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Survival and feeding of subterranean termites, Reticulitermes spp., in three relative humidity regimes

James C. Bilbrey

To the Graduate Council:

I am submitting herewith a thesis written by James C. Bilbrey entitled "Survival and feeding of subterranean termites, Reticulitermes spp., in three relative humidity regimes." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

Charles Pless, Major Professor

We have read this thesis and recommend its acceptance:

J. F. Grant, C. J. Southards

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. Charles Pless, Major Professor

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and recommend its acceptance

Carroll Southards

Jerome F. Grant

Accepted for the Council:

Cew Minkel

Associate Vice Chancellor and
Dean of the Graduate School

SURVIVAL AND FEEDING OF SUBTERRANEAN TERMITES, *Reticulitermes* spp., IN THREE RELATIVE HUMIDITY REGIMES

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

James C. Bilbrey, Jr.

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ABSTRACT

Termites caused $577 million worth of damage in the United States in 1983, and approximately $1.5 billion is spent for control of termites each year. Previous research has dealt with direct control of termites, but little has been done to determine the effects of relative humidity and wood moisture on termites isolated in a wooden structure.

Research was conducted to determine the effects of soil access or no-soil access in three relative humidity regimes (90 to 100%, 50 to 60%, and 30 to 40%) on survival and feeding of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), and a related species, *R. virginicus* Banks. Wood moisture content in southern yellow pine (*Pinus* sp.) framing was measured, and termite damage ratings were determined for weathered pine blocks and strips in each regime.

Termite survival in simulated wall voids in which termites were excluded from or allowed access to soil was determined. Colony survival at the highest humidity (90 to 100%) was full term (45 days) with 50% or more of the individuals surviving at the end of the test. The medium humidity (50 to 60%) had a greater contrast in termite survival between soil access and no-soil access voids than the lowest and highest relative humidities. At the low relative humidity (30 to 40%) significant differences in survival occurred between the soil access and no-soil access voids, but termite survival time was shortest overall.

Wood moisture content in pine frames was measured every other day at each relative humidity. There were no significant differences in wood moisture content between soil access and no-soil access frames within a single relative humidity level. However, differences were detected among the relative humidity levels, as wood moisture content was significantly greater at the highest relative humidity than at the medium and low humidities.

Wood weight loss and damage ratings were affected by termite survival, which was a function of relative humidity. There was a general trend of significantly higher wood loss and damage rating values for the highest relative humidity compared with the medium and low humidities.

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I. INTRODUCTION

Termites (Order: Isoptera) are wood-destroying organisms that feed on cellulose in the spring wood of trees and on other vegetation (Metcalf & Metcalf 1993). Termites can be either beneficial or destructive insects. Termites are considered beneficial when they convert wood which has no economic value into useful minerals in the soil. Termites are classified as destructive when they destroy wood structures or products of wood origin that have value. Except for alates (winged forms), termites are rarely noticed because they usually remain either in soil or wood and are rarely exposed to desiccating atmosphere outside of their moist environment (Borror, et al. 1989).

DISTRIBUTION

Termites occur in most parts of the world between the mean annual isotherms of 50°N and 50°S. Termites in the United States belong to three families, Kalotermitidae, Termitidae, and Rhinotermitidae. The family that includes subterranean termites, Rhinotermitidae, contains the most economically important species of termites in the United States (Borror, et al.1989). Termites occur in every state except Alaska (Brook 1967). Snyder (1954) listed 41 species of termites in North America. However, subsequent investigators have identified a destructive exotic species, *Coptotermes formosanus* Shiraki (Formosan subterranean termite), in several southern and eastern states (Beal 1967, Beal & Stauffer 1967). New termite species will undoubtedly be added to Snyder's 1954 list as research by several investigators continues.

ECONOMIC IMPORTANCE

Termites caused an estimated $577 million in losses in the United States during 1983 (Anonymous 1985). Subterranean termites were responsible for approximately 85% of that damage, and one genus, *Reticulitermes,* contains the most destructive species (Brook 1967). Approximately $1.5 billion is spent annually for termite control, and 80% of that cost is for control of subterranean termites (Su 1991, 1994).

COLONY BIOLOGY

Termites are social insects that live in groups called colonies. Colonies are made up of different castes (reproductives, soldiers, and workers), and all castes must function together for the colony to survive (Weesner 1965). The castes of individuals present in a colony vary with the age and species of the colony. Any disruption in the social structure of a colony may alter that colony's growth rate and foraging habits. The social life of termites facilitates the continuous exchange of nutrients (trophallaxis) between individuals (Weesner & Krishna 1970). Mature colonies of *Reticulitermes flavipes* (Kollar), the eastern subterranean termite, can contain between 0.2 and 5 million termites (Grace et al. 1989, Su et al. 1993, Su 1994). The ultimate size of a colony is limited by three major biological factors:

1) egg-laying capacity of the primary queen and/or supplemental queen(s),
2) rate of development and longevity of the members of the colony, and
3) loss from the colony of winged reproductive individuals (alates) (Weesner 1965).

In one study, colonies of *R. flavipes* extended their infestation by tunneling laterally from 22.8 to 30.5 meters in one year (Esenther 1961, Brook 1967). *Reticulitermes hesperus* (Banks), the western subterranean termite, can tunnel 0.39 cm/hours at 21.1°C (Smith & Rust 1993a).

INDIVIDUAL BIOLOGY

The digestive tract of most termites contains protozoans that digest cellulose, providing termites with nutrients necessary for growth and survival (Metcalf & Metcalf 1993). It has been reported that the total number of protozoa in one *R. flavipes* individual ranges from 28,700 to 32,167 with the primary species being *Pyrsonympha vertens, Dinenympha* sp., *Trichonympha agilis* Leidy, and *Spirotrichonympha* sp. (Maudlin & Rich 1980). Protozoa are most abundant in the hindgut. During molting the hindgut and its contents are discarded (Bennett et al. 1988). Therefore, termites must feed from the hindgut of another colony member to resupply the protozoa (Bennett et al. 1988). If protozoans are removed from the termites, they will continue to eat but will eventually starve to death (Borror, et al. 1989).

Each of the castes performs specialized functions that, when combined, aid in the growth of a colony. Reproductives are responsible for egg production. Primary reproductives are alates from established colonies. Alates, the only termites that leave the colony, are winged forms that have slightly larger sclerotized bodies than either workers or soldiers. Generally, alates leave the nest in swarms during the spring, but swarming also can occur at other times throughout the year (Weesner 1965). After a short flight, the wings are pressed against the substrate and broken off in a process known as dealation (Edwards & Mill 1986). After dealation the female, if not already contacted by a male, will release a pheromone (Edwards & Mill 1986). When a male finds the female, she will then locate a suitable mating site (Edwards & Mill 1986). When a suitable mating site is found and mating occurs the queen's abdomen becomes enlarged and egg production begins. Egg production begins approximately one and one half months after swarming (Snyder 1948). Egg production for a newly-mated pair could be as few as 6 to 20 eggs for the first 6 months following the mating flight (Weesner 1965). The king of the colony lives for several years and mates with the queen repeatedly throughout her life. The life span of the king and queen varies among species. The life span of *R. flavipes* is at least 5 years (Snyder 1915, Heath 1907) compared to 25 years for some tropical species (Ebeling 1975, Snyder 1954). Secondary reproductives occur when the primary reproductives die or egg production decreases, but they cannot produce winged adults (Metcalf & Metcalf 1993). Sub-colonies (satellite colonies) can form by the extension of tunnels from the parent colony. A satellite colony is one that has been isolated from the primary nest in the soil, and can form much faster than those formed by winged individuals. Supplemental queens start egg laying sooner than primary queens (Pickens 1934, Brook 1967).

