TERMITE BAIT TECHNOLOGY: PERSPECTIVES
from AUSTRALIA

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Abstract Three components are considered when developing a baiting system: active ingredient; matrix; and termite biology. Attention to variations in termite biology is often limited, so a one-fits-all approach is chosen in the design. Efficacy of a bait system developed for a locally occurring species may not be successful unless it is adapted to other termite communities. The paper presents developments in Australia with two active ingredients, a juvenoid insecticide and a biocontrol control agent, *Metharizium anisopliae*. The influence of bait matrices on bait acceptance, transfer of the active ingredient to the colony, seasonal and diurnal patterns of activity, and factors that influence exploratory tunnelling are discussed. A model is presented that relates forager movement to the quantity and quality of food resources. A dynamic foraging process operates over the existence of a food resource: food resource is discovered, then termites are recruited in proportion to its resource value. Profitable feeding sites attract building activity and persist even when disturbed. Feeding depletes the food resource and termites at the site decline. Subterranean termite colonies utilise several food resources of varied size and quality simultaneously, and at any time and location differing proportions of site-specific or of transient foragers may be found. Understanding variation in biology during the development of bait systems influences development of bait systems for termite pest management.

Key Words Active ingredient, bait matrix, quantity of food resources, non-random foraging, subterranean termites

INTRODUCTION

In the last decade there has been a dramatic increase in the research on and the development of bait systems for termite management. The increasing availability of bait systems for the control of active termite infestations is already significantly affecting termite management practices in many parts of the world. There is even discussion of using such systems as stand-alone measures for the long-term protection of a structure (Thorne and Forschler, 2000; Grace and Su, 2001). Despite these important and remarkable trends, baiting is a developing technology, and many more changes to existing bait technology can be expected (Potter 1999).

There are three separate but equally important aspects to consider when developing a baiting system. The primary focus is on finding an active ingredient (active) that meets the requirements of a bait toxicant, i.e., is non-repellent and slow acting, and the secondary focus is on designing a bait matrix on which termites will readily feed and congregate (matrix). The third and equally critical component is an understanding of the variations in termite biology (biology). Unfortunately, the third component has received scant and often rather selective attention, which may reduce the appropriateness and efficacy of any given bait system in differing situations.

Understanding variations in biology is important in the development phase of a baiting system because not all species of termites behave in a uniform manner. Regrettably, it is rarely considered. Typically, each baiting system is designed by people who work in one localised geographic area and with one or two key species that are of economic importance in that area. It is only the particular biological requirements of these local key species of termite that are considered when that bait system is designed. Often the final system is shaped to suit those local species and the specific environmental conditions in which they are found. The essential features of any

given bait system are frequently more or less fixed by the time the system moves from its area of origin to other locations, and by then considerations of production efficiency and marketing assume importance. This change in focus may override the need for adequate further research into modifications to the system to suit the biology of new target groups of termites and varied environmental conditions.

The lack of emphasis on understanding the variation in biology during the development of bait systems has impact on the acceptance of and continued development of bait systems as tools in termite pest management.

In this paper we discuss some developments concerning potential actives and bait matrices and focus on some of the many issues of biology that require further attention if bait technology is to attain proper global recognition. We do so from an Australian perspective, which is a view that has been shaped from the most diversified and competitive termite pest control market in the world.

ACTIVE INGREDIENTS

There are two fundamental requirements for an active in a bait system: 1) to be non-repellent and 2) to act slowly. In combination, these ensure uptake and transport of the active to the nest by foraging termites, and distribution of the ingredient throughout the colony via interactions between nest mates. Certain products in three categories, metabolic inhibitors, insect growth regulators, and biological control agents, have met these requirements (Su and Scheffrahn, 2000). Greatest successes, measured by population reduction and sometimes even colony elimination, have been achieved with metabolic inhibitors such as mirex, sulfluramid, hydramethalnon, and borates (Esenther and Beal, 1974; Miller and Paton, 1980; Grace et al., 1990; Logan and Abood, 1990; Jones, 1991; Ballard and Mares, 1993; Forschler, 1996; Su et al., 1995) and among insect growth regulators with chitin synthesis inhibitors such as hexaflumuron, triflumuron, and others (Su, 1994; Lenz et al., 1996; Peters and Fitzgerald, 1998; Madden, 1999; Su and Scheffrahn, 2000).

There are several other types of actives under development, but we will discuss only two in detail. The first are the juvenile hormone analogues, which are classed as insect growth regulators, and the second are biological products. Because these are so new, few data are available indicating impact on termite populations, or colony eradication (Hrdy et al., 2000; Evans, 2001a).

