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ECHNOLOGY TRANSFER CONFERENCE • CONGRÈS SUR LE TRANSFERT DES TECHNIQUES

ES RECHERCHES SUR L'ENVIRONNEMEN

ISSN 0825-4591

PROCEEDINGS

VOLUME II:

FEATURE PRESENTATIONS
EMISSIONS AND EFFLUENTS
ENVIRONMENTAL TECHNOLOGIES PROGRAM
PREVENTION, TREATMENT AND REMEDIATION
TECHNOLOGIES/BIOTECHNOLOGY

THE MULTI-MEDIA APPROACH: Integrated Environmental Protection

November 25 & 26, 1991
Four Seasons
Inn on the Park
Toronto, Ontario
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BEHAVIORAL ECOLOGY OF THE EASTERN SUBTERRANEAN TERMITE IN ONTARIO AS A BASIS FOR CONTROL

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ABSTRACT

Subterranean termites are serious structural pests which cause economic losses on the same order of magnitude as fire. Their range in Ontario has steadily increased over the last sixty years despite municipal efforts and a Ministry of Environment-funded grant program to control and contain them. Conventional chemical control is environmentally unacceptable and fails to kill the colony which simply expands its foraging range following chemical treatment. The objectives of our research have been to develop a control strategy to kill whole termite colonies based on sound fundamental knowledge of behaviour and ecology, to demonstrate the ability to extirpate localized populations, and thus to provide a means for municipal-wide termite eradication in Ontario. Through mark-release-recapture studies we have gained a much clearer understanding of the population size, biomass, density, dispersion, territory size and foraging dynamics of northern populations of this species. Populations number in the millions, covering thousands of square meters, with typical densities of about 2,000 per square meter. The caste system, population structure, and seasonal development have been studied. To understand over-wintering, experiments have been conducted on metabolic heat output and termite movement in relation to soil temperature. To understand summer moisture stress, studies were conducted on water imbibition, water transport, and regurgitation on soil and wood for microhabitat humidity control. The effect of soil structure on water availability, rates of tunnelling, and shelter tube construction were investigated. Above-ground foraging on trees is a strong behavioral tendency of *R. flavipes* which is not exhibited by other *Reticulitermes* species in North America. Tree foraging by *R. flavipes* has been further investigated. These biological findings have enabled us to improve aggregation trap designs and trap efficiencies--as many as 42,000 termites have been taken from a single trap and over a half million termites taken from a single plot. A Trap-Treat-Release approach has been investigated in which the trapped termites are treated in ways which induce delayed mortality and transmit slow-acting toxicants or vector microbial biocontrol agents back into the colony. Several borate compounds have been studied as slow-acting transmissible stomach poisons. Some show considerable promise and can be applied either in baits or as cuticular dusts. We have shown that cuticular loading of dusts can be greatly increased with various nontoxic spray paints used as sticking agents. Using sprays to increase loads of borate dust we have found effective lethal ratios of treated to untreated as low as 1:20. Several fungi, viruses, and nematodes have promise as biocontrol agents by the Trap-Treat-Release approach. Physical treatments could be used in conjunction with pathogens. Physical treatments such as gamma and X-ray, and UV irradiation all induce delayed mortality. Inter-colony agonism has not been discovered in Ontario suggesting a possible founder effect and reduced genetic variability which raises the possibility of using treated termites from one colony to invade and vector pathogens or slow-acting toxicants into another colony. Further study will improve trapping and treatment protocols and should make the Trap-Treat-Release approach a viable tool for eradicating termite populations from Canadian cities.

Introduction

The eastern subterranean termite, *Reticulitermes flavipes*, is now known to infest 32 municipalities in southern Ontario. The human population of Ontario is 9,426,100 of which 3,783,161 (40%) reside in the 32 infested municipalities. This termite species was first recorded from Point Pelee in 1929 and its introduction to Toronto is believed to have occurred between 1935 and 1938 (Kirby, 1967). As of 1988, the Toronto Housing Department reported that 5,730 houses had been treated, or about 5% of the total housing stock of the city. These infestations occur on 437 blocks or about 15% of the total city blocks. The average cost for chemical treatment and wood-soil separation in 1988 was $3,272. From 1975 to 1989 the Ontario Ministry of the Environment expended $5.6 million on its Termite Control Program which assisted home owners in covering the cost of treatment. Unfortunately, the spread of termites has not been curtailed and the assistance program has now been suspended. With financial backing from municipal, provincial and federal sources the Urban Entomology Program in the Faculty of Forestry at the University of Toronto was established in 1987 explicitly to conduct applied research for the development of an integrated pest management approach to control the eastern subterranean termite. Dr. J. Kenneth Grace directed the program from 1987 to 1990. Dr. Tim Myles has directed the program since 1990.

