TERMITE BAITING SYSTEM TECHNOLOGY: UTILIZATION AND EVALUATION FOR INTEGRATED MANAGEMENT OF *Reticulitermes flavipes* (Kollar) AND *Coptotermes formosanus* Shiraki (ISOPTERA: RHINOTERMITIDAE) SUBTERRANEAN TERMITE POPULATIONS, WITH SEASONAL VARIATION AND SPATIAL PATTERNS EXHIBITED IN FORAGING STRATEGIES

A Dissertation

by

GRADY J. GLENN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2005

Major Subject: Entomology

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Approved by:

Chair of Committee,	Roger E. Gold
Committee Members,	Jimmy K. Olson
	S. Bradleigh Vinson
	Leon H. Russell
Head of Department,	Kevin Heinz

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ABSTRACT

Termite Baiting System Technology: Utilization and Evaluation for Integrated Management of *Reticulitermes flavipes* (Kollar) and *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae) Subterranean Termite Populations, with Seasonal Variation and Spatial Patterns Exhibited in Foraging Strategies. (December 2005)

Grady J. Glenn, B.S. Texas A&M University

Chair of Advisory Committee: Dr. Roger E. Gold

Commercial termite baiting systems were utilized and evaluated under real-world conditions in order to provide a comparison of efficacy in the management of subterranean termites. Three commercial termite baiting systems available for comparison included: FirstLine® (FMC Corp.), Sentricon® (Dow AgroSciences), and Terminate® (United Industries, Inc). The time required for foraging termites to locate and begin feeding on both the Sentricon® and the Terminate® bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® system, for both *R. flavipes* and *C. formosanus*. The time required for *C. formosanus* to locate and begin feeding on all termite baiting systems was approximately one-half the time required for *R. flavipes*. There were no significant differences in efficacy between the three baiting treatment systems against *R. flavipes*, with a mean of 84% efficacy for all systems. The Sentricon® system was able to achieve efficacy (88%) results with few additional residual liquid termiticide treatments. FirstLine® efficacy (80%) and

Terminate® efficacy (84%) results required initial and subsequent multiple spot treatments with residual termiticide for comparable results.

The Sentricon® baiting system yielded positive results in the management of *C. formosanus*, if utilized in an aggressive, active management program, involving multiple supplementary in-ground and above-ground bait stations at both points of active infestation and at areas with conditions conducive to infestation. Optimum results were achieved when monitoring of the bait stations occurred twice each month, rather than the standard monthly monitoring regime. The two termite baiting systems with Sulfluramid as the active ingredient required spot treatments with termiticides in order to protect the structures.

Grids of bait stations were installed and termite activity and foraging strategies were monitored for a five-year period. Treatment with sulfluramid required 472 active ingredient tubes, over a 37-month period, in order to reduce subterranean termite populations. Observations of seasonal variation and spatial patterns of foraging by native subterranean termites, *R. flavipes*, in a typical urban/suburban setting provided information with direct application to an effective termite baiting system program.

DEDICATION

This work is dedicated, first and foremost, to the pest control industry, particularly to those specialists that take on the daunting challenge of termite control. There is no more difficult a task than to take on the treatment of termites in order to protect a family’s most valuable possession, their home! There are few subjects more emotional than the potential damage that termites can inflict on a person’s residence. The anxiety and trepidation brought on by the possibility of an infestation, as well as the treatment necessary to remedy the situation, for the homeowner as well as the termite control specialist, is never exaggerated. I fought this good fight for over 20 years as one of the brethren of this calling. If this research has helped in some small way and contributed any answers to questions about termite baiting systems and their usefulness and relevance in termite control efforts, then I will have accomplished my goal.

This work is also dedicated to Dr. Harry N. Howell, Jr., a true genius who happened to devote his time and attention to the many aspects of urban entomology. He could just as easily have devoted his life and energy to physics, or mathematics, or a myriad of other interests, but he didn’t, and we are richer for it, and for knowing him. He was always willing to assist me and anyone else with questions about entomology and pest management, and statistics, and so many other subjects. He drew answers and solutions from an amazing encyclopedic mind, and with the bonus of richly detailed, anecdotal narratives applicable to the subject matter. We mourn his passing.

ACKNOWLEDGEMENTS

Water, stories, the body,
all the things we do, are mediums
that hide and show what's hidden

Study them,
and enjoy this being washed
with a secret we sometimes know,
and then not.

Rumi (1207-1273)
Persian philosopher, naturalist, and poet

I am indebted to Dr. Roger E. Gold, the chairman of my Graduate Committee, and to the other members of that committee: Dr. Jimmy Olson, Dr. S. Bradleigh Vinson, and Dr. Leon Russell. These educators have helped me to appreciate the wonders of science, particularly the knowledge that each discovered answer initiates three more questions as well as the humility to accept the fact that some answers exceed our grasp.

Dr. Roger E. Gold has the rare ability to discern ability and provide opportunity, and I appreciate his doing both in my behalf, for employing me in a fulfilling occupation and encouraging this educational pursuit. As I returned to this educational goal late in life, I also had the privilege of being taught again by Dr. Jimmy Olson and Dr. S. Bradleigh Vinson, who had taught my undergraduate courses in entomology at Texas A&M University, and I appreciate their educational counsel even more the second time around. I thank Dr. Leon Russell for imparting the "big picture" of epidemiological studies to me, and for his unflagging encouragement. I am very thankful to have had the

counsel and friendship of Dr. Roger Meola, an original member of this committee, who passed away while I pursued this research and educational goal.

I am also indebted to Dr. Mark Wright for his wealth of knowledge of chemistry and computer hardware, software, and information technology. This work could not have been accomplished without his propitious assistance with all of these matters. Bryce Bushman was invaluable in this research, first in performing much of the fieldwork, particularly in the grid work with 400 termite bait stations that had to be inspected monthly for five years. I wonder if he realizes that he did so 24,000 times? In addition, he provided valuable computer assistance and graphics for presentations and for this dissertation.

I appreciate the assistance of cooperating pest control companies that worked diligently to provide information about the efficacy of termite baiting systems. In the work with *Reticulitermes flavipes*, I thank Ned Ewart and staff at BugMaster, Inc. in Austin, Texas; Bill Clark and staff at Bill Clark Pest Control in Beaumont, Texas; Greg and Debbie Aguirre and staff at Elite Exterminating, Inc. in Corpus Christi, Texas; Ami Borovick and staff at Chem Care Chief Pest Control in Houston, Texas; and Robert Cawood and staff at Central Pest Control in San Antonio, Texas. In the work with *Coptotermes formosanus,* I thank Bill Clark, Jeff Franks, and the rest of the staff at Bill Clark Pest Control in Beaumont, Texas and Clint May and his staff at Coastal Exterminating Co. in La Porte, Texas.

The following organizations and companies provided financial support:

The Texas Attorney General’s office, USDA-ARS Specific Cooperative Agreements: 58-6435-8-108 and 56-6435-3-0045, Dow AgroSciences LLC, FMC Corp., and United Industries, Inc.

I would like to recognize the support and encouragement of many students who are currently attending or have completed the program at the Center for Urban and Structural Entomology at Texas A&M University in College Station, Texas: Dr. Jerry Cook, Dr. Tammy Cook, Dr. Richard Houseman, Dr. Tom Macom, Dr. Bart Foster, Barry Furman, Kim Engler, Molly Keck, Anne Narayanan, Janis Reed, Bryan Heintschel, and Jason Meyers. My thanks go to Dr. Ray Frisbie, who was my advisor when I was an undergraduate student, and a mentor to me during my graduate pursuits. I also thank innumerable others of the faculty, staff, and students of the Department of Entomology at Texas A&M University who taught me and encouraged me along the way, particularly Dr. Pat Morrison. I give thanks to Dr. Don Renchie for his encouragement and counsel.

My heartfelt thanks go to Patti Hudnall and to Todd and Michelle, who encouraged me and supported my efforts down to the very end of this pursuit, and would not let me give up. Patti truly inspired me in this endeavor.

I could never have done any of this without the support and encouragement of my sons, Gabriel and Jacob, who have always cheered me on. I hope I have always inspired them, in return.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

GENERAL INTRODUCTION AND LITERATURE REVIEW

The subterranean termite is truly an enigma. It is the most destructive, xylophagous pest of human structures and economically important plants (Potter 1997, 2004; Su and Scheffrahn, 1990). Nationwide costs for prevention, control, and repair attributable to subterranean termites was estimated to be in excess of $1.7 billion annually in 1993 (Gold et al. 1993). A more recent analysis estimates these costs at $11 billion annually (Su 2002). Paradoxically, subterranean termites are also some of the most beneficial insects due to nutrient cycling of valuable biomass, particularly cellulose and lignin, which are resources that few other organisms are capable of degrading (Kofoid 1934, Thorne and Forschler 1998). Despite their economic impact, relatively little is known about these social insects. Weesner (1965) comments that we have "only fragments of information" about these cryptic organisms, yet adds that termite "control methods are initially based upon some knowledge of the biology of the particular species of termite involved." Indeed, the advent and widespread use of the chlorinated hydrocarbon termiticides as effective soil barriers following World War II vitiated extensive termite research efforts for much of the 20th century (Ware 1991).

Basic knowledge of the physiological and behavioral attributes of termites and the complex ecological relationships exhibited in their subterranean milieu is made difficult

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This dissertation follows the style and format of Environmental Entomology.

due to their cryptic mode of existence, and was given minimal attention until the loss of Chlordane and related compounds to the United States and Australia in 1988 (Kofoid 1934, Weesner 1965, Wilson 1971). This resulted in challenges in the termite control industry, with academic and industry scientists searching for alternative termiticides. Substitute termiticides formulated from organophosphate and pyrethroid chemistry were much more costly and had limited residual efficacy and longevity in soil when compared to chlorinated hydrocarbons. The end of production and subsequent loss of availability of chlordane and related compounds to the rest of the world in 1998 resulted in an atmosphere of fear and doubt concerning the future of effective, economical termite control.

Subterranean termites in the genus *Reticulitermes*, ubiquitous in North America, are well known for their destructive capability (Pearce 1997). The principal component of their diet is wood, which is also the dominant structural element of the building construction industry (Thorne and Forschler 1998). Their innate role as decomposers of wood and other vegetation in the natural ecosystem changes their status from beneficial insect to that of a “pest,” depending on whether the subject of their attack is a fallen tree or the lumber in a home or other building. The continued growth and expansion of urbanization also creates conditions conducive to infestation by subterranean termites. Wood-framed structures, well-watered lawns, bark mulch adjacent to buildings, and firewood piles beckon to the termites to feast on the plethora (Pearce 1997).

The unintentional introduction and subsequent spread of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, into large areas of the United States and other areas of the world (Bennett et al. 1997, Howell et al. 2001, Su and Scheffrahn 1988) has created even more concern to those with vulnerable structures and vegetation (Su and Tamashiro 1987). This is primarily due to the larger population size of the colonies, aggressive nature, and the ability to form aerial nests made from "carton" material with no connection to the ground (Forschler and Henderson 1995, Potter 2004). Cornelius and Osbrink (2001) report that overall wood consumption rates of *C. formosanus* are almost 25% greater than rates of *Reticulitermes flavipes*. The Formosan subterranean termite is also reported to build wider tunnels and show a greater foraging tenacity. The combination of these characteristics has led to the well-deserved destructive reputation of the species, particularly in southern coastal regions, where they cause serious damage in a relatively short period of time (Jones and Howell 2000, Lax and Osbrink 2003).

One beneficial effect that has arisen from these concerns is the increased emphasis on the research into the biology of subterranean termites, particularly as it relates to pest management (Haverty et al. 1999, 2000; Houseman 1999; Houseman et al. 2000; Macom 1999; Myles 1999; Thorne and Breisch 1996; Thorne and Forschler 1998). Alternative physical, mechanical, and chemical control methodologies have begun to be extensively researched (Cornelius et al. 1997; Forschler and Henderson 1995; Gold et al. 1996, Grace et al. 1993; Jones 1984, 1989; Kard et al. 1989; Kard 1996; Yates et al. 2000). Biological control strategies for insects such as termites have been examined (Schmid-Hempel 1998, Van Driesch and Bellows 1996, Wright et al. 2000) and studies of generalist and specific organisms and their virulence against subterranean termites have been conducted (Connick et al. 2001, Grace and Zoberi 1992, Jones et al. 1996, Osbrink et al. 2001, Ramakrishnan et al. 1999). One example is the study of ants as predators of termites (Cornelius and Grace 1994, 1996; Waller and LaFage 1986, 1987).

For most of the twentieth century, control of subterranean termites relied on liquid barrier treatments with termiticides, placed under and around structures in order to protect them. With the advent of termite baiting systems during the end of the last century, there was a shift in termite treatments utilizing the baiting concept. Current termite management efforts, as well as efficacy studies, began to concentrate on baiting system technologies (Traniello and Thorne 1994), utilizing fenoxycarb (Jones 1989, Jones and Lenz 1996), chitin synthesis inhibitors (hexaflumuron and diflubenzuron) or slow-acting stomach poisons (hydramethylnon, sulfluramid, and boric acid) as active ingredients (Ballard 1997; Getty et al. 2000; Haagsma and Bean 1998; Lewis et al. 1998; Pawson and Gold 1996; Sheets et al. 2000; Su 1991, 1994; Su and Scheffrahn 1991, 1993, 1996a, 1996b; Su et al. 1995).

The concept of a baiting technique for termite pest management dates back to 1968 (Esenther and Gray), with subsequent research investigating various slow-acting active ingredients (Beard 1974; Esenther and Beal 1974, 1978). The utilization of termite baiting system technologies was a natural outgrowth of the desire for pest management efficacy accomplished with reduced levels of pesticide use, as well as the emphasis on “reduced risk” strategies. The termite baiting system technologies were particularly appealing to those concerned with the potential risks associated with the large quantities of liquid termiticides necessary for traditional chemical barrier treatments for termite control (Pawson and Gold 1996), as well as the need for another treatment option when a traditional termiticide treatment was not successful in protecting a structure.

The objective of a termite baiting system is the management of termite populations and is accomplished through distribution of a toxicant or inhibitor into a colony within a palatable food (cellulose) substrate (Grace et al. 1996, Thorne and Forschler 1998). The strategy relies on the foraging activity of the pseudergates (workers) to gather and introduce this material into the social fabric of a colony where it will be shared through trophallaxis and subsequently kills or inhibits the normal development and metamorphosis of colony members (Potter 1997; Su 1991, 1994; Su and Scheffrahn 1996a). The goal of this management tactic is the eventual collapse and death of the colony, or to be "functionally" eliminated, as described by Su (1994). Regulatory perspectives and challenges for termite baiting system registration will be determined, ultimately, by bait-toxicant risk and efficacy results (Sweeney 2000).

It is important to note that time is required for foraging termites to locate the bait stations, consume sufficient active ingredient, and share with nestmates through trophallaxis in order to control termite populations. Each stage is dependent on the results of the previous stage, and when one event influences another, interdependence, rather than independence, is the result, particularly in a biologically complex system such as a subterranean termite colony (Buchanan 2002). This inherently yields opportunities for failure in any multi-step management strategy. Buchanan (2002) emphasizes that when a large number of elements interact with one another, the interactions lead to messy interdependence that increases the difficulty of understanding what goes on and why. The concept of probability theory, and stochastic processes, in which a sequence of values is drawn from a corresponding sequence of jointly distributed variables, comes into play in such a treatment regime. The probability of obtaining the final outcome of a multi-step process is the product of the individual probabilities; if each step of a three-step process has a 50% chance of success, then the three steps, combined, are multiplicative, and have the ultimate potential of realizing only one chance in eight of success or: ½ x ½ x ½ = 1/8 (Ott and Longnecker 2001). It is also important to note that pest management afforded by a termite baiting system is dependent on termites locating, consuming, and sharing sufficient active ingredient in that particular system to be efficacious; if no active ingredient is consumed, no control is possible.

Several of the previously cited active ingredients of baiting systems have been investigated through laboratory and field bioassays to determine their efficacy against termite populations (Forschler and Chiao 1998, Rojas and Morales-Ramos 2001, Su and Scheffrahn 1991, Su et al. 1995). Several termite baiting systems utilizing these ingredients have entered the marketplace and are being marketed to pest control companies or directly to the public as a means to achieve the control of termites (Ballard and Lewis 2000). While there is limited information available on the efficacy of termite baiting systems, unbiased scientific data comparing different systems under actual use situations, and in significant numbers, is generally lacking. This dissertation examined the evaluation of the efficacy of available termite baiting systems and their bait-toxicant active ingredients. Part of this investigation also determined if there are any differences in efficacy of commercial termite baiting systems against *R. flavipes* and *C. formosanus* subterranean termites. The seasonal variation and spatial patterns of foraging activity and strategies of *R. flavipes* in the urban/suburban setting was also examined, particularly as these relate to termite baiting systems utilized in the pest management of subterranean termites. This dissertation consists of three specific aspects:

Objectives

I. To evaluate the efficacy of commercially available termite baiting systems as a pest management strategy in structures with active infestations of subterranean termites [Null Hypothesis: There are no significant differences between termite baiting systems for the management of subterranean termites].

II. To determine any variability in the efficacy of commercial termite baiting systems between *R. flavipes* and *C. formosanus* subterranean termites [Null Hypothesis: There are no significant differences in the efficacy of termite baiting systems against these two species of subterranean termites].

III. To investigate the efficacy of sulfluramid as a “stand-alone” bait-toxicant in a management program for subterranean termite populations [Null Hypothesis: There are no significant differences in the level of control between sulfluramid as a “stand-alone” bait-toxicant or used in conjunction with spot treatments with liquid termiticides against subterranean termites].

CHAPTER II

EVALUATION OF EFFICACY OF COMMERCIAL TERMITE BAITING SYSTEMS FOR PEST MANAGEMENT OF THE EASTERN SUBTERRANEAN TERMITE, *Reticulitermes flavipes* (Kollar)

Introduction

The novel concept of the pest management of subterranean termites utilizing termite baiting systems is a paradigm in the pest control field. The standard method of termite control for many years was to exclude termites from buildings with a liquid barrier treatment. The barrier is a “passive” treatment regime, following the initial application of termiticide. The utilization of termite baiting systems, with installation, monitoring, application of active ingredient, and continuous re-monitoring and re-application, as needed, constitutes an “active” treatment regime. Bait stations are designed to facilitate the consumption of a bait-toxicant and its transfer to the rest of the colony; the goal is termite population reduction or elimination (Su and Scheffrahn 1996a, 1998).

The discovery and use of termite baiting systems to treat subterranean termites created confusion and controversy in the industry (Potter 2004). Many questions arose concerning efficacy of this novel treatment, as well as questions concerning the variable time required before termites located the monitoring stations, fed on active ingredient, spread the material to others in the colony through the food exchange process of trophallaxis, achieved some sort of control of the termite population, and ultimately protected structures. Many factors would conceivably affect this time frame, including the species of subterranean termite, season of year, ambient temperature, colony size, moisture supply, palatability of the bait matrix used, number and distance between in-ground bait stations, and whether above-ground bait stations were utilized directly on active termite shelter tubes or in carton material in aerial nests.

One of the major advantages of the baiting system approach is the capability of reducing populations of subterranean termites, with the possibility of suppressing or eliminating termite colonies (Lax and Osbrink 2003). Some of the major disadvantages of the baiting system approach are the time and effort required in the "active" treatment regime; this approach has always been very labor-intensive, and must be continuously monitored and maintained in order to perpetuate an area that is free of termites (Potter 2004, Su and Scheffrahn 1998).

Three commercial termite baiting systems were available at the onset of this study, and were evaluated. The Sentricon® system (Getty et al. 2000; Haagsma and Bean 1998; Sheets et al. 2000; Su 1994; Su and Scheffrahn 1993, 1996b) utilizes hexaflumuron. The First Line® system and the Terminate® system both contain sulfluramid (Ballard 1997, Ballard and Lewis 2000, Lewis et al. 1998, Potter 1997). Claims were made that these three baiting systems were effective in reducing termite populations and protecting structures from termite infestations. The Sentricon® system makes the claim of "colony elimination." This evaluation was initiated in order to determine and quantify the efficacy of the three available termite bait systems under diverse, "actual use" conditions.

Materials and Methods

Candidate structures with active infestations of Eastern subterranean termites, *R. flavipes*, were selected for treatment. Cooperating pest management companies were hired to install and monitor the termite baiting systems. Each company or certified applicator had the required licenses, certifications, authorization, and training necessary to participate in the research project. All baiting systems and active ingredients were provided through commercial vendors or manufacturers.

Three commercial termite baiting systems were used in the evaluation. The FirstLine® system, manufactured by FMC Corporation, used the active ingredient: N-ethylperfluoro-octane-1-sulfonamide, or sulfluramid (0.01%). The Sentricon® system, manufactured by Dow AgroSciences, utilized the active ingredient: 1-[3,5-dichloro-4-(1,1,2,2-tetrafluoroethoxy)phenyl]-3-=(2,6-difluorobenzoyl)urea, or hexaflumuron (0.5%), a chitin synthesis inhibitor. The Terminate® system, manufactured by United Industries, Inc. also contains the active ingredient sulfluramid (0.01%). Label instructions for both the FirstLine® and Terminate® systems required a spot-treatment with termiticide for any active termite infestation site.

