An integrated subterranean termite management system coupling soil amendments with insect repellent plant tissues

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AN INTEGRATED SUBTERRANEAN TERMITE MANAGEMENT SYSTEM
COUPLING SOIL AMENDMENTS WITH INSECT REPELLENT PLANT
TISSUES

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A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Forest Resources
in the Department of Forest Products

Mississippi State, Mississippi
May 2008
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Currently, soil termiticides are the primary termite defense mechanism used under and around living spaces in the continental United States. While this form of treatment has been effective for many years, the creation of a new, more environmentally friendly termite management system could reduce the amount of termiticides introduced annually into the environment around structures. A natural barrier containing soil amendments and mulches amended with insect-repellent plant tissues discourages termite foraging and directs the termites away from the structure. The proposed integrated management system developed during this project, divides a structure into three zones. Each zone has particular responsibilities to the overall biological durability of the structure. This study concentrates on the inner-detritus zone, which extends 24” (0.61m) from the outer wall of the structure, an area that can harbor potential hazards such as moisture traps, conducive termite food, water and protection sources, and other
factors that could put undue biological pressures on the structure. Altering this zone, more specifically the pH of the soil and the mixture of products used as mulch, creates an environment unsuitable for termite foraging. This integration of several termite repelling strategies should obviate or significantly reduce the need for termiticidal soil barriers under and around houses.
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CHAPTER I
INTRODUCTION

Background

An integrated subterranean termite management system based on natural minerals and plant tissues will provide a system that is effective, safe and affordable. By utilizing these naturally-occurring products and applying biological principles concerning the behavior and activity of termite foraging, an integrated system can be established to protect wood-frame structures while eliminating or reducing the use of pesticides in and around structures. Damage to structures, currently is estimated to be as much as $1 billion annually in an eleven state region of the United States mainland.¹

Through the alteration of the natural environment around wood-frame structures, the movements of foraging termites can be directed away from them. By utilizing natural products in these systems, it is hypothesized that the use of synthetic soil termiticides will be decreased and possibly eliminated over time in both new and existing dwellings. The success of each component of the proposed system will not be determined by 100% termite repellency but rather in the terms of repellency compared to control areas. The approach
combines the effects on termites of several different parts as opposed to the “knock-out punch” attitude used in traditional soil termiticide treatments for the past 50 years. The future of the pest control industry is moving toward integrated systems and the proposed products and techniques would follow this trend, yet provide avenues for innovative subterranean termite control.

By utilizing natural minerals to raise the soil pH to levels that are unattractive to foraging termites, a natural barrier will be established to repel termites from wood-frame structures. This perimeter approach to termite control is performed currently by applying synthetic chemical soil termiticides under and around a house or office. The synthetic chemical approach results in more than four hundred million (400,000,000) gallons of soil termiticides used annually in the United States alone. The proposed soil pH-altering method could drastically reduce, or combined with other products and techniques, eliminate the need for traditional soil treatments. Integrating natural plants or plant tissues with termite-repellent qualities into the natural landscape near building foundations also has the potential of decreasing the amount of synthetic termiticides used and benefiting the total landscape through decreased erosion, waste-water cleanup, and other attributes that the plantings may have other than termite repellent qualities. For example, Vetiver grass (*Vetiveria zizanioides* (L.) Nash) is a known soil erosion control agent, and extracts from its roots have termite repellent features.
The majority of the mulches utilized in the United States for flower beds and erosion control are derived from material high in cellulose (e.g., wood bark and/or chips), which is a primary food source for termites. Mulches applied in direct contact with the walls or foundations of homes create an entry point for termites by forming bridges over soil termiticides and also can cause other problems not within the scope of this project such as creating moisture traps that promote the growth of decay fungi and vector insects. Applying mulch no closer that 12-18 inches (0.31-0.46m) to foundations will help to eliminate this problem, but by utilizing plant tissues that have natural termite repellency either alone or in combination with traditional mulching material, a natural barrier will be established to direct termite foraging activity away from homes.

The traditional use and maintenance of soil and other chemical treatments for termite control in the United States has become more complex with the introduction of second and third generation termiticides. The chemicals of the past (chlordane and heptachlor) that gave a high degree of termite repellency and/or toxicity for 20-30 years were replaced with products (e.g., chlorpyrifos and isofenphos) which provided toxicity and/or repellency for a shorter time due to the accelerated degradation under some soil and climatic conditions. The current termiticides (e.g., permethrin, cypermethrin, fenvalerate, bifenthrin, imidacloprid, fipronil, and chlorfenapyr) have different modes of actions and affect termites in a different way than the earlier chemistries. The traditional soil treatments require that structures be remedially treated periodically to ensure
that the chemical termite barrier repels and/or eliminates foraging termites. While this approach is good for the pest control businesses, the replacement of the longer-lasting chemicals has resulted in a net effect of introducing 3-4 times the volume of chemicals into the environment as was done in the past. With this in mind, it has become evident that the integration of multiple control systems is needed as opposed to one “knock-out punch”. The concept of integrated pest management seems to be the way that the pest control industry is headed, but the need for a biology-based / environmentally acceptable, integrated termite management system is needed. Natural, physical and low-impact chemical termite control techniques have been explored but not widely implemented as viable control systems. The natural repellents have been more of a beginning point for the development of synthetically-produced termiticides as opposed to utilizing the natural plant or product itself\textsuperscript{5, 6, 7, 8}. Physical barriers such as basaltic sand and stainless-steel mesh have had success, but used alone they have some challenges.

The development and implementation of an integrated system that utilizes various natural repellents (in forms such as plants, mulch, extractives, etc.), physical barriers (basaltic sand, granite, stainless steel mesh, soil covers, etc.), and low-impact chemicals (borates, etc.) has not been pursued. To establish a successful system of termite control using the above-mentioned products and techniques, a broad knowledge of wood-destroying organisms and wood-frame structures is needed. By collecting, developing and combining products and
ideas that utilize design and natural, physical and low-impact chemical control methods, a component of a wood-destroying organism management system was created by this research. It is also determined that a holistic (emphasizing the importance of the whole and the interdependence of its parts)\textsuperscript{9} approach is needed for these systems to have the highest degree of success. The proper installation of this management system will discourage termite foraging and the growth of wood decay fungi within the inner detritus zone.

Three Zone Approach to Biological Structure Durability

**OVERALL CONCEPT:** If a building site is approached as a micro-environment, then it can be divided into three zones, and each zone can be customized with wood-destroying organism and moisture control techniques that will increase the biological durability of the structure.