Juvenile Hormone Analogues

Juvenile hormone analogues or juvenoids have attracted great attention in the past as potential bait toxicant candidates (Su and Scheffrahn, 1990). To date only Jones (1989) has demonstrated noticeable impact of such a bait toxicant on field populations of termites, i.e., appearance of excessive presoldiers and intercastes.

Hrdy et al.(2001) demonstrated in Australia that a juvenoid (W-328), developed by colleagues at the Prague Institute of Organic Chemistry and Biochemistry, is a suitable candidate for termite colony elimination. In trials with the mound-building species, *Coptotermes lacteus* (Froggatt), field colonies were killed within two months when exposed to the compound in feeding stations. Presoldiers and intercastes developed from several worker stages and nymphs. The fast disappearance of the workforce resulted in colony collapse (Hrdy et al., 2000).

Insect Pathogens

Milner (2001) formulated a matrix for exposure of termites to spores of the fungus *Metarhizium anisopliae* (Metschnikoff) that counteracted the repellency of the spores of the fungal isolate. It was tested on termites of the Australian mound-building species, *Nasutitermes exitiosus* (Hill), which readily entered bait containers and consumed the treated matrix. After

seven months the colonies had lost their reproductives and brood and were in decline. Delivery of *Metarhizium* spores in a food medium has limitations, because only spores that adhere to the termite cuticle kill the host; spores ingested with the palatable matrix do not affect the consumer. The ingested spores will not affect other termites because they are either exchanged by proctodaeal feeding, and so remain ineffective, or are defecated and thus sealed. Consequently, the number of spores incorporated into the matrix needs to be high and bait stations need to be visited by large numbers of foragers to ensure adequate and effective spore transfer to the nest. There is the alternative trap-and-treat strategy, whereby foragers are dusted directly with spores at aggregation sites. In Australia this approach has had limited success. The likely reason is that the termite carriers with high external spore loads may be excluded from re-entering the nest (Milner 2001), thus limiting spore transfer through mutual contact. It is evident that *Metarhizium* can play a role in solving certain termite problems. The best prospect for the fungus is as part of an integrated strategy (Milner 2001).

BAIT MATRIX

There are two prime considerations when designing matrices: what it is made of, and how much of it to use. These are considered separately as bait quality and quantity, and both can effect a bait system. Forschler (1996) reported that the bait will be in competition with alternative feeding sites, hence it needs to be the best possible food resource for the target termites.

Quality

Cellulose materials, ranging from the most raw to very refined, such as solid wood, sawdust, cardboard, paper, and powdered cellulose, are used as bait matrices and monitoring devices. Type and source of these materials can vary with each bait system. The general objective, largely for ease of production, is to use a matrix that suits as many termite species as possible. However, termites are selective feeders often with notable differences between regions and species of termite (La Fage and Nutting, 1978; Waller and La Fage, 1987a,b; Delaplane, 1991; Lenz, 1994). Variations in physical and chemical characteristics of a matrix substrate, such as whether it is from softwoods or hardwoods, sap- or heartwood, firm or soft, modified by microorganisms (Waller and La Fage, 1987a,b), the particular plant species or the specific manufacturing process (Grace et al., 2000) can result in different acceptance levels by termites. The influence of these factors on termite food selection behaviour will be exacerbated if favoured alternative food sources are available (Forschler, 1996; Lenz et al., 2000). For example, the Chinese termite, *Coptotermes formosanus* Shiraki, introduced into states of southern USA, is largely restricted to the urban environment, often not far from buildings. Under such circumstances, it is likely to experience food limitations and accept more readily a variety of bait matrices. Indigenous species of termites, which occupy natural and secondary habitats are able to utilise diverse food sources. Bait matrices and monitoring devices will have greater competition for termite favour and will have to be more carefully tailored to suit target termites and specific environments.

Acceptance by termites of a plain cellulose substrate may suggest a scenario of reduced manufacturing costs and so offers a more favourable economic situation. In practice it is not likely that the one-size-fits-all approach will be efficacious, especially as the range of target species for a bait system increases. Hence, much effort is directed at modifying a cellulose base in ways that termites will visit and feed on it preferentially, at least bringing it on par with food alternatives and encourage sustained foraging in the bait stations. The use of wood or bark rendered more attractive to termites by certain decay fungi is a feature of several bait studies and programs (Esenther and Gray, 1968; Amburgey, 1979; Esenther and Beal, 1979; Jones, 1993; Zhong and Liu, 1994).