There was a marked diversity in the size of the in-ground bait stations utilized in the termite baiting systems, although all were plastic cylinders. The FirstLine® bait station was 20.5 cm long by 5.0 cm diam, with a Smartdisc® cap footprint of 18.0 cm, and had rows of 3 mm holes drilled through the cylinder in order for termites to gain access or entry into the interior of the station (Fig. 1a). The Sentricon® bait station was 23.0 cm long by 5.5 cm diam, with a cap footprint of 15.5 cm, and exhibited rows of 4 by 22 mm rectangular slits in the plastic cylinder for termite access (Fig. 1b). The Terminate® bait station was 11.0 cm long by 3.0 cm diam with no extended cap as part of the bait station construction, and rows of 2.5 mm holes drilled through the cylinder for termite access (Fig. 1c).

1a.
FirstLine®
bait station

1b.
Sentricon®
bait station

1c.
Terminate®
bait station

Fig.1. Commercial termite bait stations used in efficacy evaluation.

Termite baiting systems were installed around the perimeter of each of the infested structures, according to label instructions. This entailed drilling the appropriate size diameter hole in the soil for each style bait station at approximately three-meter intervals around the perimeter and placing the in-ground stations into the holes, flush with the top of the lawn or turf. Appropriate spot treatments with a permethrin termiticide were made as required at structures chosen to utilize baiting systems with the active ingredient, sulfluramid. The FirstLine® system and the Sentricon® system utilized wooden monitors that were inspected on a monthly basis until termite activity was observed in the station. When termites were observed in the FirstLine® bait station, the entire station was pulled out of the ground, and a substitute station that contained the active ingredient was inserted into the existing hole. The top of the active ingredient station was permanently closed in order to maintain a tamper-resistant status. When termites were observed in the two wooden monitor slats in the Sentricon® bait station, the top of the station was removed utilizing a special key tool, the two slats were removed from the station, and an active ingredient tube was inserted in order to make the bait-toxicant available to the termite colony, then the top was re-inserted and tightened. The Terminate® system did not utilize a monitoring step prior to placement of bait toxicant; active ingredient was present in a cardboard matrix in all bait tubes placed around a structure, and the top was permanently sealed in order to maintain a tamper-resistant status.

Fifteen (15) structures infested with *R. flavipes*, in each of five (5) urban areas in Texas were selected for treatment with the commercially-available termite baiting systems. In each of the five cities, five structures were treated, with each of the three termite bait systems assigned randomly. Each structure was considered a replication of a treatment in each of the test sites. A total of 75 structures were included in this portion of the study, with 25 structures used with each of the three baiting systems. The urban areas selected for the study in Texas were: Austin, Beaumont, Corpus Christi, Houston, and San Antonio, representing a diverse cross-section of soil type and climatic conditions in Texas.

The commercial pest control companies participating in this study were provided with the termite baiting systems. They were required to cooperate with the manufacturers providing the baits and to install and monitor the baiting systems as required by the label and training provided by manufacturers of the systems. This study was conducted for two years. An annual inspection of each structure was performed to determine the effectiveness of the baiting systems in the management of subterranean termites. Supplemental monitoring stations were also established around the perimeter of each study site. These monitoring stations were used to confirm the presence or absence of foraging termites through time. These stations consisted of 4 x 4 x 15.5 cm pine stakes with a 20 mm hole drilled completely through the long axis of the stake. Regularly spaced 4 mm holes were also drilled into each of the four sides of the stake to intersect with the center hole. The top hole was closed with a #3 rubber stopper, which was removed to monitor termite activity in the station.

Results of monitoring of termite activity, active ingredient consumption, and structural inspections were used to determine “control” or management of subterranean termites populations. The efficacy of the termite baiting system for the respective test sites were ultimately determined by the presence or absence of termites in bait stations, supplemental monitoring stations, or in the structures, as well as any swarming of alates from the structures. Termite baiting systems require foraging termites to locate monitors of monitored systems and subsequently feed on the active ingredient, or feed directly on active ingredient bait tubes as in the Terminate® system. Hence, some variable time period for subterranean termites to locate the bait stations was required. A shorter period of time for this discovery should hasten the management effort, while a longer period of time would inhibit it. Uptake and processing of active ingredient is required for control, and the number of days between installation of the systems and the first observed termite activity could be used as one gauge of the efficacy of the individual systems.

In the vernacular of the pest control industry, this termite activity on monitoring stations came to be called “hits” on the stations (Potter 2004). Some protested this simplified “terminology” and requested that a more cosmopolitan and descriptive vocabulary be instituted (Robinson 1996). In response, termite foraging activity observed on termite baiting system stations was given the expression “tamu” (Glenn and Gold 2002). This was based on the Indonesian word for “visitor” or “tourist” and was deemed appropriate, as the foraging termites are visitors to the bait stations in their search for cellulose food sources. Additionally, the letters constituting “tamu” could also be considered an acronym for “termite activity on monitors underground,” which is also appropriate as all termite baiting systems being sold to the pest control industry are comprised of in-ground bait stations, while some systems also offer above-ground bait stations. All three termite baiting systems used in this study have in-ground bait stations, and the Sentricon® system also has above-ground bait stations.

Observations were made and recorded by the cooperating pest control company specialists as they monitored termite bait stations placed around the infested structures. It was impossible to start all 75 treatments on the same day, and as a result, start times were variable. All termite bait stations were monitored around each structure on a monthly basis, and active ingredient was added at all stations with termite activity on monitored stations, or recorded on those stations (Terminate®) already containing active ingredients.

Results

The time-lines for the three termite baiting systems used in the study reveal a wide variation in observed termite activity, in agreement with comments made by Potter (2004). All three baiting systems exhibited “tamu” in at least one study site within 35 days. All three baiting systems also exhibited study sites without any termite activity for an extended period of time. The Terminate® system exhibited one or more sites without any termite activity for over 300 days and the Sentricon® system and the FirstLine® system exhibited one or more sites without any termite activity for over 500 days. There were 8 of the 25 sites treated with the FirstLine® system that never exhibited termite activity on any of the bait stations at those particular sites. Three of the 25 sites treated with the Sentricon® system never exhibited termite activity on any of the bait stations at those particular sites. Only the Terminate® system exhibited 25 of the 25 sites treated with some termite activity on at least one bait station at the study sites despite this bait station’s small diameter and length. It is important to note that this particular bait station was the only one that used a cardboard matrix, rather than wood, for monitoring material. This may have had some influence on the termite activity on these particular bait stations despite their relatively small size. Experience has shown that cardboard is a favorite food choice of subterranean termites when used in bucket traps for the collection process of bringing termites into the laboratory for bioassay use.

There was a wide range in the number of alternating episodes of monitoring and feeding observed at the bait stations. Some study sites had only the lengthy monitoring period, described above, while another exhibited 14 alternating episodes of monitoring and feeding during the 2 yr study period. These observations of termite activity by *R. flavipes* are illustrated as time-lines for each of the termite baiting systems evaluated in Figs. 2, 3, and 4. When comparing these alternating episodes of monitoring and feeding, however, no significant differences were observed between the three termite baiting systems (P = 0.576). The low number of episodes of monitoring and feeding in Corpus Christi, when compared to the high number of episodes in Beaumont, was significantly different (P = 0.028). There were no other significant differences when comparing the other city sites.

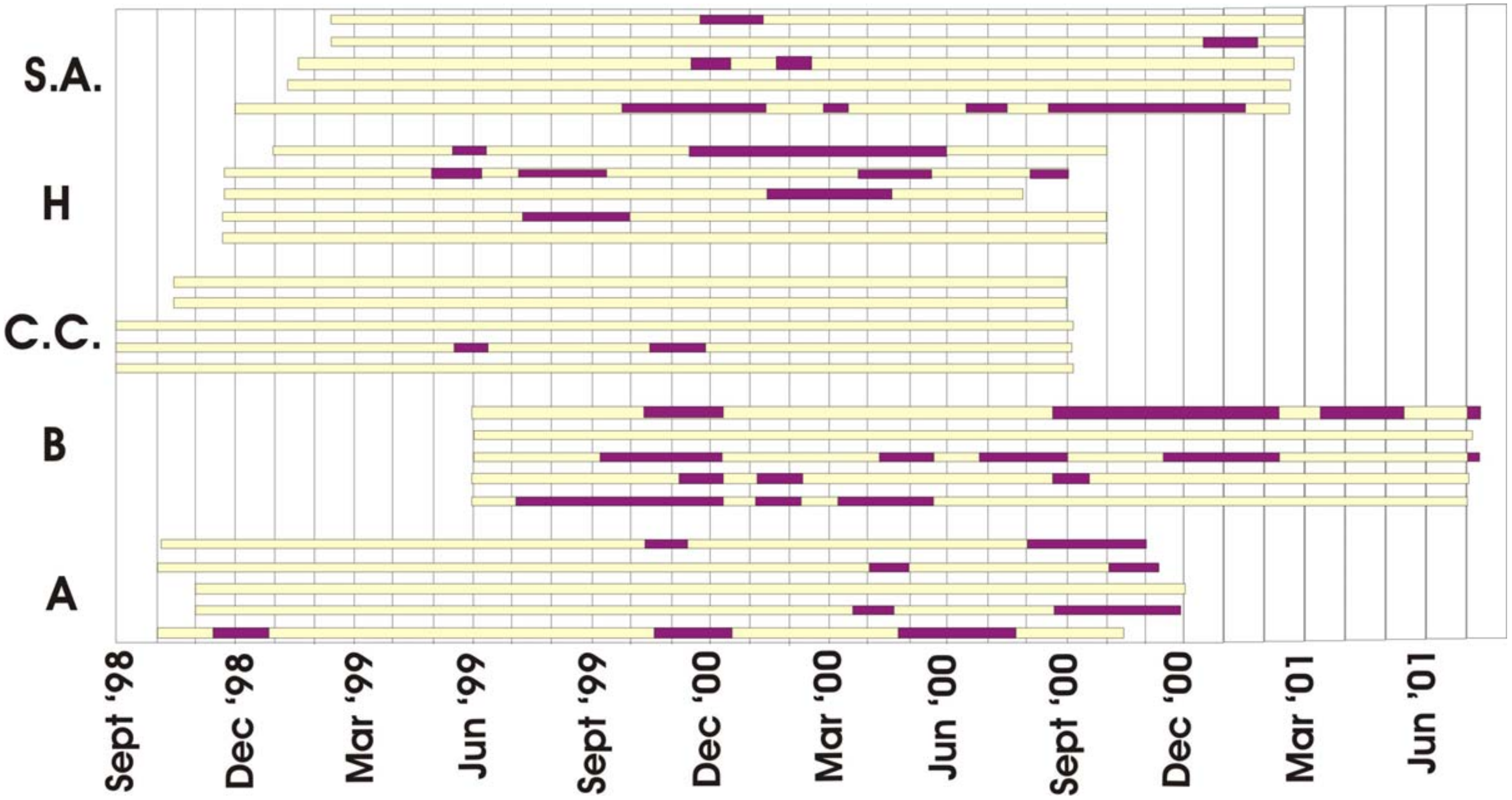


Fig. 2. FirstLine® baiting system time-line for *R. flavipes* with monitoring period (yellow) and active ingredient placement (maroon). (A: Austin, B: Beaumont, C.C.: Corpus Christi, H: Houston, S.A.: San Antonio)

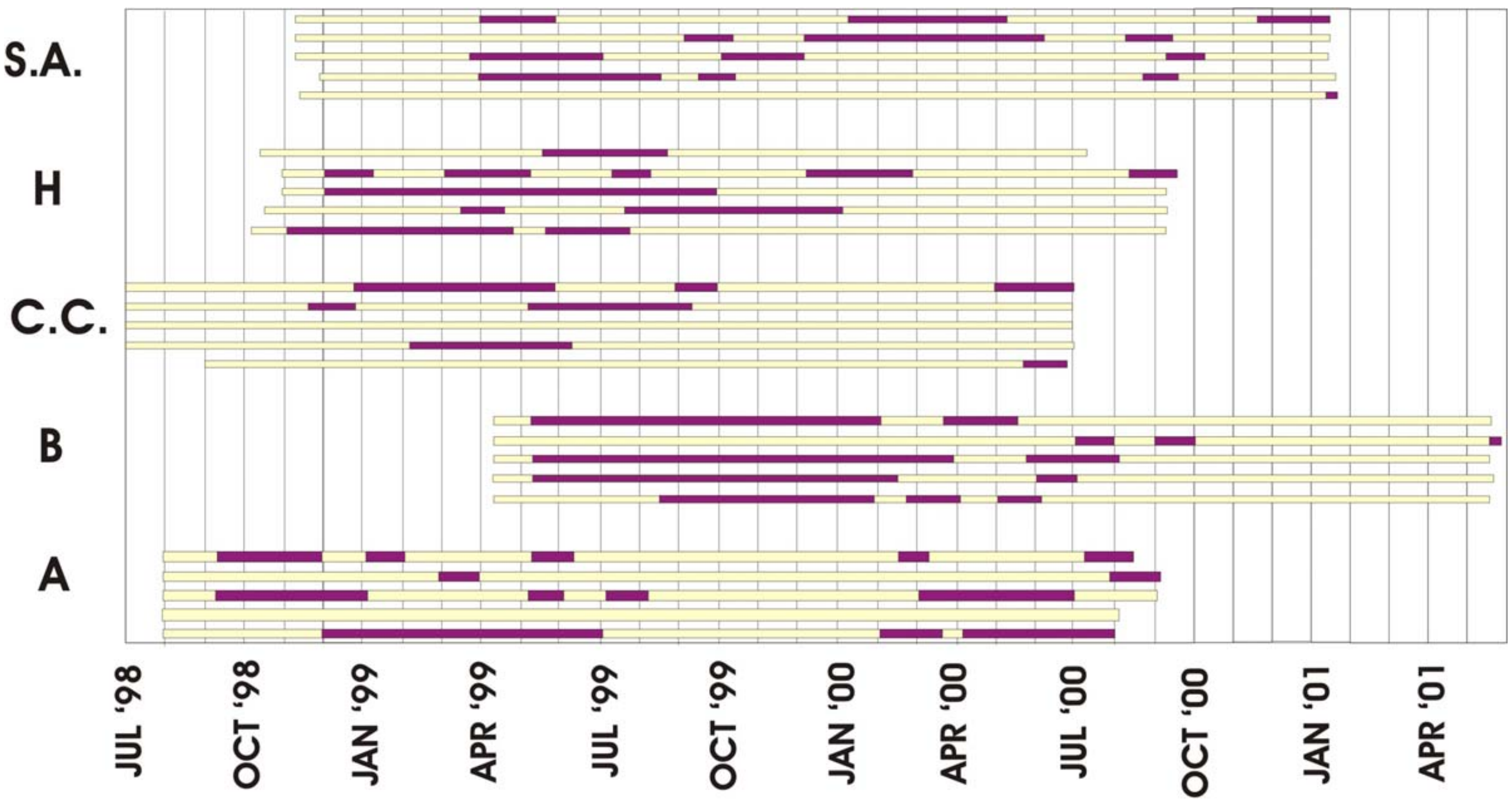


Fig. 3. Sentricon® baiting system time-line for *R. flavipes* with monitoring period (yellow) and active ingredient placement (maroon). (A: Austin, B: Beaumont, C.C.: Corpus Christi, H: Houston, S.A.: San Antonio)

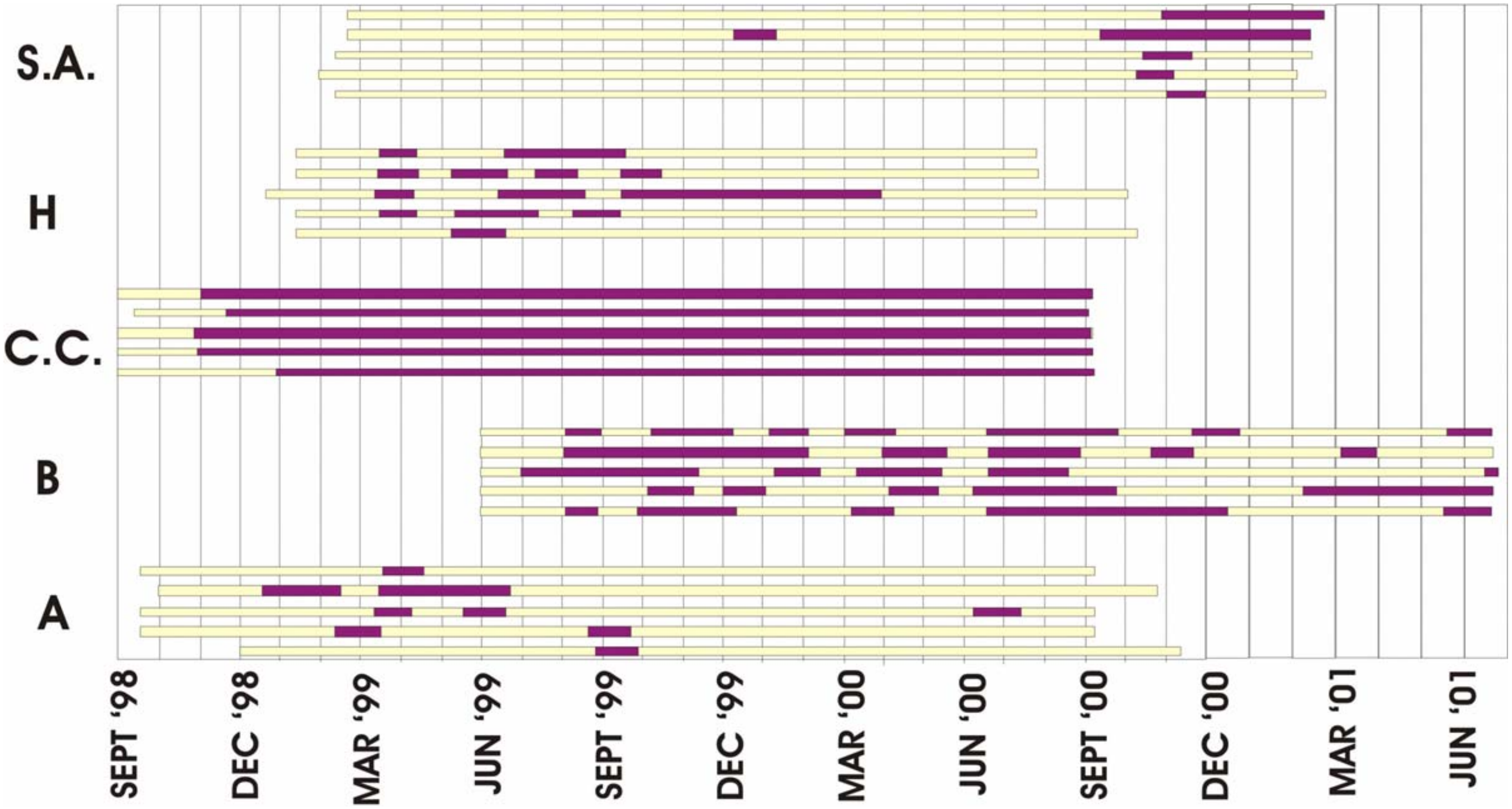


Fig. 4. Terminate® baiting system time-line for *R. flavipes* with monitoring period (yellow) and active ingredient placement (maroon). (A: Austin, B: Beaumont, C.C.: Corpus Christi, H: Houston, S.A.: San Antonio)

The range of activity of *R. flavipes* on the FirstLine® system (Table 1) was between 35 and 661 days to first “tamu” with a mean of 272.2 days. Each city had at least one study site without any “tamu” and in Corpus Christi, four of the five structures revealed no activity.

Table 1. Activity by *R. flavipes* on the FirstLine® baiting system.[1]

Sites	Days to first “tamu”	“tamu”	Mean ± SE
Austin	75, 367, 500, 540	4/5	370.5 ± 105.2
Beaumont	35, 96, 131, 159	4/5	105.3 ± 26.7
Corpus Christi	258	1/5	258.0
Houston	136, 157, 228, 413	4/5	233.5 ± 63.0
San Antonio	281, 293, 298, 661	4/5	383.3 ± 92.7
Cumulative	Range: 35-661	17/25	272.2 ± 42.8

[1] Results on sites with “tamu” (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

Activity by *R. flavipes* on the Sentricon® system (Table 2) was between 28- 622 days to first “tamu” with a mean of 153.0 days. Only three of the 25 study sites had no termite activity; one in Austin, one in Corpus Christi, and one in San Antonio. Activity by *R. flavipes* on the Terminate® system (Table 3) was between 30 and 618 days, with a mean of 185.5 days, with 100% of all sites exhibiting “tamu” on bait stations.

Table 2. Activity by *R. flavipes* on the Sentricon® baiting system.[1]

Sites	Days to first "tamu"	"tamu"	Mean ± SE
Austin	42, 42, 120, 210	4/5	103.5 ± 39.9
Beaumont	29, 29, 30, 127, 441	5/5	131.2 ± 79.7
Houston	28, 32, 32, 148, 216	5/5	91.2 ± 38.6
San Antonio	120, 134, 140, 295	4/5	172.3 ± 41.1
Cumulative	Range: 28-622	22/25	153.0 ± 31.3

[1] Results on sites with "tamu" (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

Table 3. Activity by *R. flavipes* on the Terminate® baiting system.[1]

Sites	Days to first "tamu"	"tamu"	Mean ± SE
Austin	77, 145, 174, 181, 265	5/5	168.4 ± 30.4
Beaumont	30, 62, 62, 62, 125	5/5	68.2 ± 15.5
Corpus Christi	57, 57, 63, 68, 118	5/5	72.6 ± 11.5
Houston	60, 60, 60, 81, 116	5/5	75.4 ± 10.9
San Antonio	287, 601, 606, 609, 618	5/5	544.2 ± 64.4
Cumulative	Range: 30-618	25/25	185.5 ± 39.8

[1] Results on sites with "tamu" (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

The range of termite activity by *R. flavipes* on all three baiting systems was remarkably similar, from 35, 28, and 30 days, to 661, 622, and 618 days, for FirstLine®, Sentricon®, and Terminate®, respectively (Table 4) at those sites where termite activity occurred. There were no significant differences in this characteristic between baiting systems ($P < 0.05$). There were significant differences between mean values of the number of days to first "tamu" when comparing the three baiting systems. The higher mean number of days to first "tamu" in the FirstLine® system at 272.2 days, were significantly different from those of the other two systems, when comparing Sentricon® at 153.0 days ($P = 0.002$) and Terminate® at 185.5 days ($P = 0.014$) using One Way Repeated Measures Analysis of Variance (Tukey's Test).