Development of soldiers and workers is slow; maturity is reached in one year (Snyder 1915, 1935, Brook 1967). Unlike other social insects, such as bees, wasps, and ants, termite soldiers and workers are comprised of both male and female individuals (Metcalf & Metcalf 1993). Both workers and soldiers are sterile (Weesner 1965) and do not have eyes, so they use a chemical marker to guide them along trails (Metcalf & Metcalf 1993). The chemical markers (pheromones) for *R. flavipes* are a mixture of several compounds secreted from sternal glands (Matsumura et al. 1972, Tai et al. 1971, Ebeling 1975). The function of the soldier is to protect the colony from predators. The soldier's head is much larger than that of a worker, and has enlarged mandibles (Weesner 1965). Ants are the major predator of termites (Bennett et al. 1988). The termite soldiers protect the colony against ants by placing their bodies into the tunnel with their heads to the opening (Snyder 1948). This placement allows the termite soldier to use its mandibles without allowing the ant access to his soft abdomen (Snyder 1948). The workers are responsible for caring for the young; cleaning, grooming and providing food for the reproductives, soldiers, and nymphs; extending the colony workings; assisting others in molting; and repairing the nest (Weesner 1965, Metcalf & Metcalf 1993).

ENVIRONMENTAL FACTORS

The major physical factors which limit survival and dispersal of termites are temperature and moisture (Emerson

1955, Weesner & Krishna 1970, Rudolph et al. 1990). Temperature affects both egg production and swarming (Snyder 1948). The highest egg production takes place during the warmer months (Snyder 1948). Moisture affects nesting, timing of colonizing flights and post flight behavior (Nutting 1966, Weesner & Krishna 1970), and seasonal cycles in production of young (Weesner & Krishna 1970). Soil is used as a water reservoir and building material. Soil moisture is a limiting factor affecting termite nesting and survival during dry summer months (Weesner 1965). Soil also is used as building material for the tubes of subterranean termite colonies (Borror, et al. 1989).

PREVIOUS RESEARCH

The majority of previous research deals with direct control of termites, including *Reticulitermes* spp. and *Coptotermes* spp. (Su 1994, Scheffrahn et al. 1995, Grace & Yamamoto 1994). The basis of any control measure, chemical or mechanical, is to form a barrier between the subterranean nest and wooden structures (Williams & Yanes 1993). Some of the current chemical insecticides recommended for termite control include chlorpyrifos, fenvalerate, cypermethrin, permethrin, and boric acid (Metcalf & Metcalf 1993, Grace & Yamamoto 1994). Baiting materials and techniques are currently under development for control of termites

(Esenther & Beal 1974, 1978, Paton & Miller 1980, Su et al. 1982, 1987, Su 1994). The bait system has potential for eradication of subterranean colonies over time (Su 1994). With bait control systems, because of the time needed for eradication to occur, when termites are present in a structure a chemical treatment will be necessary (Su 1994).

Post-treatment effects on satellite colonies in a structure at the time of treatment have not been evaluated. Evidence suggests that such termite groups can survive when sufficient moisture and supplemental queens are present (Weesner 1965). This theory is substantiated because colonies have been found with no connection to the soil (Rosario & Snetsinger 1990).

Little research has been conducted to determine the effects of moisture on *R. flavipes* and *Reticulitermes virginicus* (Banks) in structural situations. Earlier research determined the amount of time that three *Reticulitermes* spp. can survive in drying conditions (Strickland 1950). In that study, groups of 50 termites (46 workers, 2 soldiers, and 2 reproductives) were subjected to relative humidities of 2%. The drying agent used was anhydrous calcium sulphate. Results varied depending on species, with survival time of *R. flavipes* falling in the middle of the three species listed. Results also varied depending on the media used to maintain the colony before the test. *Reticulitermes flavipes* survived between 230 to 345 minutes (Strickland 1950).

The amount of wood moisture needed for termite survival was evaluated in the laboratory without the presence of soil (Tarumingkeng 1964). In that study, 100 *R. flavipes* and one block of shortleaf pine, *Pinus echinata* Mill. (0.84 cm by 6.35 to 7.60 cm in diameter), were placed in a plastic petri dish and stored at 73% relative humidity at 30°C for 60 days. Thirteen water/wood ratios ranging from 0.15 to 1.00 were used in the experiment (Table 1). Some of the trends observed were: 1) between 0.15 and 0.35 water/wood ratio, wood consumption increased; 2) between 0.35 to 0.60 water/wood ratio, wood consumption followed no pattern; and 3) between 0.60 to 1.00 water/wood ratio, wood consumption gradually decreased.

In another study, survival of *Reticulitermes* sp. was evaluated at different moisture contents (Esenther 1969). Termites (155) were placed into an aspen sawdust matrix (0.5 gm) containing a Douglas-fir block (0.4 by 2.5 by 2.5 cm). The sawdust had a moisture content 200 to 900% by weight, and the blocks were between 60 to 270% by weight. Termite survival ranged from 82.0 to 89.9% except for the two lowest initial block moisture conditions.

Table 1. Results from Tarumingkeng (1964) experiment.

Water/wood ratio	Survival time, days	Wood loss in grams due to termite feeding	Survival, %
0.15	3.4	0.00	0.0
0.20	9.6	0.13	0.0
0.25	30.9	1.21	0.0
0.30	60.0	3.62	15.5
0.35	60.0	4.61	19.1
0.40	60.0	4.27	23.5
0.45	60.0	5.61	24.3
0.50	60.0	4.73	26.5
0.60	60.0	5.04	29.2
0.70	60.0	5.17	34.6
0.80	60.0	4.84	35.4
0.90	60.0	5.41	53.3
1.00	60.0	4.76	55.8

Other species of termites have been evaluated to determine the effects of moisture on survival, feeding, and tunneling. *Reticulitermes hesperus* was evaluated to determine time needed for 50% mortality in four relative humidities, 29.5, 55.0, 75.0, and 92.0%, at four temperatures, 15.6, 21.1, 26.7, and 32.2°C (Smith & Rust 1993b). Termite survival ranged from 55.0 to 321.6 hours at 15.6°C, 29.5 to 156.0 hours at 21.1°C, 11.7 to 49.6 hours at humidities, 29.5, 55.0, 75.0, and 92.0%, at four temperatures, 15.6, 21.1, 26.7, and 32.2°C (Smith & Rust 1993b). Termite survival ranged from 55.0 to 321.6 hours at 15.6°C, 29.5 to 156.0 hours at 21.1°C, 11.7 to 49.6 hours at 26.7°C, and 8.3 to 18.1 hours at 32.2°C. At the two higher temperatures (26.7 and 32.2 °C) when 100% relative humidity was achieved, LT_{50} was 230.4 and 103.2 hours, respectively. Thus, high humidity noticeably increases termite survival time.