The focus of easily mass-produced matrices has moved to a processed cellulose material that has been enhanced by additives and nutritional supplements. Examples of additions to a

matrix include urea (Waller, 1996), amino acids (Chen and Henderson, 1996), fungal extracts (Rust et al., 1996), fungal extracts and nutritional supplements (Rojas and Morales-Ramos, 2001), and different semiochemicals (Amburgey, 1979; Grace, 1991).

The identification of a phagostimulant, hydroquinone, that is released onto food by feeding termites and stimulates nest mates to feed at the same site (Reinhard et al., 2002a) has led to studies in Australia aiming to incorporate a formulation of hydroquinone into bait systems (Reinhard et al., 2002b). The compound has been identified in the labial gland secretion of a wide range of species of termite, which offers the prospect that addition of such formulations can render a matrix more acceptable to a wide range of species of termite (Reinhard et al., 2002a,b).

Quantity

Forager termites appear to have a basic minimum wood consumption rate, ensuring adequate provision for themselves and a surplus to meet colony needs (Collins, 1981; Watson et al., 1978; Lenz, 1994). However, in the presence of a rich food supply, foragers can increase wood consumption considerably above the minimum level, allowing for more food to be channelled into the colony (Waller and La Fage, 1987a; Lenz, 1994; Hedlund and Henderson, 1999; Cornelius and Osbrink, 2001). Field colonies will increase recruitment to favourable, i.e., more voluminous food sources (Waller and La Fage, 1987a; Lewis et al., 1998; Lenz et al., 2000). Some termites will relocate brood and reproductives, i.e., their nest, into suitably large food resources (see below). Lenz et al.(2000) reported *Reticulitermes flavipes* (Kollar) field populations attacked and persisted in bait stakes of three different volumes irrespective of bait size in plots with less alternative food, but were more selective when natural food resources were abundant. Populations abandoned smaller volumes of bait wood well before they had been fully utilised while persisting in larger wood volumes; these larger food sources were often utilised as nesting sites also (Lenz et al., 2000).

Although the effects of increased food (matrix) volume on recruitment, matrix consumption, and site tenacity have been well known for some time, they are not necessarily reflected in bait design. One of the main goals of an effective bait system is that the active is introduced into the colony via foragers as fast and in as large amounts as possible, hence monitors and volumes of matrix ought to be maximised in size (Waller and La Fage, 1987b; Hedlund and Henderson, 1999) either by using devices of larger volume or offering smaller ones in multiples. If self-recruiting into treated matrix is a feature of a bait system (Su, 1994), then the volume of material offered may have to be large enough to attract sufficient numbers of foragers, most notably in environments where termites rely on alternative resources. One of the primary attractions of a building may be as a source of water instead of a source of food; this scenario is not uncommon in the drier parts of the Australian continent.

TERMITE BIOLOGY

Termite behaviour has been little studied with the view to design of baiting systems. The greatest effort has been expended in determining food preferences for the identification of suitable quality of bait matrices, and reference has been made above to termite behaviour in the context of recruitment levels to different bait matrices.

Seasonal and Diurnal Patterns of Activity

Grass-feeding harvester termite species have distinct foraging patterns that are dependent on the weather: most intense when temperatures are high, but not extreme, and when the air is humid, such as after rain. These daily and seasonal patterns might be expected due to their exposure during harvesting (Bodot, 1967; Bouillon, 1970). Daily and seasonal changes in foraging activity of subterranean wood-feeding termites are not well known, but their subterranean habit is

widely assumed to reduce the effect of the weather on their behaviour. Evans and Gleeson (2001) reported distinct seasonal and daily patterns in visits by foraging *C. lacteus* to artificial feeding stations. In summer, greater numbers are found away from the mound-nests, in winter termites were clustered in very high numbers near to the mound-nests. Forager numbers fluctuated over the day: in summer peaks occurred in late morning and late afternoon and troughs at dawn and noon. In winter a peak occurred at noon and a trough at dawn. These patterns were associated with air and soil temperatures, indicating that daily and seasonal weather patterns do influence subterranean wood-feeding termites. Similar results have been reported for *C. formosanus* in artificial baits in Louisiana (Waller and La Fage, 1987c) and *Reticulitermes* spp. in California (Haagsma and Rust, 1995; Haverty et al., 1999).