Wood-destroying organisms cause tremendous amounts of damage in wood-framed structures yearly. With some very basic steps, these pests can be reduced and/or eliminated by using proper techniques and basic biological principles. These during-construction techniques and principles are: (1) Keep wood dry (2) Use seasoned wood (3) Provide adequate ventilation in and around structures (4) Limit wood/ground contact (5) If 1-4 cannot be achieved, use chemically-treated wood.\textsuperscript{10, 11} It is very important to keep these principles in mind when designing and constructing wood-framed structures.
Wood-destroying organisms can be divided into two groups: (1) decay fungi and (2) insects. For wood-frame structures, the two sub-groups of organisms which cause the most economical devastation in the United States are brown-rot decay fungi (Basidiomycetes) and subterranean termites. Brown-rot fungi are primarily associated with softwood (coniferous) species which are the predominant materials used in new home construction in the United States. These fungi primarily enzymatically degrade the wood cell wall carbohydrates, leaving behind a network consisting of modified lignin, with small amounts of more resistant crystalline cellulose. On drying, the surface of the decayed wood checks in a characteristic cube-like pattern, and the decayed wood collapses and decreases in size and shape. The strength of the wood decreases rapidly as the decay proceeds, and the decayed wood is converted into a powdery mass of varying shades of brown. Some species of these particular fungi form asexual spores that can withstand desiccation, and survive for years in dry wood. When a sufficient amount of moisture and proper temperature levels are introduced into the system, these fungi will resume growth.

The primary wood-destroying insects that cause economic losses to structures in the United States are species of the subterranean termites. Termites occur throughout the United States except Alaska and in all U.S. territories. Termites in general have extended their natural range to approximately the 50°F (10°C) annual mean isotherm north and south of the equator. Years ago, their damage was concentrated to the southern half of
the United States, but since the widespread installation of central heating units in residences, the damage from termites is becoming common in the northern states. The two most economically destructive species of termites in the United States are the native Eastern subterranean (*Reticulitermes flavipes* Kollar) and the introduced Formosan subterranean (*Coptotermes formosanus* Shiraki).

Integrated pest management programs and holistic structure designs can be developed to minimize the effect that wood destroying fungi and insects have on structures. A building site can be divided into three zones (Figure 1).

![Three-Zone Approach to Biologically-Durable Structures](image)

Figure 1. Three-Zone Approach to Biologically-Durable Structures.

The first zone is the structure’s footprint. Specific care should be taken when the structure is designed and constructed to make sure that potential problem areas that encourage attack by wood-decay fungi and subterranean termites (e.g., soil drainage) be addressed in a pro-active manner. The second zone is the Inner Detritus (matter produced by the decay or disintegration of an organic
substance) Zone. This area would be defined as the space from the edge of the structure footprint out 24 inches (0.61m). This zone is the critical point at which wood-destroying organisms would typically enter the structure. This area is often the viable zone to create an unfavorable environment for termites and wood-decay fungi. Vegetation and/or mulch in direct contact with a structure trap moisture and promote termite and decay activity in this zone. Various soil and mulch amendments can be used to minimize termite activity in the Inner Detritus Zone. Proper moisture control techniques, for example French drains at the roof drip zone, can also be used to minimize the occurrence of wood-decay fungi in this area (Figure 2).

The third zone is defined as the Outer Detritus Zone. This area would extend from greater than two feet (0.61m) from the structure footprint and include the property’s landscaping features. This area should be well planned to provide proper water mitigation (e.g., site drainage) and proper shading for the structure. The landscape features can provide aesthetic beauty to the structure as well as functional protection. The use of French drains to move water away from the structures and the incorporation of plants that have natural insecticidal qualities are a few of the things that would allow this area to contribute to the overall biological durability of the structure. Plants such as Vetiver (V. zizanioides) have been evaluated for their termite repellency, and plant oils have been extracted and analyzed. There has been very little if any focus on utilizing the plants in landscaping schemes or incorporating the plant tissues in mulches.
Figure 2. French drain illustration. A trench should be excavated, a barrier installed, perforated pipe inserted, and then filled with washed aggregate.
Non-biocidal Soil Amendments and Insect Repellent Plant Tissues and Extracts

1. Hypothesis 1: If soil amendments are used to increase the pH of a micro-environment, then a barrier can be established that will discourage termite foraging and form natural termite “shields” around the perimeter and under wood-frame structures.

2. Hypothesis 2: If products used for mulch are produced from, or amended with, tissues and extractives from plants with insecticidal or repellent qualities, then a barrier can be established to discourage termite foraging and form natural termite “shields” around the perimeter of wood-frame structures.

A pH level of approximately 6.3-6.8 is the optimum range preferred by most soil bacteria and the sweet decay processes associated with the decay of organic matter, which immeasurably benefits the soil. Termites naturally forage and survive in the organic or living layer of the soil, which is typically the upper 24 inches (0.61m). This depth can vary depending on the geographic region, but for the scope of this project, 24 inches (0.61m) will be the focal zone. Non-biocidal soil amendments, such as lime or ammonium nitrate, are utilized in agriculture to increase the soil pH to create a favorable environment for the crops being grown in the area. By altering the pH of this Inner Detritus zone with non-biocidal soil amendments, such as hydrated lime, the pH will increase to a level that is not favorable to the foraging termites. The increased pH level of the
zone will also deter roots of foundation plantings from entering this zone. The removal of plant roots will minimize the food source available in the zone and further deter termite foraging in this area. Past experience has shown that termites can enter a structure, even if it has been treated with a traditional soil treatment or basaltic sand, when roots from foundation plantings breach the termiticide barrier. The plants and/or roots provide an entry and a food source for foraging termites.\textsuperscript{19} Roots of most plants would not grow through areas which had high pH levels.

Termite control without using synthetic pesticides has been reviewed and several areas pursued in conjunction with the organic gardening trend for food production without the aide synthetic biocides. The Henry Doubleday Research Association (HDRA) – the organic organization - has a publication that establishes some basic data on termite control without synthetic termiticides.\textsuperscript{20} A Colorado State University review article highlighted alternative biological control methods for termites.\textsuperscript{21} Researchers at Louisiana State University have isolated naturally-occurring compounds known to repel termites. They are currently pursuing the synthetic production of these substances for potential soil treatments.\textsuperscript{22} Others have also been working on different areas with relation to the control of termites using alternative methods.\textsuperscript{23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36} Laboratory procedures for evaluating termite repellents have been developed by Puche and Su\textsuperscript{37} and Duryea.\textsuperscript{38, 39} The citations mentioned above describe
laboratory experiments to evaluate termite tunneling and foraging behavior as it relates to introduced variables.

In the past, most of the work with plants containing insecticidal qualities has centered on isolating the substances responsible for the termiticidal and/or repellent activity and producing them synthetically for soil treatments. Many of the current pesticides have been synthetically produced to mimic “natural pesticides”. Two common examples of this are pyrethroid insecticides which are modeled after pyrethrins, which occur naturally in some plants, and insect growth regulators that are synthetically produced to mimic hormones that affect insect growth. This research examines whether organic plant tissues and extracts themselves can be utilized as part of the landscape and provides natural termite barriers.