Previous research indicates how termites react to different moisture conditions, but no studies have been conducted to determine the effects of relative humidity and presence or absence of moist soil in a structural simulation. The objectives of my research were to:

1) determine the effects of three relative humidity regimes on survival of isolated termite colonies

which have or do not have access to an external moist soil source, and 26.7°C, and 8.3 to 18.1 hours at 32.2°C. At the two higher

2) determine the effects of three relative humidity regimes on the wood moisture content and the amount of damage caused by the isolated colonies.

II. MATERIALS AND METHODS

TERMITES

Two species of subterranean termites, *Reticulitermes flavipes* (Kollar), the eastern subterranean termite, and a related species, *Reticulitermes virginicus* (Banks), were collected from fallen pine logs in the DeSoto National Forest, Harrison County, MS, with assistance from personnel at the Southern Research Station (USDA Forest Service). The logs were cut into 0.3 m lengths, split lengthwise, and the heartwood was discarded. The sapwood and termites were stored in 114 l galvanized metal cans until they could be transported to the laboratory and separated. Termites were separated from the wood by further splitting and jarring the sapwood pieces. Termites were then placed into a metal pan whose bottom was covered with several layers of damp paper towels. Termites were allowed to crawl out of the wood debris and move between layers of damp towels where they were collected and transferred to a clean dry pan. The cleaned, non-injured termites were stored temporarily in 2.25 l plastic dishes containing moistened paper towels. The number of termites in 10 (0.500 g) lots were counted. The highest and lowest counts were disregarded, and the mean number of termites per gram was calculated from the remaining counts.

EXPERIMENTAL UNITS

Test units used in these experiments were wood-frame structures which simulated sections of wall voids of a building (Fig. 1). The outside dimensions of the voids were 44.5 cm wide, 60.9 cm tall and 7.6 cm deep (Fig. 2). The materials used to construct the voids were [pine studs 3.8 cm by 8.9 cm (wooden frame), 6.3 mm thick masonite (back panel), and 3.17 mm thick plexiglass (front panel)]. The joints of the frame were secured with Liquid Nails (Macco Adhesives, Cleveland, OH) and 6.35 cm galvanized deck screws. The back panels were fastened to the frame with Liquid Nails and 1.9 cm roofing nails. Before the front panels were attached, the simulated wall voids were weighed using a Toledo Model 2061 scale (Toledo, OH). The front panels were fastened to the frame with #6, 1.3 cm flat-head screws and sealed with metal tape. Ventilation (air ports) and examination ports were drilled through the front panels (Fig. 2). A 1.9 cm hole was drilled through the top of the frame to serve as an entrance port through which termites could be introduced (Fig. 2). Two 3.2 mm holes were drilled through the bottom of the frame in half of the voids to provide the termites with access to the moist soil beneath the voids (Fig. 2).

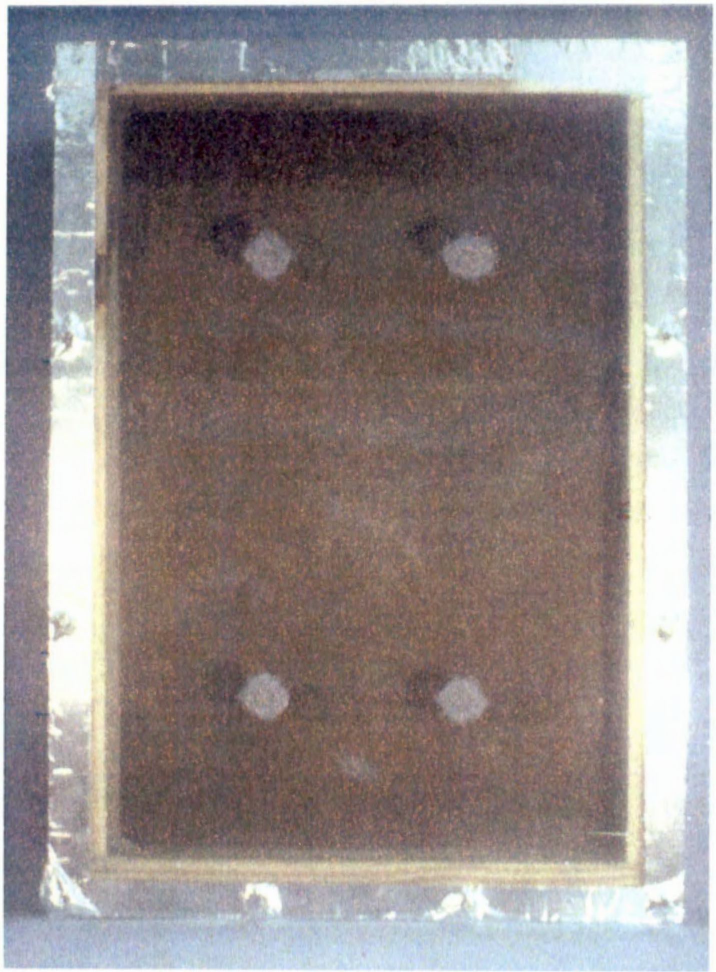

Fig. 1. Front view of simulated wall void.