Table 4. Summary of *R. flavipes* activity by termite baiting system, all systems.[1]

Baiting System	Range of days to first "tamu"	"tamu"	Mean ± SE
FirstLine®	626/ (35-661)	17/25	272.2 ± 42.8
Sentricon®	594/ (28-622)	22/25	153.0 ± 31.3
Terminate®	588/ (30-618)	25/25	185.8 ± 39.8
Cumulative	633/ (28-661)	64/75	197.5 ± 22.5

[1] Results on sites with "tamu" (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

Many of the study sites required spot treatments with termiticides, subsequent to the spot treatments required by label instructions for the FirstLine® and Terminate® baiting systems, which required these spot treatments in all of the study sites, initially. Any new signs of termite infestations that occurred during the duration of the study required multiple re-treatments with termiticides (Table 5).

Table 5. Subsequent termiticide spot treatments required, *R. flavipes*.

Sites	FirstLine®	Sentricon®	Terminate®
Austin	0	0	1
Beaumont	2	1	13
Corpus Christi	1	1	4
Houston	1	0	2
San Antonio	3	0	2
Cumulative	7*	2	22*

*In addition to initial spot treatments of structures, required by label.

Observations of termite activity on monitors was an important factor in the consideration of a termite baiting system’s efficacy, but the real test of a baiting system for the pest management of subterranean termites has to be whether a structure was protected from infestation and damage. Five of the 25 structures treated with FirstLine® continued to have an infestation of termites at the end of the study (Table 6). One was in

Beaumont and four were in Houston. Three of the 25 structures treated with Sentricon® continued to have an infestation of termites at the end of the study; these were the same three structures without active ingredient consumption. Two were in Corpus Christi and one was in San Antonio. Four of the 25 structures treated with Terminate® continued to have an infestation of termites at the end of the study. One was in Beaumont, two were in Houston, and one was in San Antonio.

Table 6. Summary of results of termite control with termite baiting systems, all systems, *R. flavipes*.

	FirstLine®	Sentricon®	Terminate®
Structures without A. I. consumption	8/25 (0.32)	3/25 (0.12)	0/25 (0.00)
Structures with A. I. consumption	17/25 (0.68)	22/25 (0.88)	25/25 (1.00)
Structures with termites at end of study:	5/25 (0.20)	3/25 (0.12)	4/25 (0.16)
Austin	0	0	0
Beaumont	1	0	1
Corpus Christi	0	2	0
Houston	4	0	2
San Antonio	0	1	1
Structure without termites at end of study:	20/25 (0.80)**a**	22/25 (0.88)**a**	21/25 (0.84)**a**

a = no significant difference

At the end of the study, 80.0% of structures treated with FirstLine® and spot treatments with Permethrin did not have termites. Of the Sentricon® treated structures, 88.0% did not have termites, and 84.0% of the structures treated with Terminate® and spot treatments with Permethrin did not have termites. There was a cumulative mean value of 63 out of the 75 structures without termites at the end of the study, or 84.0%, among all treatments using the three termite baiting system regimes.

Discussion

Observations of the time-lines and tables of the three baiting systems illustrate the wide variance in the days to first "tamu" for termite baiting systems. Overall, for all structures and all systems in the study, this ranged from 28 to 661 days. The time required for foraging *R. flavipes* to locate and begin feeding on both the Sentricon® and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system. Wide variance was exhibited in the alternating episodes of monitoring and active ingredient consumption, up to 14 episodes when treating with the Terminate® baiting system.

There were no significant differences in the treatments of structures with the three termite baiting system systems, with 80.0%, 88.0%, and 84.0% of the structures without termite infestations, at the end of the study, for FirstLine®, Sentricon®, and Terminate® baiting systems, respectively. It is noteworthy that the baiting systems containing sulfluramid required spot treatments with termiticides, in addition to the baiting regime, for all active termite infestations discovered. With this additional treatment, these baiting systems did not produce inferior or superior results. Several of these study sites also required subsequent spot treatments with termiticide in order to maintain protection of the structures, with up to 22 spot treatments made on structures baited with Terminate® (Table 5). The three structures with no active ingredient consumption with the Sentricon® treatments were the three of 25 study sites that continued to have termite infestations (12.0%).

Conclusion

There is evidence that, in a limited number of cases, termite baiting systems can control *R. flavipes* populations. When comparing efficacy results of termite control in this evaluation, there were no significant differences between the three termite baiting systems used in the study. The limitations of the time factors and probability theory relating to a multi-step process like a termite baiting system discussed previously in Chapter I must be addressed. Each stage was dependent on the results of the previous stage, with many opportunities for failure in the multi-step management strategy (Ott and Longnecker 2001). The time required for foraging termites to locate the bait stations, consume sufficient active ingredient, and share with nestmates through trophallaxis in order to control termite populations was widely variable, and this can obviously be problematic in the management of termite populations. This time factor is in stark contrast to traditional liquid termiticide treatments applied as a barrier to subterranean termite populations. Protection is afforded immediately after treatment. Protection against termites utilizing a baiting system occurs only if and when sufficient active ingredient is consumed and shared among nestmates in a colony; this may take months, years, or may never occur in those instances where active ingredient was never consumed.

The use of a termite baiting system is also both time and labor intensive for the pest management specialists utilizing them, with the corresponding economic costs associated with these factors. In addition to efficacy issues, pest management company owners must examine and analyze the cost/benefit ratio of using termite baiting systems as an “active” treatment strategy for termite control over a period of time in order to determine profitability and efficacy. All of these factors have influenced many pest management specialists to move away from termite baiting systems as treatment tools, and to return to traditional termiticide barrier treatments for the protection of structures. Termite baiting system treatments are still viable options in situations where there is societal or environmental restrictions to the use of conventional termiticide treatments, or when based on consumer request for this treatment strategy.

CHAPTER III

EVALUATION OF EFFICACY OF COMMERCIAL TERMITE BAITING SYSTEMS FOR PEST MANAGEMENT OF THE FORMOSAN SUBTERRANEAN TERMITE, *Coptotermes formosanus* Shiraki

Introduction

There is much to learn about the biological and behavioral differences between *R. flavipes* and *C. formosanus* termites. Any variability could affect the success or failure of a control program (Cornelius and Osbrink 2001, Lax and Osbrink 2003). Differences in foraging behavior, colony expansion and fragmentation, food preference, or trophallaxis frequency would influence a termite management strategy, including one involving baiting systems (Traniello and Thorne 1994). This portion of the study examined any significant differences in the efficacy of the three termite baiting systems acting on *C. formosanus* as opposed to *R. flavipes*.

Current subterranean termite management strategies have turned toward baiting system technologies (Traniello and Thorne 1994) utilizing chitin synthesis inhibitors (hexaflumuron and diflubenzuron) or slow-acting stomach poisons (sulfluramid) as active ingredients (Getty et al. 2000, Pawson and Gold 1996, Sheets et al. 2000, Su 1991, 1994). The objective of a termite baiting system is to protect a structure through the management of termite populations. This is accomplished through the distribution of a toxicant or inhibitor into a colony within a palatable food (cellulose) substrate (Grace et al. 1996; Thorne and Forschler 1998). The strategy relies on the foraging activity of the pseudergates (workers) to gather and introduce this material into the social fabric of a colony in its subterranean milieu where it would be shared through trophallaxis and subsequently kill or inhibit the normal development and metamorphosis of colony members (Potter 1997, Su and Scheffrahn 1996a). The ultimate goal of this subterfuge tactic is population reduction and the eventual collapse and death of the colony.

The previously discussed active ingredients used in baiting systems have been investigated through laboratory and field bioassays to determine their efficacy against subterranean termite populations (Forschler and Chiao 1998, Rojas and Morales-Ramos 2001, Su et al. 1995, 2004). Several termite baiting systems utilizing these ingredients are being marketed to pest control companies or directly to the public as a means to achieve management of subterranean termites (Ballard and Lewis 2000). Comparisons of effectiveness of these different termite baiting systems under actual use situations are generally lacking. This is particularly true for the active ingredient, sulfluramid. It is currently marketed as the active ingredient in two different termite baiting systems. The objective of this evaluation was the investigation of effectiveness of available termite baiting systems as a pest management strategy in structures infested with Formosan subterranean termites, *Coptotermes formosanus* Shiraki.

The Formosan subterranean termite is an invasive species into the U.S., and its unintentional introduction and subsequent spread (Bennett et al. 1997, Howell et al. 2001, Su and Scheffrahn 1988) has created concern for many people with vulnerable structures and vegetation. This species of termite has spread rapidly in Texas, primarily through the human movement of infested cellulose materials, such as recycled railroad ties used in landscaping, pallets used in moving various articles, and timbers and lumber used in the construction industry. Formosan subterranean termite infestations have been confirmed in 22 counties of Texas by 2005 (Fig. 5). The disparate locations of these infestations are indicative of human or commercial movement, rather than a progressive expansion that would be attributable to normal swarming of reproductives of the species. Of the 22 counties in Texas with confirmed infestations of Formosan termites, 11 have been added in the last five years (Table 7). The large population size of the colonies, aggressive nature, and the ability to form aerial nests of "carton" material with no connection to the ground has led to the well-deserved destructive reputation of the species, particularly in southern coastal regions, where they cause serious damage in a relatively short period of time (Cornelius and Osbrink 2001, Jones and Howell 2000). Because of its destructive capability, this target pest was chosen as the most severe test of efficacy of termite baiting systems.

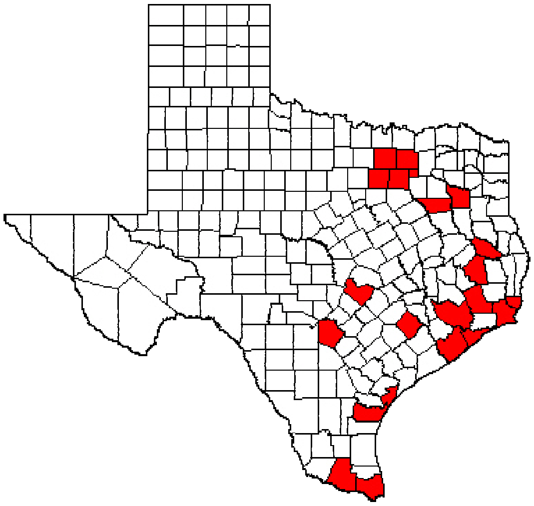


Fig. 5. Texas counties with confirmed infestations of *C. formosanus* (2005).

Table 7. Texas counties/(cities) with confirmed infestations of *C. formosanus* [counties confirmed in the last five years of discovery survey are footnoted].

Counties	(Cities)
Angelina (Lufkin)	Henderson (Athens)˜
Aransas (Rockport)	Hidalgo (McAllen)
Bexar (San Antonio)°	Jefferson (Beaumont)
Brazoria (Alvin)*	Liberty (Liberty)^
Cameron (Harlingen)+	Nueces (Corpus Christi)°
Collin (Wylie)˜	Orange (Orange)
Colorado (Altair)+	Polk (Onalaska)+
Dallas (Garland)	Rockwall (Rockwall)*
Denton (Denton)	Smith (Tyler)^
Galveston (Galveston)	Tarrant (Ft. Worth)
Harris (Houston)	Travis (Austin, Lakeway)

^Year 2000
°Year 2001
˜Year 2002
*Year 2003
+Year 2004/2005

Materials and Methods

Candidate structures with active infestations of Formosan subterranean termites were selected for treatment. Cooperating pest control companies were hired to install and monitor the termite baiting systems under the supervision of Department of Entomology staff. Each had the required licenses, certifications, authorization, and necessary training to participate in the evaluation and utilize the commercial baiting systems evaluated. Termite baiting systems were provided through commercial vendors or manufacturers, and all installations and inspections followed the manufacturer's label directions and instructions.

Three commercial baiting systems were available at the onset of the evaluation. The Sentricon® system, manufactured by Dow AgroSciences, utilized the bait-toxicant, hexaflumuron (0.5%), a chitin synthesis inhibitor (Getty 2000, Su and Scheffrahn 1996b). The FirstLine® system, manufactured by FMC Corporation, and the Terminate® system, manufactured by United Industries, Inc., both contained N-ethylperfluoro-octane-1-sulfonamide, [sulfluramid (0.01%)], a slow-acting stomach poison (Ballard and Lewis, 2000). Detailed physical descriptions and images of these baiting system stations were provided in Chapter I. Label instructions for both of these sulfluramid-containing bait systems required a spot-treatment with termiticides for any active termite infestation. Termite baiting systems were installed around the perimeter of each of the infested structures, according to label instructions. Appropriate spot treatments (permethrin termiticide) were made as required at structures chosen to utilize baiting systems with the active ingredient, sulfluramid. The Sentricon® system and the FirstLine® system utilized wooden monitors that were examined on a monthly basis until termite feeding activity was revealed, at which time an active ingredient tube was inserted in order to make the bait-toxicant available to the termite colony. The Terminate® system did not utilize a monitoring step prior to placement of bait toxicant; active ingredient was present in a cardboard matrix in all bait tubes placed around a structure.

A total of 30 structures infested with *C. formosanus* were selected, with 15 structures in each of the two major areas of infestation in Texas (Galveston/Texas City/La Porte area and Beaumont/Port Arthur/Orange area). Five structures were treated with each of the three baiting systems in each area. The evaluation had a two-year time-line, and pest management specialists, accompanied by Department of Entomology staff, also performed an annual inspection of each structure. Supplemental monitoring stations were also used to confirm the presence or absence of foraging termites through time. These stations consisted of 4 x 4 x 15.5 cm pine stakes with a 20 mm hole drilled through the length of the long axis of the stake. Regularly spaced 4 mm holes were also drilled into each of the four sides of the stake to connect with the larger hole, which allowed subterranean termite’s access to the center cavity. The top hole was closed with a #3 rubber stopper, which was removed in order to monitor termite activity in the station.

Results from termite baiting system activity, monitoring, bait-toxicant consumption, and structural inspections were utilized to determine efficacy or “control” of termites. The number of days between the installation of the baiting systems and the first “tamu” (termite activity on monitors underground) were recorded for each structure. Presence or absence of termites in baiting systems, supplemental monitoring stations, or in structures, and reproductive swarming were considered in the determination of efficacy against the termites for each test site. Observations were also made of any differences in the methods of application or monitoring utilized by pest control company personnel.

Observations were made and recorded by the cooperating pest management specialists as they monitored termite bait stations placed around the infested structures. The period of time for “monitoring” of bait stations prior to any “tamu” on the bait stations by termites, and the number of days of active feeding on the active ingredient were recorded to ascertain the interaction of termites and the bait systems surrounding the infested structures.

Comparisons of days to first termite activity observed on monitors for each of the termite bait systems at all sites were performed using a nonparametric Kruskal-Wallis analysis of variance (ANOVA on Ranks). An All Pairwise Multiple Comparison Procedure (Dunn's Method) differentiated the significantly different treatment. All data were analyzed using SPSS (1997).

Results were analyzed to determine any significant differences in foraging behavior or efficacy between *R. flavipes* and *C. formosanus* utilizing the three termite baiting systems. Observations were also be made by cooperating pest management specialists and by Entomology Department personnel of any differences in the methods of application in the baiting system methodology required for pest management of the two different species of termites.

Results

Results of the evaluation revealed numbers of days for first feeding of *C. formosanus* on monitors in monitored systems or active ingredient bait tubes in non-monitored systems comprised an extremely wide range. All three baiting systems had termite activity in at least one bait station in at least one study site within 61 days. There were also examples for each of the three baiting systems where there was no termite activity in the bait stations for an extended period of time. The Sentricon® system had at least one site without any termite activity for over 350 days and both the FirstLine® and Terminate® systems had one or more study sites that exhibited over 700 days without any termite activity in the bait stations.

Results of the evaluation reveal mean numbers of days for first feeding of *C. formosanus* on monitors, in monitored systems, or active ingredient bait tubes in non-monitored systems, with an extremely wide range. There was no discernible pattern of control with either of the sulfluramid baiting systems; termite management at those sites relied on spot treatments with liquid termiticides. Rather than constituting a comparison between termite baiting systems, methodologies used by the two pest management specialists for the Sentricon® baiting system were drastically different, and the subsequent efficacy results were significantly different between the two test sites. In the La Porte, Texas area, 100% control was achieved with the baiting system, without a termiticide spot treatment, and continued to exhibit control for an extended period of time. An aggressively active management program involving the utilization of multiple supplementary in-ground bait stations, above-ground bait stations, and biweekly monitoring contrasts sharply with the traditional termite baiting program and corresponding reduced efficacy results in the Beaumont, Texas area. These observations of termite activity at test sites with *C. formosanus* infestations are illustrated as time-lines for each of the termite baiting systems evaluated in Figs. 6, 7, and 8. Termite activity on the bait stations was observed at eight of the 10 structures treated with the FirstLine® system, at all 10 structures treated with the Sentricon® system, and at nine of the 10 structures treated with the Terminate® system over the two-year time period of the evaluation. The monitoring period is represented as yellow and the period of active ingredient placement is represented as maroon in the time-line bar graphs for each termite baiting system.

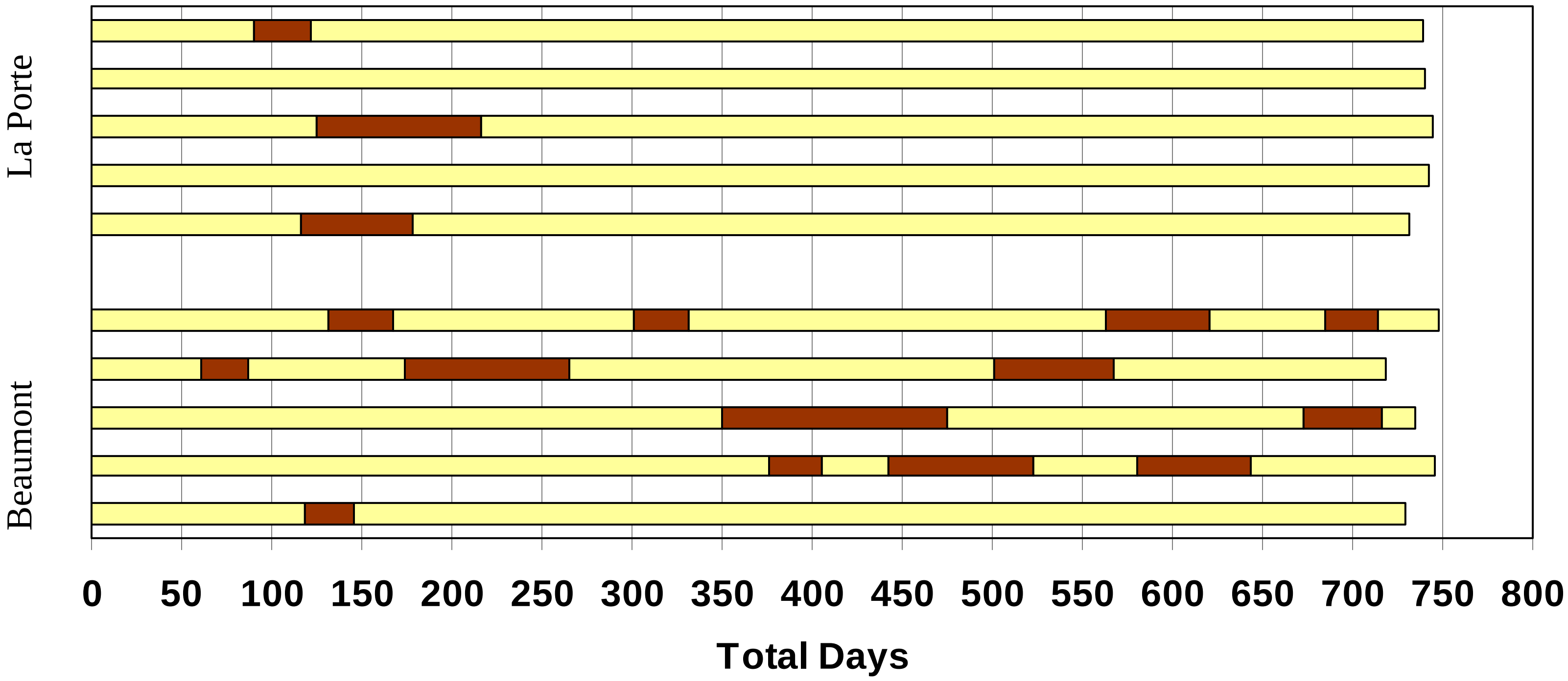


Fig. 6. FirstLine® baiting system time-line for *C. formosanus* with monitoring period (yellow) and active ingredient placement (maroon).