Exploratory Tunnelling

It is not entirely clear how termites find food. Alates presumably use their eyes and antennae to locate suitable nesting sites, but such stimuli and perception have not been investigated. Some more effort has been expended in identifying factors that influence exploration for new food sources in subterranean termite workers. Several studies have focussed on tunnelling behaviour in uniform sand in arenas of less than 1 m^2. These studies have shown that termites vary tunnel size according to food resource size (Hedlund and Henderson, 1999). They spread their tunnelling activity evenly and not randomly (Robson et al., 1995; Reinhard et al., 1997), but that once a food source is found, further tunnelling activity is in the direction of that food source (Campora and Grace, 2001). Such pattern in laboratory arenas is similar to that found in natural field colonies of *Coptotermes acinaciformis* (Froggatt), *C. brunneus* Gay, and *C. lacteus* in Australia (Ratcliffe and Greaves, 1940; Greaves, 1962). The presence of gaps or guides in the uniform sand arenas alters termite searching and tunnelling. Gaps are investigated thoroughly and promote tunnelling, and guides promote tunnelling especially if they are edible, though not exclusively (Pitts-Singer and Forschler, 2000; Evans, 2001b).

The above quoted work has shown that termites exploit gaps in the soil before any other guide. This should not be surprising as digging tunnels is energetically demanding, so any reduction in costs should be exploited. These results are illustrative, because the natural soil environment is heterogeneous and includes silicious sand particles, but also clay, roots, and rhizomes of plants, animals, such as ants, worms, other termites, and their tunnels, humus, fungi, bacteria, air and water pockets, and rocks.

Forager Movement Patterns

Termite foragers are widely believed to move randomly between established feeding sites, i.e., without any site preferences (Su et al., 1984; Delaplane, 1991). Two key directions in termite research and management have been influenced by the possibility of random forager movement: estimation of forager population size using mark-recapture methods; and baiting as a control strategy. Random movement is a prerequisite for the reliability of population estimates derived from mark-recapture protocols (see Su and Scheffrahn, 1988; Thorne et al., 1996; Southwood and Henderson, 2000). It was also important for developing the concept of baiting, because, over time all foragers will visit the treated bait stations and so increase the chances of the active being distributed in sufficient quantity in the colony. The two have been combined, as mark-recapture methods have been used to monitor colony population decline following exposure to bait toxicant (e.g., Su, 1991, 1994; Su et al., 1991; Su and Scheffrahn, 1996; Evans, 2001a).

Studies with different species of termite indicate that marked termites do not distribute themselves evenly throughout the population (Forschler and Townsend, 1996; Thorne et al., 1996; Evans et al., 1998, 1999). There are no indications of continuous cycling of individuals among feeding sites in *Reticulitermes* (Thorne et al., 1996), which is supported by studies with Australian

C. lacteus and *N. exitiosus* (Evans, 2002). Foragers of both species showed strong tunnel fidelity, with 60-75% of foragers present at feeding sites in the original tunnels, whereas only 2-16% were found at sites on the opposite side of the nest. Results also showed that termites abandoned paper-only bait stations after disturbance, perhaps because they were a poor food resource, while termites remained feeding in wood-filled stations.

The importance of food quality and quantity to the termite colony (Lenz, 1994) has received little attention, but this is a major factor in determining foraging behaviour. For example, foraging termites do not just visit feeding sites; many termite species will relocate their reproductives and brood, primary or secondary, or even the entire nest, to significant food sources, such as *Schedorhinotermes* (Renoux, 1972; Miller, 1994) and *Reticulitermes* (Lenz et al., 2000). *Coptotermes* build nest-like structures (bivouacs) that are food dumps, to relocate distant food sources closer to the nest (CSIRO, unpubl. results). These examples show exploitation of food resources with a directed and at least temporarily residing work force rather than with one that continuously and randomly changes composition. Once a large volume or high quality resource is located, it would be energetically costly if it were exploited by randomly appearing and disappearing foragers. Random foraging as the key foraging strategy simply does not make evolutionary sense.

We envisage a simple, dynamic foraging process over the life of a food resource. First, the food resource is discovered, and the more valuable the resource, the more termites are recruited to it. The more profitable feeding sites will attract building activity and persist even when disturbed. Many of the foragers will stay at the feeding site, or regularly return to it; relocation of reproductives and nest may occur. As feeding depletes the food resource, the proportion of termites staying at a site will decline. Termites that displayed site fidelity will readily abandon such sites when disturbed or relocate to new resources. They may move erratically to gain information about new food resources, but become targeted again once another valuable resource is located. Since subterranean termite colonies utilise several food resources of varied size and quality simultaneously, we should expect to find at any one time and location differing proportions of more site-specific or transient foragers depending on the extent to which each resource has been exploited. There will be many factors that affect the process, especially regarding the threshold at which termites switch from one food item to the next. These include, age and size of the colony, kin-biased behaviour (Kaib et al., 1996), seasonal differences, and species differences. For example, *C. formosanus* displays greater foraging site tenacity than species of *Reticulitermes* (Delaplane and La Fage, 1989; Cornelius and Osbrink, 2001).