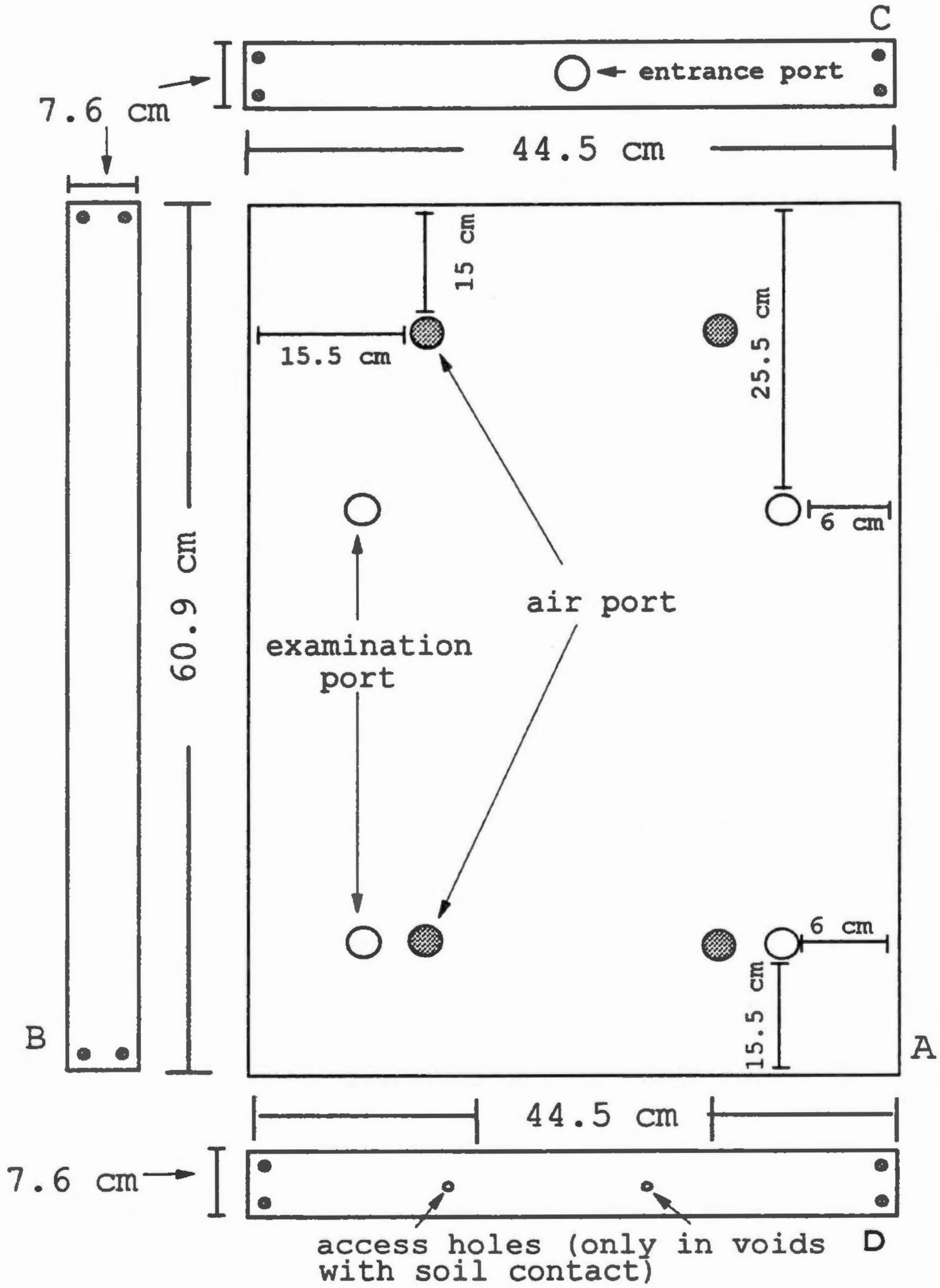

Fig. 2. Diagram of simulated wall void. A = front, B = side, C = top, D = bottom.

SOIL AND OTHER MATERIALS

The artificial soil mixture used in these experiments was composed of vermiculite, sand, and soil. Topsoil was obtained from the University of Tennessee, Plant Science Field Laboratory, Knoxville, TN. Sand and soil were steam autoclaved for 30 minutes and oven dried for two days at 100°C. A mixture of 200 ml vermiculite, 200 ml sand, 300 ml soil, and 250 ml water was uniformly spread across the base within each void. A mixture of 800 ml vermiculite, 800 ml sand, 1,000 ml soil, and 750 ml of water was added to plastic trays [60.9 cm (long), 12.7 cm (wide), and 12.7 (deep)] to provide simulated ground contact when placed beneath but not in direct contact with half of the wall voids. Soil in the trays was kept moist throughout the experiments.

Wooden pieces were cut from pine that had weathered outside for one year to provide an acceptable food source (Dr. B. Kard, Southern Research Station, personal communication). Two wooden blocks (5.72 cm × 5.72 cm × 3.81 cm) and a wooden strip (15.24 × 3.81 × 0.64 cm) were oven dried at 100°C for two days and weighed using a Mettler Balance, Model PM (Mettler Instrument Corporation, Highstown, NJ) before being placed into the soil at the base of each void.

Experiments were conducted in three bioclimatic chambers maintained at a controlled temperature and relative humidity. The environmental conditions established for these chambers were: 1) 90 to 100% (high) relative humidity, 2) 50 to 60% (medium) relative humidity and 3) 30 to 40% (low) relative humidity. The high relative humidity was maintained by constant operation of two steam vaporizers (DeVilbiss Model 1600, Sumerset, PA). Low relative humidity was regulated using an Edison Model DHE25W dehumidifier (W. C. Wood Company Inc., Ottawa, OH). Medium relative humidity utilized ambient relative humidity with no modification. All of the rooms were maintained at 22 to 26°C.

PROCEDURE

After the simulated wall voids were prepared, wooden blocks and strips were partially buried in the moist soil within each void. The front panels of the voids were then sealed to the frame with metal tape, and rubber stoppers were placed into all examination ports. Between 10.0 and 11.2 gm ($\bar{x}$ = 10.7 g) of termites were introduced into each void, thus providing approximately 5,200 termites including workers, larvae, reproductives, and soldiers (90%, 4%, 3.5%, and 2.5% for each caste, respectively). Initially, all voids were placed in a dark location at 50 to 60% relative humidity and 22 to 26°C for 7 days. Water was added as needed to maintain a moist condition within each void to allow the termites to acclimate to their new environment. After 7 days the voids were placed into their respective relative humidity chambers. Each treatment (relative humidity and soil or no-soil access) was replicated seven times (five times with *R. flavipes* and two times with *R. virginicus*) and run for a maximum of 45 days or until all termite foraging stopped. Each treatment consisted of two voids, one with soil access, and one without soil access within a specific relative humidity regime.

Wood moisture and relative humidity were monitored every other day using a moisture meter (Wood Encounter Tramex, Ireland) and psychrometer (Model 566 Bendix, Balitomre, MD), respectively. The voids were removed from their respective relative humidity chambers after 45 days or when termite activity was no longer observed. The voids were subsequently dismantled, and their contents were removed. The wood blocks and strips were then brushed and washed clean with water, oven dried and reweighed for comparison with their weights prior to the experiment. Wood blocks and strips were rated for termite damage using a damage rating index (DRI, Fig. 3)(Dr. B. Kard, unpublished):

