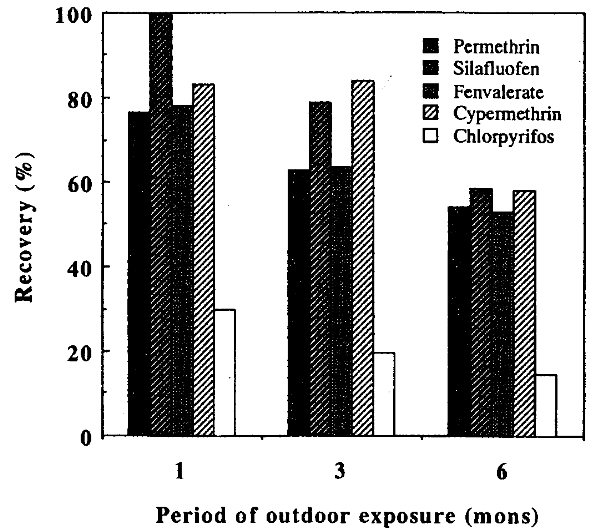



Fig. 3.10. Recovery rate of termiticides at 1.0% treatment after 1, 3 and 6 months' outdoor exposure in above ground situation.

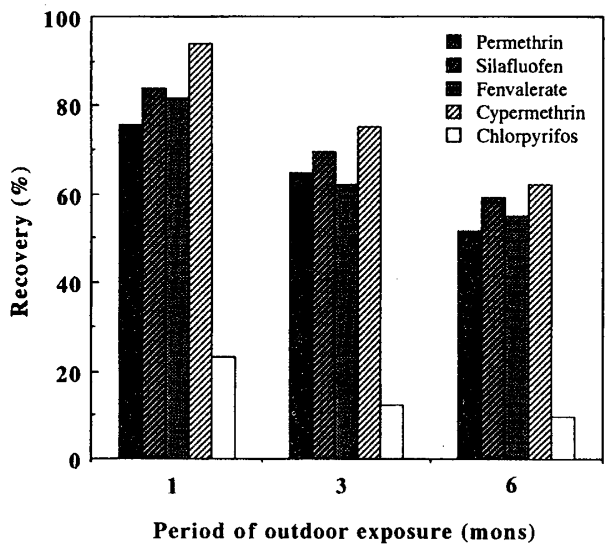



Fig. 3.11. Recovery rate of termiticides at 2.0% treatment after 1, 3 and 6 months' outdoor exposure in above ground situation.

generally superior to the organophosphate, chlorpyrifos, in term of resistance to natural indoor and outdoor weathering in above ground situation, and to soil burial.

**Effect of natural weathering on termiticidal performance**

The results of bioassay were summarized in Figs. 3.12–3.16. In the case of indoor exposure (Figs. 3.12 and 3.13), all chemicals performed well against *C. gestroi* within 24 months even at the lowest concentration at 0.5%, showing less than 2.5% wood consumption. On the other hand, 12 months' outdoor exposure caused more than 10%

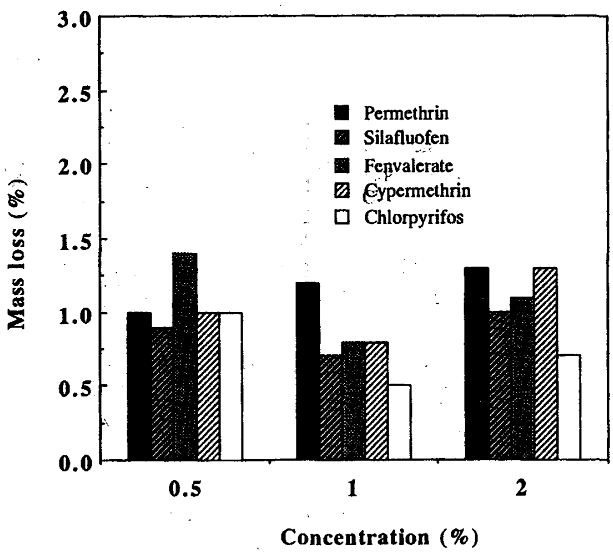



Fig. 3.12. Termiticidal efficacy after 12 months' indoor exposure.

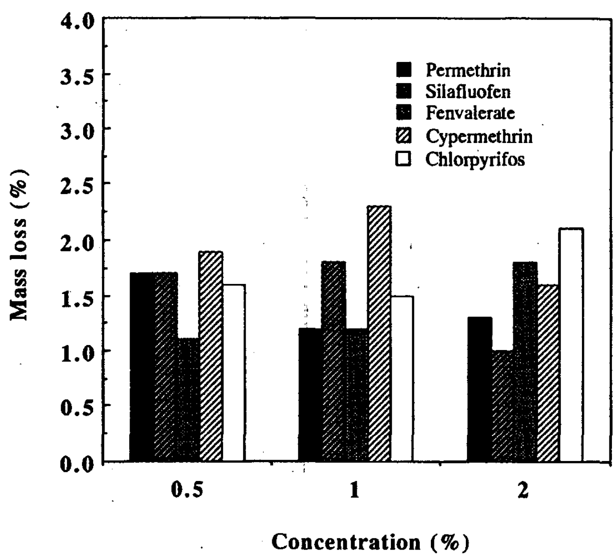



Fig. 3.13. Termiticidal efficacy after 24 months' indoor exposure.

wood consumption at 0.5% treatment in some chemicals (Fig. 3.14). But at the higher concentrations of 1.0% and 2.0 %, wood consumption were generally less than 5% (Figs. 3.15 and 3.16). Among the test termiticides, cypermethrin showed the highest performance after 12 months' outdoor exposure at 0.5% treatment, followed by permethrin and fenvalerate (Fig. 3.14). Interestingly, silafluofen, which showed the highest recovery rate after 1 and 3 months' outdoor exposure (Fig. 3.9), drastically lost its termiticidal effectiveness after 12 months' exposure, and exhibited 10%, 5% and 3.1% wood consumption at 0.5%, 1.0% and 2.0% treatment, respectively. A organophosphate,

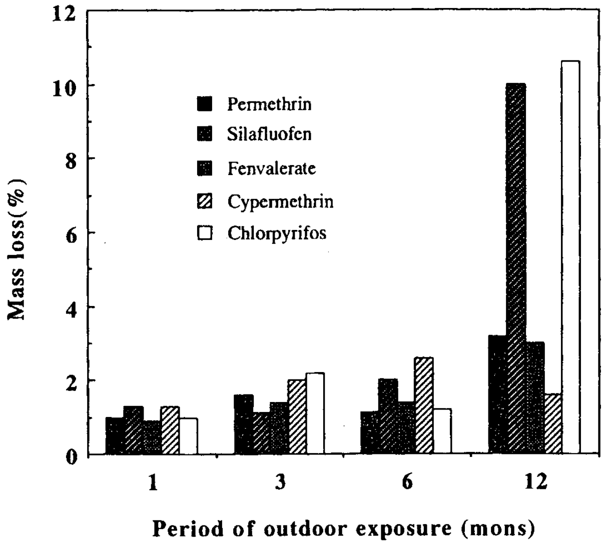



Fig. 3.14. Termiticidal efficacy at 0.5% treatment after 1, 3, 6 and 12 months' outdoor exposure in above ground situation.

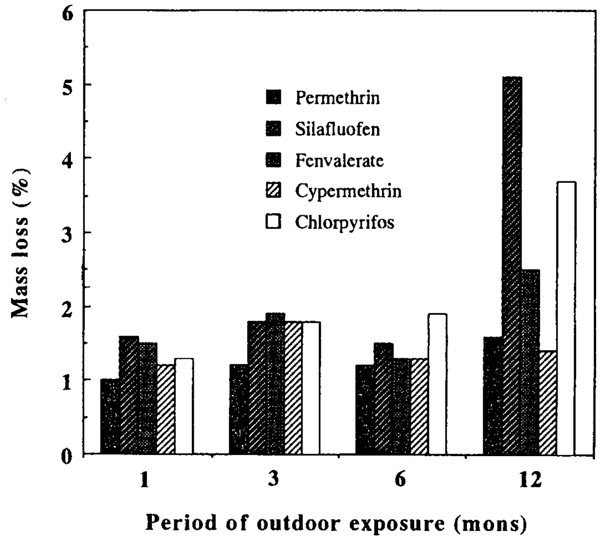



Fig. 3.15. Termiticidal efficacy at 1.0% treatment after 1, 3, 6 and 12 months' outdoor exposure in above ground situation.

chlorpyrifos, showed the highest performance among the test termiticides after 12 months' outdoor exposure at 2.0% treatment, even though the recovery rate of chemical seemed to be less than 10% (Fig. 3.11).