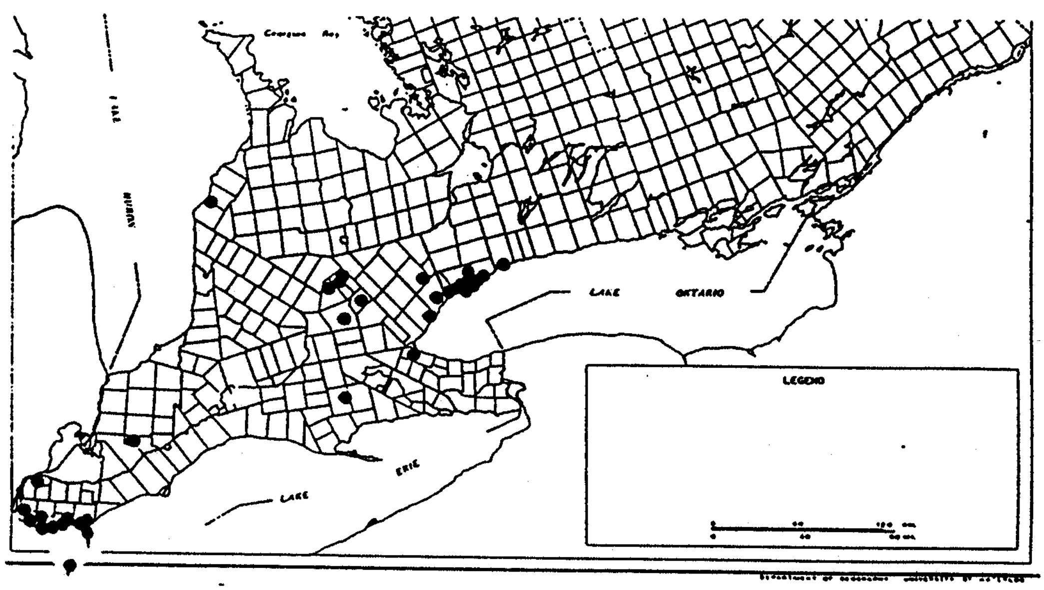

Figure 1. Known distribution of termites in Ontario. Infested municipalities include: Windsor, Malden Centre, Colchester, Kingsville, Leamington, Oxley, Harrow, Mersea, Gosfield South, Amherstberg, Point Pelee, Pelee Island, Dresden, Kincardine, Guelph, Elora, Fergus, Nichol, Woolwich, Kitchener, Hamilton, Oakville, Brampton, Mississauga, Toronto, North York, York, Etobicoke, Scarborough, East York, Pickering, Markham, Old Windham(?).

Population Dynamics and Foraging Behaviour

Esenther (1970) was the first to use the mark-release-recapture method to estimate *R. flavipes* population size in the field. His population estimates varied from 0.32 to 9.5 million termites. Grace et al (1989) and Grace (1990) used similar methods and arrived at estimates of 0.72 to 3.2 million termites. An intensive mark-release-recapture study on a single plot in Kincardine was conducted during the summer of 1990. The daily rate of mortality was adjusted to minimize variation among sequential 4-day estimates. A final population estimate of 4.2 million termites was calculated. The mark-release recapture method is also useful for measuring the foraging territories of colonies. Grace et al reported territories up to 1,091 m^2. The Kincardine study in 1990 indicated a foraging territory of 1,344 m^2. Typical lot sizes on the east side of Toronto are 25 X 100′ indicating that a single colony could overlap five or more entire properties.

Penultimate nymphs overwinter and transform to final stage nymphs and then to winged alates from March through May. Winged alates do develop in Ontario populations but flight records are uncommon due to the inconspicuous nature of most flights. The most abundant reproductive caste in field populations are the nymphoid supplementary neotenics and field evidence indicates a seasonal peak of neotenic development also occurs in the spring. Eggs, small larvae and presoldiers are found through the summer months.

Local populations are undoubtedly more stressed by winter coldness than by summer dryness but in both cases are able to cope well enough in urban-suburban environments. Our experiments have shown that termites do not generate appreciable metabolic heat in aggregations and overwintering therefore depends on finding subterranean hot spots associated with buried wood. Dead trees, stumps, sewer systems and heated structures are likely to provide overwintering hot spots. In the laboratory we typically operate growth chambers at temperatures from 85-90°F at which termites do well and have the highest rates of food consumption. However, the soil temperature preference experiments we have found that when given a choice termites will actually seek much cooler soil temperatures (50-70°F).