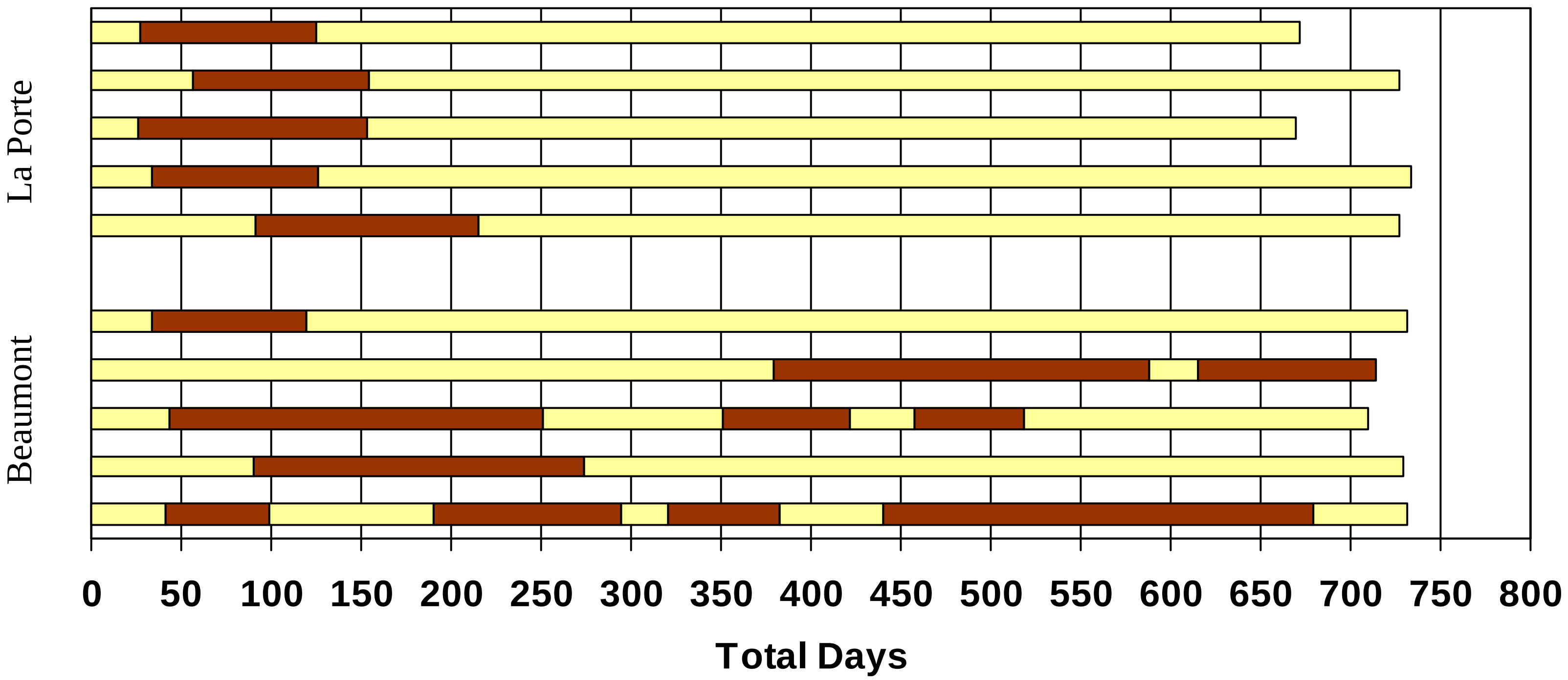


Fig. 7. Sentricon® baiting system time-line for *C. formosanus* with monitoring period (yellow) and active ingredient placement (maroon).

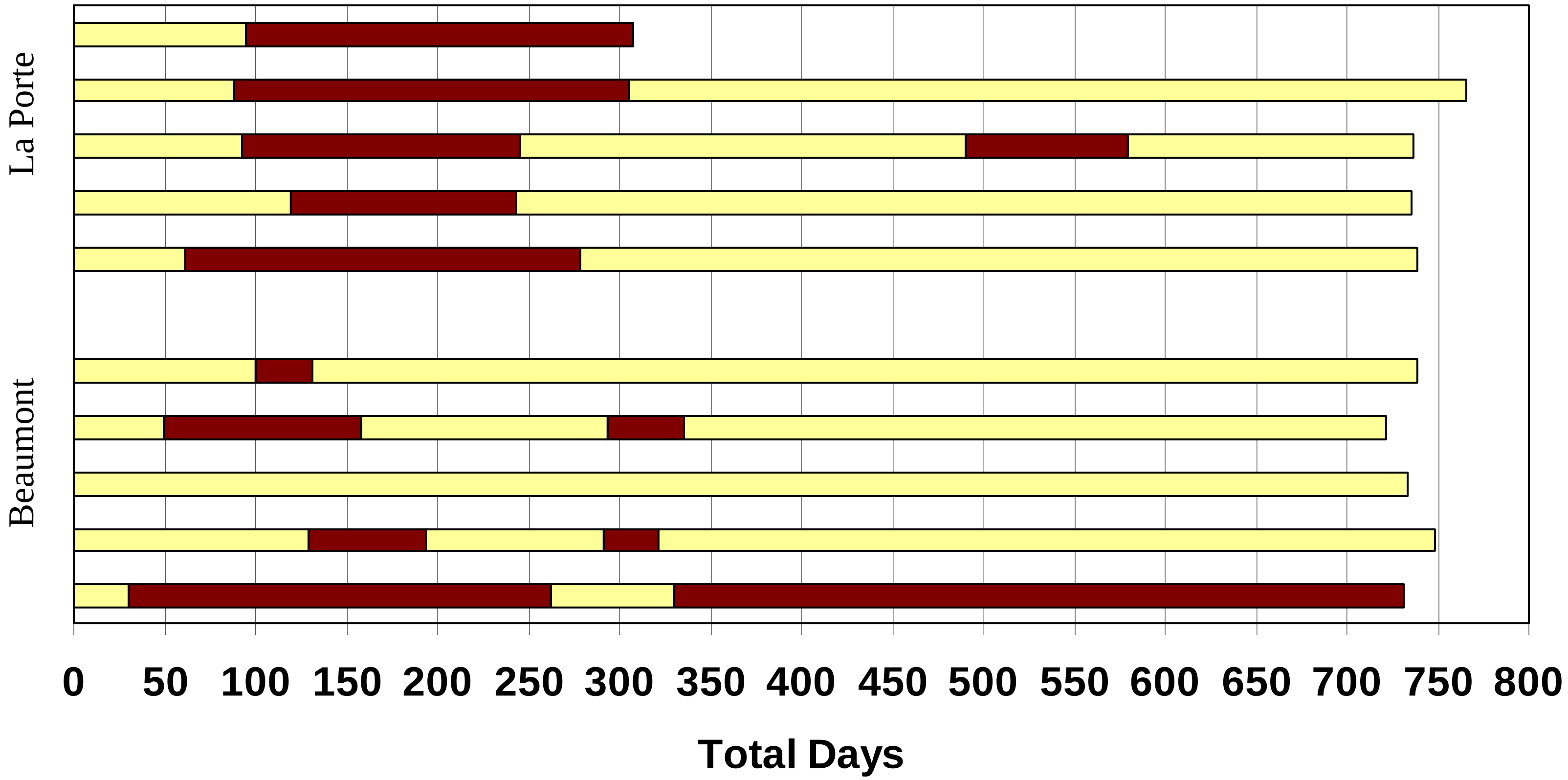


Fig. 8. Terminate® baiting system time-line for *C.* formosanus with monitoring period (yellow) and active ingredient placement (maroon).

The number of days to first “tamu” by termites, on any one of the bait stations installed around the perimeter of the structures, for all bait systems, ranged from a low of 26 days to a high of 379 days (Tables 8, 9, and 10, respectively). There was no significant difference between groups when comparing (t-test) days to first “tamu” data from the two sites for each baiting system (P = 0.307, 0.325, and 0.555, respectively for FirstLine®, Sentricon®, and Terminate®). When comparing the number of days to first tamu in the three baiting systems at all sites; there was a significant difference (Kruskal-Wallis test: H = 8.638, df = 2, P = 0.013) between the FirstLine® and the Sentricon® system treatments by “All Pairwise Multiple Comparison Procedure (Dunn’s Method).” The mean number of days to first “tamu” for the FirstLine® system was 170.9 ± 42.7, while it was only 82.1 ± 33.8 and 84.8 ± 10.8 for the Sentricon® and Terminate® systems, respectively, at all treatment sites.

Table 8. Activity by *C. formosanus* on the FirstLine® baiting system.[1]

Sites	Days to first “tamu”	“tamu”	Mean ± SE
Beaumont	61, 118, 131, 350, 376	5/5	207.2 ± 64.8
La Porte	90, 116, 125	3/5	110.3 ± 10.5
Cumulative	Range: 61-376	8/10	170.0 ± 42.7

[1] Results on sites with “tamu” (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

Table 9. Activity by *C. formosanus* on the Sentricon® baiting system.[1]

Sites	Days to first "tamu"	"tamu"	Mean ± SE
Beaumont	34, 41, 43, 90, 379	5/5	117.4 ± 66.1
La Porte	26, 27, 34, 56, 91	5/5	46.8 ± 12.3
Cumulative	Range: 26-379	10/10	82.1 ± 33.8

[1] Results on sites with "tamu" (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

Table 10. Activity by *C. formosanus* on the Terminate® baiting system.[1]

Sites	Days to first "tamu"	"tamu"	Mean ± SE
Beaumont	30, 49, 100, 129	4/5	77.0 ± 22.8
La Porte	61, 88, 92, 95, 119	5/5	91.0 ± 9.3
Cumulative	Range: 30-129	9/10	84.8 ± 10.8

[1] Results on sites with "tamu" (termite activity on monitors underground) and A. I. placement; does not include sites without termite activity.

The performance of the two sulfluramid-containing bait systems on *C. formosanus* was low, based in part on the limited amount of the active ingredient that was consumed. Examples of successful pest management and subsequent protection of structures relied on spot treatments with liquid termiticides, which repelled the termites away from one area, often to have them reappear in other locations of the structure at a later date, which was similar to the results of baiting system treatments on *R. flavipes*. Several structures required multiple spot treatments during the two-year evaluation period. These results were similar to that of the previous evaluation of these baiting systems on the Eastern subterranean termite, *R. flavipes*, discussed in Chapter II. In addition, the relatively small Terminate® system bait stations did not contain a sufficient amount of active ingredient impregnated in cardboard to be efficacious as a stand-alone treatment. The bait station was emptied of cardboard and corresponding active ingredient in a short period of time by foraging Formosan subterranean termites, and subsequently abandoned; termites had to be re-recruited to the area after insertion of a substitute or replacement bait station. The pest management specialists also found it very difficult to find the bait stations of this system in any turf areas due to the absence of any expanded top cap, resulting in a small observable “footprint” of the stations.

The most significant observation made during this evaluation was the difference in treatment regime and corresponding results between the two different pest control companies utilizing the Sentricon® system. While both were authorized and trained to use this technology, the regime followed by pest management specialists in the La Porte, Texas area differed markedly from that used by the corresponding specialists in the Beaumont, Texas area. Pest management specialists in the La Porte area utilized what would have to be termed an “aggressive” regime, utilizing many supplementary in-ground bait stations at areas having conditions conducive to subterranean termites (existing cellulose and moisture sources), as well as areas having detected termite activity on existing monitors. They also relied heavily on the placement of above-ground bait stations that were available in this system. They placed multiple units on active shelter tubes, whether on vertical surfaces of walls, slab foundations, or piers, or inside wall voids, after determining the presence of infestation by means of a non-destructive moisture meter and gaining access by means of keyhole saw or removal of wood trim. The treatment regime also involved frequent visits to the bait stations to insure active ingredient availability in the bait stations with termite activity. The visits were never less than every 2 weeks, rather than the monthly visits suggested in the system protocol. The treatment regime by the Beaumont personnel, on the other hand, involved a protocol “by the book” with few supplementary in-ground or above-ground bait stations utilized. Inspections to monitor bait stations and add active ingredient tubes to stations with termite activity were limited to standard monthly visits.

The results of this difference of treatment regime are quite apparent in Figure 7. After early, consistent “tamu” on monitors and heavy feeding of active ingredient at all five sites in La Porte, Texas, *C. formosanus* were not detected again in either the structures or the bait stations for an extended period of time. No liquid termiticide treatments were performed, or required, in any of the five sites treated with this regime in the La Porte, Texas area. The mean values of termite activity for the five structures in Table 11 illustrates the results of this aggressive regime with a very abbreviated (46.8 days) period of time to first “tamu” by foraging termites, followed by 107.8 days of active feeding of the active ingredient in the system, and only 154.6 days between installation of the baiting system to feeding cessation. The mean number of days that elapsed after feeding cessation without any new “tamu” on bait stations, indicative of any subsequent termite activity in or around the test site structures, was 455.6 days for the five structures. In contrast, frequent, alternating periods of "tamu" by *C. formosanus*, followed by periods of inactivity and no consumption of active ingredient in the bait stations were exhibited at three of the five Sentricon® system sites in the Beaumont, Texas area (Fig. 7). Bait stations would frequently "run dry" of active ingredient during the monthly inspection regime and the foragers would abandon the station in their search for cellulose food sources. Termites would then have to be re-recruited to a bait station, which took additional time in the baiting process. At the end of the two-year evaluation period, *C. formosanus* was still active in two of the five structures and in surrounding bait stations in the Beaumont, Texas area.

Table 11. Treatment results of the Sentricon® termite baiting system utilized against *C. formosanus* in the La Porte, Texas area.[1]

Site	Days to first "tamu"	Days feeding on A. I.	Days from installation to cessation of feeding on A. I.
1	91	124	215
2	34	92	126
3	26	127	153
4	56	98	154
5	27	98	125
Mean ± SE	46.8 ± 12.3	107.8 ± 7.3	154.6 ± 16.3

[1] Results on sites with "tamu" (termite activity on monitors underground) and A.I. placement.

A summary comparison of the days to first "tamu," as well as the range of days to first "tamu," for the three termite baiting systems in the study is shown in Table 12. The overall range of days to first “tamu” is extremely large, from 26 to 379 days. This range was noticeably reduced for the Terminate® system at 30-129 days. Three of the study sites did not have termite activity for the duration of the study, two of the FirstLine® and one of the Terminate® baiting system sites.

Table 12. Summary of *C. formosanus* activity; all termite baiting systems.[1]

Baiting System	Range of days to first “tamu”	“tamu”	Mean ± SE
FirstLine®	315 / (61-376)	8/10	170.9 ± 42.7
Sentricon®	353 / (26-379)	10/10	82.1 ± 33.8
Terminate®	99 / (30-129)	9/10	84.8 ± 10.8
Cumulative	353 / (26-379)	27/30	109.3 ± 19.1

[1] Results on sites with “tamu” (termite activity on monitors underground) and A.I. placement; does not include sites without termite activity.

Discussion

The pest management of subterranean termites utilizing a baiting system would have to be characterized as an “active” management strategy. Rather than placing a “passive” barrier of liquid termiticide around and beneath a structure, which has been a standard treatment in the management of these cryptic organisms, the baiting systems require a labor-intensive regime. It is noteworthy that despite the placement and regular monitoring of these systems, there are examples of little termite activity on the bait stations for an extended period of time. This occurred despite the aggressive foraging and feeding reputation of *C. formosanus*. The termite activity timelines exhibited in Figures 6, 7, and 8, for each of the respective baiting systems evaluated show such erratic patterns of feeding and monitoring that one can, without difficulty, understand the comment by Weesner (1965) that we have “only fragments of information” about termites. The monitoring stations at some structures remained inactive for an extended period of time, for years in some cases, despite the presence of active *C. formosanus* infestations, either in the structure, or in other cellulose sources on site.

The period of time between installation of the baiting systems and the first “tamu,” revealing termite feeding/activity, exhibited an extremely wide range for the systems. The time period observed was from a low of 26 days to a high of 379 days for the various systems that exhibited tamu or termite activity on the stations (Table 12). As was observed with *R. flavipes*, the mean time required for foraging *C. formosanus* to locate and begin feeding on both the Sentricon® and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system (Table 12). It was also observed that the mean time required for foraging *C. formosanus* to locate and begin feeding on any baiting system station was approximately one-half the time required for *R. flavipes* to do the same (Table 4 and 12). Three of the 30 structures (10%) <u>never</u> exhibited termite activity in any of the bait stations during the two-year time frame of the evaluation, two structures treated with FirstLine® in La Porte, Texas, and one structure treated with Terminate® in Beaumont, Texas. Hence, no active ingredient of bait-toxicant was consumed at those structures, and no possibility of management was afforded by the technology of a termite baiting system.

Conclusion

The evaluation results observed in the two different baiting systems utilizing sulfluramid corroborate the need for current instructions on the label and training materials provided by the manufacturers that a liquid termiticide spot treatment is required at points of active infestation, and the baiting systems subsequently installed in a "supplementary" manner to the barrier treatments. Termiticide spot treatments were required for protection of structures treated with a termite baiting system with sulfluramid active ingredient. Of the termite baiting systems evaluated, the Sentricon® system proved to be effective in the management of structural infestations of *C. formosanus*, but only if used in a diligent, labor-intensive manner. If used as an "aggressive" pest management strategy with the necessary labor and materiel devoted to the process and with multiple supplementary in-ground and above-ground stations monitored in a frequent, two-week schedule, the system was successful in protecting the structures in a relatively short period of time. The period of time between installation of termite bait stations to feeding cessation for this system at the five La Porte, Texas sites had a mean value of 154.6 ± 16.3 days (Table 11), and after the termite management was achieved, the days elapsed since feeding cessation without any new tamu had reached 455 days by the end of the study (Fig. 7). It has to be concluded that the "human" involvement of the pest management specialist is the determining factor in a successful termite baiting system regime, requiring that sufficient time, energy, and “problem-solving” diligence be devoted to the “active” treatment process. It is important to note that this treatment regime was successful for one-half of the structures treated with the Sentricon® termite baiting system, which were the structures in La Porte, Texas. The treatment on those five structures diverges, or expands on, the standard regime listed in the label to the point that the eventual efficacy comparison was not between baiting systems, as planned, but between a standard and an aggressive pest management regime utilizing the Sentricon® termite baiting system.

CHAPTER IV

EFFICACY OF SULFLURAMID AS A STAND-ALONE BAIT TOXICANT IN A TERMITE BAITING SYSTEM FOR PEST MANAGEMENT OF SUBTERRANEAN TERMITE POPULATIONS

Introduction

Sulfluramid (N-ethylperfluoro-octane-1-sulfonamide) is the active ingredient in two termite baiting systems currently sold, with claims that this active ingredient controls subterranean termites in consumers' homes and businesses. Label instructions for both of these systems, FirstLine® and Terminate®, also require spot-treatments with a liquid termiticide for any active termite infestations discovered in or on the structure being baited. This contrasts with the treatment regime of other termite baiting systems containing chitin synthesis inhibitors as their active ingredient, which are marketed as stand-alone treatment systems, without the need for liquid termiticide spot treatments.

Laboratory and field investigations with sulfluramid as a bait-toxicant have been conducted in limited numbers (Ballard and Lewis 2000, Forschler and Chiao 1998, Grace et al. 2000, Lewis 1998, Su et al. 1995). Very little research has been published confirming efficacy of sulfluramid under actual use conditions (Potter 1997), yet it is currently marketed to the pest control industry, as well as directly to the consumer. Under consideration, then, is whether this bait-toxicant material is efficacious as a "stand-alone" treatment without the termiticide spot treatments required by the label instructions of termite baiting systems containing this active ingredient. A field study was designed and implemented to evaluate the efficacy of sulfluramid as a stand-alone bait toxicant in a termite baiting system against populations of subterranean termites.

Materials and Methods

Study Area. An urban/suburban location within the city limits of Bryan, Texas was chosen for this study. The site was chosen because of its accessibility, size, security, and the presence of naturally occurring populations of *R. flavipes* discovered in a woodpile derived from a home remodeling project. The area was approximately 0.4 hectare in size and adjoined a residential home (Fig. 9).

The site was primarily an open grass and sedge meadow ringed by trees and shrubs and adjacent to a narrow lake derived from Turkey Creek and impounded by a concrete dam. The meadow was mowed on a regular basis and exhibited a lawn-like appearance. The predominant grass on the site was *Cynodon dactylon* (Bermuda grass). Predominant trees on the site included *Quercus nigra* (Water oak), *Ulmus crassifolia* (Cedar elm), *Sapium sebiferum* (Chinese tallow), *Sapindus saponaria* (Western soapberry), and *Quercus stellata* (Post oak). Shrubs located on the study site were primarily clusters of *Ilex vomitoria* (Yaupon Holly) and *Ligustrum* spp. (Privet). Extensive stands of *Phyllostachys* spp. (bamboo) were also located on the site, particularly in areas adjacent to Turkey Creek, surrounding the open meadow.

Four grids of 100 FirstLine® bait stations in each grid were installed at the site for a total of 400 termite bait stations (Fig. 10). These bait stations were utilized to monitor the activity of subterranean termite populations over time at the site. The active ingredient Sulfluramid was introduced into bait stations as required.