In comparison to the results of soil burial, the sensitivity of silafluofen to outdoor natural weathering seems noteworthy. Silafluofen-treated wood block showed only approximately 5% wood consumption at 0.5% even after 12 months' soil burial when other four chemicals exhibited more than 14% consumption (Section 3.1). As discussed above, a

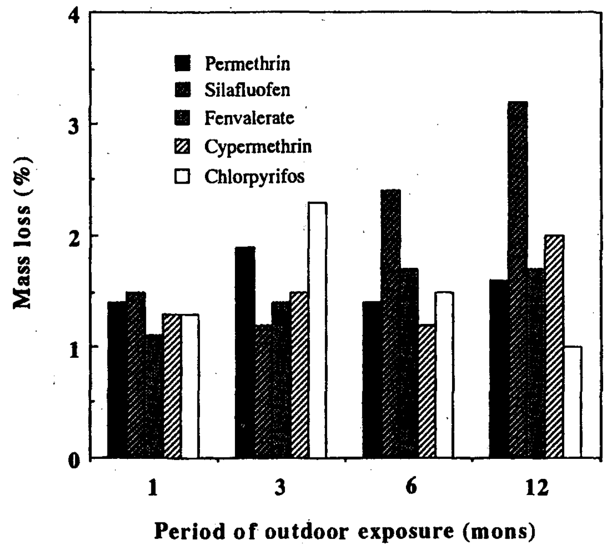



Fig. 3.16. Termiticidal efficacy at 2.0% treatment after 1, 3, 6 and 12 months' outdoor exposure in above ground situation.

UV irradiation appears to be the most important factor for affecting the chemical degradation in outdoor exposure. However, silafluofen was reported to have the higher photo stability in comparison to that of permethrin when the chemical was directly exposed to sun light for 100 hrs[106]. Therefore, it can be concluded that the combined effect containing both chemical and physical factors causes the drastic loss of termiticidal performance of silafluofen in outdoor exposure of treated wood blocks.

The results of the present investigations indicate the potential use of three synthetic pyrethroids, silafluofen and chlorpyrifos as alternative termiticides in Thailand. Higher concentrations are suggested for long-term protection of timbers in outdoor above ground situation. As stated before[111], a paint film or other coating may prevent the chemical degradation by the environmental influence during natural weathering. Pressure treatment could also prolong the service life of timbers.

As described before, soil treatment occupies the important position in controlling the invasion of subterranean termite into buildings as well as timber treatment. In the next section, various formulations of termiticides containing the chemicals used in Sections 3.1 and 3.2 will be evaluated for their performance in the field situation.

## 3.3 Longevity of soil termiticides after field exposures in Thailand

### 3.3.1 Introduction

There are no official restrictions on the use of any kind of wood preservatives or insecticides in the country, and various chemicals of organic solvent or emulsified type are available on the market. Among them, some chlorinated hydrocarbons such as aldrin and chlordane are still used for termite control, while their use has been curtailed in many countries. Although their long-term efficacy has been evaluated and their use are limited to urban areas of the country, their increasing loading in the environment might cause adverse effects in the future on human health and ecosystem.

Soil treatment with termiticides has been generally applied to the subterranean termite prevention. Organophosphates and synthetic pyrethroids have been currently used in many countries, and their long-lasting performance has been reported in field tests against *Coptotermes* spp., *Mastotermes* spp. *Heterotermes*, spp. *Schedorhinotermes* spp. and *Nasutitermes* spp. in Australia[10,24] and against *Coptotermes formosanus*, *Reticulitermes* spp. and *Heterotermes* spp. in the United States[7–9,13,25,112–115]. Recently, Kard[116] and Kard and Mauldin[117] reported the longevity of several soil termiticides in the modified ground board test in south United States (Florida, Arizona, Mississipi and south Carolina) as follows : Years of 100% control were 6–12 for 1.0% chlorpyrifos ; 4–11 for 0.5% cypermethrin ; 5–15 for 1.0% permethrin ; 6–12 for 1.0% fenvalerate ; and 2–7 for 0.125% bifenthrin, when the test plot was treated with each 5 $l/m^2$. However, these data are not necessarily transferable to tropical regions, with higher microbial and termite activities and more severe weathering conditions.

In this section the author describes the longevity of several marketable chemicals that were applicated to soil for 3–4 years at the three test sites in Thailand[118]. The visual observations of termite attack were made on the feeder stakes or boards which were contacted with termiticide-treated soil. Also, soil samples collected from test sites were bioassayed both for mortality and for tunneling activity of *Coptotermes gestroi* Wasmann, as the most economically important species in Thailand. The bioassay using this species is more useful for actual termite control, since results from field test in rural areas, with different termite species, are not always applicable to urban areas in the country.

### 3.3.2 Materials and methods

#### Test chemicals

Eight emulsifiable formulations with organic solvent (EC) and a newly developed soluble formulation without organic solvent (SC) of nine termiticides were used in the original field test. Tested formulations were one organophosphate formulation (chlorpyrifos 40 EC), six synthetic pyrethroid formulations (alpha-cypermethrin 1.5 SC, alpha-cypermethrin 10 EC, bifenthrin 2.5 EC, cypermethrin 25 EC, fenvalerate 10 EC, permethrin 36.8 EC) and two chlorinated hydrocarbon formulations (chlordane 72 EC and Aldrin 40 EC).

#### Field test sites

Three field test sites were established in three different provinces of Thailand. Their profiles including location, climatic condition, soil type and distributing termite species, are shown in Table 3.1.

#### Field test methods

Two test methods were adopted to evaluate the persistence of soil termiticides in field exposure.

**Ground stake test method (GST)**

A specific volume of soil was dug out from a hole, 100 cm × 100 cm by 50 cm deep, filled back after crushing to facilitate the penetration of treated solution and treated with an aqueous solution of formulated termiticide by spraying at 5 l/m$^2$. After the treatment, a rubber wood stake with 5 cm × 2.5 cm by 50 cm length was driven into the center of treated area (Fig. 3.17).

Table 3.1. Profile of the three field test sites in Thailand to evaluate the termiticidal efficacy of commercially available chemicals for soil treatment.

| Province | Distance from Bangkok (km) | Above sea level (m) | Annual rainfall (mm)* | Mean annual temp. (°C)* | Soil type and pH** | Dominant termite species*** |
|---|---|---|---|---|---|---|
| Saraburi | 130N | 13.0 | 1,123 | 27.9 | Clay 7–8.5 | *Odontotermes* spp.<br>*Microcerotermes* spp.<br>*Microtermes* sp.<br>*Hypotermes* spp. |
| Khon Khean spp. | 450NE | 200.3 | 1,246 | 27.1 | Sandy clay 6–7 | *Odontotermes* spp.<br>*Microcerotermes* spp.<br>*Globitermes sulphureus*<br>*Macrotermes* spp.<br>*Microtermes* sp. |
| Chiang Mai | 700N | 369.4 | 1,142 | 25.8 | Sandy loam 6–6.5 | *Odontotermes* spp.<br>*Microcerotermes* spp.<br>*Macrotermes* spp.<br>*Coptotermes gestroi*<br>*Microtermes* sp. |

*: Data Processing Sub-division, Climatology Division, Meteorological Department, Bangkok, **: Classified by Agricultural Chemistry Division, Department of Agriculture, Bangkok, *** : Identified by author at Forest Products Research Division, Royal Forest Department, Bangkok, based on their morphological key.

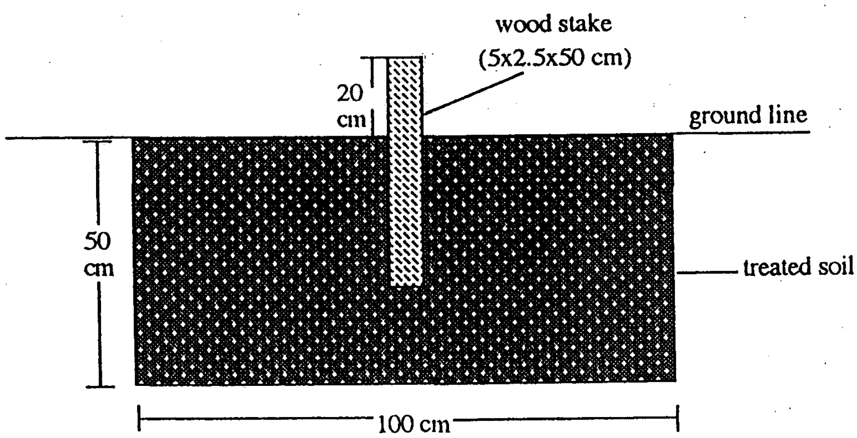



Fig. 3.17. Standard ground stake test (GST).

**Modified ground board test method (MGBT)**

After treatment of soil with the same procedure to GST, PVC pipe, 10 cm diameter by 12 cm long, with cap at top-end was placed upright at the center of treated area to serve as an inspection port. Concrete was then poured over the treated area to make a slab of 100 cm × 100 cm with 8 cm thickness. A rubber wood board, 5 cm × 5 cm by 2.5 cm thick was placed inside the pipe in contact with the treated soil (Fig. 3.18).