Objectives

1. To test hypothesis 1 above that by increasing the soil pH with non-biocidal soil amendments (N-BSA), a natural barrier will be formed around and under wood-framed structures that will discourage subterranean termite foraging.

2. To test hypothesis 2 above that by utilizing mulch that consists of, or has been amended with, plant material or extractives (T-RPT) derived from plants which have insecticidal qualities, a natural barrier will be established to discourage termite foraging.
CHAPTER II
MATERIALS AND METHODS

Introduction

This research project was designed to test on a laboratory scale hypotheses 1 and 2 above. The main focus was to determine effects of soil amendments and mulches containing, and/or amended with, tissues and extracts derived from plants exhibiting natural insect-repellent properties on the foraging activities of subterranean termites. Both Choice and No-Choice laboratory techniques and test protocols were utilized to evaluate the effects of different soil and mulch amendments on termite foraging. The Choice protocol (Figure 2) permits termites to freely forage in a test arena. For the purpose of this test, the termites were permitted to choose a preferred foraging path between test media or untreated sand. In contradiction to this method, a No-Choice protocol (Figure 3) was utilized to force the termites to forage in a given medium to acquire food and water to survive. The focus of this project covered two procedures:

1. Increase soil pH with soil amendments to form a subterranean termite barrier to discourage foraging.
2. Utilize plant material and plant extracts with insecticidal or insect repellent properties as mulch and/or mulch amendments to discourage termite foraging.
Figure 3. Choice Test Layout

Figure 4. No-Choice Test Layout.
Establishing Protocols for Evaluating Non-Biocidal Soil Amendment (N-BSA) and Termite Repellent Plant Tissue and Extractives (T-RPT)

Objectives

1. Establish laboratory choice protocols to test hypothesis 1 and 2 above.

2. Establish laboratory no-choice protocols to test hypothesis 1 and 2 above.

3. Record the foraging and feeding activities of subterranean termites in a controlled environment.

Choice and No-Choice testing protocols to evaluate different N-BSA and T-RPT products to discourage termite foraging were established during this project. The traditional American Wood Protection Association (AWPA) Standard E1-06 Choice and No-Choice procedures were not used due to the special needs for this test. The idea behind this testing protocol was to develop a method by which termite foraging could be observed and measured. There were several iterations of both the Choice and No-Choice protocols during the course of the research project, but there were several common procedures between the iterations. The pH determination was established at the beginning of the project. The plants needed for tissue acquisition were procured, grown, harvested, and dried. As the tests were conducted, the plant tissues were chopped and blended. The termites (*Reticulitermes* spp.) were collected for
both tests from one of two locations within a 30 mile (48.25 km) radius of Starkville, MS. The termites were stored in metal cans in the wood on which they were feeding until they were needed for the No-Choice tests. The termites for the Choice test were reestablished in bottles containing moist sand and a seasoned SYP wood block and stored in a climate-controlled (75°F (24°C) at 50% RH) area until needed. While the initial intention of this research was to have a yes or no as to the termite foraging within the arenas, the final Choice and No-Choice evaluations included the initial and final weights of the wood blocks and AWPA termite feeding ratings to provide another data point for verification of termite activity within a test arena.

pH Determination of Different N-BSA Products

The pH of the Non-Biocidal Soil Amendments (N-BSA) was determined to establish a benchmark. The different products were acquired locally in Starkville, MS. All materials used are readily available and common at farm and garden establishments. The chopped used tires and the recycled glass was purchased from American Specialty Glass, Inc located in North Salt Lake, Utah. Hydrated lime, pelletized lime, pulverized limestone, basic slag, chopped used tires, recycled glass, hydrated lime + sand (50:50), pelletized lime + sand (50:50), pulverized limestone + sand (50:50), basic slag + sand (50:50), chopped used tires + hydrated lime (50:50), recycled glass + hydrated lime (50:50), sand, and distilled water were analyzed to determine the pH of each. This was
accomplished by placing 10 g of each product and 20 ml of distilled water in a
beaker, shaking for three minutes, covering with aluminum foil for 24 hours,
straining through a medium to separate the liquid and then the liquid was tested
with a pH meter to determine the pH of each product.

Procuring and Preparing Termite Repellent Plant Tissues and
Extracts (T-RPT)

Procuring and preparation of the plant tissue and extracts were performed
with a common procedure throughout the different experimental iterations. The
plants from which the T-RPT samples selected for this experiment were chosen
for their historical use as insecticides and insect repellents and their ability to be
cultivated in the Southeastern United States. The availability of seeds and
mature plants of each species was evaluated to determine the individual plants
that would be utilized during this project. Drs. Richard Harkess and Richard
Watson of the Plant and Soil Science Department at Mississippi State University
(MSU) cultivated several of the plant species in green houses located on the
North Farm complex at MSU. The plants were grown in green houses and, with
flowering species, were harvested during the maturity stage while flowers were in
full bloom. The above-ground and/or root tissues were then allowed to dry
before being utilized. The dried tissues were stored in breathable paper bags to
prevent the growth of mold fungi. A food processor was used to reduce the plant
tissues to a concentrated form.
Four plant species and two commercially available oil extract products were selected to be utilized in this research project. Yarrow (*Achillea millefolium* L.), Mexican Marigold (*Tagetes minuta* L.), French Marigold (*Tagetes patula* L.), and Vetiver (*Vetiveria zizanioides* (L.) Nash), as well as, two commercially available products (Yard Safe and BestYet) which contained Cedar (*Juniperus* spp.) oil extract. The Yarrow, Mexican Marigold and French Marigold plants were grown from seed, the Vetiver was grown from plants procured from the MAFES Coastal Experiment Station located in Gulfport, MS and the cedar oil extract was provide in two commercially available forms by CedarCide Industries located in The Woodlands, TX.

**Acquiring Termites for Choice and No-Choice Tests**

The laboratory tests were conducted with native subterranean termites (*Reticulitermes* spp.) collected from the Dorman Lake test site and a site located in the Bradley community. Both of these sites are located in Oktibbeha county Mississippi which lies within AWPA wood-decay hazard zone 4 (Figure 4).
Log sections on which the termites were feeding were placed in metal cans and transported to the Forest Products Department complex on the campus of MSU. The termites in each case were collected in logs, stored in metal cans and separated from the log tissue when needed. When termites were needed for the No-Choice test, they were collected from the logs using a fine mesh screen and a hand-held hatchet. The termites were knocked out of the log sections, separated from debris, and weighed. The No-Choice test required the termites to be established in bottles for a minimum of
seven days (more preferably fourteen days) before being used. The glass bottles were filled with 150ml of sand, 30ml of distilled water, a weathered southern yellow pine wooden block. One gram of termites was added to each bottle. The lids were placed on the bottles, loosened by ¼ turn, and then the bottles were placed in cardboard boxes. The bottles were stored in a climate-controlled laboratory (75°F (24°C) at 50% RH) until needed for a test.