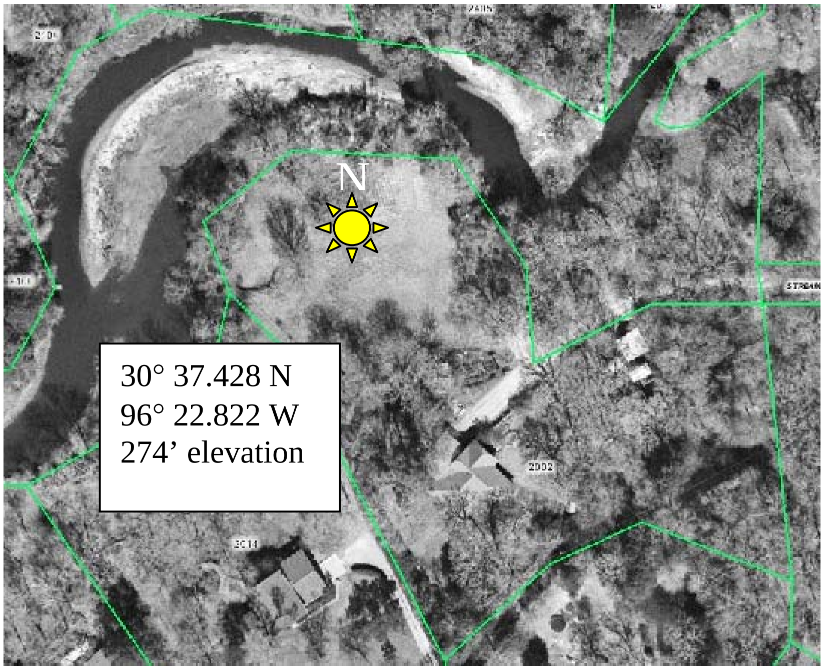


Fig. 9. Aerial view of location of termite bait station study area.

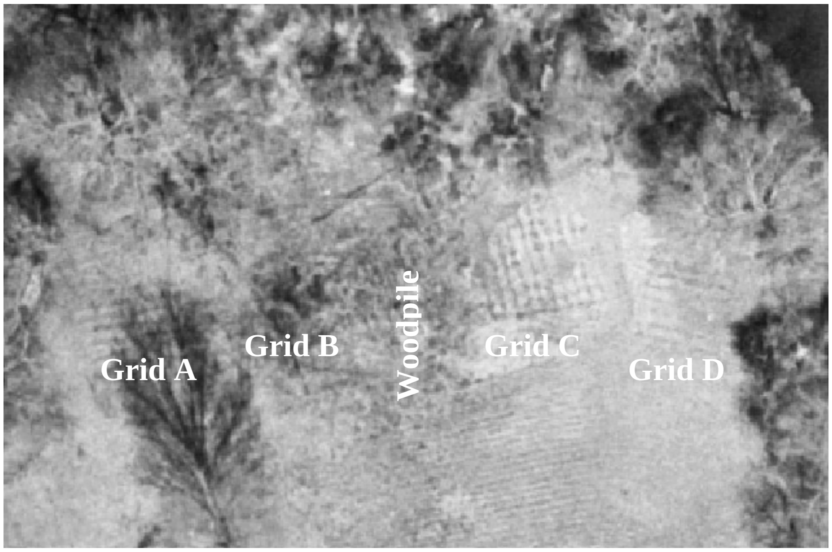


Fig. 10. Close-up aerial view of study site with grids A-D and woodpile.

A diagrammatic representation of this grid system was created in order to record monthly observations of termite foraging activity on the baiting system (Fig. 11).

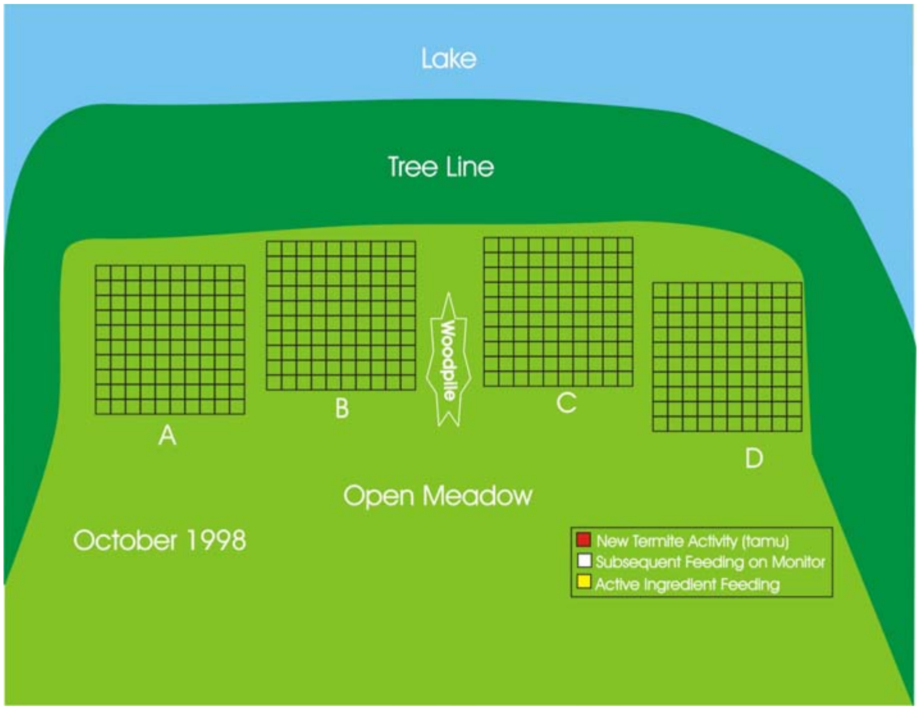


Fig. 11. Diagrammatic representation of 4 x 100 termite bait station study site.

Termite Foraging and Baiting. The efficacy of sulfluramid as a “stand-alone” bait-toxicant material in a management program for subterranean termites was investigated. The field site pictured in Figs. 9 and 10, with naturally occurring *R. flavipes* subterranean termites, was utilized. Species identifications of existing subterranean termites were made according to labrum morphology (Hostettler et al. 1995 and pronotum width (Potter 2004). FirstLine® termite bait stations were placed in a grid pattern within the landscape in the four separate grids. Each grid was installed in a 10 x 10 array in October 1998. Grids A and B were installed west of the existing woodpile, and grids C and D were installed east of the woodpile (Fig. 11). Each grid measured 27 X 27 m, with stations placed at 1 m intervals, or ten stations square. A supplemental bucket trap (3-gallon bottomless, plastic bucket, with wood matrix installed in contact with soil) was installed below grade in each grid between the existing bait stations and utilized for monitoring subterranean termite populations with dyed, mark-recapture technique (Grace 1990) using fat-soluble dyes, Nile Blue and Sudan Red.

Wooden monitors in each bait station were inspected monthly. Following any observations of new termite activity on the wooden monitoring material in each station, it was necessary to pull the entire station out of the ground, and a substitute station that contained the sulfluramid active ingredient was inserted into the existing hole in the ground. Observations of feeding, bait consumption, and bait replacement were recorded. Observations of new or continuing feeding and activity in the bait stations were also recorded. Numbers and locations of bait stations with termite activity were recorded and tabulated for analysis. Any decline in the population levels due to the sulfluramid bait-toxicant was recorded.

Results

The results of the first monthly inspection of the 4 x 100 bait stations in November 1998 is represented in Fig. 12. These monthly inspections were performed for the five-year period of the study with the active ingredient, sulfluramid, applied as a separate bait tube in the FirstLine® termite baiting system, following detection of termite activity and removal of the monitoring station. Subsequent consumption of the active ingredient in the bait tube was represented as “active ingredient feeding” in the diagram. A third category in the category was designated “subsequent feeding on monitor” for those instances when termite activity was detected on untreated wooden monitors after active ingredient had been removed from the grid site. This designation was utilized in the diagram following the management of the subterranean termite populations in the grid site. A separate diagram was compiled for each month of the study, based upon observations of subterranean termite activity on monitors or bait stations.

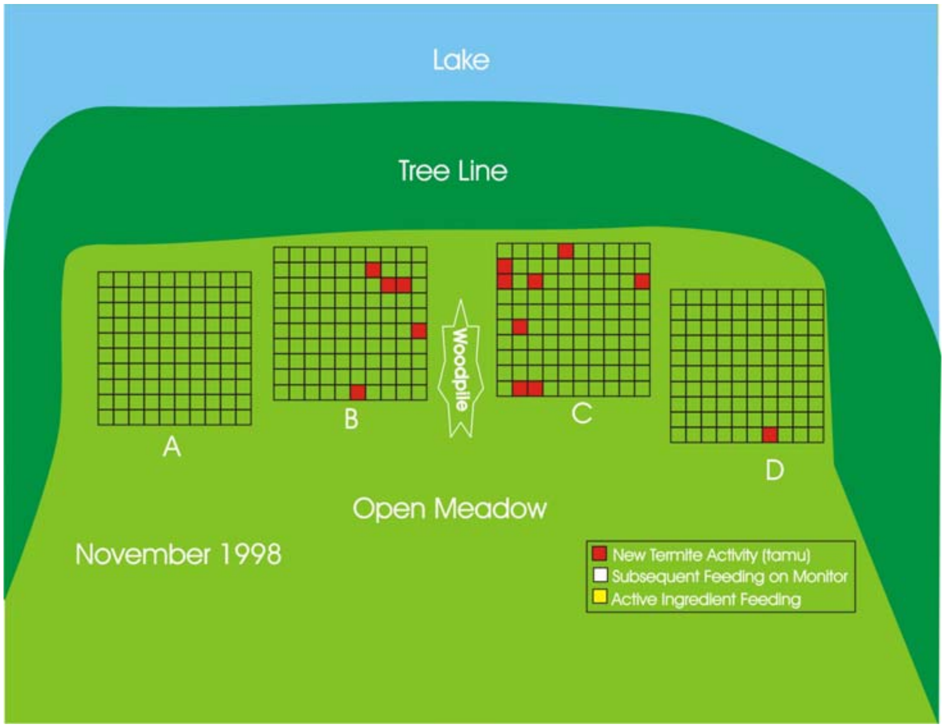


Fig. 12. Diagram of 4 x 100 termite bait station study site with termite foraging activity observed at first monthly inspection.

Results of monthly observations of the monitoring stations in grids A, B, C, and D of the 400-grid are represented in Fig. 13. The total number of monitoring stations with new “tamu,” or initial visits by foraging termites, is represented by a blue, dotted line. The total number of bait stations with subsequent feeding of active ingredient and with the title “total active feeding” is represented by a violet, solid line. Fluctuations in the total number of bait stations with feeding activity over the duration of the study can be observed. Termite activity and feeding was variable over the course of the study, with large numbers of bait stations with termite activity during some months and very little termite activity observed during other months.

Over time, the number of bait stations with observable termite feeding activity declined in numbers as the active ingredient, sulfluramid was added via bait tubes and consumed by *R. flavipes* foraging in the 400-grid area. Feeding activity ceased 37 months after the study began. The next month, one bait station in the grid was observed to have activity, followed by zero termite activity for three consecutive months, until March 2002. Hence, the active ingredient, sulfluramid was capable of eliminating termite populations, albeit following a long period of extensive active ingredient consumption (Fig.13).

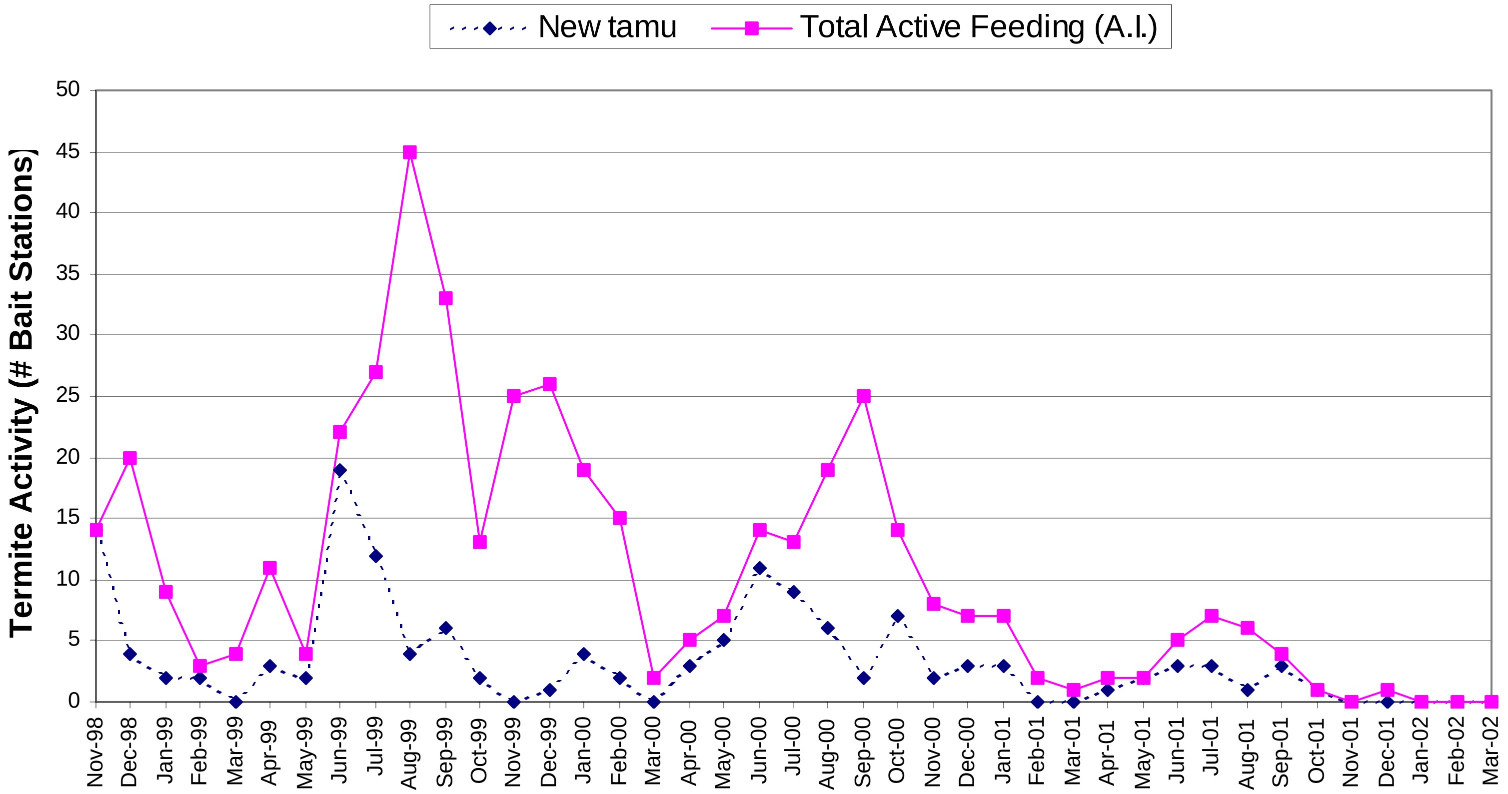


Fig. 13. Termite foraging activity in 400-grid FirstLine® bait stations with sulfluramid A.I. treatment, *R. flavipes*. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

The total number of active ingredient (A.I.) bait tubes consumed by *R. flavipes* in the grid was tabulated at the end of the study, and represented as yellow squares in Fig. 14. The majority of the termite feeding, and active ingredient consumption, occurred in grids B and C. A total of 472 active ingredient bait tubes were consumed in the four grids during the 37 months of termite activity and feeding on the sulfluramid active ingredient.

All bait stations with initial termite activity that did not continue to have activity when this replacement procedure was performed, and no active ingredient (A.I.) was consumed, and were thus “undeveloped” as to their contribution of active ingredient toxicant into the termite population, were recorded from the monthly observations and are represented as blue squares in Fig. 14. Two separate colonies of *R. flavipes* were delineated in the study area through a dyed mark-recapture technique using fat-soluble Nile blue and Sudan red dyes. Colony “1” constituted the termite population located in grids A, B, and C. Colony “2” was located along the tree line in grid D (Fig. 15).

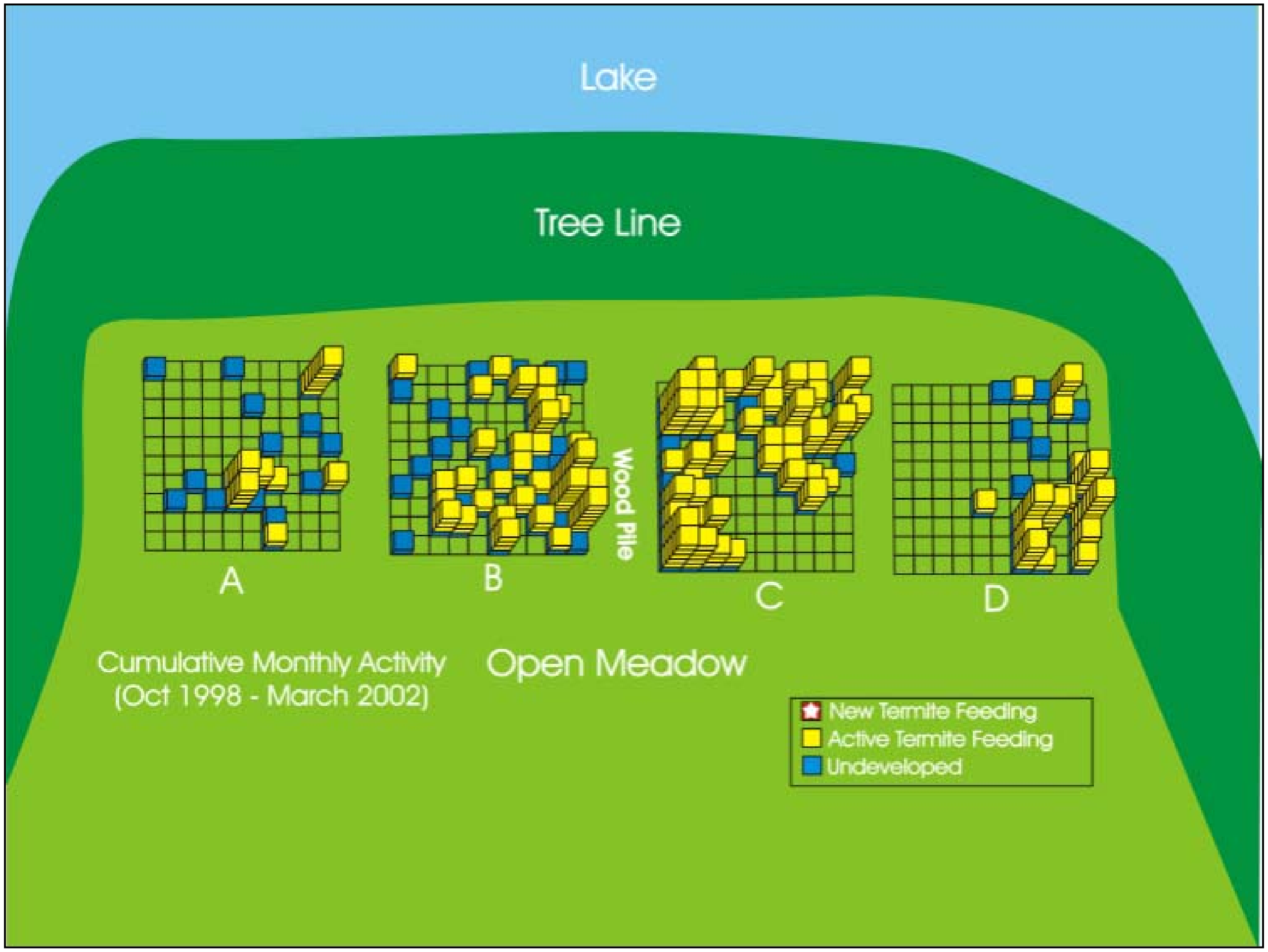


Fig. 14. Cumulative monthly termite activity during treatment period and sulfluramid bait tube consumption, *R. flavipes*.

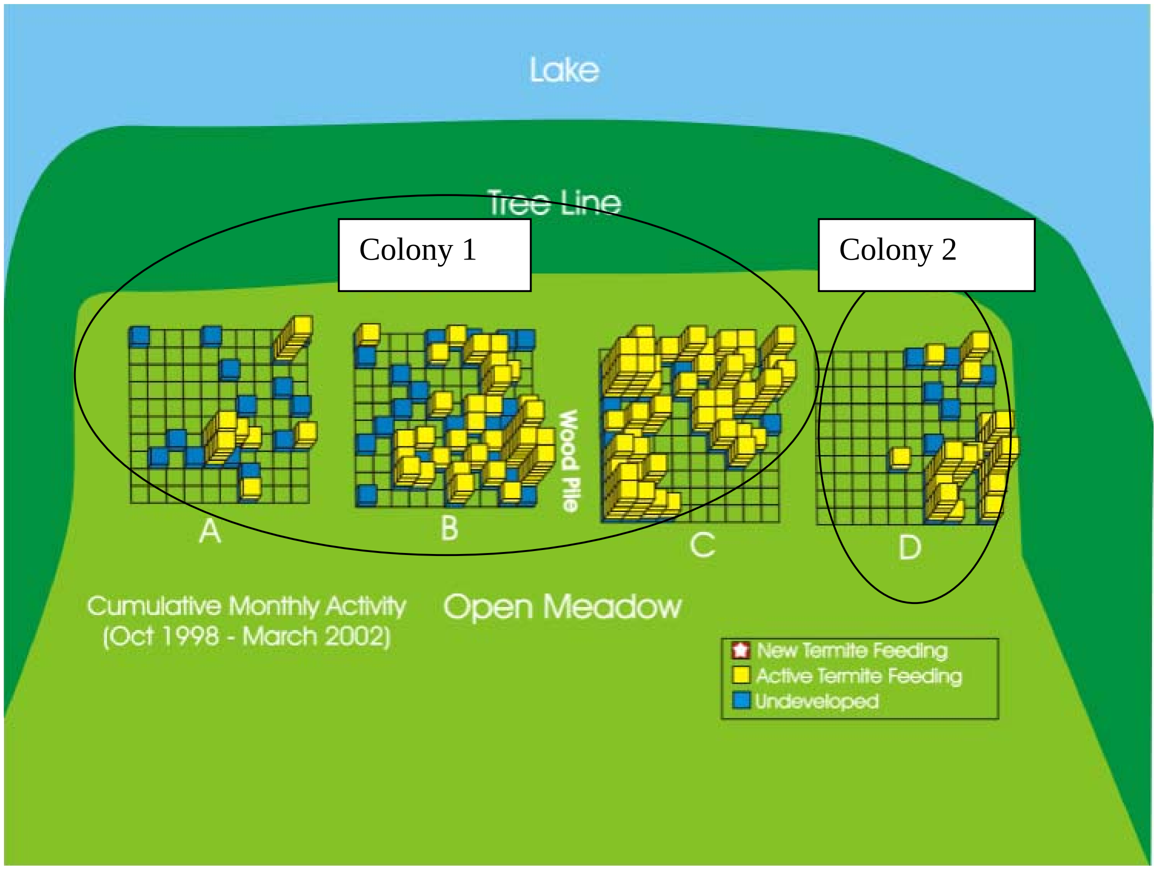


Fig 15. Colonies of *R. flavipes* in 400-grid, determined by dyed, mark-recapture.