Experiments on termite movement relative to soil structure have indicated significant effects of particle size on rates of soil penetration, soil tunnelling, and shelter tube construction. Termites are unable to lift particles heavier than 7 mg (about twice the weight of a large worker) and rarely move particles weighing more than 4 mg. Generally termites are unable to move particles with diameters greater than 1.4 mm and rarely move particles greater than 1 mm in diameter. When soil particles exceed 2.8 mm in diameter the interstices between the particles are just large enough for small worker termites to crawl through. Thus, a mixture of sand composed of particles with diameters ranging from 1.4 to 2.8 mm is completely impenetrable by *R. flavipes*. Below 1.4 mm the rate of tunnelling increases continuously with decrease in particle size. For example, in one experiment over ten days groups of 25 workers tunnelled 0.5 cm through particles 1.4 to 1.18 mm, 4.5 cm through particles 1.18 to 1.0 mm, 7.0 cm through particles 1.0 to 0.85 mm, and 8.5 cm through particles of 0.85 to 0.71 mm. With finer particle sizes the termites penetrated 10 cm in 6 days with particle sizes from 0.71 to 0.5, in 4 days with particle sizes 0.5 to 0.25, and in less than one day with particle sizes below 0.25 mm. Termites were unable to use particles from 1.4 to 1.0 mm for shelter tube construction. Shelter tubes were built slowly and were poorly made when termites were provided with particles ranging in size from 1.0 to 0.71 mm. Shelter tubes were constructed most rapidly (1 cm/day/500 termites) with particles from 0.71 to 0.075 mm. Shelter tubes were most uniform in shape when constructed of particles from 0.25 to 0.075 mm. These experiments suggest that termites probably prefer fine sandy soil (.35 to .075 mm). However, the important effects of soil structure on oxygen availability and soil microorganisms are not known.

Soil particle size also has important effects on water retention and free water availability. Imbibition of hydrostatic water from the soil and water transport have been studied. Termites are able to regulate the microhabitat by transporting water in the crop and regurgitating it for moistening soil and wood. Substantial volumes of water may be involved. Volumes of approximately 10 nanolitres per worker have been measured. Ten water transport trips per worker per day would result in the movement of 100 ml per million workers. Water transport may account for much of the traffic in termite colonies and possibly is critically important in mixing the population. Population mixing has important implications on the use of transmissible toxicants or pathogens for termite control.

Tree foraging by northern populations of *R. flavipes* was first noted by Hagen (1885) in the Boston, Massachusetts area. The importance of this behaviour in Ontario was re-emphasized by Grace and Cooper (1987). In a study of 17,800 trees in Toronto, Cooper (1981) reported the following rates of termite attack: horse chestnut (19%), silver maple (18%), sugar maple (14%), red oak, Poplar spp., and red maple (5%), Manitoba maple, Norway maple (4%), and locust, white ash, elm, tree of heaven and basswood (2% or less). Over the last year we have noted that tree inspection for the presence of external mud shelter tubes is a rapid and effective method of determining the presence of termites on a property. This method was also used to rapidly identify the location of termites on one infested block in Winnipeg in August 1991. Recently numerous observations of shelter tubes on red pine trees have also been made. Shelter tubes are more likely to occur on older trees and trees with rough bark texture. Studies of orientation responses of the termites to wood extractives of various species also indicate the presence of chemical attractants in horse chestnut and repellents in tree of heaven (Grace, 1991).

Aggregation and Mass Trapping of Termites

As individuals, termites are small delicate insects that are easily killed. As a superorganism of millions of sterile workers, thousands of soldiers, and dozens of reproductives occupying a diffuse network of subterranean galleries over a few thousand square meters they are most difficult to kill. The genus in question, *Reticulitermes*, is particularly difficult because of its ecological adaptation as a *xylophagous forager*. Many other kinds of subterranean termites that harvest renewable cellulose resources (such as grass, humus, dung or fungus combs) from a fixed territory are able to establish a permanent nest or mound. It is relatively easy to control termites that build mounds and conspicuous nests. Xylophagous foragers, however, rely on non-renewable, isolated pieces of surface dead wood. The size and dispersion of this food resource, especially in temperate northern parts of the world, is such that their best strategy is never to invest effort in nest-building, but instead, to always be foraging and searching for new resources so that they can move as resource items are consumed. It is also to their advantage to have numerous, scattered, interconnected feeding sites so that they move from place to place adjusting to the ever changing conditions of temperature, soil moisture, and predation from ants. These ecological adaptations have made the control of subterranean termite colonies a challenge that has defied the creative efforts of researchers for decades. It now seems that the key to controlling such colonies is to develop a *delivery system*. With an effective delivery system a variety of toxic or physiologically active materials might be used to kill the colony.