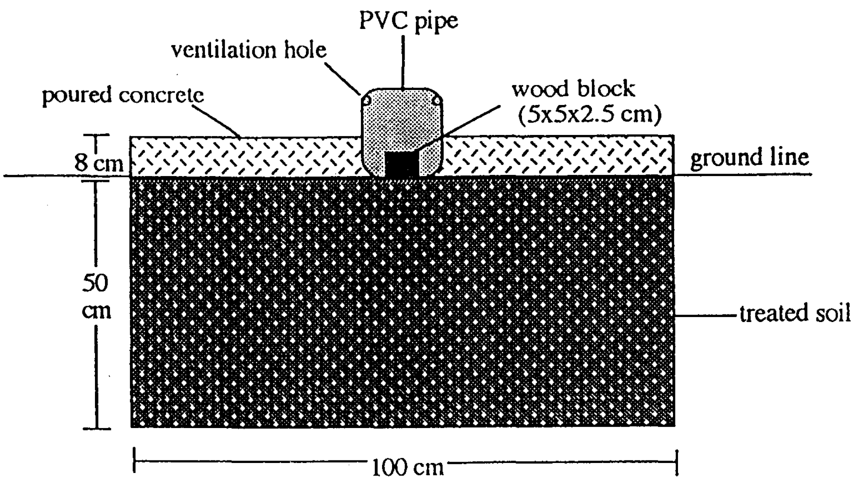



Fig. 3.18. Standard modified ground board test (MGBT) or concrete slab test.

**Combinations with termiticides, test methods and test sites**

Due to the difficulties in establishing test sites and in getting formulated termiticides in Thailand, each test was not initiated simultaneously and combinations with termiticides, test methods and test sites were far beyond our original planning. However, as shown in Table 3.2, combination between termiticides and test methods were almost attained at Saraburi test site. In both test methods, each treatment was replicated three times and arranged in randomized complete block design.

**Visual inspection of termite penetration**

Stakes or boards of rubber wood were visually inspected of attack by termites to evidence their penetration into treated soil layer. The inspection was made at the first sixth month after installation and thereafter annually. Decayed or moulded wood was replaced by new one at every inspection. When two or three of the replicates were attacked by termites, the test was continued no longer.

**Bioassays**

About 30 $cm^2$ soil was sampled from the center of each plot at 1.5 cm below the surface and placed in a plastic bag. After removing the gravels and plant debris, sample soil was served to "Tunneling Test" prescribed in JWPA Standard 13-1(1992). The test soil was stuffed into the center portion (5 cm) of a glass tube (1.5 cm I.D. and 10 cm long) as soil-

Table 3.2. Combination with termiticides, test method and test sites.

| Termiticides | Concentration of active ingredient (%) | Test sites | | |
|---|---|---|---|---|
| | | Saraburi | Khon Khean | Chiang Mai |
| | | Method*–Start** | Method*–Start** | Method*–Start** |
| Organophosphate | | | | |
| Chlorpyrifos 40 EC | 0.5, 1.0, 2.0 | GST–11/'92<br>MGBT–11/'92 | —<br>MGBT–01/'91 | GST–09/'92<br>— |
| Synthetic pyrethroid | | | | |
| Permethrin 36.8 EC | 0.5, 1.0, 2.0 | GST–12/'92<br>MGBT–03/'92 | —<br>— | GST–09/'92<br>— |
| Fenvalerate 10 EC | 0.5, 1.0 | GST–12/'92<br>MGBT–06/'93 | —<br>— | —<br>— |
| Cypermethrin 25 EC | 0.125, 0.25, 0.5 | GST–12/'92<br>MGBT–03/'92 | —<br>MGBT–01/'91 | GST–09/'92 |
| Alpha-cypermethrin 1.5 SC | 0.05, 0.1, 0.2 | —<br>MGBT–03/'92 | —<br>MGBT–01/'91 | —<br>— |
| Alpha-cypermethrin 10 EC | 0.05, 0.1, 0.2, 0.3 | GST–12/'92<br>MGBT–03/'92 | —<br>MGBT–01/'91 | GST–09/'92<br>— |
| Bifenthrin 2.5 EC | 0.025, 0.05, 0.1 | GST–11/'92<br>MGBT–03/'92 | —<br>— | GST–09/'92<br>— |
| Chlorinated hydrocarbon | | | | |
| Chlordane 72 EC | 1.0 | GST–11/'92<br>MGBT–03/'92 | —<br>— | GST–09/'92<br>— |
| Aldrin 40 EC | 0.5 | —<br>— | MGBT–01/'91<br>— | —<br>— |

* GST: Ground stake test, MGBT: Modified ground board test.
** Month/year.

poisoning barrier. It was connected at both ends with the two glass cylinders. Two hundreds workers and 20 soldiers of *C. gestroi* was put into one of them with moistened untreated soil, and flakes of rubber wood were put into the other as foods. The assembled unit was kept in room conditions for three weeks.

After the test duration, the length of termite tunneling into the test soils was measured and rated on the basis of the following scale.

0: No tunneling
1: Length of tunnelings below 1 cm
2: Length of tunnelings below 2 cm
3: Length of tunnelings below 3 cm
4: Length of tunnelings below 4 cm
5: Length of tunnelings over 4 cm

When all termites were dead before the end of the test, the time elapsed (in days) was recorded.

### 3.3.3 Results and discussion

**Termite activity at the test site**

Termite activity was quite high at all the three test sites, and about 80% of untreated control plots were severely infested by subterranean termites at the sixth month after installation. The activity and the severity of attack on the bait rubber wood were higher at the ground stake test (GST) plots than were at the modified ground board test (MGBT) plots. Both test plots were shaded by the fast-growing vegetation at the former or by the concrete slab at the latter. The reason for the higher activity at GST plots might be related to the preference of open space to closed space, considering the ethnology of the field termites most of which are foraging in open forest and grass field. As is generally known, termite activity was always greater in wet season than in dry season at every test sites. Although *C. gestroi* was found at all test sites, their activity was suppressed by other species such as *Odontotermes* spp., *Microcerotermes* spp., *Microtermes* spp. and *Macrotermes* spp.

**Longevity of soil termiticides evaluated by in situ inspection of termite attack at field test site**

Tables 3.3–3.5 show the performances of nine formulated soil termiticides which were given in the length of year to hold the 100, 67 and 33% (or less) of effectivenesses. For example, 100% effectiveness was gained when none of 3 replicates of rubber wood in contact with treated soil were attacked by termites. Practically, longevity of soil termiticides should be ranked as the length of year for 100% effectiveness. Although the duration of our field test was only 4 years at the longest, it was enough to exclude some formulations of soil termiticides with poor longevity.

Chlorpyrifos has been widely used especially in United States and Japan as an alternatives to chlordane as well as other organophosphates. However, the present results with chlorpyrifos clearly evidenced the lowest stability of this chemical among those tested under the actual ambient conditions in Thailand. Even at twice the recommended concentration of 1.0%, 100% effectiveness of chlorpyrifos lasted for only three years at the longest (in MGBT method at Khon Khane test site) (Table 3.4). At Saraburi and Chiang Mai test sites, its toxicity decreased quickly and year for 100% effectiveness was just 6 months or less (Tables 3.3 and 3.5). This was extremely shorter than 6–12 years for its 1.0% solution in the United States[116,117] and an application of chlorpyrifos to termite control is considered actually inappropriate chemical for a long-term protection in Thailand.