A physiological basis for the dynamics of foraging termites has been described by Reinhard and Kaib (1995). Aggregations of foragers at a feeding site are promoted by the interaction of sternal and labial gland secretions. These aggregations disband once the food resource is depleted and hence less rewarding. This is a dynamic process that is likely to be used for every food resource, and ought to be considered more frequently in designing experiments that test foraging behaviour, or in analyses of results.

The dynamic behaviour proposed here for foraging is really only one component of task allocation. The number of tasks, such as foraging, building, tunnelling, nursing, and cleaning, that worker termites perform in their colonies, and the rate at which they switch between these tasks is largely unknown in subterranean termites. Few of the many tasks in a behavioural repertoire can be studied in the field due to the cryptic nature of the termites, but one attempt has occurred for *N. exitiosus* in Australia. Evans (2000) reported that only about 100 marked foragers of 10,000 became builders when their mound nests were damaged, and that an estimated 600 out of 20,000 marked builders became foragers; fewer than 3 termites per day switched tasks. More work is required to understand these complicated processes and what impact they have on the distribution of a bait toxicant from a bait station throughout the colony.

For termite bait systems to succeed globally many factors have to be considered. Rather than assuming that the one-fits-all approach will deliver, it would be more prudent to retain sufficient flexibility to enable adaptation of the technology to biological requirements of different target species and local circumstances. There are important aspects of biology, such as inter and intra species interactions, different reproductive strategies, and practical considerations of working around human habitation, with a bearing on the success of bait technology across geographic areas. There is no doubt that bait technology is awaiting many more exciting developments (Potter 1999).

BAITING HISTORY: NOT ALL BAIT TECHNOLOGY IS NEW

Many people consider current bait technology a recent invention, yet there exist some remarkable and much earlier developments. G.F Hill, the founder of termite research in Australia, devised in 1921 a recipe for poisoned baits which used arsenical solutions as the active in a matrix of four materials. His bait recipe changed over time, as later he recommended sheets of cellulose treated with varying amounts of arsenite of soda.

Monitoring devices were used in varying forms well before the current crop of plastic constructions. Kalshoven (1955) inserted bamboo cylinders filled with loose wooden cores into the soil around a building in Indonesia to monitor termite activity. The wooden cores could readily be removed for inspection. Kalshoven's devices were often placed in groups "in order to enhance the opportunity for termites to trace them." Both practices are reminiscent of modern examples. The devices allowed detecting termite presence and revealing the interactions between several species on site. F.J. Gay (CSIRO correspondence, 1959), another leader in Australian termite research, wrote about monitoring stakes with a hollow centre which could be closed by a cork plug. The plug could be removed for inspection of evidence of termite presence without having to remove the stake, and further, arsenic dust could be applied to the centre of the stake. Much later such a monitoring stake was actually developed and put to use in Hawaii, coincidentally by another Australian (Ewart et al., 1992).

It is illuminating and humbling to realise that such pioneering work existed up to 80 years ago. Perhaps we can learn something from these examples and combine their work with current bait system design. Modern bait systems have introduced the concept of colony elimination into the termite management lexicon, one that did not exist historically. Deliverance still depends critically on the successful combination of the three factors of active, matrix, and biology.

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REFERENCES

Amburgey, T.L. 1979. Review and checklist of the literature on interactions between wood-inhabiting fungi and subterranean termites: 1960-1978. Sociobiol. 4: 279-296.

Ballard, J.B. and Mares, J.T. 1993. The development of fluorosulfonate baits for the control of structural pests. In: Wildey, K.B. and Robinson, W.H., eds. Proc. 1st Internat. Conf. Urban Pests, Cambridge, pp. 381-384.

Bodot, P. 1967. Cycles saisonniers d'activité collective des termites des savannes de Basse Côte-d'Ivoire. Insectes sociaux 14: 359-388.

Bouillon, A. 1970. Termites of the Ethiopian region. In: Krishna, K. and Weesner, F., eds. Biology of Termites, vol. 2. New York: Academic Press, pp. 153-280.

Chen, J. and Henderson, G. 1996. Determination of feeding preference of Formosan subterranean termite (*Coptotermes formosanus* Shiraki) for some amino acid additives. J. Chem. Ecol. 22: 2359-2369.

Collins, N.M. 1981. Consumption of wood by artificially isolated colonies of the fungus-growing termite *Macrotermes bellicosus*. Entomol. exp. appl. 29: 313-320.

Campora, C.E. and Grace J.K. 2001. Tunnel orientation and search pattern sequence of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 94: 1193-1199.