The total number of active ingredient tubes that were consumed (472) over the course of the sulfluramid treatment period, as well as the number of bait stations where active ingredient was consumed, and thus “developed” into sources of toxicant for the termite population (98), or those bait stations that showed initial termite activity, but without subsequent active ingredient consumption, and were thus “undeveloped” (46) as sources of toxicant, are tabulated in Table 13 and are differentiated for each individual grid.

Table 13. Termite activity on 400-grid during treatment period, by individual grid.

Grid	A	B	C	D	Total
Total # Active Ingredient Tubes Consumed	43	127	200	102	472
Developed Bait Stations (A.I. consumed)	7	30	46	15	98
Undeveloped Bait Stations (No A.I. consumed)	13	19	7	7	46

Discussion

The 472 active ingredient tubes consumed by *R. flavipes* in Grids A, B, C, and D of the 400-grid were comprised of multiple tubes consumed on the 98 bait station sites that had developed as sources of bait toxicant following initial feeding activity on monitors (Fig. 14). At the current listed price on the Univar USA Inc. pricelist in June 2005, each active ingredient bait tube in the FirstLine® baiting system costs $16.32. The cost for 472 bait tubes approaches $8,000.00, without considering labor costs to install, monitor, and maintain active ingredient in the baiting system, or the cost of the original monitoring stations, which cost $4.29 each. Since there were 46 other bait station sites in the 400-grid where active ingredient was not consumed following initial termite activity on monitors, almost 32% of bait stations that were observed to have initial termite activity did not develop into sources of toxicant for the subterranean termite populations over the course of the study. The design of the FirstLine® termite baiting system requires that monitoring stations be completely removed from the ground prior to the replacement by insertion of bait tubes containing the active ingredient, sulfluramid. The large number of bait stations in the study area that never “developed” into sources of toxicant, despite initial termite activity on the monitors, contributed to concerns about disturbance and abandonment issues influencing foraging tenacity associated with this physical removal of the monitoring station and the insertion of a separate active ingredient tube (Cornelius and Osbrink 2001).

The largest numbers of bait stations with termite activity over the course of the study were observed to be in Grid B and Grid C, in areas adjacent to the woodpile. Other areas with high numbers of bait stations with termite activity were along the tree line adjacent to Grid C and along the tree line adjacent to Grid D (Fig. 15). All of these areas were characterized by the presence of existing cellulose sources, such as trees, shrubs, and fallen limbs from these sources. These observations, as well as observations of seasonal peaks and valleys in termite activity (Fig. 13) and spatial patterns (Fig. 14) exhibited in foraging by *R. flavipes* in the 400-grid study site, are discussed in Chapter V.

Conclusion

In the typical scenario of a termite baiting system treatment, an average of 20 bait stations are placed every three meters around a structure, and monitored for termite activity. Active ingredient is placed in bait stations when and where termite activity is detected, and follow-up monitoring and re-baiting is maintained until termite activity ceases. The large number of active ingredient bait tubes of sulfluramid required to bring about mortality in the two colonies of termites in the 400-grid, and the long period of time required to accomplish it, would not be acceptable in an actual use, stand-alone treatment of a structure in order to reduce the subterranean termite population and thus protect it from the infestation. The necessity of utilizing 472 active ingredient bait tubes, although ultimately effective, was time-consuming and cost-prohibitive and would be extremely difficult to place into a typical 20-bait station treatment scenario around a structure. Allowing 37 months of continuous termite feeding on the structure until the population was eliminated, via the sulfluramid toxicant, would constitute an unacceptable time period in an actual use termite treatment. The goal of such a treatment program is to reduce termite populations and ultimately protect the structure, not just install bait stations and monitor them while active ingredient is added over time. Considering the time and active ingredient necessary to effectively reduce subterranean termite populations, it must be concluded that sulfluramid is not suitable as a stand-alone active ingredient for a termite baiting system. Current label requirements of spot treatments with a termiticide at any point of termite infestation when using sulfluramid as the active ingredient in a baiting system are prudent and necessary.

CHAPTER V

SEASONAL VARIATION AND SPATIAL PATTERNS EXHIBITED IN FORAGING STRATEGIES OF THE EASTERN SUBTERRANEAN TERMITE, *Reticulitermes flavipes* (Kollar) IN AN URBAN/SUBURBAN SETTING

Introduction

The successful use of any termite baiting system as a pest management tool requires the application of information about the biology and population ecology of termites (Nutting and Jones 1990). Investigations of termite baiting systems must consider the foraging patterns of subterranean termites, because this technology relies on the discovery and consumption of active ingredients by termites. Optimum placement of bait stations and subsequent feeding of active ingredient toxicants in those stations by termites would improve efficacy and rate of control (Lax and Osbrink 2003). Optimum placement would also necessarily involve temporal as well as spatial factors. For termites to locate the bait stations in a timely manner, they must be placed where the termites will locate them and at times when they are foraging.

Hodiernal investigations of termite biology and ecology provide timely information with application to termite baiting system efficacy. It has been reported that relative proportions of the major termite castes change seasonally, according to the reproductive cycle (Howard and Haverty 1980, 1981). Some work has also been done to examine the abundance, distribution, and estimates of colony size of *Reticulitermes* spp. (Howard et al. 1982), foraging tenacity of subterranean termites (Delaplane and LaFage 1989), seasonal foraging and feeding behavior of *Reticulitermes* spp. (Haverty et al. 1999), and spatio-temporal patterns of foraging activity in subterranean termites (Grace 1996, Houseman 1999, Su et al. 2003).

Observations of termite foraging in a 400-grid, originally designed to examine the efficacy of sulfluramid as a stand-alone bait toxicant in a termite baiting system, contributed information about seasonal variation and spatial patterns exhibited in *R. flavipes* foraging strategies. Termite activity on monitoring stations during the five-year study period provided information of specific seasonal highs and lows in their foraging activity at this study site. The placement of the 400 FirstLine® bait stations in an open meadow adjacent to existing cellulose sources enabled quantification of foraging distances from these sources. Termite foraging activity by *R. flavipes* observed during and after sulfluramid treatment also provided information comparing rates of termite population reduction with this active ingredient and population recovery after treatment ceased. This approach could be utilized in comparative studies with other active ingredients used in termite baiting systems.

Materials and Methods

Study Area. The study area utilized for the determination of sulfluramid as a stand-alone active ingredient in the pest management of subterranean termites (Chapter IV) provided a site to examine seasonal variation and spatial patterns of foraging by the Eastern subterranean termite, *R. flavipes*. Species identifications were made according to labrum morphology (Hostetler et al. 1995) and pronotum width (Potter 2004). As the monitoring stations were examined monthly, observations of new or continuing feeding by the termites were recorded. After the termite activity was reduced to zero for three months, the active ingredient was removed from the study site, and subsequent observations of subterranean termites foraging on monitoring stations were recorded. It was not possible to determine if the termites were surviving sub-colonies of the original colonies located in the 400-grid study site or from colonies outside the study site that were establishing themselves. The numbers of original termites located in the study site had been reduced in a gradual process and dyes used in previous marked recapture studies could not be detected in any of the termites observed in monitoring stations following removal of sulfluramid.

At the onset of the installation of the termite baiting system in the study site described in Chapter IV, *R. flavipes* foragers had been detected in downed tree and shrub limbs along the tree line adjoining all four grids, as well as in the woodpile between grids B and C (Fig. 14). No subterranean termites had been detected in the open grass and sedge meadow prior to the baiting system installation. The placement of the 400 FirstLine® monitoring stations in four grids along the tree line and on both sides of the woodpile in the study site (Fig. 14) enabled the measurement and calculation of foraging distance from existing cellulose sources to the new introductions of cellulose in the form of the monitoring stations. Utilizing monitoring station placement of one meter apart in each grid, foraging distances were delineated into four specific categories: 0 to 3 m, > 3 to 6 m, > 6 to 9 m, and > 9 m distance from existing cellulose sources surrounding the grids. The categories of the termite foraging distances were tabulated for comparative analysis to determine significant differences.

Results

The summary of termite activity on monitoring stations during the treatment period with sulfluramid, as well as during the recovery period, was tabulated. During the first two years of the treatment period, peak foraging periods were detected. A major peak in termite foraging was consistently observed during the summer months of July, August, and September, and a minor peak was observed during November and December of each year. As the termite population diminished due to the sulfluramid treatment it was harder to distinguish the peaks in termite foraging, but once the sulfluramid was removed, termite foraging again occurred in the study site. The same foraging peaks were then again apparent in the summer months of July, August, and September, and to a lesser extent in November and December.

Termite foraging was consistently at its lowest level during the typical swarming season for *R. flavipes*, which was during February and March of each year. This diminished foraging activity was observed both during and after the sulfluramid treatment period. This is the time period when colony members and resources are converted to the important reproductive stage and pseudergates (workers) are converted to alates and energy reserves accumulated for post-swarming survival (Noirot and Pasteels 1987). Foraging was observed to drop to a very limited amount during this time period and then increased rapidly following the swarming period. The consistent seasonal pattern of increased and decreased termite foraging was observed over the five-year time period of the study, and is illustrated in Fig. 16. Total termite foraging activity (# bait stations) diminished over time due to the sulfluramid active ingredient in the termite baiting system, but this toxicant did not affect typical seasonal highs and lows. Observations of termite foraging activity (# of bait stations), whether decreasing from the effects of active ingredient toxicant, or increasing as the termite population returned to the study site, were used as frames of reference of efficacy and longevity of activity by the active ingredient, sulfluramid. First, the rate of decline of the foraging activity due to the sulfluramid treatment was analyzed. Utilizing the observations of termite foraging (total active feeding) during the three years of treatment with sulfluramid, the linear regression of the decline, and its resulting line, was: $Y = 20.67 – 0.47 X$ (Fig. 17). Utilizing the observations of termite foraging on bait stations (total active feeding) during the next two years of recovery of termite foraging after sulfluramid active ingredient tubes were removed, the linear regression of the increase, and its resulting line, was: $Y = -1.46 + 1.9 X$ (Fig. 18). For convenience, the return of termite foraging activity in the 400-grid study site was designated as zero on the x-axis for linear regression calculations. The rate of recovery of termite populations was thus four times that of the rate of reduction of termite populations due to treatment with sulfluramid, or 1.9/0.47.

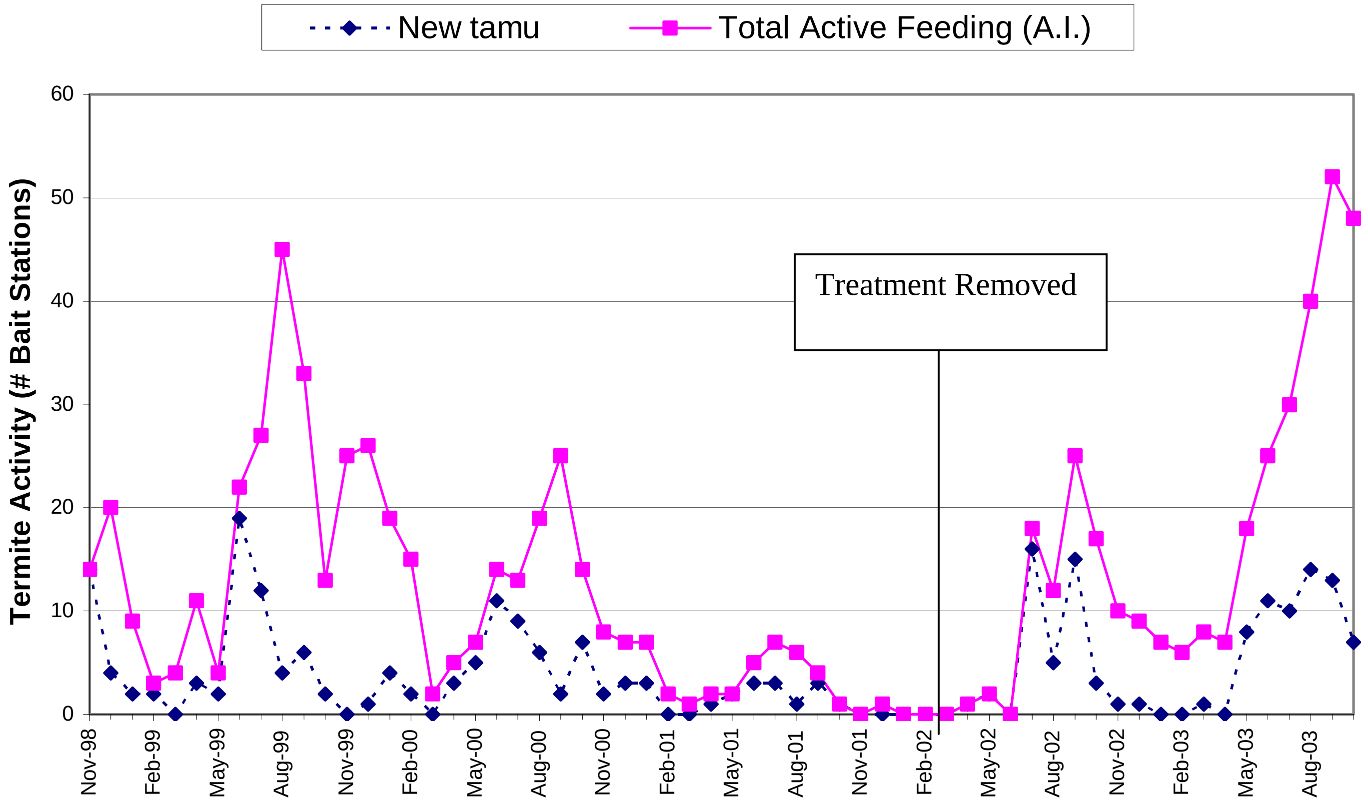


Fig. 16. Termite foraging activity of *R. flavipes* during sulfluramid treatment and recovery period, all grids. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

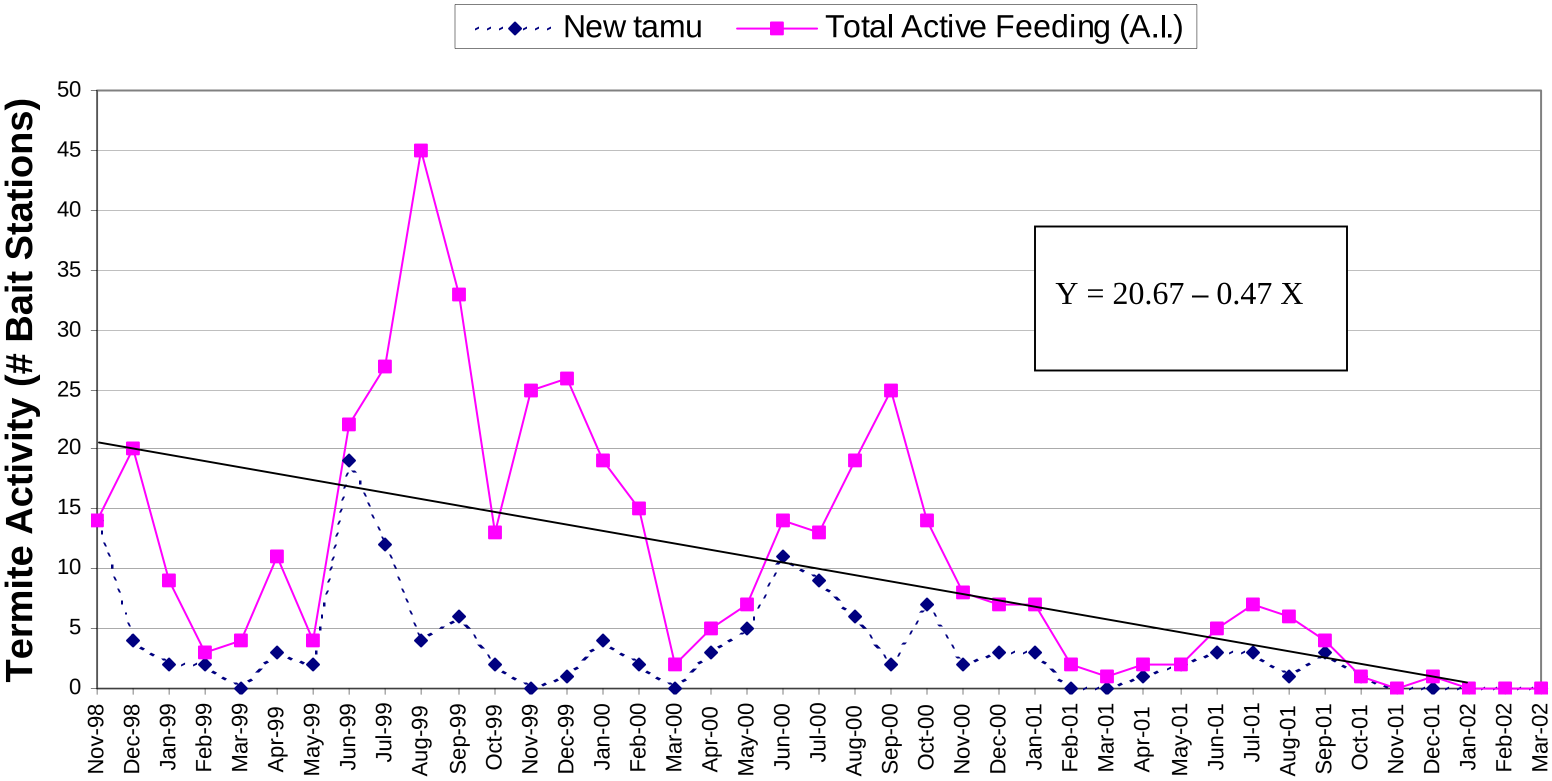


Fig. 17. Linear regression of termite foraging during treatment with sulfluramid, *R. flavipes*, all grids. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

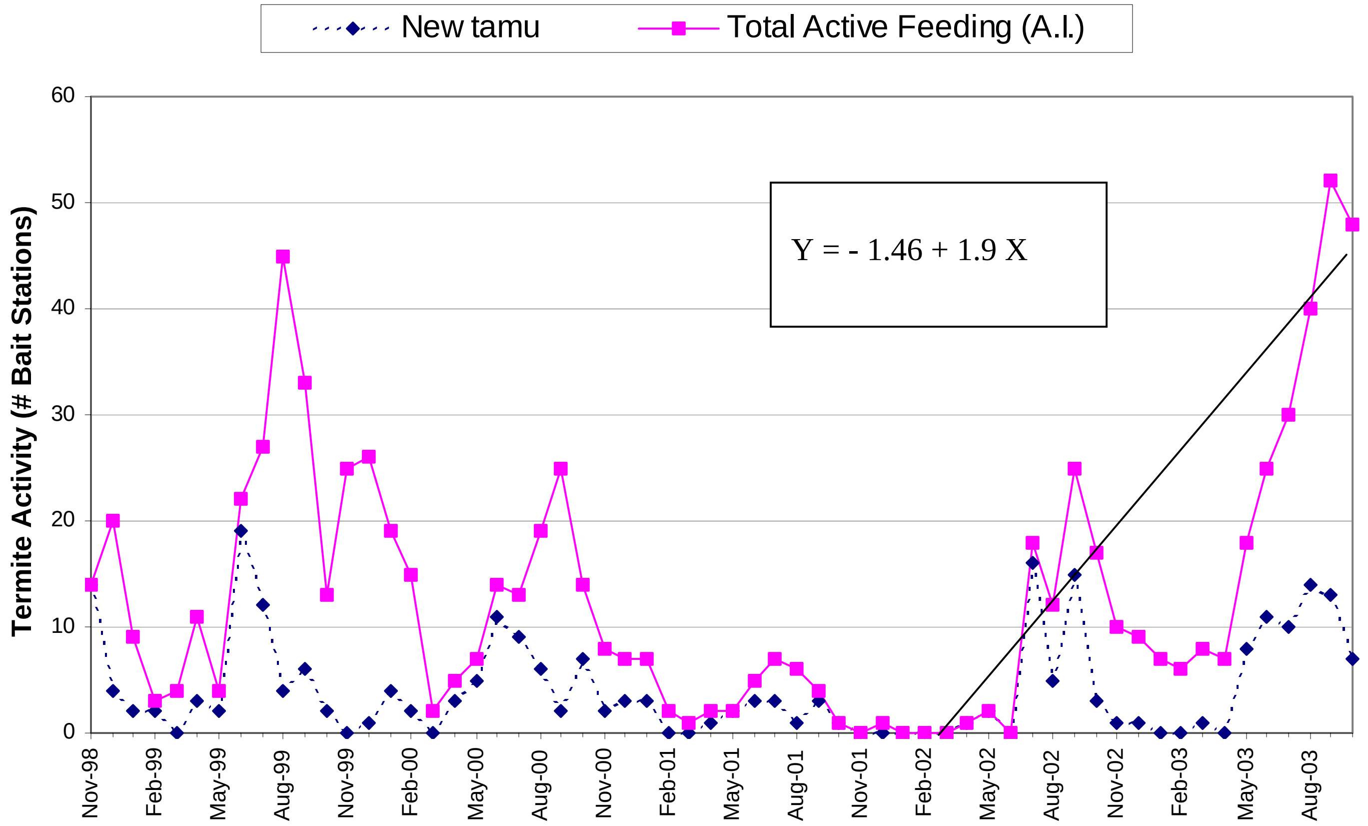


Fig. 18. Linear regression of termite foraging during recovery period following sulfluramid treatment, *R. flavipes* (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

The cumulative monthly termite foraging activity during the recovery period, following removal of sulfluramid active ingredient bait tubes, is represented in Fig. 19. This representation was derived from recorded observations of termite activity in Grids A, B, C, and D of the 400-grid between April 2002 and April 2004. In contrast to the treatment period, during which termite foraging was concentrated in Grid C (Fig. 14), the largest numbers of termite foraging during the recovery period occurred in Grids B and D. Migration of termites from the adjoining tree line areas into Grids B and D was evident in the large numbers of “active termite feeding” represented in yellow squares or blocks in those areas.