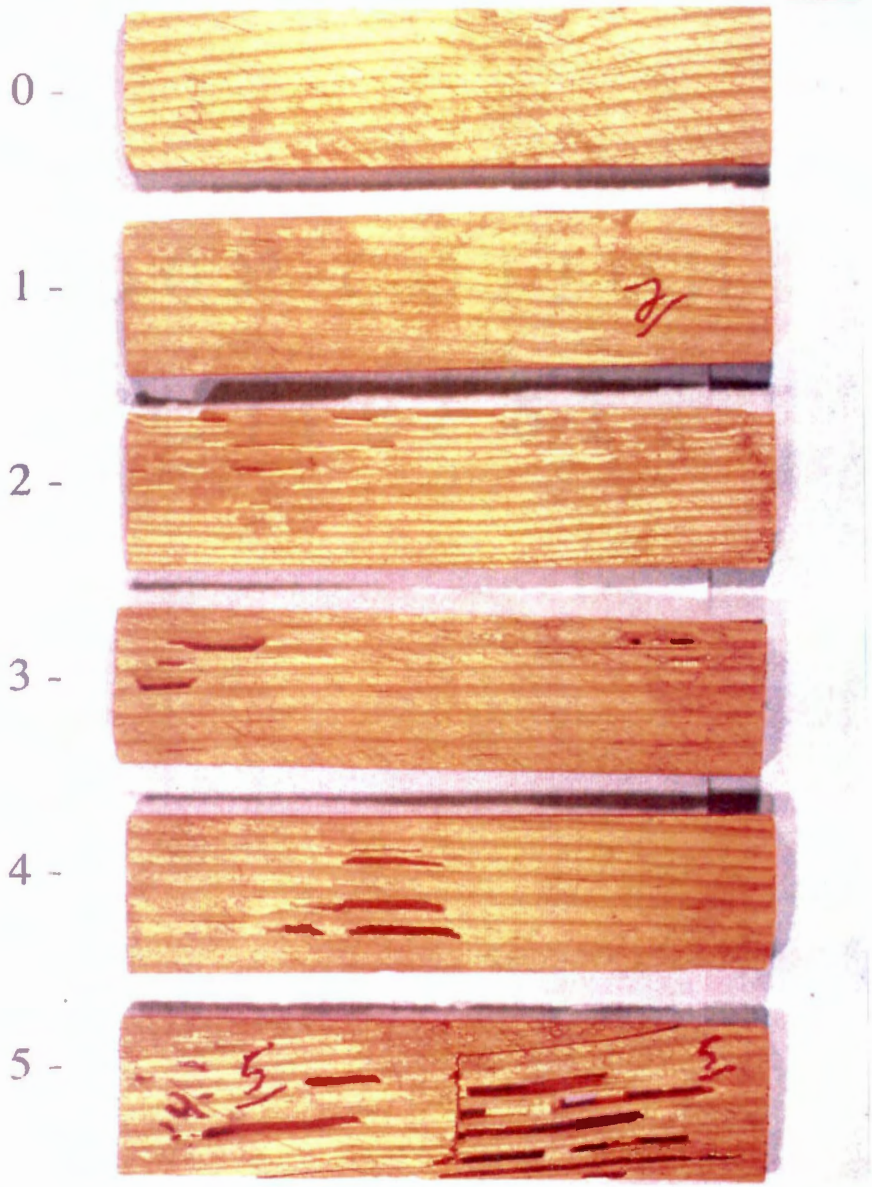

Fig. 3. Damage rating index (DRI).

0 = no damage to wood

1 = surface nibbling only

2 = light penetration into wood

3 = moderate penetration into wood

4 = extensive penetration into wood

5 = major portion of wood destroyed

DATA ANALYSES

Data were subjected to statistical analysis using General Linear Model (GLM) ($P \leq 0.5$) (SAS Institute 1988). A least significant difference (LSD) test was conducted to separate means. A univariate test was conducted to insure normality of the data.

III. RESULTS AND DISCUSSION

RELATIVE HUMIDITY/WOOD MOISTURE

Relative humidity significantly influenced wood moisture content of the voids. Significant differences in percent wood moisture content were observed among relative humidity levels (Fig. 4). The voids in the high relative humidity had a significantly greater wood moisture content than the voids in both the medium and low relative humidities (Fig. 4). No significant differences in percent wood moisture content were detected between the soil access voids and the no-soil access voids within a given humidity regime (Fig. 4). These data indicate that a positive relationship exists between the relative humidity level and wood moisture content.

SURVIVAL TIME

At the high humidity, termite colony survival time did not vary between soil access and no-soil access voids; greater than 50% of the individual termites survived the full term of 45 days in all voids (Fig. 5). Live supplemental queens were found in some of the no-soil access voids at the high humidity level. These results combined with data reported by Esenther (1969), Tarumingkeng (1964),and Smith & Rust (1993b) indicate that relative

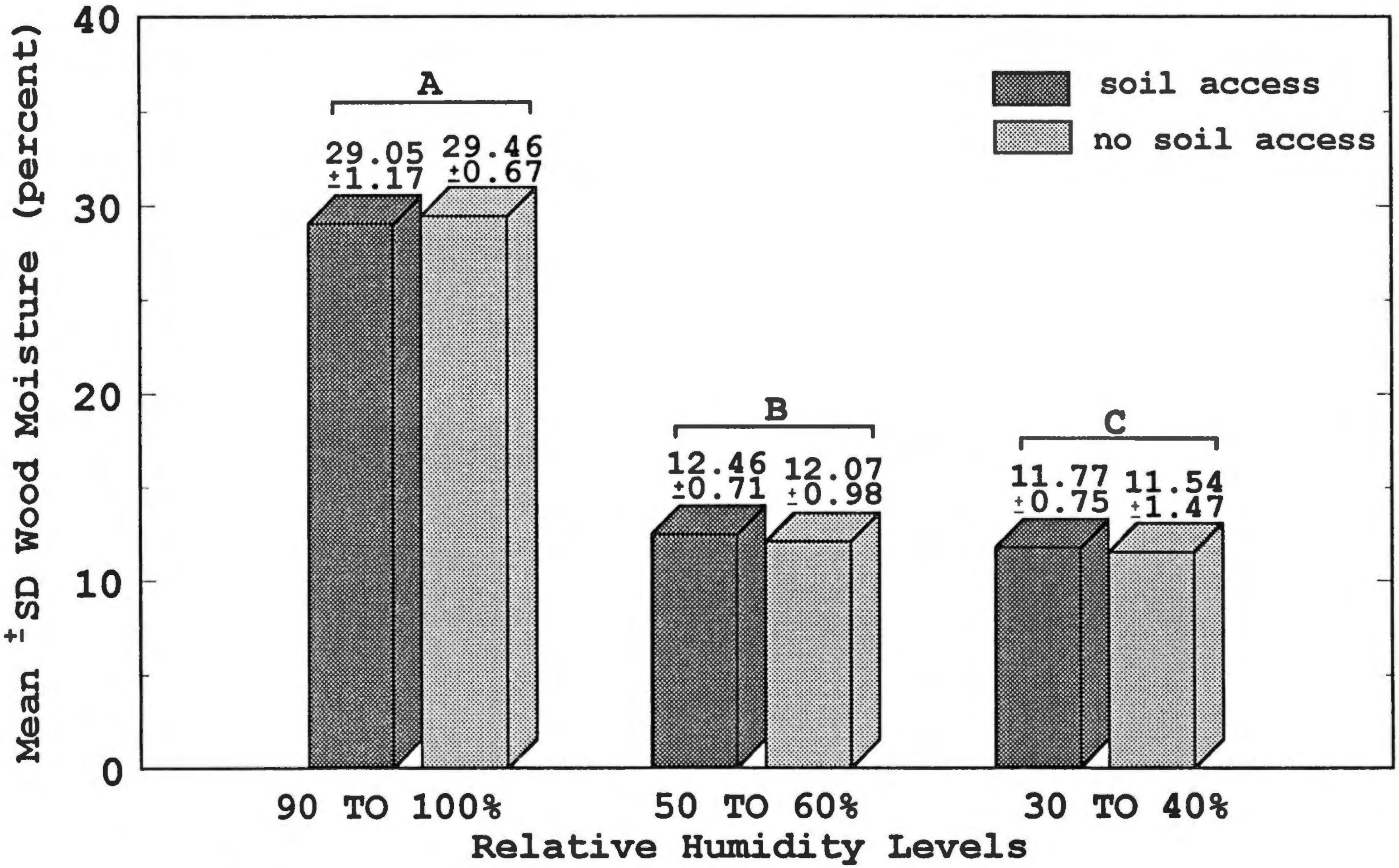

Fig. 4. Wood moisture content in different relative humidities. Upper case letters above the brackets indicate significant differences among relative humidity levels, ($P \leq 0.05$).