Cornelius, M.L. and Osbrink, W.L.A. 2001. Tunnelling behavior, foraging tenacity, and wood consumption rates of Formosan and Eastern subterranean termites (Isoptera: Rhinotermitidae) in laboratory bioassays. Sociobiol. 37: 79-94.

Delaplane, K.S. 1991. Foraging and feeding behaviors of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Sociobiol.19: 101-114.

Delaplane, K.S. and La Fage, J.P. 1989. Foraging tenacity of *Reticulitermes flavipes* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiol.16: 183-189.

Esenther, G.R. and Beal, R.H. 1979. Termite control: Decayed wood bait. Sociobiol. 4: 215-222.

Esenther, G.R. and Gray, D.E. 1968. Subterranean termite studies in southern Ontario. Can. Ent. 100: 827-834.

Evans T.A. 2000. Foraging, building and task switching in worker termites. Sect. Française IUSSI Ann. Colloque, Dijon 6-8 September 2000, p. 20.

Evans, T.A. 2001a. Estimating relative decline in populations of subterranean termites (Isoptera: Rhinotermitidae) due to baiting. J. Econ. Entomol. 94: 1602-1609.

Evans T.A. 2001b. Tunnelling behaviour in subterranean termites. Meeting of the European Sections IUSSI, Berlin 25-28 September 2001, p. XX.

Evans, T.A. 2002. Tunnel specificity and forager movement in subterranean termites (Isoptera: Rhinotermitidae and Termitidae). Bull. Ent. Res. 92: In press.

Evans, T.A. and Gleeson, P.V. 2001. Seasonal and daily activity patterns of subterranean, wood-eating termite foragers. Austral. J. Zool. 49: 311-321.

Evans, T.A., Lenz, M., and Gleeson, P.V. 1998. Testing assumptions of mark-recapture protocols for estimating population size using Australian mound-building, subterranean termites. Ecol. Entomol. 23: 139-159.

Evans, T.A., Lenz, M., and Gleeson, P.V. 1999. Estimating population size and forager movement in a tropical subterranean termite (Isoptera: Rhinotermitdae). Environ. Entomol. 28: 823-830.

Ewart, D. McG., Grace, J.K., Yamamoto, R.T., and Tamashiro, M. 1992. Hollow stakes for detecting subterranean termites (Isoptera: Rhinotermitidae). Sociobiol. 20: 17-22.

Forschler, B.T. 1996. Baiting *Reticulitermes* (Isoptera: Rhinotermitidae) field colonies with Abamectin and Zinc Borate-treated cellulose in Georgia. Sociobiol. 28: 459-484.

Forschler, B.T. and Townsend, M.L. 1996. Mark-release-recapture estimates of *Reticulitermes* spp. (Isoptera: Rhinotermitdae) colony foraging populations from Georgia, U.S.A. Environ. Entomol. 25: 952-962.

Grace, J.K. 1991. Semiochemical mediation and manipulation of *Reticulitermes* behavior (Isoptera: Rhinotermitdae). Sociobiol. 19: 147-162.

Grace, J.K. and Su, N.-Y. 2001. Evidence supporting the use of termite baiting systems for long-term structural protection (Isoptera). Sociobiol. 37: 301-310.

Grace, J.K., Abdallay, A., and Sisson, J.M. 1990. Preliminary evaluation of borate baits and dusts for eastern subterranean termite control. Internat. Res. Group Wood Preservation, IRG/WP/1433, 7 pp.

Grace, J.K., Yamamoto, R.T., and Tome, C.H.M. 2000. Toxicity of Sulfluramid to *Coptotemes formosanus* (Isoptera: Rhinotermitdae). Sociobiol. 35: 457-466.

Greaves, T. 1962. Studies of foraging galleries and the invasion of living trees by *Coptotermes acinaciformis* and *C. brunneus* (Isoptera). Austral. J. Zool. 10: 630-651.

Haagsma, K.A. and Rust, M.K. 1995. Colony size estimates, foraging trends and physiological characteristics of the western subterranean termites (Isoptera: Rhinotermitidae). Environmental Entomology 24: 1520-1528.

Haverty, M.I., Getty, G.M., Copren, K.A., and Lewis, V.R. 1999. Seasonal foraging and feeding behaviour of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in a wildland and residential location in northern California. Environ. Entomol. 28: 1077-1084.

Hedlund, J.C. and Henderson, G. 1999. Effect of available food on search tunnel formation by the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 92: 610-616.

Hrdy, I., Kuldova, J., and Wimmer, Z. 2001. A juvenile hormone analogue with potential for termite control: laboratory tests with *Reticulitermes santonensis, Reticulitermes flavipes* and *Coptotermes formosanus* (Isopt., Rhinotermitidae). J. Appl. Ent. 125: 403-411.