Mass-trapping and direct treatment of the trapped termites appears to be an effective means of delivering toxicant. A relatively recent innovation in applied termite studies has been the development of various traps which employ corrugated cardboard as a food source and matrix for aggregating and harvesting large numbers of termites (La Fage et al, 1983; French and Robinson, 1985; Grace, 1989; Myles and Smith, unpublished). Using traps containing two small cardboard rolls (15 X 4 cm) Grace (1989) reported average collections of 2,612 termites per 3-10 day interval, with maximum catch of 7,622 and total catch of over 200,000 within one 15 day period. Using larger cardboard rolls (15 X 30 cm) placed in PVC shafts 0.5 to 1.5 m deep, we have been collecting an average of 9,200 termites per trap, frequently with 15,000 to 20,000 per trap and with a maximum of 42,542 from one trap! Through the use of cardboard roll traps we were able to trap 526,000 termites in a three week period from our field site in Kincardine, Ontario. In short, it is now possible to trap hundreds of thousands of termites from single colonies within a few weeks.

We have now devised and installed various "trapping system" consisting of rolls of corrugated cardboard of various sizes, in various arrangements, interconnected with buried fibre tubing. The performance of traps is quite variable from site to site, depending on a great number of uncontrollable variables in the urban environment. Refinement of trap system designs will be an ongoing area of research.

Trap-Treat-Release Approach to Colony Annihilation

The centrepiece of our research is to develop a Trap-Treat-Release (TTR) technique for killing whole colonies of subterranean termites. This concept evolved out of previous research on the Bait Block method and mark-release-recapture studies. The technique involves trapping several hundred thousand termites from buried rolls of cardboard. The trapped termites are treated in the laboratory with small doses of chemicals, insect growth regulators, nematodes, or by physical means. A massive number of treated termites are then released back into the colony. A sudden, massive, widespread mortality sets in throughout the extensive soil tunnel network about one to two weeks after release. The growth of saprophytic and pathogenic microorganisms on the dead will disrupt colony homeostasis. Trap-treat-release cycles could be repeated, if necessary, until the whole colony dies.

By the Trap-Treat-Release approach, trapped termites can be treated under controlled conditions. This creates the opportunity for methods of treatment and types of treatment which have never before been contemplated for termites. For example, cuticular dusting or direct topical application of materials is possible. The Trap-Treat-Release technique is a method of quickly treating a large proportion of the colony within a much shorter period of time than is possible by gradual free-choice feeding at baits. Trapping and treating, though somewhat labour intensive, is a far superior *delivery system*. It is necessary that the lethal effect have a delayed onset so that the treated termites disperse back into the colony. With an effective delivery system, a wide array of *delayed-action* lethal treatments might be used, for example: slow-acting toxicants, insect pathogens, parasitic nematodes, insect growth regulators, or physical treatments such as radiation. Various treatments could also be used in combination. In time, the trap-treat-release technique should be perfected as a routine pest control procedure. Alternatively, trapping, on its own, might become sufficiently perfected that it could become possible to exhaustively trap whole termite colonies out of the ground.

Delayed-Mortality Inducing Treatments

Borate compounds are the primary materials that we have investigated so far (Grace, 1990; Grace & Abdallay, 1991, Grace 1991a,b). Several tested compounds applied as cuticular dusts are effective including: disodium octaborate tetrahydrate (Tim-Bor®), barium metaborate (Busan 11-M1), zinc borate, and boric acid. Sodium borate (borax) was not effective. In experiments in which termites were on filter paper in petri dishes, Effective Lethal Ratios (ELRs) of dusted to undusted termites were at least 1:16. Realizing that in the field the ELR will be affected by the loss of dust from the treated individuals as they disperse through the soil tunnels, we decided to evaluate the ELR after various periods of dust loss. To assess the dust loss we have conducted an experiment in which the dusted termites are placed on moist sand for various time periods prior to transferring them to a group of untreated termites. Even after 24 hours of isolation on moist sand the termites carried enough Tim Bor dust to kill untreated termites at a ratio 1:5. This suggests that Tim Bor dust would be an effective toxicant for a Trap-Treat-Release approach if we can trap 20% of the population. As the mark-release-recapture study suggests we can trap around 10% of the colony. Next we studied the serial transmission of Tim Bor. This was done by exposing an initial group of untreated termites to an equal sized group of dusted termites. After one day the exposed termites were transferred to a new group of untreated termites. This was done for a series of 5 days. The experiment showed that after the first transmission by grooming (termites avidly lick each other) there follows one more effective lethal serial transmission, presumably via trophallaxis of gut content. Thereafter no further lethal transmission in the series occurred.