During the recovery period, Grid C was noticeably vacant of activity. It was characterized as the grid with the least amount of termite foraging (Fig. 19), despite its previous status as the grid with the largest number of bait stations with termite foraging and feeding activity during the treatment period. The only significant bait stations with termite foraging activity during the recovery period in Grid C were also located adjacent to the tree line, and these numbers were very limited in comparison to the numbers of bait stations with termite activity during the treatment period (Fig. 14).

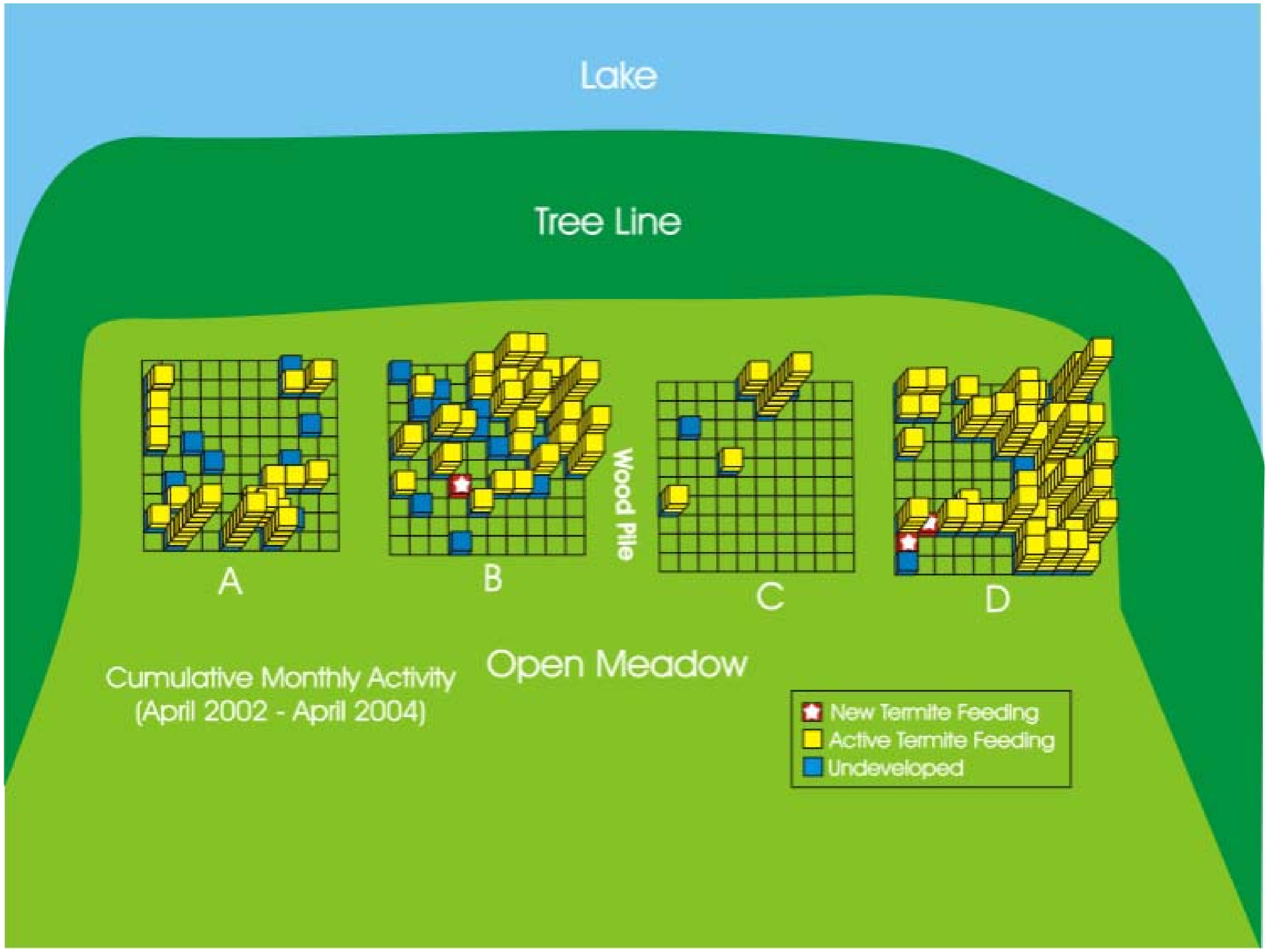
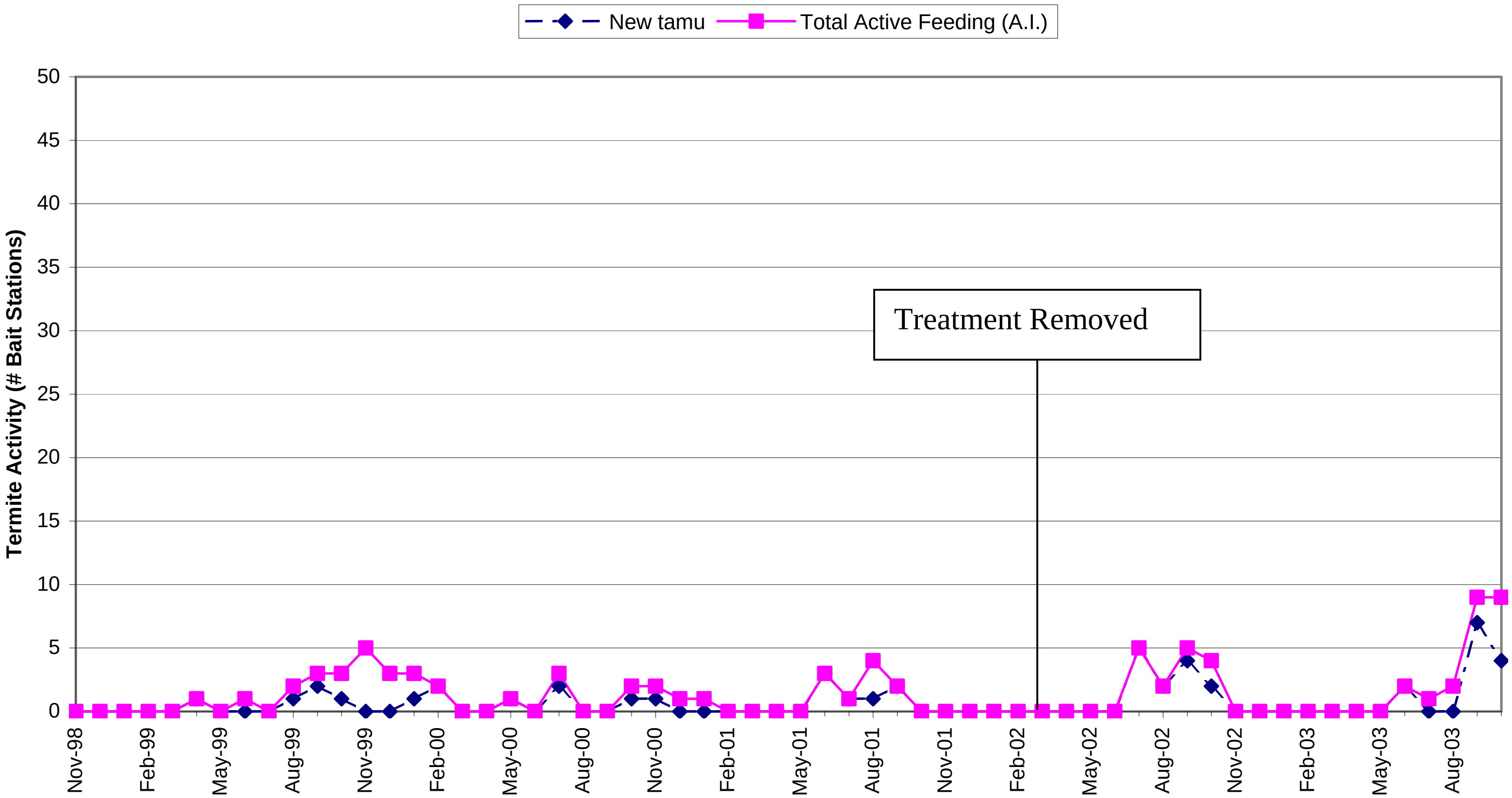


Fig. 19. Cumulative monthly termite activity during recovery period following removal of sulfluramid, *R. flavipes*, all grids.

The termite foraging activity on FirstLine® termite bait stations for each of the four grids during the five year period of treatment with sulfluramid and the recovery period following removal of sulfluramid, are represented in Figs. 20, 21, 22, and 23. Peak termite foraging in Grid A (Fig. 20) occurred during the expected time periods of summer, and to a lesser extent, winter, while the least amount of foraging occurred during the swarming season of February and March, as was observed in the overall foraging picture (Fig. 16). Grids B, C and D were observed to exhibit the same seasonal highs and lows of termite foraging described in the results from Grid A.

The time period with the greatest termite foraging in Grid A was that following removal of the sulfluramid active ingredient. Termite foraging activity in Grid B (Fig. 21) was characterized by a greater contribution to overall termite foraging during the treatment period than Grid A as well as during the recovery period. Termite foraging in Grid C (Fig. 22) contributed the largest component of termite foraging in the 400-grid during the treatment period, yet the lowest numbers during the recovery period. Termite foraging in Grid D (Fig. 23) contributed the largest component of recovery of termite foraging during the time period following removal of the sulfluramid active ingredient toxicant in the study site.



Treatment Removed

Fig. 20. Grid A termite foraging activity, *R. flavipes*, during sulfluramid treatment and recovery period. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

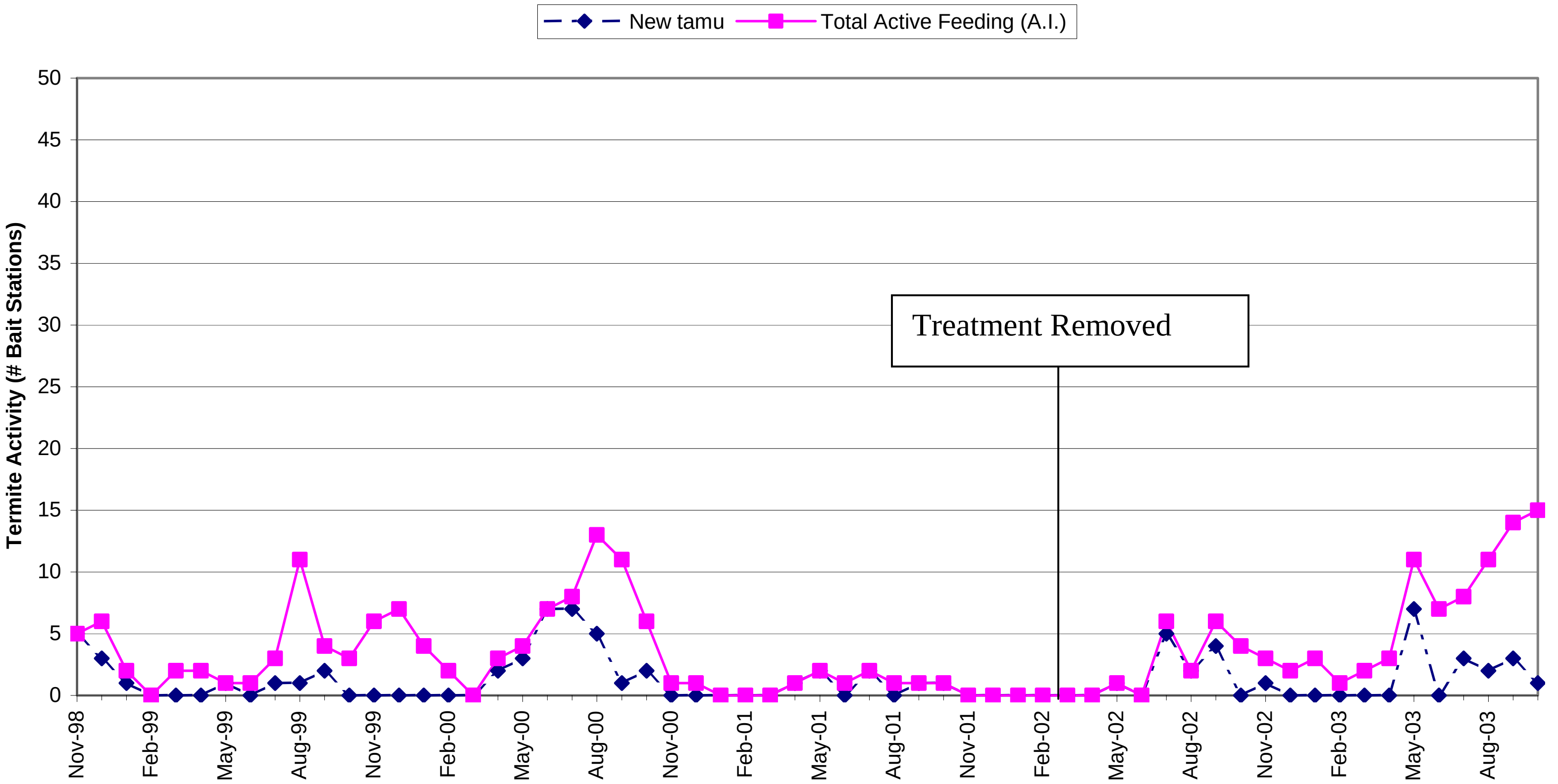


Fig. 21. Grid B termite foraging activity, *R. flavipes*, during sulfluramid treatment and recovery period. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

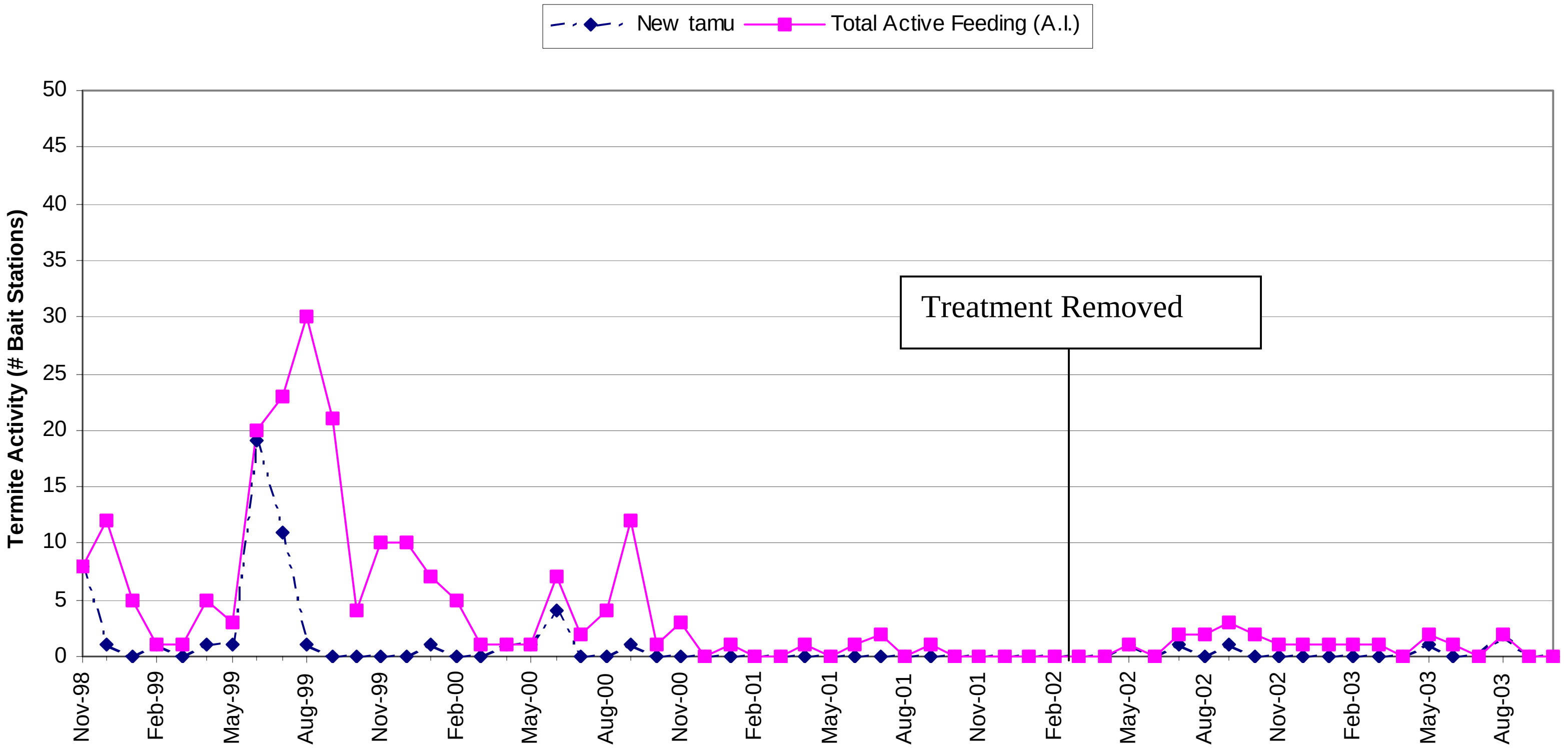


Fig. 22. Grid C termite foraging activity, *R. flavipes*, during sulfluramid treatment and recovery period. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

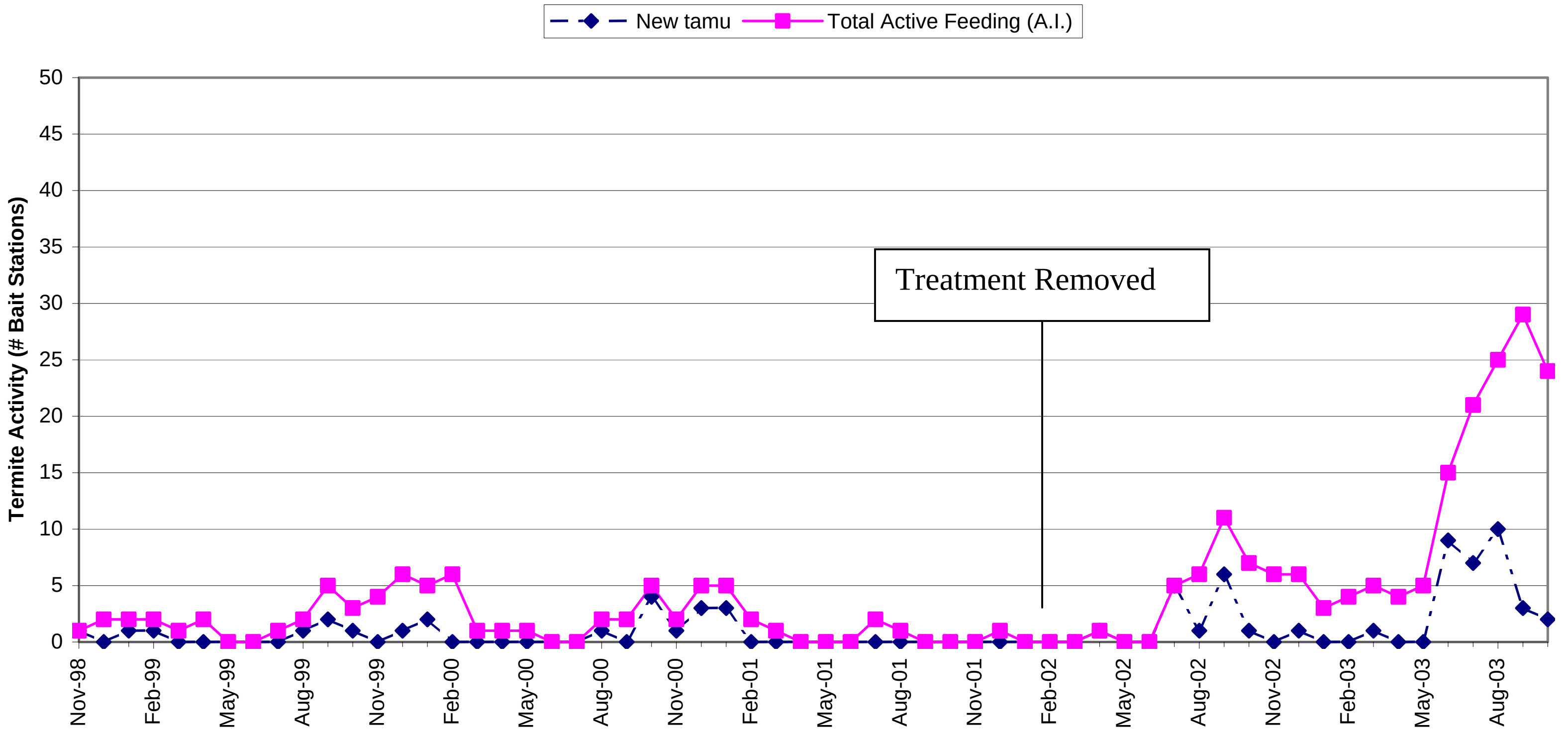


Fig. 23. Grid D termite foraging activity, *R. flavipes*, during sulfluramid treatment and recovery period. (New tamu: new termite activity on monitors underground. Total Active Feeding: all bait stations with termite activity).