Choice Test Development

The Choice test was developed by modifying a similar test protocol utilized by Amburgey and Smythe\textsuperscript{44} to evaluate the foraging activities of termites. For each test, three identical replicates were used for each individual medium that was being tested. The initial tests were conducted using covered plastic containers with four southern yellow pine (SYP) sapwood blocks (one in each corner) with the termites being released in the center of the container (Figure 5). The procedure was modified, and the final test used two SYP blocks placed on one end of the container and the termites were released on the other end by inverting the glass jar in which they had been established and placing it on two pieces of wire (pvc coated). The test chamber in all tests consisted of a plastic container (12-1/4in x 9in x 4-1/8in or 31.55cm x 22.86cm x 10.48cm deep) and was divided into four zones (Figure 6). One hundred fifty milliliters (150ml) or (approximately ½ inch) of sand was added along with 26ml of distilled water distributed evenly over the sand. The procedure was modified for the final tests.
by making the following changes: (1) 250ml of sand was used, (2) 62.5 ml (25% by volume) of water distributed evenly, (3) smaller termite feeding jars so the chamber could be shut to minimize the evaporation of water. Two 9oz (266.16cc) plastic cups with the bottoms cut out were inverted on one end of the chamber. Three inches of sand was placed in one of the cups and the test medium (N-BSA or T-RPT) was placed in the other cup. One seasoned SYP feeder block (3⁄4 inch or 1.905cm cube) was placed on top of the sand in cup 1 and another identical block was placed on top of the test medium in cup 2 (Figure 7). The SYP feeder blocks were manufactured from seasoned southern yellow pine sapwood lumber. The initial test recorded only visual foraging activity and feeding activity on the SYP feeder block, but the final testing protocol added initial and final block weight and AWPA (American Wood Protection Association) Standard E-1 termite rating numbers as additional data points. For the final protocol, each SYP block was oven-dried, pre-weighed and added to the testing arena as a feeding element. The duration of the Choice tests was 28 days in a climate-controlled laboratory (75°F (24°C) at 50% RH) with periodic visual data sets gathered during the duration of the test to determine the termite foraging activities. The termite activity was recorded using a digital camera to determine which zone (Figure 2) the termites were foraging through. Visual observations were also made during each inspection. The termite activity was recorded 12, 24, and 48 hours and 4, 8, 12, 20, and 28 days after introducing termites into the containers.
Several N-BSA, T-RPT, common mulch products and a commercially available plant extract were evaluated in the first tests to determine which products demonstrated termite toxicity and/or repellent activity. Several of the N-BSA products were diluted to a 50:50 ratio with sand to determine any concentration effects on the capacity of a product to discourage termite foraging. The following products were tested in the initial screening:

- Hydrated lime
- Hydrated lime and sand 50:50
- Pelletized lime
- Pelletized lime and sand 50:50
- Pulverized lime
- Pulverized lime and sand 50:50
- Basic Slag
- Basic Slag and Sand 50:50
- Glass (fines)
- Glass (fines) and hydrated lime 50:50
- Used tires (chopped)
- Used tires (chopped) and hydrated lime 50:50
- Mulch (shredded rubber)
- Mulch (hardwood shredded)
- YardSafe (cedar oil product)
- Ree-Pell (cedar oil product)
• Mexican Marigolds (T. minuta) – air dried for one week
• French Marigolds (T. patula) – air dried for one week
• Yarrow (A. millefolium) – air dried for one week
• Wormwood (Artemisia absinthium L.) – air dried, cut and sifted
  (purchased from Richter's located in Goodwood Ontario, Canada)
• Vetiver Grass (V. zizanioides) – air dried for 48 hours
• Hardwood Mulch sprayed with Best Yet (CedarCide Industries commercial cedar oil product) allowed to dry for 2 hours

The products were rated on performance in preliminary tests, and those selected for use in the final tests were:

• Yarrow (A. millefolium)
• Mexican Marigold (T. minuta)
• French Marigold (T. patula)
• Vetiver (V. zizanioides)
• Hardwood Mulch
• Hardwood Mulch + Best Yet (cedar oil product)
• Used Tires (chopped)
• Rubber Mulch (purchased from Lowe’s)
• Yard Safe (cedar oil product)
• Hydrated Lime
• Pelletized Lime
• Basic Slag
Figure 6. Four Block Choice Test Protocol

Plastic container divided into four sections
- Forms were used to keep products from mixing during construction

Sand was added to the container

Test medium and wooden feeder blocks were added
- The test medium was added to opposite corners (top right and bottom left)
- The remaining corners were sand only

Termites were added to the center of the container
Figure 7. Choice Protocol Description and Final Configuration.
The No-Choice test was developed by modifying a protocol utilized by Grace\textsuperscript{45} to observe and record the foraging activity of subterranean termites. The same N-BSA and T-RPT test media were used for the No-Choice test as were used in the Choice test. There also were several iterations of this test before a final protocol was established. The termites were collected as described above and collected when needed to set up individual tests. For the initial evaluation, the termite workers and soldiers were counted to get a

Figure 8. Two Block Choice Test Procedure.

---

**Step 1:**
- Plastic container with sand, termites, sand control, and test media

**Step 2:**
- Termites were released into the test arena by inverting the glass jar (center right) and placing the jar on two spacers.
- The sand control (top left) and the test medium (bottom right)
- The wooden feeder blocks were placed on top of the sand control and test medium.

**Step 3:**
- Steps were repeated for all test mediums

**Step 4:**
- Plastic containers were stacked and data was recorded at pre-set intervals to determine the termite foraging activity
representation of a natural caste ratio (98% workers and 2% soldiers). The termite sample was then weighed and this weight was used for the remaining tests. The initial tests were stored in a climate-controlled environmental chamber but during the final test, they were stored in a climate-controlled laboratory.