In recent experiments using Tim Bor, we have tried to improve the adhesion of the dust to the cuticle using a nontoxic adhesive marker pen solutions (Sanford, Sharpie® permanent markers). The marker solution has excellent adhesive properties however we were unable to effectively mark and dust large numbers of individuals. We next experimented with spray paints. Depending on rate of application, several spray paints were found that were non-toxic and effectively aided the adhesion of dust. Two or three cycles of spraying and dusting result in maximal loading. We selected a fluorescent orange because this also conveniently marked the treated individuals. Using this method we have achieved effective lethal ratios of 1:20 in petri dishes and 1:10 in soil tunnel arenas which simulate field conditions. Although dusting-spraying is effective and thousands can be treated within minutes, we are now trying to improve treatment by formulating the toxicant directly in an adhesive aerosol spray.

An alternative to the use of insecticides is the use of microbial agents. Zoberi and Grace (1990a) isolated 40 fungal species from *R. flavipes* field material. These included several facultative pathogens and a virulent strain of *Beauveria bassiana* (Zoberi and Grace, 1990b). Recently, we have also initiated studies with Dr. Martin Hubbes of the Faculty of Forestry at the University of Toronto on various nematodes that are pathogenic to subterranean termites. In collaboration with Dr. David Levin of the Department of Biology, York University we are undertaking preliminary investigations of several entomogenous viruses. Several non-occluded forms of nuclear polyhedrosis viruses and one entomopox virus have been found that infect and kill *R. flavipes*.

Direct exposure of termites to physical treatments is possible in the Trap-Treat-Release approach. Physical treatments are of considerable interest because they do not produce immediate behavioral impairment and do not burden the insect with carrying a chemical load (allowing the termites to disperse widely from the release point). Physical treatments might be used alone or in conjunction with transmissible chemical or microbial agents. We have investigated various physical treatments as methods of inducing delayed mortality. Short wave UV (9 watts) induced 100% mortality in 9 days after 2-3 minute exposure. With gamma radiation from a Co^{60} source LD_{50}s from 3 to 28 days were obtained with exposures to 3064 to 383 Rads. Portable gamma emitters with Co^{60} and Ir^{192} pellets required 1 and 2 hours of exposure time respectively to induce 100% mortality in 12 days. Termites were X-rayed with a portable 200 KV unit which required only 25 minutes exposure to induce 100% mortality in 10 days. UV is the least hazardous form of physical treatment and requires the shortest exposure time. However since gamma and X-rays could penetrate cardboard and soil they could be used in an "aggregate and irradiate" strategy. A portable X-ray or gamma emitter could be mounted on a small wagon and driven to any location. It could then be used to irradiate the aggregated termite *in situ* in the aggregation traps without even removing the trap from the ground. Two or three exposure cycles might be enough to kill a colony. This would entail relatively small labour costs, and would leave no toxic chemicals in the soil.

Benefits of Research

Present methods of control are property-specific and heavily dependent on large gallonages of persistent pesticides applied as a chemical barrier in the soil around an infested structure. This method is usually effective for protecting a given structure (although re-treatment is often required). However, the chemical barrier method is almost never effective in killing the termite colony which simply moves from the treated site to an adjacent untreated property. By the Trap-Treat-Release technique it will be possible to eradicate isolated pockets of termite infestation in Ontario municipalities rather than simply protecting properties one at a time. Eventually it may be possible to eradicate termites block by block to re-establish "termite free zones" in Metro Toronto.

With further development, the Trap-Treat-Release technique will become an integral component in urban pest management. Effective development of the Trap-Treat-Release method will substantially reduce or eliminate the amount of persistent pesticide used for subterranean termite control. By reducing the need for termiticides, it will dramatically lower the load of persistent toxicants in the urban environment. The reduction of termiticide treatments will also decrease the long-term health hazard to residents of termiticide-treated homes, arising from lingering vapours in in-door atmospheres and from accidental contact with treated soil. It will also reduce or eliminate the health hazards to applicators of termiticides arising from spills and misapplications.

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