Results of observations and calculations of foraging distances that *R. flavipes* traveled from existing cellulose sources to the new introductions of cellulose via monitoring stations in the study site are presented in Fig. 24. These tabulations are total numbers of bait stations with termite activity at each distance category for each of the five years of the study. The distance category with the greatest amount of foraging by termites from existing cellulose sources to new introductions was that from 0 - 3 m. The distance category with the next most numerous bait stations with termite activity was that group > 3 - 6 m, followed by the >6 – 9 m category. Since the termite foraging activity was reduced to low numbers of bait stations in year three, due to sulfluramid, and was still low in year four, it was difficult to visualize the contribution of each distance category from these results. The results in numbers of bait stations were converted to a percentile contribution of each distance category (Fig. 25).

For each year of the treatment and recovery period, each distance category was significantly different from the other distance categories ($P < 0.001$, All Pairwise Multiple Comparison Procedures, Student-Newman-Keuls Method), with the most common distance traveled from existing cellulose in the 0 - 3 m category. There was a mean value of 70.7% contribution for this foraging distance category. There was a 20.9% contribution for the >3 - 6 m category, and a 7.9% contribution for the >6 – 9 m category. There was no significant difference in these results of termite foraging from existing cellulose to the monitoring stations, from year to year in the five-year study, despite the influence of the sulfluramid treatment on the population of *R. flavipes* in the study site (Fig. 25).

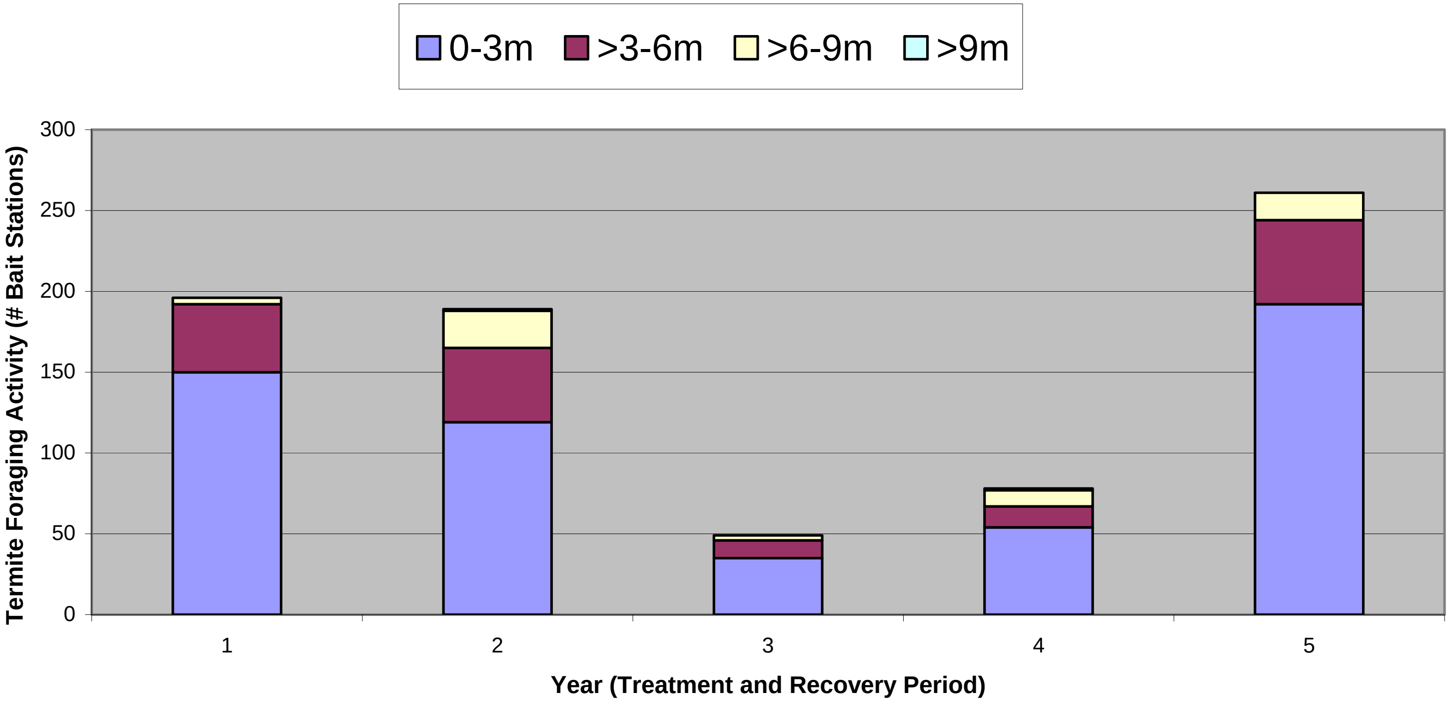


Fig. 24. Termite foraging activity in 400-grid: distance category observations, *R. flavipes*.

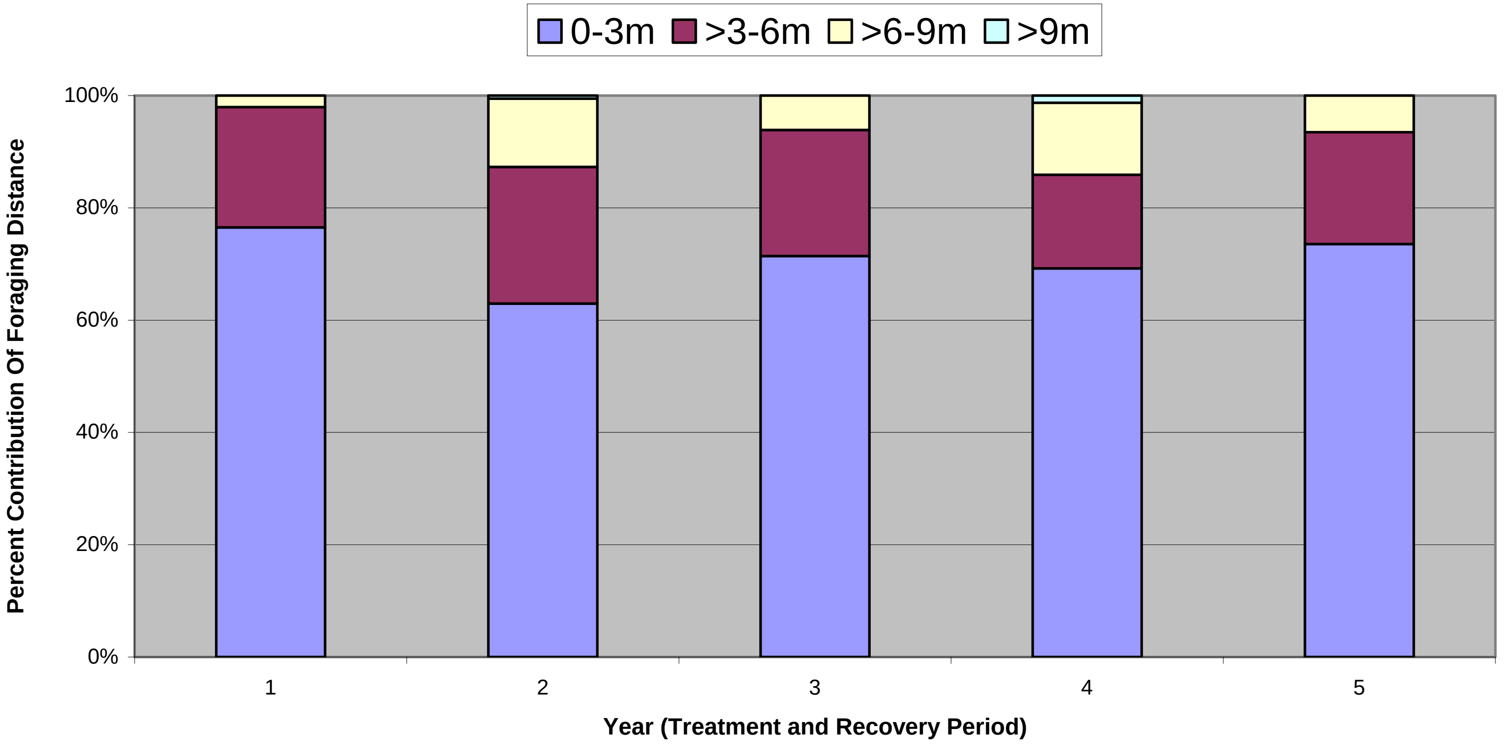


Fig. 25. Termite foraging activity in 400-grid: percent contribution of each distance category, *R. flavipes*.

Discussion

Observations of termite foraging in the 400-grid over a five-year study period contributed information with direct application to an effective termite baiting system program. Consistent, seasonal highs and lows of foraging activity by *R. flavipes* were observed that could apply to an effective monitoring program on termite baiting system stations. These subterranean termites would be expected to be actively foraging during the summer months, as well as in the winter months prior to the swarming season. They would not be expected to be foraging during the spring swarming season.

A population of *R. flavipes* was reduced over time with the active ingredient, sulfluramid. The rate of decline of the termite population, as well as the rate of recovery of a termite population back into the study site, was calculated using observed peaks in foraging activity of the population. The rate of recovery of a termite population into the study site was calculated to be four times faster than the rate of decline of the original termite population with this particular active ingredient toxin. Grid C was the location of the majority of termite foraging activity during the treatment period, particularly along the tree line and adjacent to the woodpile. Grid D was the location of the majority of termite foraging activity during the recovery period after treatment ceased, particularly along the tree line. Hence, the location of termite foraging activity observed after termite baiting system treatment and associated population reduction does not necessarily coincide with the foraging observed before and during a baiting system treatment. The termites do not necessarily fill the same niche that was previously occupied.

Subterranean termite foraging activity was observed to be concentrated at relatively short distances from existing cellulose sources already being fed upon. The majority (70.7%) of foraging by *R. flavipes* was observed to be only 3 m or less from existing cellulose food sources in the study site. The utilization of this relatively short foraging distance by subterranean termites would undoubtedly contribute to conservation of energy and colony resources. This observation could be applied in a termite baiting system treatment by installing monitoring and baiting stations near existing cellulose food sources, such as stacked firewood, bark mulch, tree trunks, or any other condition conducive to infestation, as well as any location where subterranean termites are already observed to be feeding in an infestation. This “targeted” bait station placement would be advantageous in enabling termites to locate bait stations and active ingredient toxin, which would hasten effective management (Jones 2003). Decreasing the distance between termite bait stations would also take advantage of this observed foraging behavior of *R. flavipes* by increasing the density of bait stations available to be located and utilized by the termites.

Another observation that was made concerning foraging distances in the study site was the remarkable consistency of the foraging distance noted over the five-year study. Despite the influence and affect of the sulfluramid active ingredient on the subterranean termites and the resulting decrease in termite population over time, there was no discernible change in foraging behavior (Fig. 25). The foraging behavior of termites returning to the study site after treatment ceased in year four was identical to the foraging behavior exhibited during the treatment regime in years one through three.

Conclusion

Increased termite foraging activity by *R. flavipes* during summer months and again during the winter months prior to the swarming season could be used in an advantageous manner for the distribution of active ingredient toxins in a termite baiting system treatment to target and reduce termite populations. Reduced termite foraging activity in a termite baiting system, which commonly occurs during the swarming season of the year, should not necessarily be construed to be a sign of pest control success, or population reduction of the target subterranean termites, when observed at that time of the year.

The rates of decline of a subterranean termite population due to a treatment regime and recovery of termite populations following such a treatment could be used as frames of reference in comparative studies of efficacy against termites with other active ingredients. Rates of decline and recovery could be determined through non-destructive observations of grid studies, as performed in this research, or through data from termite baiting system treatments around structures with active termite infestations. Subterranean termites returning to an area following a baiting system treatment do not always fill the same void left by those that previously foraged there, yet there is a remarkable consistency in the foraging distance traveled from existing cellulose to new sources, despite the action of a toxicant eliminating the population, or following the removal of the treatment which allows termites to return. Buchanan (2002) remarks that complex systems are frequently unpredictable, but also paradoxically exhibit precise regularities. The remarkable regularity of foraging behavior of the *R. flavipes* termite population under investigation, both temporally and spatially, supports this conclusion. It is also interesting to note the relatively short period of time required for *R. flavipes* to return into an area following a termite baiting system treatment regime and capitalize on the cellulose sources there (Fig. 19). Hence, a termite baiting program would require continuous monitoring and maintenance of active ingredient in the system in order to achieve long-term efficacy.

CHAPTER VI

CONCLUSIONS

Eastern Subterranean Termites, *R. flavipes*

Of the 75 test structures with *R. flavipes* infestations, 11 of them (14.7%) never exhibited "tamu," or termite activity on monitors underground placed around the structures (eight for FirstLine® and three for Sentricon®) for a period of 24 months. The absence of termite activity on bait stations at these structures means no active ingredient was consumed and no protection of the structures were afforded by the baiting system. This constitutes a real conflict for both the pest management specialist and the homeowner, both of whom are expecting termite control.

There was wide variance in the time required for termites to locate monitoring or baiting stations in a termite baiting system; this ranged from 28 to 661 days for *R. flavipes,* for those structures that exhibited termite activity on stations. The wide range of time for termites to feed on active ingredient on the structures can be problematic in the impact on termite populations. There was no significant difference in the efficacy of treatments of structures with the three termite baiting systems, with 80.0%, 88.0%, and 84.0% of the structures without termite infestations at the end of the study, for FirstLine®, Sentricon®, and Terminate® termite baiting systems, respectively.

The systems with the active ingredient, sulfluramid, required spot treatments with liquid termiticides for all active infestations discovered, at the onset of the study. Several of these study sites also required subsequent spot treatments in order to maintain protection of the structures, over the course of the study. The termite baiting system, Sentricon®, which is labeled as a stand-alone baiting system, did not require a liquid termiticide spot treatment. There was no active ingredient consumption on three of the 25 study sites used in this study. All three of these structures (12%) had an active termite infestation at the end of the study. The time required for *R. flavipes* to locate and begin feeding on both the Sentricon® and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system.

Formosan Subterranean Termites, *C. formosanus*

Despite careful placement and regular monitoring of termite baiting systems in areas with *C. formosanus* populations, there were instances of little, or no foraging activity on the bait stations for up to 24 months, despite the aggressive foraging and feeding reputation of the species. Three of the 30 structures (10%) in the study with *C. formosanus* never exhibited termite activity on any of the bait stations during the two-year time frame of the evaluation (two structures treated with FirstLine® in La Porte, Texas, and one structure treated with Terminate® in Beaumont, Texas). Hence, no active ingredient of bait toxicant was consumed at those structures, and no possibility of management was afforded by the technology of a termite baiting system.

As in the case of *R. flavipes*, there was wide variance in the time required for *C. formosanus* to locate baiting stations, ranging from 26 to 379 days. The mean time required for foraging *C. formosanus* to locate and begin feeding on both the Sentricon®

and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system. The mean time required for foraging *C. formosanus* to locate and begin feeding on any of the baiting systems was approximately one-half the time required for *R. flavipes* to do so.

The Sentricon® baiting system, if used in a diligent, labor-intensive manner, with multiple supplementary in-ground and above-ground stations, monitored in a frequent, two-week schedule, was successful in protecting structures from *C. formosanus*. This regime expands on the standard protocol for termite baiting listed on the label, and was used on one-half of the structures treated with this baiting system, in La Porte, Texas. Treatment on the other one-half of the structures, in Beaumont, Texas, was according to label instructions. These structures exhibited intermittent periods of active ingredient consumption, and one structure continued to have an active termite infestation at the end of the study.

Sulfluramid as a Stand-Alone Active Ingredient in a Termite Baiting System

The evaluation of sulfluramid as a stand-alone bait toxicant required 472 active ingredient bait tubes, over a 37-month treatment period, in order to control *R. flavipes* populations in a study site. This constitutes an excessive chemical cost, and unacceptable time period, with corresponding labor costs, in order to achieve termite control. Current label requirements for spot treatments with a liquid termiticide, when using these termite baiting systems, are prudent.

Termite Foraging Observations

Optimum timing of placement of monitors in a termite baiting system should take into consideration the peak foraging activity of *R. flavipes* in the summer months and winter months prior to swarming season. Reduced termite foraging by this species during swarming season should not necessarily be construed to be a sign of pest control success, or population reduction of the target termites. The rates of decline of a subterranean termite population due to a treatment regime with a termite baiting system, as well as the rates of increase of a termite population following such a treatment, could be used as frames of reference in comparative studies of efficacy against termites with other active ingredients. Subterranean termite populations returning to an area following a baiting system treatment do not always fill the same void or niche left by termites that were previously active there. There is remarkable consistency in the foraging distance traveled from existing cellulose to new sources of food, despite the action of a toxicant eliminating the population, or following the removal of the treatment, that allows termites to return to the site. Since termite populations are capable of foraging into and establishing themselves in previously treated areas, a termite baiting system would require continuous monitoring and maintenance of active ingredient in the system in order to achieve long-term efficacy.

Summary Conclusions

Termite baiting systems rely on the discovery and consumption of active ingredient matrix by termites. Understanding the underlying foraging behavior of termites could conceivably improve the effective placement of monitoring stations for increased efficacy. Termite baiting systems have the potential advantage of population suppression and reduction when foraging termites feed on the toxicant and share with nestmates through trophallaxis. The corresponding drawback for these systems is the amount of time that it takes for termite control; adverse effects on the termite population may take months, years, or may never occur at all if active ingredient is never located, ingested, or shared with nestmates. The multiple stages in a termite baiting system offer multiple opportunities for failure. The application of toxin only when termite activity is present makes the baiting system an environmentally friendly approach, but this also makes the system labor intensive, with corresponding costs associated with this activity. This makes it an “active” rather than “passive” termite control regime. In the effort to make the system work, pest management specialists are required to become intimately familiar with subterranean termite biology and population ecology, as well as become problem solvers in order to increase efficacy.

Success with termite baiting system technology is more than labor intensive; it is labor dependent. The multiple steps required for effective termite control through baiting require higher order thinking than the application of a liquid termiticide barrier. Just as a liquid termiticide application must be done thoroughly and carefully in order to create a continuous barrier to termite invasion, all steps involved in the placement and maintenance of a termite baiting system requires the pest management specialist to be observant and flexible. Buchanan (2002) emphasizes the importance of taking note of this human element in efforts to become adaptable, for adaptability is synonymous with efficacy in the utilization of a termite baiting system. This is also applicable to the "master of change" who is prepared to attain successful results in a technologically advanced age by readily acquiring new information, solving problems, and adjusting to changing circumstances (Gardner 1999). Increased knowledge of termite behavior, improvements in bait matrix and active ingredients, and developments of improved baiting strategies will continue to contribute to effective baiting systems, and enable the use of this technology in the integrated management of subterranean termites.

Hypotheses

In considering the original objectives of this research, three null hypotheses were presented. The first null hypothesis that there were no significant differences between termite baiting systems for the management of subterranean termites is accepted. Ultimately, all three systems examined were capable of controlling subterranean termites. It is important to note that this termite control was achieved with termite baiting systems containing the active ingredient, sulfluramid, by relying on multiple spot treatments with liquid termiticides.

The second null hypothesis that there was no significant difference in the efficacy of termite baiting systems against *R. flavipes* and *C. formosanus* termites is rejected. Because of the voracious appetite exhibited by *C. formosanus* termites, control required a more aggressive labor-intensive regime for successful control. Multiple supplementary in-ground and above-ground stations, monitored in a more frequent, two-week schedule were required for efficacy. Also, the mean time required for foraging *C. formosanus* termites to locate and begin feeding on any of the baiting systems was approximately one-half the time required for *R. flavipes* termites to do so.

The third null hypothesis that there was no significant difference in the level of control between sulfluramid as a “stand-alone” bait-toxicant, or used in conjunction with spot treatments with liquid termiticides against subterranean termites, is rejected. The large amount of active ingredient necessary to control termites in a “stand-alone” regime, and the extended period of time required to do so, attest to the need for supplementary spot treatments with liquid termiticides for effective termite control.

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