Hrdy, I., Kuldova, J., Wimmer, Z., Lenz, M., and Gleeson, P.V. 2000. Potential of juvenoids in bait technology for the management of subterranean termites (Isoptera) – Laboratory and field studies with a carbamate derivative (W-328). In: Gazzoni, D.L., ed. Abstract Book II, XXI Int. Congr. Entomology, Brazil, p. 684.

Jones, S.C. 1989. Field evaluation of fenoxycarb as a bait toxicant for subterranean termite control. Sociobiol.15: 33-41.

Jones, S.C. 1991. Field evaluation of boron as bait toxicant for control of *Heterotermes aureus* (Isoptera: Rhinotermitdae). Sociobiol. 25: 187-209.

Jones, S.C. 1993. Effect of decay fungus on subterranean termite (Isoptera: Rhinotermitidae) response to bait toxicant treated wood. In: Wildey, K.B. and Robinson, W.H., eds. Proc. 1st Internat. Conf. Urban Pests, Cambridge, pp. 199-206.

Kaib, M., Husseneder, C., Epplen, C., Epplen, J.T., and Brandl, R. 1996. Kin-biased foraging in a termite. Proc. R. Soc. Lond. B 263: 1527-1532.

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

La Fage, J.P. and Nutting, W.L. 1978. Nutrient dynamics of termites. In: Brian, M.V., ed. Production ecology of ants and termites. Cambridge: Cambridge Univ. Press, pp. 165-232.

Lenz, M. 1994. Food resources, colony growth and caste development in wood-feeding termites. In: Hunt, J.H. and Nalepa, C.A., eds. Nourishment and evolution in insect societies. Boulder: Westview Press, pp. 159-209.

Lenz, M. Kard, B., Mauldin, J.K., Evans, T.A., Etheridge, J.L., and Abbey, H.M. 2000. Size of food re- sources determines brood placement in *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Internat. Res. Group on Wood Preservation, IRG/WP/00-10351, 8pp.

Lewis, V.R., Haverty, M.I., Getty, G.M., Copren, K.A., and Fouche, C. 1998. Monitoring station for studying populations of *Reticulitermes* (Isoptera: Rhinotermitidae) in California. Pan-Pacific Entomologist 74: 121-133.

Logan, J.W.N. and Abood, F. 1990. Laboratory trials on the toxicity of hydramethylnon (Amdro; AC 217,300) to *Reticulitermes santonensis* Feytaud (Isoptera: Rhinotermitidae) and *Microtermes lepidus* Sjöstedt (Isoptera: Termitidae). Bull. Ent. Res. 80: 19-26.

Madden, W.R. 1999. Efficacy of triflumuron dust for eradication of subterranean termite (Isoptera: Rhinotermitidae) colonies. In: Robinson, W.H., Rettich, F. and Rambo, G.W., eds. Proc. 3rd Internat. Conf. Urban Pests, Prague, pp. 391-398.

Miller, L.R. 1994. Nest and queen migration in *Schedorhinotermes actuosus* (Hill), *Schedorhinotermes breinli* (Hill) and *Coptotermes acinaciformis* (Froggatt) (Isoptera: Rhinotermitidae). J. Aust. Ent. Soc. 33:317- 318.

Milner, R.J. 2001. Application of biological control agents in mound building termites – Experiences with *Metarhizium* in Australia. Proc. 2nd Internat. Symp. on *Coptotermes formosanus*. New Orleans, 15 pp.

Paton, R. and Miller, L.R. 1980. Control of *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae) with mirex baits. Austral. For. Res. 10: 249-258.

Peters, B.C. and Fitzgerald, C.J. 1998. Field exposure of borate-treated softwood to subterranean termites (Isoptera: Rhinotermitidae, Mastotermitidae). Material u. Organismen 32: 41-66.

Pitts-Singer, T.L. and Forschler, B.T. 2000. Influence of guidelines and passageways on tunnelling behavior of *Reticulitermes flavipes* (Kollar) and *R. virginicus* (Banks) (Isoptera: Rhinotermitidae). J. Insect Behavior 13: 273-290.

Potter, M.F. 1999. The changing face of termite control. Part 1: The role of baits. Pest Control Technol. 27 (2): 23, 26, 28, 30, 110.

Ratcliffe, F.N. and Greaves, T. 1940. The subterranean foraging galleries of *Coptotermes lacteus* (Frogg.). J. Council of Scientific and Industrial Res. 13: 150-160.

Reinhard, J. and Kaib, M. 1995. Interaction of pheromones during food exploitation by the termite *Schedorhinotermes lamanianus*. Physiological Entomol. 20: 266-272.