Six formulations of synthetic pyrethroids were tested but the comparison of their longevity was not made satisfactory in full combinations of termiticides, test methods and test sites. However, among the treating solutions of these pyrethroids, 1.0% and 2.0% permethrin, 0.5% cypermethrin, 0.2% alpha-cypermethrin (10 EC) and 0.1% bifenthrin were ranked higher than other solutions because they kept longer years for 100% effectiveness at the different two test sites. Since the initiation of each test plot was less than

Table 3.3. Performance of soil termiticides in the two field tests at Saraburi Province, Thailand.

| Termiticides (%) | Concentration of active ingredient (%) | Ground stake test Years of % effectiveness[a] | | | Modified ground board test Years of % effectiveness[a] | | |
|---|---|---|---|---|---|---|---|
| | | 100% | 67% | ≦33% | 100% | 67% | ≦33% |
| Chlorpyrifos 40 EC | 0.5 | —* | —* | 1/2** | 1/2 | —* | 1–2* |
| | 1.0 | —* | —* | 1/2** | 1/2 | 1 | 2 |
| | 2.0 | —* | —* | 1/2** | 1/2 | 2 | —** |
| Permethrin 36.8 EC | 0.5 | —* | 1/2 | 1–2 | 3 | —** | —** |
| | 1.0 | 1/2 | 1 | 2 | 3 | —** | —** |
| | 2.0 | 1 | —* | 2 | 3 | —** | —** |
| Fenvalerate 10 EC | 0.5 | 1/2 | —* | 1–2 | 2 | —** | —** |
| | 1.0 | 1/2 | 1–2 | —** | 2 | —** | —** |
| Cypermethrin 25 EC | 0.125 | —* | —* | ≧1/2 | 2 | —* | 3 |
| | 0.25 | —* | 1/2 | ≧1 | 3 | —** | —** |
| | 0.5 | —* | 1/2–1 | 2 | 3 | —** | —** |
| Alpha-cypermethrin 1.5 SC | 0.05 | ND[b] | ND[b] | ND[b] | 2 | 3 | —** |
| | 0.1 | ND[b] | ND[b] | ND[b] | 3 | —** | —** |
| | 0.2 | ND[b] | ND[b] | ND[b] | 3 | —** | —** |
| Alpha-cypermethrin 10 EC | 0.05 | ND[b] | ND[b] | ND[b] | —* | 1/2 | 1–2 |
| | 0.1 | —* | —* | 1/2 | 1/2 | 3 | —** |
| | 0.2 | —* | 1/2 | 1 | 2 | 3 | —** |
| | 0.3 | —* | 1/2 | 1 | 3 | —** | —** |
| Bifenthrin 2.5 EC | 0.025 | —* | —* | 1/2 | 1/2 | 1 | 2–3 |
| | 0.05 | —* | 1/2 | 1 | 1 | 2–3 | —** |
| | 0.1 | 2 | —** | —** | 3 | —** | —** |
| Chlordane 72 EC | 1.0 | 2 | —** | —** | 3 | —** | —** |

a : Year for 100% effectiveness means the duration in which none of 3 replicates of stake or board in contact with treated soil were attacked after treatment. When one and two or three of the replicates were attacked, years were expressed as 67% and ≦33% effectiveness, respectively, b : Field test was not installed, * : Not counted due to early failure before inspection, ** : Not known due to the higher % protection.

five years ago, length of 100% effectiveness for these pyrethroids-treated plots are not decided yet. As cited before, 1.0% permethrin, 0.5% cypermethrin and 0.125% bifenthrin gave 4–15 years of 100% effectiveness comparable to 1.0% chlorpyrifos in United States. However, as far as present results, most of synthetic pyrethroids tested were clearly superior to chlorpyrifos in Thailand.

As reported by Kard *et al.*[25)], Kard[114)] and Tamashiro *et al.*[113)] longevity of chlorinated hydrocarbons exceeded that of organophosphates and pyrethroid termiticides in our results, too.

Table 3.4. Performance of soil termiticides in modified ground board test at Khon Khean Province, Thailand.

| Termiticides | Concentration of active ingredient (%) | Years of % effectiveness[a] 100% | 67% | ≦33% |
|---|---|---|---|---|
| Chlorpyrifos 40 EC | 0.5 | 2 | —* | 3–4 |
| | 1.0 | 2 | 3–4 | —** |
| | 2.0 | 3 | 4 | —** |
| Cypermethrin 25 EC | 0.125 | 2 | —* | 3–4 |
| | 0.25 | 2 | 3–4 | —** |
| | 0.5 | 2 | 3–4 | —** |
| Alpha-cypermethrin 1.5 SC | 0.05 | 1 | 2 | 3–4 |
| | 0.1 | 1 | 2 | 3–4 |
| | 0.2 | 1 | 2 | 3–4 |
| Alpha-cypermethrin 10 EC | 0.05 | —* | 1/2 | —* |
| | 0.1 | 2 | 3 | ≧4 |
| | 0.2 | 2 | 3–4 | —** |
| Aldrin 40 EC | 0.5 | 4 | —** | —** |

Note: For legend see Table 3.3.

Table 3.5. Performance of soil termiticides in ground stake test at Chiang Mai Province, Thailand.

| Termiticides | Concentration of active ingredient (%) | Years of % effectiveness[a] 100% | 67% | ≦33% |
|---|---|---|---|---|
| Chlorpyrifos 40 EC | 0.5 | 1/2 | —* | 1–2 |
| | 1.0 | 1/2 | 2 | —** |
| Permethrin 36.8 EC | 0.5 | 1/2 | 2 | —** |
| | 1.0 | 2 | —** | —** |
| | 2.0 | 2 | —** | —** |
| Cypermethrin 25 EC | 0.125 | 1/2 | 1 | 2 |
| | 0.25 | 1/2 | —* | 1–2 |
| | 0.5 | 2 | —** | —** |
| Alpha-cypermethrin 10 EC | 0.1 | 1/2 | 2 | —** |
| | 0.2 | 1/2 | 2 | —** |
| Bifenthrin 2.5 EC | 0.025 | 1/2 | 1 | 1 |
| | 0.05 | 1/2 | 1 | 2 |
| | 0.1 | 2 | —** | —** |
| Chlordane 72 EC | 1.0 | 2 | —** | —** |

Note: For legend see Table 3.3.

**Residual toxicity of weathered termiticide-treated soil to *Coptotermes gestroi***

Tunneling activity and days for 100% mortality of *Coptotermes gestroi* excepted to weathered test soil were shown separately in each termiticide, from Tables 3.6 to Table 3.13. According to the qualitative requirements prescribed in JWPA Standard 13, the candidate chemical is considered promising if it is ranked as 0 or 1 of the tunneling scale (the length is below 1 cm).

Concerning the chlorpyrifos-treated soils, the weathered time in years, during which the tunneling scale was kept at 0 or 1, could not exceed 3 years even at the highest 2.0% solution (Table 3.6). Poor longevity of chlorpyrifos was evidenced again from the bioassay using Coptotermes gestroi, while different residual toxicity was also existing among test sites. At Saraburi, toxicity of 2.0% chlorpyrifos was drastically lost within 6 months, when it was excepted to open condition in GST, but the initial decreased rate of toxicity was slower in Chiang Mai soil. The reason was probably related to the different soil properties and it was discussed later. As shown in Tables 3.3 and Table 3.6, persistence of chlorpyrifos was greatly affected by the weathering conditions, even if the chemical was applied to the same test site. This was also discussed later.

Table 3.6. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Chlorpyrifos 40 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | |
| | | Ground stake test | | | Modified ground board test | | |
| | | 0.5 | 1.0 | 2.0 | 0.5 | 1.0 | 2.0 |
| Saraburi | 1/2 | 5/N[b] | 5/N[b] | 5/N[b] | —* | —* | —* |
| | 1 | —* | —* | —* | 0/4 | 0/4 | 0/3 |
| | 2 | —* | —* | —* | 5/N[b] | 3/14 | 2/N[b] |
| | 3 | —* | —* | —* | 5/N[b] | 5/N[b] | 4/N[b] |
| | 4 | —* | —* | —* | —* | —* | —* |
| Khon Khean | 1/2 | No field test | | | —* | —* | —* |
| | 1 | | | | —* | —* | —* |
| | 2 | | | | 0/4 | 0/4 | 0/3 |
| | 3 | | | | 5/N[b] | 4/14 | 0/4 |
| | 4 | | | | —* | 4/N[b] | 4/9 |
| Chiang Mai | 1/2 | 0/4 | 0/3 | 0/4 | No field test | | |
| | 1 | 1/5 | 1/5 | 0/3 | | | |
| | 2 | 5/N[b] | 4/10 | 0/7 | | | |
| | 3 | —* | 5/N[b] | 4/17 | | | |

a : Length of tunnelings is, 1 : below 1 cm, 2 : below 2 cm, 3 : below 3 cm, 4 : below 4 cm, 5 : over 4 cm, b : Not reached 100% mortality in 21 days, * : Not assayed.

Table 3.7. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Permethrin 36.8 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | |
| | | Ground stake test | | | Modified ground board test | | |
| | | 0.5 | 1.0 | 2.0 | 0.5 | 1.0 | 2.0 |
| Saraburi | 1/2 | 1/N[b] | 1/21 | 0/N[b] | —* | —* | —* |
| | 1 | 4/N[b] | 1/20 | 0/21 | 0/N[b] | 0/N[b] | 0/N[b] |
| | 2 | 5/N[b] | 4/21 | 4/19 | 1/N[b] | 1/N[b] | 1/18 |
| | 3 | —* | 5/N[b] | 5/N[b] | 4/N[b] | 4/N[b] | 1/16 |
| | 4 | —* | —* | —* | —* | —* | —* |
| Chiang Mai | 1/2 | 0/N[b] | 0/N[b] | 0/21 | No field test | | |
| | 1 | 1/N[b] | 0/20 | 0/18 | | | |
| | 2 | 5/N[b] | 5/N[b] | 5/N[b] | | | |
| | 3 | —* | —* | —* | | | |

Note: For legend see Table 3.6.