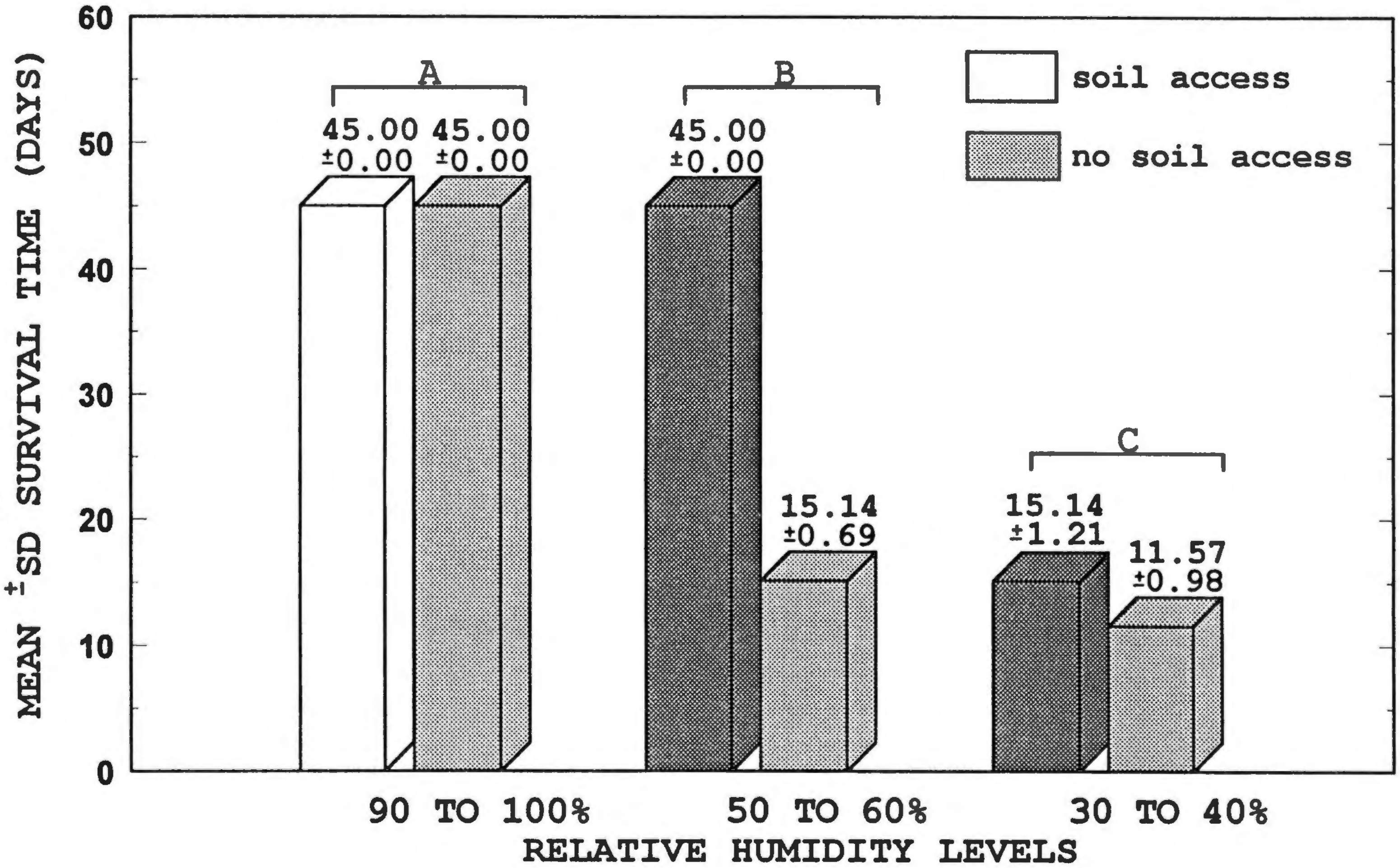

Fig. 5. Survival time of termites in different relative humidities. Letters above the bars indicate significant differences among relative humidity regimes, ($P \leq 0.05$).

humidity/wood moisture content may be as important as soil contact for termite survival.

Survival time at the medium humidity level differed significantly between soil access and no-soil access voids (Fig. 5). Termite survival time in soil access voids was the full term of 45 days with greater than 50% of the individual termites surviving, compared with 15.14 days in the no-soil access voids (Fig. 5). Termites were observed tunneling on the outside of the voids more in the medium humidity level than in either the high or low humidity levels. Termites constructed tunnels most often from soil mixture in the pan upwards to the base of the voids. This activity contrasts with the high humidity level where on two occasions termites tunneled downward out of the voids. Data and observations indicate that at the medium humidity level, soil access was more important for termite survival than relative humidity or wood moisture content.

Significant differences between termite survival time in the soil access voids and no-soil access voids in the low humidity level also occurred (Fig. 5). Although the significance between soil access voids and no-soil access voids indicates the importance of soil access, the overall low termite survival time in the low humidity level indicates the importance of higher relative humidity/wood moisture content levels in the termites' environment. In comparing the data from the low relative humidity level with the data reported by Tarumingkeng (1964), and Smith & Rust (1993b) relative humidity plays an important role in termite survival. Both Tarumingkeng (1964) and Smith & Rust (1993b) demonstrated a dramatic difference in termite survival at low relative humidity/wood moisture content.

Significant differences in termite survival occurred among the three humidity levels. These differences indicate that under normal conditions (50 to 60% relative humidity) relative humidity and wood moisture content combined with soil access are important limiting factors for termite survival. The difference in termite survival between high and low humidity levels indicates that under extreme conditions (either very moist or very dry) a major factor affecting termite survival is the relative humidity or the wood moisture content. In the low humidity voids termites foraged downward to the soil in the pans beneath the voids. However, in low humidity regimes termites could not survive long enough to construct mud tubes from the soil in the pan upward to the voids.

WOOD WEIGHT LOSS

The voids in the high humidity level did sustain slight feeding damage; however, feeding did not noticeably alter the weight of the voids. All wood strips were damaged, but there were no significant differences in weight loss among strips within voids, regardless of humidity level or accessibility of soil (Table 2). Although no significant differences in weight change were found among the strips, there was a general trend of more damage in the voids with soil access at both the high and medium humidity levels.

At the high humidity, no significant differences in percent wood weight loss occurred in the blocks between the soil access and no-soil access voids (Fig. 6). However, there was a trend toward greater wood loss in the no-soil access voids compared with the soil access voids (Fig. 6).

In the medium and low humidity voids there were no significant differences in wood weight loss (Table 2). However, there was a slight trend towards more damage in the soil access voids than in the no-soil access voids (Fig. 6). This possible trend is too slight to determine if soil access is more important than the relative humidity/wood moisture content in termite feeding behavior. Any possible trends may have become more apparent over time in the medium humidity voids.

Comparisons among the different humidity levels indicated significant differences in mean block weight loss among all three levels. Wood loss decreased as the humidity levels decreased (Fig. 6). These differences in wood weight loss, particularly between the high humidity and the low

Table 2. Mean ±SD weight loss from wooden blocks and strips due to termite feeding in three relative humidity (RH) regimes.

		Weight in Grams and Percent Loss					
		Block			Strip		
RH %	Soil Access[1]	Initial	Final	% Loss	Initial	Final	% Loss
90 to	NO	66.84	64.49	3.52 ± 1.71 a	15.57	14.72	5.43 ± 3.58 a
100%	YES	66.85	64.88	2.97 ± 1.09 ab	15.38	14.04	8.71 ± 5.48 a
50 to	NO	64.74	63.72	1.57 ± 0.16 c	14.44	13.90	3.74 ± 2.05 a
60%	YES	62.72	61.56	1.85 ± 1.12 bc	15.30	14.00	8.49 ± 1.23 a
30 to	NO	63.08	62.61	0.75 ± 0.51 c	15.70	14.94	4.84 ± 3.47 a
40%	YES	62.53	61.99	0.86 ± 0.73 c	16.14	15.40	4.58 ± 5.26 a

[1]Termite access to moist, sterilized artifical soil mixture.
Means within columns followed by the same letter are not significantly different ($P \geq 0.05$).