The initial test evaluated the effectiveness of N-BSA and T-RPT in deterring termite foraging. The N-BSA products used were hydrated lime, dolomitic lime, pelletized lime, potash and zinc borate. The T-RPT products used were vetiver tops, vetiver roots, vetiver tops and roots and two commercial cedar oil products (CedarCide Ree-Pell 1014 Nocdown V, and CedarCide Yard Safe). Termite foraging and movement was evaluated within a tunneling arena. The arena was created from compartment storage containers that measured 6-1/4" x 3-1/2" (15.875cm x 8.89 cm) and had five compartments that measured 1-1/2" x 3-1/2" (3.81cm x 8.89cm) each. The containers were modified by drilling holes in the base of each end of each compartment to accept 1-1/2" (3.81cm) long ¼" OD Tygon tubing. Each compartment represented a tunneling arena and was connected to the base of two 55 ml polystyrene vials, each containing 20 g of silica sand and 4 ml of distilled water (Figure 8). The center tunneling areas between the two vials were filled with hydrated lime, dolomitic lime, zinc borate, potash or sand. A block of weathered SYP wood was placed in one of the two vials. Two hundred (195 workers and 5 soldiers, to mimic natural caste proportions) termites were collected from the wood, counted, separated, weighed and placed in one of the two vials. The averages of three samples were taken to
determine the 0.50g of termites by weight would equal a proportion equal to the natural caste within a *Retculitermes* spp. colony. For the initial test, five replicates of each N-BSA, T-RPT and sand controls were constructed. All replicates were placed in an unlit incubator at 80°F for 4 weeks (28 days). At the end of the period, the termite tunneling through the arena and feeding activity on wood was recorded. For the next test the procedure was modified slightly by placing the five replicates of each non-biocidal soil amendment (N-BSA), termite-repellent plant tissue (T-RPT) and sand controls in a temperature–controlled (75°F (24°C) at 50% RH) room that remained unlit for 4 weeks (28 days). A computer-controlled temperature/humidity recorder was placed in the room to record the climatic data for the duration of the test. At the end of the period, the termite tunneling through the arena and feeding activity on wood was recorded.
The final No-Choice arrangement was constructed by attaching a three compartment plastic container to two other identical containers using clear vinyl tubing (Figure 9). The first container was the release chamber where the termites were introduced. The second chamber was the test arena where either sand or a variable was placed to determine the termite foraging activity through the substance. The third chamber was the feeding arena where a seasoned SYP block was placed to record feeding activity. At the conclusion, the blocks were oven dried, weighed and rated according to the AWPA Standard E1 for termite attack. The duration of the test was changed from 28 days to 14 days.
The testing arenas measure 3-1/4 inches x 6-3/4 inches (82.55mm x 171.45mm) and were divided into three equal compartments measuring 3-1/4 inches x 2-1/4 inches (82.55mm x 57.15mm). Three of these units were used to create one testing apparatus (Figure 10). Holes 3/16 inch (4.76mm) in diameter were drilled into the compartments of each unit so a 2-1/4 inch (57.15) piece of 3/8 inch (9.53mm) OD x 1/4 inch (6.35mm) ID clear vinyl tubing could be inserted to connect the three units. Sand (60ml) and distilled water (4 ml) were placed in the initial arena, the center compartment in the middle arena, and in the feeding arena. The variables (N-BSA and T-RPT) were placed in the two outer

Figure 10. Three Compartment No-Choice Arrangement
compartments of each middle area. A seasoned SYP block (3/4 inch (19.05mm) x cube) wood block was placed in each feeding arena and 0.50 gram (approx. 200) of termites (*Reticulitermes* spp.) were placed in each release arena (Figure 10). The termite activity was monitored for 14 days. At the end of 14 days, the feeder blocks were oven-dried, weighed and rated according to the AWPA termite rating standard. The products tested are listed below.

- Yarrow (*A. millefolium*)
- Mexican Marigold (*T. minuta*)
- French Marigold (*T. patula*)
- Vetiver (*V. zizanioides*)
- Hardwood Mulch
- Hardwood Mulch + Best Yet (cedar oil extract)
- Used Tires
- Rubber Mulch
- Yard Safe (cedar oil extract)
- Hydrated Lime
- Pelletized Lime
- Basic Slag
Figure 11. No-Choice Protocol Description and Final Configuration.
CHAPTER III
RESULTS AND DISCUSSIONS

This research project has uncovered some very crucial pieces to the puzzle of repelling termites in the Inner Detritus Zone utilizing natural minerals and plants. The research performed for this project is only a portion of what is needed to develop a holistic approach to biological structure durability utilizing the three zone approach. Future work is needed to collect field data on the techniques and products as well as evaluating the combined effect that the soil and mulch amendments have on discouraging termite foraging. It is theorized that the integration of these approaches could be equal to or greater than current termite control techniques and products utilized.

pH Determination

The results of the pH test on the amendments being utilized were recorded (Table 1) and were used as a basis for product selection and subsequent testing.
Table 1. Three Compartment No-Choice Arrangement.

<table>
<thead>
<tr>
<th>Non-Biocidal Soil Amendment (N-BSA)</th>
<th>pH of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated Lime</td>
<td>12.7</td>
</tr>
<tr>
<td>Pelletized Lime</td>
<td>7.7</td>
</tr>
<tr>
<td>Pulverized Limestone</td>
<td>8.1</td>
</tr>
<tr>
<td>Basic Slag</td>
<td>12.5</td>
</tr>
<tr>
<td>Used Tires (chopped)</td>
<td>6.9</td>
</tr>
<tr>
<td>Recycled Glass</td>
<td>10.3</td>
</tr>
<tr>
<td>Hydrated Lime + Sand (50:50)</td>
<td>12.8</td>
</tr>
<tr>
<td>Pelletized Lime + Sand (50:50)</td>
<td>7.7</td>
</tr>
<tr>
<td>Pulverized Limestone + Sand (50:50)</td>
<td>9.3</td>
</tr>
<tr>
<td>Basic Slag + Sand (50:50)</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Termite-Repellent Plant Tissue (T-RPT) Procurement and Preparation

The process utilized to prepare the samples for this test proved to be very efficient and effective. The plant species utilized (Table 2) grew well in the greenhouses and yielded high quality tissue for this project.
Table 2. Plants grown, dried, prepared and evaluated for ability to deter subterranean termite foraging in both Choice and No-Choice tests.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarrow</td>
<td><em>Achillea millefolium</em> L.</td>
</tr>
<tr>
<td>Mexican Marigold</td>
<td><em>Tagetes minuta</em> L.</td>
</tr>
<tr>
<td>French Marigold</td>
<td><em>Tagetes patula</em> L.</td>
</tr>
<tr>
<td>Vetiver</td>
<td><em>Vetiveria zizanioides</em> (L.) Nash</td>
</tr>
</tbody>
</table>

Termite Establishment in Feeder Jar for Choice Test Protocol

The termites in the initial configuration had 100% mortality. It was determined that the jar lids were placed on too tightly and therefore the oxygen supply within the jars was depleted which resulted in termite mortality. Subsequent feeder bottles that utilized the modified protocol which required the jar lids to be loosened by 1/4 turn, had positive results with no termite mortality and provided healthy termites for the Choice tests.