Table 3.8. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Fenvalerate 10 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | |
|---|---|---|---|---|---|
| | | Concentration (%) | | | |
| | | Ground stake test | | Modified ground board test | |
| | | 0.5 | 1.0 | 0.5 | 1.0 |
| Saraburi | 1/2 | 0/N[b] | 0/N[b] | —* | —* |
| | 1 | 5/N[b] | 1/21 | 0/N[b] | 0/17 |
| | 2 | —* | 4/N[b] | 0/N[b] | 0/21 |
| | 3 | —* | —* | —* | —* |
| | 4 | —* | —* | —* | —* |

Note: For legend see Table 3.6.

Permethrin (1.0% and 2.0%) was ranked higher among pyrethroids tested in protecting rubber wood contacted with treated soil for longer years. However, excepting the only one case (2.0% permethrin-MGBT-Saraburi test site), any permethrin-treated soil could not prevent the tunneling of *C. gestroi* at below 3 cm, after 2 years weathering (Table 3.7).

Fenvalerate was tested only at Saraburi site. Concerning this chemical, results of bioassay well corresponded with those of the visual inspection at field test site. Because of the late initiation of test, longevity of fenvalerate was not fixed yet. As far as the modified ground board test, all treated soil sample prevented *C. gestroi* from tunneling (Table 3.8).

Cypermethrin was tested at the three test sites. From the results of field observation, the highest 0.5% cypermethrin performed well. Bioassay of weathered soil, however, show that the resistance to *C. gestroi* declined after 2–4 years field exposure (Table 3.9).

Of the two types of alpha-cypermethrin, at least 0.3% solution of both types was required to suppress the tunneling activity at scale 0 or 1 for more than three years (Tables 3.10 and 3.11).

Termite tunneling into the 0.1% bifenthrin-treated soil was inhibited for more than three years, although the result was limited to the MGBT at Saraburi test site (Table 3.12). Toxicity of this termiticide decreased in GST at Saraburi and Chiang Mai test sites to allow more than 2 scale of tunneling activity.

Bioassays of the soil treated with the two chlorinated hydrocarbons (1.0% chlordane and 0.5% aldrin) showed their highest persistence irrespective of weathering conditions (Table 3.13). Even when these chlorinated hydrocarbons will be banned in Thailand, effect of these applications to soil should be assessed for longer time on the aspects of the longevity of termiticidal efficacy and the degree of environmental contamination.

Table 3.9. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Cypermethrin 25 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | |
| | | Ground stake test | | | Modified ground board test | | |
| | | 0.125 | 0.25 | 0.5 | 0.125 | 0.25 | 0.5 |
| Saraburi | 1/2 | 4/N[b] | 1/17[b] | 1/N[b] | —* | —* | —* |
| | 1 | 5/N[b] | 4/N[b] | 4/N[b] | 0/N[b] | 0/21 | 0/N[b] |
| | 2 | —* | 5/N[b] | 5/N[b] | 4/N[b] | 4/N[b] | 0/17 |
| | 3 | —* | —* | —* | 5/N[b] | 5/N[b] | 5/N[b] |
| | 4 | —* | —* | —* | —* | —* | —* |
| Khon Khean | 1/2 | No field test | | | —* | —* | —* |
| | 1 | | | | —* | —* | —* |
| | 2 | | | | 0/N[b] | 0/20 | 0/14 |
| | 3 | | | | 4/N[b] | 1/N[b] | 1/14 |
| | 4 | | | | 5/N[b] | 5/N[b] | 4/N[b] |
| Chiang Mai | 1/2 | 0/N[b] | 0/21 | 0/20 | No field test | | |
| | 1 | 4/N[b] | 4/19 | 0/14 | | | |
| | 2 | 5/N[b] | 5/N[b] | 5/N[b] | | | |
| | 3 | —* | —* | —* | | | |

Note: For legend see Table 3.6.

Table 3.10. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Alpha-cypermethrin 1.5 SC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | |
| | | Ground stake test | | | Modified ground board test | | |
| | | 0.5 | 1.0 | 2.0 | 0.5 | 1.0 | 2.0 |
| Saraburi | 1/2 | | | | —* | —* | —* |
| | 1 | | | | 0/21 | 0/17 | 0/N[b] |
| | 2 | | No field test | | 4/N[b] | 4/N[b] | 1/N[b] |
| | 3 | | | | 5/N[b] | 5/N[b] | 5/N[b] |
| | 4 | | | | —* | —* | —* |
| Khon Khean | 1/2 | | | | —* | —* | —* |
| | 1 | | | | —* | —* | —* |
| | 2 | | No field test | | 1/15 | 1/14 | 0/10 |
| | 3 | | | | 4/N[b] | 4/N[b] | 0/12 |
| | 4 | | | | 5/N[b] | 4/N[b] | 4/N[b] |

Note: For legend see Table 3.6.

Table 3.11. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand. (Alpha-cypermethrin 10 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | | | |
| | | Ground stake test | | | | Modified ground board test | | | |
| | | 0.05 | 0.1 | 0.2 | 0.3 | 0.05 | 0.1 | 0.2 | 0.3 |
| Saraburi | 1/2 | —* | 5/N[b] | 1/N[b] | 1/N[b] | —* | —* | —* | —* |
| | 1 | —* | —* | 5/N[b] | 5/N[b] | 4/N[b] | 1/N[b] | 0/21 | 0/N[b] |
| | 2 | —* | —* | —* | —* | 5/N[b] | 4/N[b] | 3/21 | 0/19 |
| | 3 | —* | —* | —* | —* | —* | 5/N[b] | 5/14 | 0/10 |
| | 4 | —* | —* | —* | —* | —* | —* | —* | —* |
| Khon Khean | 1/2 | | | | | —* | —* | —* | —* |
| | 1 | | | | | —* | —* | —* | —* |
| | 2 | | No field test | | | 3/N[b] | 0/14 | 0/10 | —* |
| | 3 | | | | | 5/N[b] | 1/N[b] | 1/14 | —* |
| | 4 | | | | | —* | 4/N[b] | 1/N[b] | —* |
| Chiang Mai | 1/2 | —* | 0/N[b] | 0/21 | —* | | | | |
| | 1 | —* | 1/N[b] | 1/18 | —* | | | | |
| | 2 | —* | 5/N[b] | 5/N[b] | —* | | No field test | | |
| | 3 | —* | —* | —* | —* | | | | |

Note: For legend see Table 3.6.

Table 3.12. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand.
(Bifenthrin 2.5 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentration (%) | | | | | |
| | | Ground stake test | | | Modified ground board test | | |
| | | 0.025 | 0.05 | 0.1 | 0.025 | 0.05 | 0.1 |
| Saraburi | 1/2 | 4/N[b] | 1/18 | 0/N[b] | —* | —* | —* |
| | 1 | 5/N[b] | 5/N[b] | 0/21 | 1/N[b] | 0/19 | 0/N[b] |
| | 2 | —* | —* | 4/N[b] | 4/N[b] | 3/21 | 0/21 |
| | 3 | —* | —* | 5/N[b] | 4/N[b] | 4/N[b] | 0/N[b] |
| | 4 | —* | —* | —* | —* | —* | —* |
| Chiang Mai | 1/2 | 0/N[b] | 0/21 | 0/21 | No field test | | |
| | 1 | 4/N[b] | 1/N[b] | 1/14 | | | |
| | 2 | 5/N[b] | 5/N[b] | 3/21 | | | |
| | 3 | —* | —* | 4/N[b] | | | |

Note: For legend see Table 3.6.

Table 3.13. Tunneling activity and days for 100% mortality of *C. gestroi* exposed to termiticide-treated soil weathered for 3–4 years in Thailand.
(Chlordane 72 EC) (Aldrin 40 EC)

| Test site | Year | Tunneling activity[a]/Days for 100% mortality | | | |
|---|---|---|---|---|---|
| | | GST | MGBT | GST | MGBT |
| | | Concentration (%) | | | |
| | | 1.0 | 1.0 | 0.5 | 0.5 |
| Saraburi | 1/2 | 0/ 4 | —* | No field test | |
| | 1 | 0/10 | 0/14 | | |
| | 2 | 0/ 4 | 0/12 | | |
| | 3 | —* | 0/14 | | |
| | 4 | —* | 0/15 | | |
| Khon Khean | 1/2 | No field test | | No field test | —* |
| | 1 | | | | 0/5 |
| | 2 | | | | 0/7 |
| | 3 | | | | 0/9 |
| | 4 | | | | 0/7 |
| Chiang Mai | 1/2 | 0/5 | No field test | No field test | |
| | 1 | 0/7 | | | |
| | 2 | 0/6 | | | |
| | 3 | —* | | | |

Note: For legend see Table 3.6.