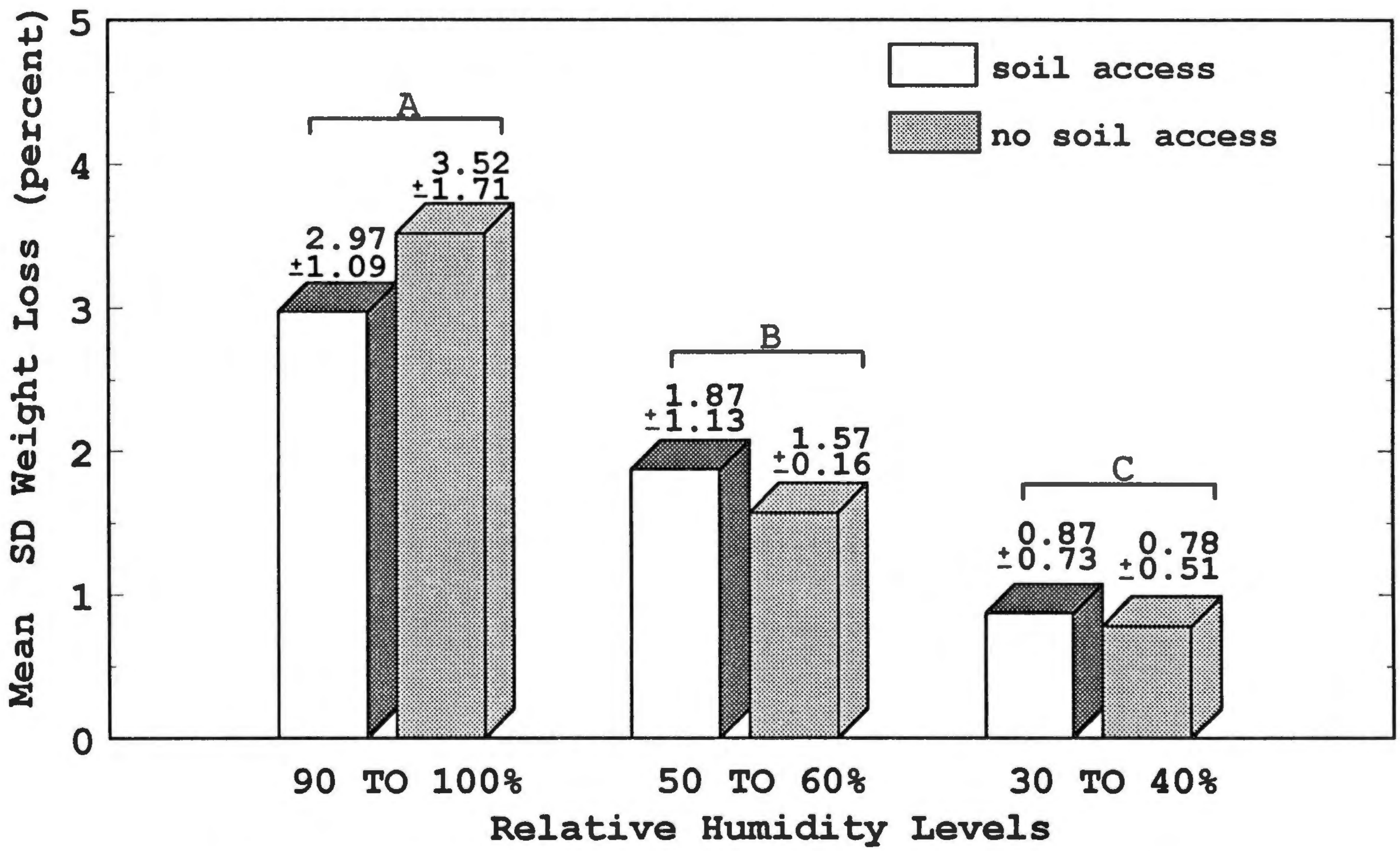

Fig. 6. Weight losses in blocks due to termite damage. Upper case letters above the brackets indicate significant differences among relative humidity levels, ($P \leq 0.05$).

humidity voids, indicate the importance of relative humidity/wood moisture levels.

DAMAGE RATING

No significant differences in damage ratings between the soil access voids and no-soil access voids within each humidity level were detected (Fig. 7). Furthermore, the results indicate a slightly higher damage rating in the no-soil access voids than in the soil access voids (Table 3). Any possible trend was too slight to determine if relative humidity/wood moisture levels were more critical than soil access for termite survival and feeding within each humidity level.

Significant differences in the damage ratings between the medium and low humidity voids were observed (Fig. 7). The same trend observed in other parts of the study again appeared with the lower damage ratings occurring in the low humidity voids (Fig. 7). These results coupled with the overall differences in wood damage ratings among the three humidity levels, indicate that relative humidity/wood moisture content play an important role in termite feeding behavior (Table 3).

Throughout this study wood in the high humidity level sustained greater amounts of damage and thus higher damage ratings, and termites survived longer than at any other