No-Choice Testing Protocol

The No-Choice protocol established during this project proved to be a very effective way of evaluating the termite foraging behavior of N-BSA and T-RPT. Through several attempts, the proper container size (3-1/4 inches x 6-3/4 inches (82.55mm x 171.45mm) three compartments), the proper amounts of sand, water, and time were established for a successful evaluation. The N-BSA products (hydrated lime, pelletized lime and basic slag) that were chosen through
the different iterations performed very well in discouraging termite foraging (Tables 3 and 4). The T-RPT products (Tables 3 and 4) had mixed results with the best performer being the Mexican Marigold and Yarrow and the worst performer being the Vetiver (Tables 3 and 4). This was unexpected due to the previous work done on the repellent nature of the Vetiver plant on termites by other researchers. This definitely warrants more research on the Vetiver product.

The pure mulch products (hardwood mulch, rubber mulch and chopped tires) had very little effect on discouraging termite foraging (Tables 3 and 4). The amended mulch performed much better and discouraged termite foraging (Figure 11). Both of the cedar oil products (YardSafe and Best Yet) tested in the project yielded very promising results (Tables 3 and 4).

Table 3. Results from the No-Choice Test 1.

<table>
<thead>
<tr>
<th>Product</th>
<th>Average Block Rating $^a$</th>
<th>Median Block Rating</th>
<th>Average Block Weight Loss $^a$%</th>
<th>Median Weight Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-RPT</td>
<td>9.13</td>
<td>10.00</td>
<td>1.23</td>
<td>1.07</td>
</tr>
<tr>
<td>T-RPT Control</td>
<td>8.25</td>
<td>8.00</td>
<td>3.62</td>
<td>3.28</td>
</tr>
<tr>
<td>Mulch Products</td>
<td>9.43</td>
<td>9.50</td>
<td>1.33</td>
<td>0.37</td>
</tr>
<tr>
<td>Mulch Products Control</td>
<td>8.33</td>
<td>9.00</td>
<td>1.55</td>
<td>1.51</td>
</tr>
<tr>
<td>CC Products</td>
<td>10.00</td>
<td>10.00</td>
<td>0.30</td>
<td>0.34</td>
</tr>
<tr>
<td>CC Products Control</td>
<td>7.00</td>
<td>7.00</td>
<td>7.98</td>
<td>7.98</td>
</tr>
<tr>
<td>N-BSA</td>
<td>10.00</td>
<td>10.00</td>
<td>0.70</td>
<td>0.72</td>
</tr>
<tr>
<td>N-BSA Controls</td>
<td>7.00</td>
<td>7.00</td>
<td>2.65</td>
<td>1.67</td>
</tr>
</tbody>
</table>

$^a$ Average of three replicates.
Table 4. Results from the No-Choice Test 2.

<table>
<thead>
<tr>
<th>Product</th>
<th>Average Block Rating a</th>
<th>Median Block Rating</th>
<th>Average Block Weight Loss a %</th>
<th>Median Weight Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-RPT</td>
<td>9.50</td>
<td>10.00</td>
<td>0.79</td>
<td>0.38</td>
</tr>
<tr>
<td>T-RPT Control</td>
<td>7.00</td>
<td>7.00</td>
<td>3.97</td>
<td>4.07</td>
</tr>
<tr>
<td>CC Products</td>
<td>10.00</td>
<td>10.00</td>
<td>0.68</td>
<td>0.77</td>
</tr>
<tr>
<td>CC Products Control</td>
<td>7.00</td>
<td>7.00</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td>Mulch Products</td>
<td>9.13</td>
<td>9.50</td>
<td>1.13</td>
<td>0.75</td>
</tr>
<tr>
<td>Mulch Products</td>
<td>8.00</td>
<td>7.00</td>
<td>2.33</td>
<td>2.26</td>
</tr>
<tr>
<td>Control</td>
<td>10.00</td>
<td>10.00</td>
<td>0.54</td>
<td>0.53</td>
</tr>
<tr>
<td>N-BSA Control</td>
<td>7.67</td>
<td>7.00</td>
<td>1.49</td>
<td>1.50</td>
</tr>
</tbody>
</table>

a Average of three replicates.

Figure 12. Hardwood mulch compared to hardwood mulch amended with BestYet (cedar oil extract). In the AWPA rating system, 10 is the best and a rating of 7 or below is a failure. All figures are the average of three replicates.
Figure 13. Hardwood mulch compared to hardwood mulch amended with BestYet (cedar oil extract). The SYP feeder blocks were oven dried and weighed before and after the test to determine percentage weight loss. All figures are the average of three replicates.

Results using the initial test configuration utilizing a five compartment testing arena, as shown in (Figure 13), indicated that the soil amendments (Table 5) chosen discouraged termite foraging and provided a natural barrier. The termites did not move through the test medium and locate the food source (wood block) and subsequently died over the 28 day test. The termites did move through the sand controls and locate the food source (wood block). The termites were actively feeding on the food source at the conclusion of the 28 day test. After the second test, the five compartment testing arena was replaced by a three compartment testing arena (Figures 14 and 15).
Figure 14. Five Compartment No-Choice Protocol.

- Five compartment plastic container
  - Holes were drilled in each side of each compartment

- Plastic vials with Tygon tubing inserted
  - Vials were attached to each side of each compartment

- Finished configuration
  - Each compartment was filled with the test medium
  - Vials on one side contained sand and termites and the other side contained sand and a wooden feeder block.

- Closeup of configuration
Table 5. Results after 28 days from Five Compartment No-Choice Test. This was the initial test before wood weight loss and AWPA E1 block rating was added. The initial test recoded “Yes” or “No” to termites foraging in the three different arenas.

<table>
<thead>
<tr>
<th>Product</th>
<th>Termite Activity in Release Arena</th>
<th>Termite Activity in Foraging Arena</th>
<th>Termite Activity in Feeding Arena</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Yes: x</td>
<td>No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td>Yes: x, No: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Pelletized Lime</td>
<td>Yes: x, No: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Potash</td>
<td>Yes: x, No: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>CedarCide Ree-Pell 1014</td>
<td>Yes: x, No: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>CedarCide Yard Safe</td>
<td>Yes: x, No: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Vetiver Tops</td>
<td>Yes: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Vetiver Roots</td>
<td>Yes: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
<tr>
<td>Vetiver Tops &amp; Roots</td>
<td>Yes: x</td>
<td>Yes: x, No: x</td>
<td>Yes: x</td>
</tr>
</tbody>
</table>
The three compartment testing arena was replicated several times with similar results. The termites foraged through the sand and the N-BSA and T-RPT deterred termite foraging (Tables 3 and 4). The weight loss and AWPA termite feeding rating of the blocks (Figures 16 and Figure 17) compare the feeding activity of the different media tested. There is a relationship between high block ratings (which indicate less feeding) and low block weight losses (which indicate less feeding). There is also a relationship between low block ratings (which indicates more feeding) and high block weight losses (which
indicates more feeding). All N-BSA and cedar extractive amended products tested (Figure 16) had the highest block rating of 10 (no feeding) and a weight loss of less than 1%. The T-RPT samples had a slightly lower block rating of 9.5 but the weight loss percentage was still less than one. The N-BSA and cedar extractive products had slightly higher wood feeder block ratings and lower weight loss percentages than the T-RPT products in a replicated test (Figure 17). Both sets of data showed a large difference between the N-BSA and T-RPT test products and the sand control arenas indicating the modification of the environment with N-BSA, T-RPT, or cedar extractives deter termite foraging in these areas and likely will prove to be useful in the Inner Detritus Zone around structures.