## Assessment of field testing procedure and laboratory bioassay to determine the longevity of soil termiticides

As generally recognized, a long residual life is advantageous in termiticide application. Long-term field studies have been conducted to estimate the longevity of commercial or candidate termiticides under different environmental conditions. Various procedures of termite field-testing have been devised and resulting informations have been applicated to establish the termite control techniques. While the conventional field tests have been considered useful way to estimate the longevity of termiticides, some disadvantages are pointed out in the availability of field test data to the actual termite control. In tropical countries, various species of subterranean termites are distributing in their own habits with their biological natures. Some species are found in rural area but not in urban area, and vice versa. Field test sites are generally established in rural areas mainly due to the management situations. *Coptotermes formosanus* and *Reticulitermes speratus* are serious structural pests in Japan and both are found in urban and rural areas. However, the most economically important Thai termite, *C. gestroi* is not found commonly in rural areas. Most of test wood samples are attacked by other species of subterranean termites, when field test plots were installed in rural areas. Informations from these tests have been much contributed to termite control, but they are not always applicable to *C. gestroi*.

Recently, laboratory bioassays were recommended by Grace *et al.*[13], to determine the residual toxicity of organochlorine-treated soils weathered for many years. The main object was to measure the longevity of toxic termiticidal efficacy against *C. formosanus*, which is becoming very important in Hawaii and south continental United States and is dominating urban areas in these regions. While we made the different procedure of bioassay to compare the longevity of several alternative termiticides to chlorinated hydrocarbons using *C. gestroi*.

In soil-tunneling test combined with field-weathering of termiticides, their longevity should be evaluated by the length of weathering year during which the tunneling scale was kept at 0 or 1. In consideration of the actual requirements to soil termiticides, at least 3 years should be required to keep this scale. Only a few treating solutions other than chlorinated hydrocarbons were considered promising under this basis: 2.0% permethrin, 0.3% alpha-cypermethrin (10 EC), and 0.1% bifenthrin.

Although several other solutions yielded over 3 years of 100% effectiveness under the field inspection of termite attack, such as 0.5% and 1.0% permethrin, 0.25% and 0.5% cypermethrin, and 0.1% and 0.2% alpha-cypermethrin (1.5 SC), they could not pass the selection under the tunneling test using *C. gestroi*.

Considering these facts and the economical importance of *C. gestroi*, laboratory bioassay combined with field weathering was considered more reliable to determine the longevity of soil termiticides in Thailand and also in humid tropical countries. Concerning the mortality of termites in tunneling test, most of synthetic pyrethroids give the slower killing rate irrespective of weathering, but this is not much disadvantageous in actual termite control. Therefore, days for 100% mortality were recorded just for references and not discussed here.

**Factors affecting the longevity of soil termiticides after weathering at field test sites in Thailand**

We evaluated the longevity of several alternative soil termiticides to chlorinated hydrocarbons at the three field test sites under the two testing procedures. As shown in the figures and tables in this chapter, results were greatly varied with the test sites and testing procedures.

Concerning with the fluctuations of data in the test sites, physical, chemical and biological properties of soil might play an important role as earlier pointed out by Harris[13]. The poor longevity of chlorpyrifos was shown at every test site but it was most clear at Saraburi. Because the climate conditions such as annual rainfall and mean annual temperature were not so different among the three test sites, soil type and soil pH were probably most responsible in affecting the longevity of chlorpyrifos. As shown in Table 3.1. Saraburi soil is composed of clays and is in alkaline condition (pH 7–8.5). Also the test site is surrounded by lime stone production area and it caused the soil to contain much amounts, of exchangeable bases (Ca, Mg, K, *etc.*). Moreover, clay soil is generally more rich in organic matter so that microbial activity of this soil must be higher than that of other soil type. As is generally known,, organophosphorous termiticides are liable to alkaline condition. They are also susceptible to hydrolysis caused by exchangeable cations[124]. The role of microbial degradation of termiticides must be related to the activity of soil microflora[4,109]. Rapid decline of termiticidal efficacy of chlorpyrifos at Saraburi test site are probably caused by complex action of agents. Rapid degradation of chlorpyrifos at Saraburi was rather extreme case but this termiticide was not also so stable at the other test sites. For other termiticides tested, different longevity among test sites was not so noticeable.

Concerning the testing procedure, GST caused unexceptionally the higher rate decline of termiticidal efficacy than did MGBT. In GST, treated soil surface was open to weather and termiticide has been directly exposed to water-leaching by rainfall and thermal and photo degradation by sunlight. In MGBT, action of these agents was not strong and therefore decreased rate of termiticide might be slower than in GST). MGBT was the modification of GST to simulate the structure of slab-on-concrete which is currently very common in Thailand. MGBT are considered well-suited to the behaviour of *C. gestroi* and should be standardized to evaluate the performance of soil termiticides against this species.

### 3.4 Efficacy of gravel physical barriers for termite prevention measure

#### 3.4.1 Introduction

With the increased public concern about environmental hazards and effects on human health, some of the conventional termiticides have been recently banned all over he world. Although a few chemicals of low toxicity have been extensively evaluated and commercialized as alternative termiticides[7,8,10,17,19,21,23,24,26,120], relatively heavy use of them is still warned against by environmentalists.

Subsequently, a non-chemical treatment (gravel physical barrier) was investigated in terms of its safety cost effectiveness, and duration of performance. Early studies indicated that the relationship between particle size and termite body size was an important factor in controlling tunneling activity of subterranean termites[121]. Tamashiro *et al.*[29], later proved that termites could never penetrate gravel barriers consisting of particular sizes of particles.

In the final section, tunneling of two subterranean termites into gravel barriers was compared in laboratory tests. Field evaluation was also done for a Thai termite species for future consideration[122].

#### 3.4.2 Materials and methods

**Preparation of the physical barrier substrate**

Commercially available gravel, which is commonly used for decorative purpose with concrete, was taken as the physical barrier substrate. Gravel barriers of specified sizes were prepared by passing the material through copper wire sieves of 1.2, 1.4, 1.7, 2.0, and 2.4 mm in diameter.

**Laboratory test**

*Termites*

Externally undifferentiated larvae (workers) of two subterranean termite species were used. Those were an economically very important Thai species, *Coptotermes gestroi* Wasmann, and the most destructive Japanese species, *Coptotermes formosanus* Shiraki. Two hundred workers were introduced into each experimental unit together with 20 soldiers.

*Tunneling test apparatus*

Glass test units, which are designated in the JWPA Standard 13, were used to evaluate vertical tunneling by termites (Fig. 3-19). As shown in the figure, sandy soil (20 mesh pass) was used supplementarily to give test termites easy access to the test particles. A wood block of *P. densiflora* (2 cm × 2 cm × 1 cm) was placed in one of the glass containers as a bait. In addition, horizontal penetration was investigated using similar units (Fig. 3-20).

*Gravel sizes*

The particle sizes range were <1.2, 1.2–1.4, 1.4–1.7, 1.7–2.0, and 2.0–2.4 mm in diameter for *C. gestroi*, and 1.2–1.4, 1.4–1.7, 1.7–2.0, and 2.0–2.4 mm for *C. formosanus*., and a 20 mesh pass sandy soil was used as a control.

*Incubation procedure*

The assemble test units were kept at 28±2°C under high relative humidity (>85%) for 4 weeks. At the end of the experiments, penetration depths were measured. The test was

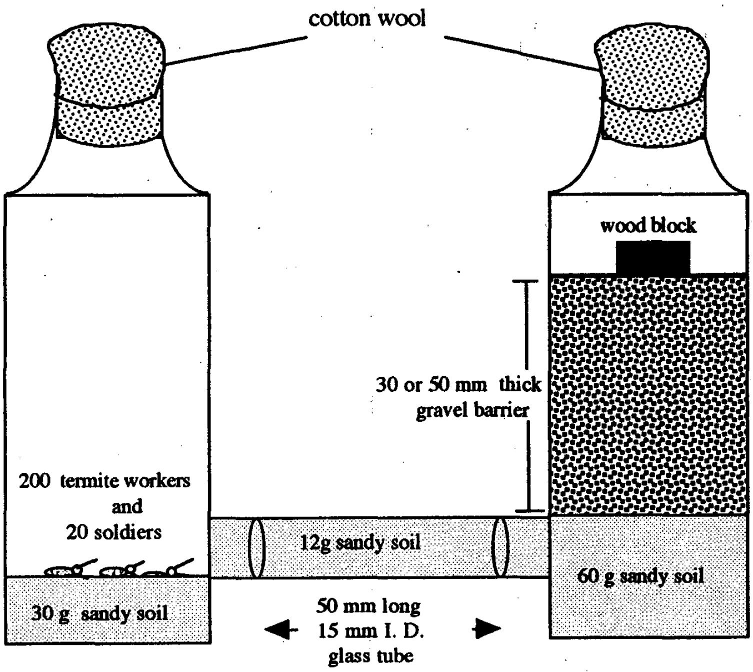



Fig. 3.19. An assembled test unit to evaluate vertical penetration by termites through gravel physical barrier.