Reinhard, J., Hertel, H., and Kaib, M. 1997. Systematic search for food in the subterranean termite *Reticulitermes santonensis* De Feytaud (Isoptera, Rhinotermitidae). Insectes sociaux 44: 147-158.

Reinhard, J., Lacey, M.J., and Lenz, M. 2002b. Application of a natural phagostimulant in bait systems for termite management. Sociobiol. 39: 1-17.

Reinhard, J., Lacey, M.J., Ibarra, F., Schroeder, F.C., Kaib, M., and Lenz, M. 2002a. Hydroquinone: A general phagostimulating pheromone in termites. J. Chem. Ecol. 28: 1-14.

Renoux, J. 1972. Le nid du termite *Schedorhinotermes lamanianus* (Sjöstedt) (Isoptera, Rhinotermitidae). Ann. Univ. Brazzaville 8 (C): 43-68.

Robson, S.K., Lesniak, M.G., Kothandapani, R.V., Traniello, J.F.A., Thorne, B.L., and Fourcassie, V. 1995. Non-random search geometry in subterranean termites. Naturwiss. enschaften 82: 526-528.

Rojas, M.G. and Morales-Ramos, J.A. 2001. Bait matrix for delivery of chitin synthesis inhibitors to the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 94: 506-510.

Rust, M.K., Haagsma, K., and Nyugen, J. 1996. Enhancing foraging of the Western subterranean termites (Isoptera: Rhinotermitidae) in arid environments. Sociobiol. 28: 275-286.

Southwood, T.R.E. and Henderson, P.A. 2000. Ecological Methods, 3rd ed. Oxford: Blackwell Science.

Su, N.-Y. 1991. Evaluation of bait toxicants for suppression of subterranean termite populations. Sociobiol. 19: 211-220.

Su, N.-Y. 1994. Field evaluation of hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 87: 389-397.

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

Su, N.-Y. and Scheffrahn, R.H. 1990. Potential of insect growth regulators as termiticides: A review. Sociobiol. 17: 313-328.

Su, N.-Y. and Scheffrahn, R.H. 1991. Laboratory evaluation of two slow-acting toxicants against Formosan and Eastern subterranean termites. J. Econ. Entomol. 84: 170-175.

Su, N.-Y. and Scheffrahn, R.H. 1996. Fate of subterranean termite colonies (Isoptera) after bait applications. Sociobiol. 27: 253-275.

Su, N.-Y. and Scheffrahn, R.H. 2000. Termites as pests of buildings. In: Abe, T., Bignell, D.E. and Higashi, M., eds. Termites: Evolution, sociality, symbiosis, ecology. Dordrecht: Kluwer Academic Publishers, pp. 437-453.

Su, N.-Y., Ban, P.M., and Scheffrahn, R.H. 1991. Suppression of foraging populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) by field applications of a slow-acting toxicant bait. J. Econ. Entomol. 84: 1525-1531.

Su, N.-Y., Tamashiro, M., Yates, Y.R., and Haverty, M.I. 1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 13: 1466-1470.

Thorne, B.L. and Forschler, B.T. 2000. Criteria for assessing the efficacy of stand-alone termite barrier treatments of structures. Sociobiol. 36: 245-255.

Thorne, B.L., Russek-Cohen, E., Forschler, B.T., Breisch, N.L., and Traniello, F.F.A. 1996. Evaluation of mark-release-recapture methods for estimating forager population size of subterranean termite (Isoptera: Rhinotermitidae) colonies. Environ. Entomol. 25: 938-951.

Waller, D.A. 1996. Ampicillin, tetracycline and urea as protozoicides for symbionts of *Reticulitermes flavipes* and *R. virginicus* (Isoptera: Rhinotermitidae). Bull. Entomol. Res. 86: 77-81.

Waller, D.A. and La Fage, J.P. 1987a. Nutritional ecology of termites. In: Slansky, F. and Rodriguez, J.G., eds. Nutritional ecology of insects, mites and spiders. New York: Wiley & Sons, pp. 487-532.

Waller, D.A. and La Fage, J.P. 1987b. Food quality and foraging response by the subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Bull. Ent. Res. 77: 417-424.

Waller, D.A. and La Fage, J.P. 1987c. Seasonal patterns in foraging groups of *Coptotermes formosanus* (Rhinotermitidae). Sociobiology 13: 173-181.

Zhong, Junhong and Liu, Liling. 1994. Control of the Formosan subterranean termite in China. Internat. Res. Group on Wood Preservation, IRG/WP/94-10088, pp. 11.