![No-Choice Test Configuration](image1)

![No-Choice Test after 14 Days](image2)

Figure 16. Results from 14 day No-Choice Test. The "V" represents the variable, the "C" represents the control, and the "T" represents the termites. See the termite feeding on the SYP feeder block from the sand control arena.
Figure 17. Results after 14 Day No-Choice Test. Comparing AWPA SYP Wood Feeder Block Termite Rating and Wood Feeder Block Weight Loss %. The sets of bars represent the overall ratings and weight loss % for each group. The bars in each group represent from left to right, T-RPT, T-RPT Control, Cedar Oil Products, Cedar Oil Product Control, Mulch Products, Mulch Products Control, N-BSA, and N-BSA Control. All figures are averages of three replicates.
Figure 18. Results after 14 Day No-Choice Test. Comparing AWPA Wood Feeder Block Termite Rating and Wood Feeder Block Weight Loss %. The sets of bars represent the overall ratings and weight loss % for each group. The bars in each group represent from left to right, T-RPT, T-RPT Control, Cedar Oil Products, Cedar Oil Product Control, Mulch Products, Mulch Products Control, N-BSA, and N-BSA Control. All figures are averages of three replicates.

Choice Testing Protocol

The Choice protocol established during this project proved to be a very effective way of evaluating the termite foraging behavior of N-BSA and T-RPT. Through several attempts, the proper container size (12-1/4in x 9in x 4-1/8in or 31.55cm x 22.86cm x 10.48cm deep) the proper number of wood feeder blocks and the proper amounts of sand, water, and time were established for a successful evaluation (Figure 19). The termite foraging was visually recorded by which zone the termites foraged through as it relates with the duration of the test (Table 6). Three of the N-BSA products (hydrated lime, pelletized lime and basic...
slag) consistently performed very well in discouraging termite foraging. The T-RPT products had mixed results with the best performers being the Mexican Marigold and Yarrow with the worst performer being the Vetiver (Table 6 and Figure 18). This was unexpected due to the previous work done on the repellent nature of the Vetiver plant on termites. This definitely warrants more research. All of the cedar oil products tested in the project yielded very promising results.
Table 6. No-Choice Test 1 Results. This was the visual observations to determine where the termites were foraging. "Y" equals yes, termites were present in the foraging arena and "N" equals no termites were present in the foraging arena.

<table>
<thead>
<tr>
<th>Products</th>
<th>Termites in Control</th>
<th>Termites in Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarrow Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Yarrow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexican Marigold Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Mexican Marigold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>French Marigold Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>French Marigold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vetiver Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Vetiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HM+BestYet Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>HM+BestYet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardwood Mulch Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Hardwood Mulch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used Tires Chopped Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Used Tires Chopped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber Mulch Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Rubber Mulch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YardSafe Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>YardSafe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrated Lime Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelletized Lime Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Pelletized Lime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic Slag Control</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Basic Slag</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 19. No-Choice Test 1 T-RPT. The % weight loss and the AWPA block rating are compared between Arena 1 and Arena 2. All figures are averages of three replicates.
Figure 20. Bottom View of Choice Test Protocol. Termites were released on the left of the box (see concentration of tunnels) and the sand control was located in the top right corner (see outline of circle) and the test medium was placed in the bottom right.
The initial test configuration was constructed in a four-block design which yielded varying results. This procedure had acceptable termite foraging in the first few days, but the termite foraging activity decreased between days six and fourteen. Smaller termite feeding jars were used to avoid drying of sand in the testing arenas, and a few of the products produced volatiles which cause termite mortality. Vent holes were placed in the tops of the plastic containers for future tests to solve this challenge. The testing protocol was modified and the final design was created using a two block configuration. The two block protocol results are represented in (Figures 21 and 22 and Tables 7 and 8). The majority of the sand control arenas were breached by the termites and feeding on the wood feeder block ensued (Figure 20). The majority of the N-BSA arenas were not breached. The best performing N-BSA was the hydrated lime product which performed well in all of the tests (Figures 23 and 24). There were a few instances where some of the N-BSA arenas where partially or completely breached, but visual observations showed that the termites died and that there was consistently less damage to the SYP wood feeder blocks than to those exposed in the corresponding untreated controls. The block weight losses and ratings are shown in (Figures 21 and 22 and Tables 7 and 8). The N-BSA and T-RPT samples performed very well in discouraging the termite foraging while the sand control samples were very favorable for termite foraging. The termites were not as aggressive in this test (Figure 22 and Table 8) and did not consume as

much of the SYP wood feeder block but they did breach the sand controls more aggressively than the test media.

![Choice Test Configuration](image1)

![Choice Test after 28 Days](image2)

\[ V = \text{Variable (N-BSA, T-RPT)} \]
\[ C = \text{Control (Sand)} \]
\[ T = \text{Termites} \]

Figure 21. Results from 28 day Choice Test. The "V" represents the variable, the "C" represents the control, and the "T" represents the termites. Termites breached the sand control “C” and completely covered the SYP wood feeder block with sand as shown above. Termites did not breach the test medium “V” as shown above.
Figure 22. Feeder Block Termite Ratings and Weight Loss %. The sets of bars represent the overall ratings and weight loss % for each group. The bars in each group represent from left to right, T-RPT, T-RPT Control, Cedar Oil Products, Cedar Oil Product Control, Mulch Products, Mulch Products Control, N-BSA, and N-BSA Control. All figures represent the average of three replicates.
Figure 23. Feeder Block AWPA Termite Rating and Weight Loss %. The sets of bars represent the overall ratings and weight loss % for each group. The bars in each group represent from left to right, T-RPT, T-RPT Control, Cedar Oil Products, Cedar Oil Product Control, Mulch Products, Mulch Products Control, N-BSA, and N-BSA Control. All figures represent the average of three replicates.

Table 7. Results Choice Test 1.