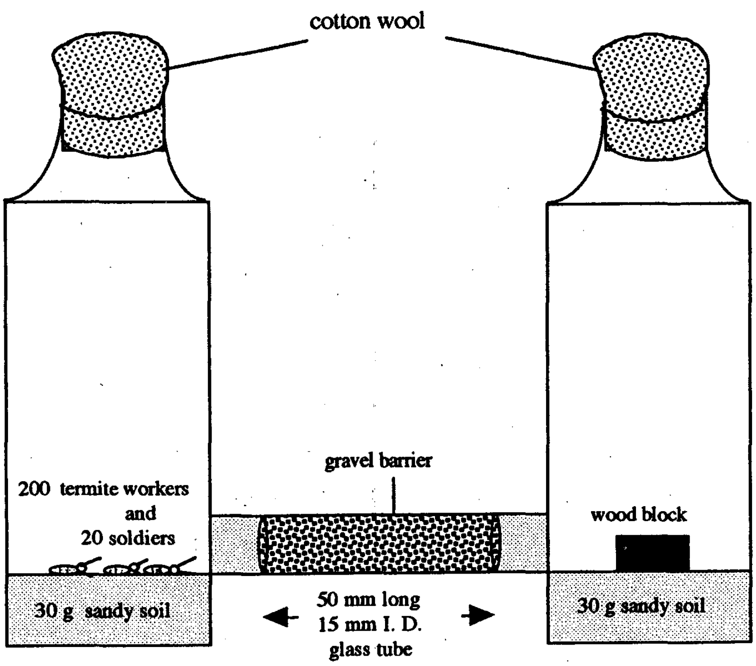



Fig. 3.20. An assembled test unit to evaluate horizontal penetration by termites through gravel physical barrier.

replicated three times for each termite species and gravel size combination.

**Field test**

*Test Site*

Field test was done on the grounds of the Royal Forest Department, Bangkok, Thailand. The field trials were begun in August, 1993. *C. gestroi* was expected to gain access to the field test units as the species was known as a common subterranean termite in the test area.

*Field test apparatus*

Experimental units consisted primarily of a PVC pipe (150 mm in diameter and 200 mm high) as shown in Fig. 3.21. Wood flakes were placed beneath the 20 mm thick soil and 50 mm thick test particles (20 mesh pass sandy soil for control) to form a bottom for the pipe.

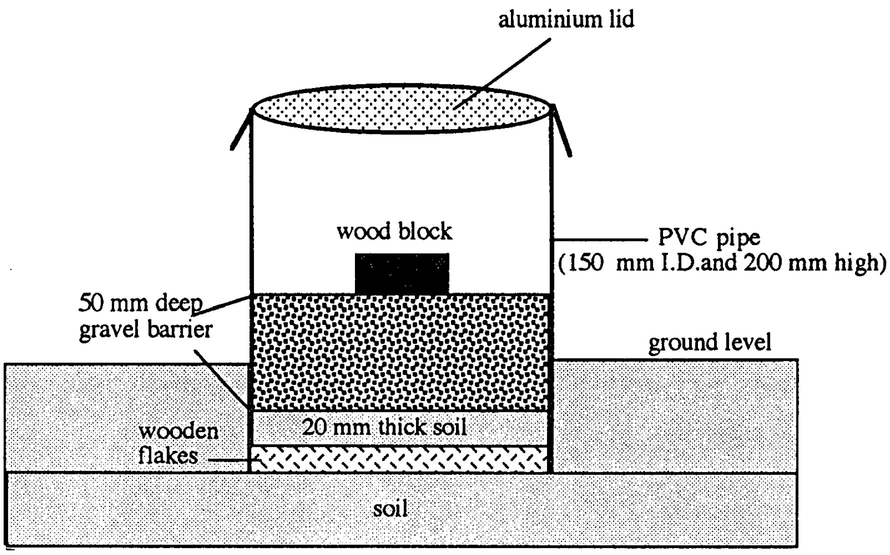



Fig. 3.21. A field experimental unit to evaluate termite penetration through gravel physical barriers.

A block of rubber wood measuring 25 mm × 50 mm × 100 mm was placed on the top of tunneling substrate as a bait.

*Gravel sizes*

The gravel sizes tested were 1.2–1.7 mm, 1.7–2.4 mm, and over 2.8 mm in diameter.

*Evaluation of efficacy*

Inspection was done 3, 6 and 12 months after the start of the tests.

### 3.4.3 Results and discussion

**Effects of gravel barriers on the tunneling activity of *Coptotermes formosanus***

As shown in Table 3.14, *C. formosanus* was able to vertically penetrate through the gravel particles of 1.2–1.4 mm in the 30 mm thick barrier tests, although it took termites 2 days

Table 3.14. Effects of gravel particle sizes on tunneling activity of *C. formosanus*.

| Particle sizes (mm) | Vertical tunneling | | Horizontal tunneling |
|---|---|---|---|
| | Penetration length (mm)* | | Penetration length (mm)* |
| | 30 mm thick barrier | 50 mm thick barrier | 50 mm thick barrier |
| 1.2–1.4 | 30** (100) | 45 (90) | 50** (100) |
| 1.4–1.7 | 5 ( 17) | 0 ( 0) | 50*** (100) |
| 1.7–2.0 | 0 ( 0) | 2.5 ( 5) | 35 ( 70) |
| 2.0–2.4 | 0 ( 0) | 0 ( 0) | 25 ( 50) |
| Control (20 mesh-pass sandy soil) | 30**** (100) | 50**** (100) | 50**** (100) |

*: % penetration through gravel physical barrier in the brackets, **: 100% penetration within 3 day, ***: 100% penetration within 7 days, ****: 100% penetration within 1 days.

longer to attack a pine wood block in comparison with sandy soil control.

Similarly, termites were able to gain access to a pine wood block in the 50 mm thick barriers with 1.2–1.4 mm particles. Larger particles tended to prevent tunneling, and the termites could not penetrate gravel particles in the 1.4–2.4 mm range. The largest size, 2.0–2.4 mm particles throughly stopped the tunneling by termites, regardless of barrier thickness. This agreed with the earlier results[29]. On the other hand, the test termites were able to bore into any size of the gravels tested to some extent in our horizontal tunneling tests. Full penetration was observed in the particle sizes of 1.2–1.4 and 1.4–1.7 mm and a wood block was attacked by termites within 3–7 days, while larger particle sizes of 1.7–2.0 and 2.0–2.4 mm performed better in depressing tunneling activity of *C. formosanus*.

**Effects of gravel barriers on tunneling activity of *Coptotermes gestroi***

Vertical tunneling ability of *C. gestroi* was similar to that of *C. formosanus*, as shown in Table 3.15. The termite species could not penetrate gravel barriers in the 1.2 to 2.4 mm range in both 30 mm and 50 mm thick barrier tests.

In the horizontal tunneling test, *C. gestroi* succeeded in excavating through the gravel barriers of the smallest particles of $<1.2$ mm, and reached the pine wood block within one day. Bigger particles were definitely of great advantage to the prevention of horizontal tunneling by the test termites.

No conspicuous difference in vertical tunneling activity was noticed between the two tested *Coptotermes* species (Tables 3.14 and 3.15).

However, *C. formosanus* was more aggressive than the other in horizontal tunneling in the gravel barriers of smaller particles. Since gravel particle sizes ranging from 1.2 to 2.4 mm did not permit *C. gestroi* to penetrate, the small body size of the termite species (average maximum head width: 1.2 mm) might partly account for this difference. As pointed out

Table 3.15. Effects of gravel particle sizes on tunneling activity of *C. gestroi*.

| Particle sizes (mm) | Vertical tunneling | | Horizontal tunneling |
|---|---|---|---|
| | Penetration length (mm)* | | Penetration length (mm)* |
| | 30 mm thick barrier | 50 mm thick barrier | 50 mm thick barrier |
| <1.2 | 30** (100) | 50** (100) | 50** (100) |
| 1.2–1.4 | 0 ( 0) | 0 ( 0) | 13.3 ( 27) |
| 1.4–1.7 | 0 ( 0) | 0 ( 0) | 6.7 ( 13) |
| 1.7–2.0 | 0 ( 0) | 2.5 ( 5) | 1.7 ( 3) |
| 2.0–2.4 | 0 ( 0) | 0 ( 0) | 3.3 ( 7) |
| Control (20 mesh-pass sandy soil) | 30** (100) | 50** (100) | 50** (100) |

*: % penetration through gravel physical barrier in the brackets, **: 100% penetration within 1 day.

before, the individual specific particle sizes were too large to be moved or carried away by the specific termites species and morphological or physiological characteristics of different termite species might be important causes of the variation of tunneling activity[31,33,36]. Careful observation showed that both termite species could build passages only along the gaps between packed particles and the upper sides of the glass tubes, as the gap provided footing for excavation for the termites. Thus, the packing conditions of particles in the glass tubes seemed to influence the results.