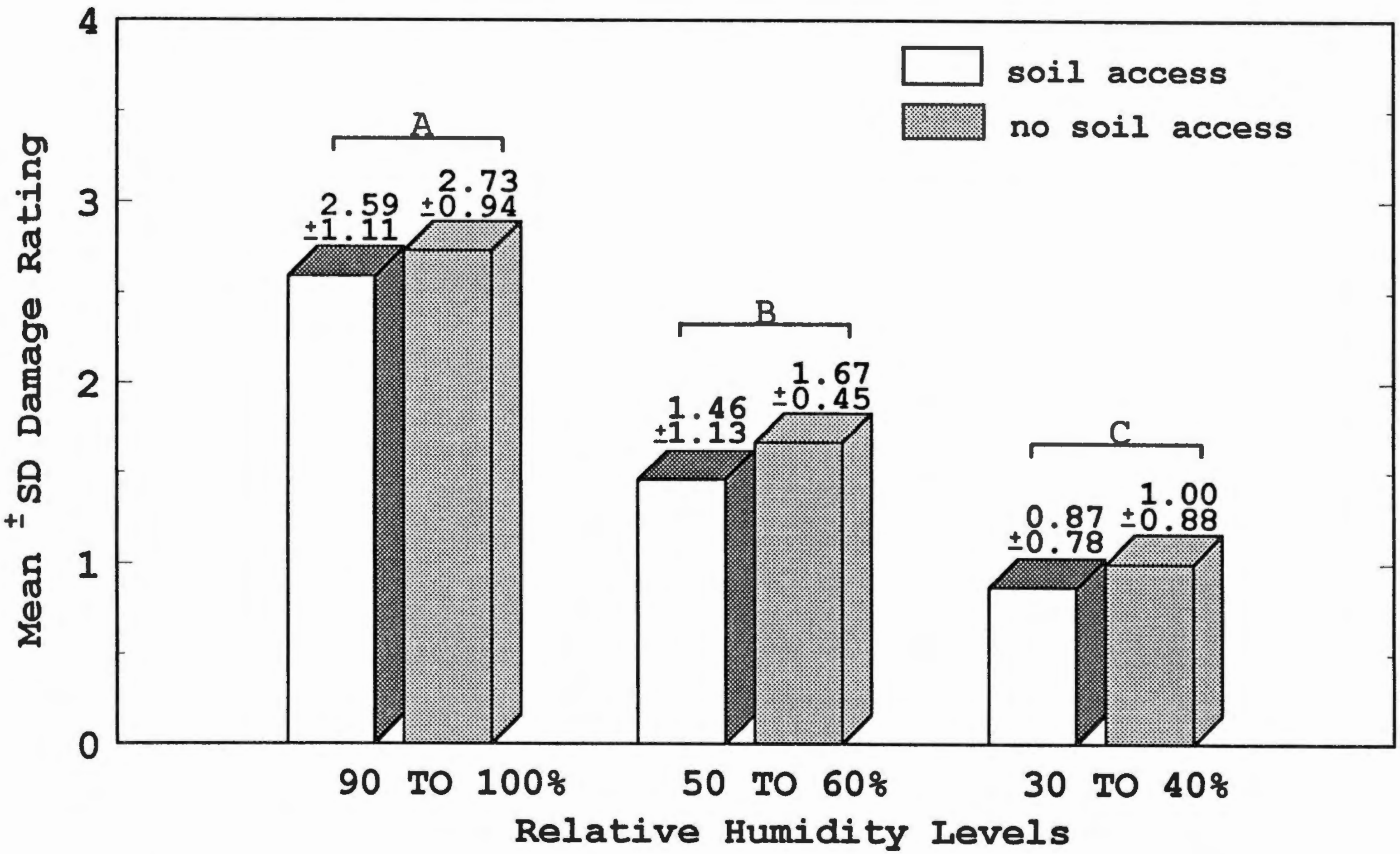

Fig. 7. Damage rating due to termite damage on blocks and strips. Ratings based on a scale of 0 (no damage) to 5 (heavy damage). Upper case letters above the brackets indicate significant differences among relative humidity levels, ($P \leq 0.05$).

Table 3. Mean ±SD damage rating index (DRI) for wooden blocks and strips due to termite feeding in three relative humidity (RH) regimes.

		DRI			
RH %	Soil Access[1]	Block 1	Block 2	Strip	Mean
90 to	NO	3.5 ± 1.0	2.6 ± 1.5	2.1 ± 1.6	2.8 ± 1.1 a
100%	YES	3.1 ± 1.5	2.9 ± 1.4	2.9 ± 1.4	2.7 ± 0.9 a
50 to	NO	1.7 ± 0.6	1.3 ± 1.0	2.0 ± 0.8	1.7 ± 1.1 b
60%	YES	1.0 ± 0.5	1.4 ± 0.9	2.1 ± 2.2	1.5 ± 0.5 bc
30 to	NO	1.5 ± 1.4	0.8 ± 0.8	0.9 ± 0.9	1.1 ± 0.9 bc
40%	YES	0.7 ± 0.8	1.1 ± 1.1	0.7 ± 0.9	0.8 ± 0.8 c

[1]Termite access to moist, sterilized artificial soil mixture. Means within columns followed by the same letter are not significantly different ($P \geq 0.05$)

humidity level. When these results are compared with results of Tarumingkeng (1964) and Esenther (1969), the primary factor affecting termite survival and feeding of colonies isolated from soil is moisture.

In this study wood moisture was provided through artificial means, and relative humidity was regulated. However, in a wooden structure wood moisture could be provided through other means, such as water pipe or roof leaks, or condensation within wall voids. This moisture could support a termite satellite colony that has been separated from the primary ground colony by chemical treatment, for example.

IV. SUMMARY AND CONCLUSIONS

SUMMARY

This study was designed to evaluate the effects of relative humidity on wood moisture content, termite survival, and wood weight loss due to termite damage. The test units (voids) used in this study were designed to simulate wall voids in a wooden structure. These simulated wall voids were constructed of pine wall studs, masonite boards, and plexiglass. A small satellite colony of approximately 5,200 termites was established in each void. Wall voids with soil access had two small holes drilled in the base to allow for foraging by termites. The experiment utilized three relative humidity levels: 90 to 100% (high), 50 to 60% (medium), and 30 to 40% (low). The 50 to 60% relative humidity level was considered normal for eastern Tennessee. A 1.3 cm deep layer of soil, and wood blocks and strips for feeding, were placed inside each void at its base.

Data were collected every other day. Wood moisture content was determined using a Tramex Wood Encounter moisture meter. Relative humidity was determined using a Bendix battery powered psychrometer. Wood damage ratings (DRIs) were based on a 0 (no damage) to 5 (damage) scale.

Data were analyzed using Proc GLM. An LSD test was used to separate means.

A direct relationship between relative humidity levels and wood moisture content was documented. Termite survival was sharply contrasted among the high, medium, and low relative humidity levels. In the high humidity level, termites in both soil access voids and no-soil access voids survived for the full 45-day test period. Supplemental queens were found among the living termites in the no-soil access voids within the high humidity level. Termites in the soil access voids at the medium relative humidity level survived for the full test period. In contrast, termites in the no-soil access voids survived approximately 15 days. Termite damage ratings and wood weight loss increased as relative humidity increased.

CONCLUSIONS

The data for wood moisture content indicate a direct relationship between relative humidity levels and wood moisture content. Knowledge of this relationship is important because wood moisture content can be regulated by means other than artificially adjusted relative humidity. Any water source in the area of wood, such as a leaking pipe, condensation, or a leaking roof, can increase moisture available to termites in a structure.

Termite survival data in this study indicate that in the eastern Tennessee region under normal conditions of 50 to 60% relative humidity and no artificial water source, soil contact is a critical factor for termite survival. However, as relative humidity and wood moisture content rise, termites can survive without soil contact. The survival of supplemental queens in the no-soil access voids at the high relative humidity level indicates that not only a satellite colony can survive, but population growth is possible.

Wood weight loss due to termite feeding was affected by both termite survival and wood moisture content. Termites in the medium relative humidity spent more time in the moist soil in pans beneath the voids than within their respective voids. Therefore, this time beneath the voids is one possible explanation for the lower wood weight loss in the medium humidity level. The termite damage ratings followed the same trend as the wood weight losses.

Termite survival in the eastern Tennessee region depends on soil contact. However, when an artificial water source is available, this indicates that termite survival is possible without soil access. This is important in determining if a structure needs to be retreated or if other factors, such as moisture problems, need to be corrected before termites can be effectively managed.

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VITA

James Bilbrey, Jr. was born in Nashville, TN, in 1968. He graduated from Mt. Juliet High School in 1987. He attended Volunteer State Community College from 1987 to 1990. He attended The University of Tennessee, starting in 1990, and graduated with a Bachelor of Science in Ornamental Horticulture and Landscape Design with a minor in Plant and Soil Science in 1993. After Graduation he started a Master of Science program in Entomology and Plant Pathology at The University of Tennessee which he finished in the summer of 1997. James Bilbrey is an active member of the Tennessee Entomological Society as well as the Entomological Society of America.