<table>
<thead>
<tr>
<th>Product</th>
<th>Average Block Rating $^a$</th>
<th>Median Block Rating</th>
<th>Average Weight Loss $^a$ %</th>
<th>Median Weight Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-RPT</td>
<td>9.25</td>
<td>10.00</td>
<td>1.27</td>
<td>0.47</td>
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<tr>
<td>T-RPT Control</td>
<td>6.75</td>
<td>7.00</td>
<td>5.61</td>
<td>5.92</td>
</tr>
<tr>
<td>CC Products</td>
<td>9.17</td>
<td>9.00</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>CC Products Control</td>
<td>8.33</td>
<td>9.00</td>
<td>1.71</td>
<td>0.51</td>
</tr>
<tr>
<td>Mulch Products</td>
<td>8.33</td>
<td>9.00</td>
<td>2.06</td>
<td>1.37</td>
</tr>
<tr>
<td>Mulch Products Control</td>
<td>7.22</td>
<td>7.00</td>
<td>4.98</td>
<td>5.53</td>
</tr>
<tr>
<td>N-BSA</td>
<td>9.11</td>
<td>9.00</td>
<td>0.60</td>
<td>0.49</td>
</tr>
<tr>
<td>N-BSA Controls</td>
<td>7.22</td>
<td>7.00</td>
<td>6.20</td>
<td>6.65</td>
</tr>
</tbody>
</table>

$^a$ Average of three replicates.
Table 8. Results Choice Test 2.

<table>
<thead>
<tr>
<th>Products</th>
<th>Average Block Rating</th>
<th>Median Block Rating</th>
<th>Average Block Weight Loss (^a)</th>
<th>Median Weight Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-RPT Control</td>
<td>9.17</td>
<td>9.00</td>
<td>0.49</td>
<td>0.00</td>
</tr>
<tr>
<td>T-RPT</td>
<td>9.08</td>
<td>9.00</td>
<td>0.44</td>
<td>0.00</td>
</tr>
<tr>
<td>CC Products</td>
<td>9.17</td>
<td>9.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>CC Products Control</td>
<td>9.00</td>
<td>9.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mulch Products</td>
<td>8.67</td>
<td>9.00</td>
<td>0.90</td>
<td>0.00</td>
</tr>
<tr>
<td>Mulch Products Control</td>
<td>8.33</td>
<td>9.00</td>
<td>2.54</td>
<td>1.18</td>
</tr>
<tr>
<td>N-BSA Control</td>
<td>9.11</td>
<td>9.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>N-BSA Products</td>
<td>7.67</td>
<td>7.00</td>
<td>2.70</td>
<td>2.48</td>
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</tbody>
</table>

\(^a\) Average of three replicates.

Figure 24. Choice Test 1 Results. AWPA E1 block rating between the three replicated configurations. All figures represent the average of three replicates.
Figure 25. Choice Test 1 Results. Percentage weight loss of SYP feeder block for the three replicated configurations. All figures represent the average of three replicates.
Structure Durability – Biodegradation Discussions

The results of this initial study indicate that by developing an integrated termite repellent system consisting of non-biocidal soil amendments and tissue and extracts from insect repellent plants, termite foraging can be discouraged or minimized in laboratory tests. It is believed that similar results will occur in field tests. While this particular study focused on the Inner Detritus Zone as described in Figure 1, it is very critical that future field tests are performed to expand on the other zones and the overall system be evaluated for total biological durability of wood-framed structures. Durability as it relates to this project was defined as the ability of a structure to withstand attack from subterranean termites. Within the southern climatic zones, the main elements that should be addressed are moisture and wood destroying organisms. The structure should be designed, constructed and maintained in a fashion that recognizes these challenges, and techniques, products, and maintenance schedules should be used to address the challenges. The marketing of building materials, lack of education or other factors that result in the misuse of products can affect the overall durability of a structure by allowing the intrusion of moisture. Proper landscaping is very important in creating the holistic approach to residential wood frame structures. The choice of flower bed placements, plants, and drainage plays a very large role in the long-term durability of a residential structure.

Traditional structures that have withstood time in the southern United States, China and other areas with hot / humid climates can provide a wealth of
knowledge about designs and materials that are durable and will stand the test of time. In traditional southern designs the raised floors; ventilated sub-floor areas, walls, and roofs; large roof overhangs; and porches extending around the entire residential structure provided air circulation and shade for comfort and moisture management for wood-destroying organism control. These ideas and techniques can be equated to the pagoda style used in Chinese structures. The durability of wood-frame structures has been demonstrated through historical reviews of structure design techniques and in general observations about what works and what doesn’t in areas where hot humid conditions prevail.\textsuperscript{46,47,48,49,50,51,52,53,54,55,56,57, 58,59,60,61} This knowledge and insight should be drawn upon and used for the creation of a contemporary southern climatic housing model. Due to changing comfort demands by current generations and the creation of new technologies, new and improved designs and techniques are needed. Even though we have to make accommodations for air-conditioning, energy efficiency, building materials, etc, we don’t have to weaken the integrity of the structure. The basic principles of durability, comfort and efficiency still hold true as they did in structures of the past. By examining these structures and techniques used, we as researchers, professionals and students can learn the basic foundation principles needed to create a biologically durable wood-frame structure that will perform well under southern climatic conditions.
CHAPTER IV

CONCLUSIONS

This research project provided very valuable information on the effects of different Non-Biocidal Soil Amendments (N-BSA) and Termite-Repellent Plant Tissues (T-RPT) on the foraging behavior of subterranean termites. Laboratory tests indicate that the addition of N-BSA products around the perimeter of a structure and the T-RPT and plant extracts to the mulch located in the Inner-Detritus Zone should be very effective alternatives to traditional soil treatments. When these products were added to the termite environment in the laboratory tests, the foraging activity was altered by directing the termites away from the amended areas. By incorporating these products into an integrated pest management system, the termite pressure on a wood-frame structure should be minimized by providing natural barriers around structures. These results need to be verified in field tests.
CHAPTER V

POTENTIAL APPLICATIONS AND FUTURE RESEARCH

The overall pest management industry is changing due to many factors, and consumers are interested in minimizing chemical use in and around homes, schools, churches, and businesses. These areas can be considered mini-environments and each area can be broken into three zones: (1) the structure footprint, (2) inner detritus zone, and (3) outer detritus zone. The principal area of concern in the structure footprint is moisture control. The inner detritus zone (24 inches or 0.61m from the edge of the footprint) needs to contain moisture minimizing features as well as termite repelling / eliminating products, and the outer detritus zone should contain both moisture control and termite repellent features. By utilizing an integrated system consisting of non-biocidal soil amendments, termite repellent plant tissues and extracts, a sound knowledge of wood destroying organisms, low-impact insecticides, regional structure design and planned landscape designs, the overall biological durability of a structure will be increased by minimizing the environmental factors needed by wood destroying organisms to survive. This project has warranted future expansion into field tests and more integration of structure design and natural plantings into a master plan. The laboratory protocols developed during this project can be
utilized in future screening tests of materials that could be added to an area to reduce or eliminate foraging by subterranean termites.
REFERENCES


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