**Field evaluation of gravel barriers**

Field trials well demonstrated that gravel sizes of 1.2–1.7 mm and 1.7–2.4 mm were effective in preventing excavation by the subterranean termite *C. gestroi* because no termite attack on a wood block was recorded after 12 months' test (Table 3.16).

On the other hand, gravels of a bigger size (>2.8 mm) failed in stopping tunneling of *C. gestroi* through the barrier as a wood block was attacked by termites soon after the test started. This suggested that oversized gravel particles (>2.8 mm in diameter) were so big

Table 3.16. Efficacy of gravel physical barrier on excavation by Thai subterranean termite, *C. gestroi* in the field.

| Particle sizes (mm) | Efficacy evaluation | | |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| 1.2–1.7 | Not attacked | Not attacked | Not attacked |
| 1.7–2.4 | Not attacked | Not attacked | Not attacked |
| >2.8 | Attacked | | |
| Control (20 mesh-pass sandy soil) | Wood block was attacked by termites within 2 weeks | | |

that the particles could not pack well but formed big cavities between particles for termites to walk or penetrate through. To measure duration of efficacy of gravel barriers, yearly examination will be done.

Although non-chemical barriers have been proposed some years before in a few countries[29,31–33,36,123], the gravel barrier method is not well established in any country and still a new idea to both Japan and Thailand.

Considering the impact on the environment of chemical treatment, stability of performance, and other factors, it seems worthwhile to examine non-chemical protection of wooden and cellulosic materials from termite attacks.

## Conclusion

Chapter 1 of this review article dealt with the current termite problems in Thailand as the background information for this study. Thailand is located in tropical region where the climate is always hot and humid and therefore whole region of the country is favorable for activity of termites. Structural parts of Thai house have been traditionally wood or a mixture of wood and masonry. Most of these buildings were not treated before construction and built on the clay soil ground where is rich in termite diversity. Several subterranean termite species are found very economically important, by causing the serious damage of building constructions in this country. Among them, *Coptotermes gestroi* Wasmann was evidenced as the most important species, causing serious damage in building constructions, timber products and other lignocellulosic materials in both urban and rural areas (Section 1.1). It was found widely distributed in the whole regions of the country. The features of damage caused by *C. gestroi* was the deep excavation of galleries along the grain of wood. Damaged part was partially filled with soil or sponge-like structure, and honey-combed carton nest was formed later there.

In Thailand, an arsenic compound called Paris green and several chlorinated hydrocarbon insecticides such as aldrin, dieldrin, chlordane, heptachlor and DDT are still used for termite control, although most of them have been already banned in many developed countries. In order to develop the safe and effective control measure, mode of infestation of subterranean termites was investigated in model and real buildings (Section 1.2). Infestation was mostly caused by underground colonies but aerial colonies was considered as infestation source into high-storied buildings. Basement and wall were the most susceptible parts in slab-on-ground and crawl space types of buildings. Pole or column, irrespective of its material, was the termite entry into high pole type. Roof was also the second most susceptible part in every construction type. Favorable situations for infestation were established from direct ground contact of wooden members, improper construction of foundation, improper drainage, insufficient ventilation, and storage of wood and cellulosic materials in and around buildings. Some mound-building termites other than *C. gestroi* were also important in rural area.

In Chapter 2, biology and ecology of *C. gestroi* were described. The foraging activity, territory and population were investigated in urban area by the mark-release-recapture method using Nile Blue A as a dye marker (Sections 2.1 and 2.2). The foraging territory reached maximum 30 cm below the ground line, but foraging activity was highest at the depth of 15 cm. Soldier ratio was quite high at the subsurface of foraging territory. The maximum foraging distance was approximately 500 cm from the first release station. The foraging population ranged between 1.13 and $2.75 \times 10^6$ per colony. The variation might be due to the age of colony, surrounding situation and seasons. The modified wood block test using glass bottle with moist sand matrix and the group size of 250 workers was developed for evaluating the feeding activity of *C. gestroi* against several Thai timbers. Among the timbers tested, *Anogeissus acuminata*, *Chukrasis tabularis* and *Lagerstroemia floribunda* were ranked as resistant to moderately resistant to *C. gestroi* in the forced and choice tests. The four *Dipterocarpus* spp. and most of fast-growing timbers were non-resistant (Section 2.3).

Chapter 3 was targeted to evaluate the efficacies of several alternative termiticides in laboratory and field tests. Effectiveness of gravel physical barriers was also examined.

Organophosphates, synthetic pyrethroids and a silane seemed potential to use as the alternative termiticides in Thailand for replacing conventional chlorinated hydrocarbons, both for wood and soil treatments. However, some of them were found unstable in soil-burial or natural weathering out of ground contact. When they were applied to wood treatment, the decline of termiticidal effectiveness was largest in the soil burial, followed by the outdoor weathering out of ground contact and the indoor keeping. An organophosphate chlorpyrifos degraded more rapidly than did synthetic pyrethroids and a silane. Termiticidal effectiveness of chlorpyrifos was lost within 3 months in the soil-burial. However, it had still a good performance after outdoor and indoor exposures out of ground contact for 12 and 24 months, respectively. Among the three synthetic pyrethroids and a silane, the silane (silafluofen) and fenvalerate were resistant to the soil-burial for 12 months, when they were applied to wood by 2% solution. However, under the outdoor weathering out of ground contact, cypermethrin was most resistant and silafluofen was ranked lowest. The value of 2% is extraordinary high for an practical application of synthetic pyrethroids and the silane, but higher concentration should be needed in tropical countries than recommended 0.1–0.8% in temperate region (Sections 3.1 and 3.2).

Soil treatment with termiticide is also essential to prevent subterranean termites from their invading into buildings. Longevity of several termiticides was evaluated under field-exposure tests and laboratory bioassays of weathered termiticide-treated soils. Because of decreased toxicity after short-term weathering, an application of chlorpyrifos to termite control was considered less effective in Thailand. Laboratory bioassay combined with field weathering was more reliable method to determine the longevity of soil termiticides in the tropical country. Among the termiticides tested, permethrin (2.0%), alpha-cypermethrin (0.3%) and bifenthrin (0.1%) were promising in consideration of their longevity (Section 3.3).

Finally, a possible application of physical barrier to the prevention of termite invasion was examined (Section 3.4). Barrier of gravel with 1.2–2.4 mm diameter was effective to prevent the penetration of *C. gestroi* at least for 12 months in the field test. Since the gravel is commonly used in Thailand for decoration of concrete wall and floor, its utilization as a measure of termite control should be investigated in more detail and for more longer time.

Based on the results presented above, the author proposed the following designs of termite control to overcome the current problems in Thailand as a tropical country.

*1. For pre-construction of buildings*

*1.1 Site* sanitation

Termite mounds, tree stumps and wood debris, and any other lignocellulosic materials should be removed clearly from the construction area.

*1.2 Good design of buildings and proper construction*

Use of non-resistant timbers without termiticide treatment should be avoided at the basement and at the other structural parts to allow easy penetration of termites. Even when the resistant timbers are used, treatment with termiticide is preferable in consideration of service life of the buildings, especially for slab-on-ground and crawl space types. For high pole type, concrete post is better than wooden post. Even the concrete post is allowed to termite entry but it is easier to find out without any direct damage. Open crawl space type is preferable to the closed type, since the former provides the better ventilation and easy detection of termite infestation. Concrete slab without any crack or cavity should be carefully constructed. Proper drainage design is also strongly recommended.

*1.3 Woodwork treatment*

Susceptible parts such as pole, foundation sill, flooring, beam, joist, and members of wall and roof should be carefully treated with suitable termiticides. Synthetic pyrethroids are preferable to chlorpyrifos. Silafluofen is most promising for treatment of wood in ground contact. Cypermethrin is applicable to exterior wood out of ground contact situation.

*1.4 Soil treatment*

Chemical barrier of termiticides should be established beneath and around area of construction, before concrete is poured. Synthetic pyrethroids, particularly permethrin, alpha-cypermethrin and bifenthrin, are more promising than chlorpyrifos.

*2. For post-construction of buildings and their remedial treatment*

*2.1 Inspection of termite infestation*

Periodical and careful inspection of infestation should be made, concentrating in susceptible parts of buildings described above. Site sanitation is also necessary.

*2.2 Eradicative or remedial treatment for woodwork*

Synthetic pyrethroids should be used for this purpose. Chlorpyrifos is also effective because of its fast termiticidal activity.

*2.3* Soil treatment

Soil termiticides described above should be penetrated by drilling beneath and around area of construction, instead of chlorinated hydrocarbon.

For the future aspects of integrated termite control, fundamental study should be promoted on the ecological and physiological characteristics of important termites in Thailand. Data from various countries are available but they are not necessarily transferable to different country.

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