

SURVIVAL OF SUBTERRANEAN TERMITES (ISOPTERA: RHINOTERMITIDAE)
ISOLATED IN WOOD OF VARIOUS MOISTURE CONTENTS

By

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To my family

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Abstract of Thesis Presented to the Graduate School
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SURVIVAL OF SUBTERRANEAN TERMITES (ISOPTERA: RHINOTERMITIDAE)
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Subterranean termites nest in the soil, where they forage looking for a source of food, because they are dependent on its moisture for survival. However, some subterranean termite species are able to form aerial infestations, with no soil contact. This experiment looked at the mortality rate and water weight loss in the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the Eastern subterranean termite, *Reticulitermes flavipes* (Kollar), at various levels of wood moisture content (WMC). Termites were isolated in northern red oak (NRO) and southern yellow pine (SYP) wood blocks ranging from 5 to 35% WMC. Using destructive sampling, termite mortality and body water content were measured over a two-week period. Separate bioassays were conducted to measure relative humidity in the air surrounding wood at 5 to 35% moisture content. Termite mortality decreased significantly with increase in WMC. Termites were unable to survive two weeks when placed in wood with <20% WMC. Termites in 30% WMC and above is the point at which the wood is at or above full saturation, showed little to no mortality over the two week period in both NRO and SYP. Termite body water contents (BWC) decreased with a decrease in WMC. When BWC reached approximately 40%, rapid mortality occurred due to desiccation. Results showed that within air space surrounded by wood at $WMC \geq 25\%$, relative humidity was measured at 98%. $WMC \leq 25\%$

resulted in significantly lower RH values. Termites stressed for moisture showed ability to conserve water by reabsorbing from their feces, producing fecal pellets. Our results suggest that, while termites do require their ambient environment to be close to 100% relative humidity, they depend on free water in wood for long term survival when not in contact with other moisture sources as in aerial infestations.

CHAPTER 1 INTRODUCTION

Termites are structural pests that damage homes and buildings aesthetically and physically. Of the 2,300 species of termites that exist worldwide, about 50 are found in the United States, and about 18 are pests of structures (Su and Scheffrahn 1990). The Formosan subterranean termite, *Coptotermes formosanus* Shiraki, is the most destructive and aggressive subterranean termite species found in the United States, whereas the Eastern subterranean termite, *Reticulitermes flavipes* (Kollar), is one of the most widespread and important economic pests.

All termites are social insects living in colonies that can consist of over a million individuals (Thorne 1998). In social colonies, each member completes certain tasks, dividing their work among specific members. Termite colonies have specific pheromones which are used to recognize nest mates of different castes and maintain separate existence from other colonies (Potter 2004). Castes are groups of individuals of distinct morphological characteristics that perform certain tasks within the colony. This division of labor results in an efficient, productive, and cooperative society that can continue for years (Thorne 1998). Termite castes consist mainly of reproductives, workers and soldiers. Colonies will also contain eggs and immatures. The subterranean life cycle begins as an egg which hatches into larvae. These larvae later become workers which can then turn into separate castes, including nymphs, secondary reproductives, or soldiers.

Worker termites are considered the most important caste of the colony (Snyder 1948). They consist of both males and females and are blind. Workers consume wood and other cellulose based products, and are responsible to feeding and hydrating other caste members.

They are responsible for tending the nursery, tunneling through soil, building mud tubes, and grooming the nest mates from mites and fungal infestations (Thorne 1998). These workers can

Soldier termites are the defensive caste. They act aggressively toward invaders but sometimes can become passive and retreat from a confrontation (Thorne 1998). Their mandibles are very effective against certain predators such as ants, and certain species that have a chemical defense system (Lee and Wood 1971). Colonies of *C. formosanus* consist of ~5-10% soldiers, whereas in the species *R. flavipes* soldiers are only ~1-2% of the colony (Haverty 1977, Haverty et al. 2000). Proportion of soldiers in a colony is dependent on food availability, seasonal changes, worker nurturing capacity, and other factors (Su and La Fage 1987). Because soldier mandibles are developed for defense rather than for chewing food, soldiers are dependent on workers for nourishment. Although soldiers do not eat directly from the food source, they do forage and participate in food scouting (Potter 2004).

Workers can also molt into apterous neotenics, which are wingless secondary reproductives. These are sexually mature and can reproduce if needed by the colony. Workers can also molt into nymphs. Nymphs are not sexually mature but have a small set of wing buds. These nymphs can lose their wing buds and molt back into a worker or can grow into an alate. Nymphs also have the ability to molt into brachypterous neotenics, which are secondary reproductives with wing buds. Like the apterous neotenics, brachypterous neotenics are also sexually mature. The abdomen of these females becomes enlarged by physogastry, but they are less mature than the queen and king of the colony.

Termites live underground in wood or in nests and will typically form tunnels in the soil in search of food. Underground, termites are able to acquire resources and are protected from predators, sunlight, air currents, and desiccation (Potter 2004). In moist, loose sand, the

subterranean termite will form tunnels by either pushing its head forward and then pressing the grains of soil from side to side with its head, body, and mandibles (Ebeling and Pence 1957) or by removing soil particles in compact soil. Su and Puche (2003) showed tunnel differences within different moisture gradients in *R. flavipes* and *C. formosanus*. Termites tunnel more in sand with higher moisture.

Termite species differ considerable in moisture requirements, some being able to live in wood above ground and in dry and hot environments while others are restricted to mesic or wetter regions (Collins 1969). Unlike other insects, which have a cuticle that forms an effective barrier to protect them from water evaporation, subterranean termites are lightly sclerotized (Wigglesworth 1945). They are soft-bodied insects and are prone to desiccation because of their inability to retain water very well; therefore, subterranean termites are more dependent on moisture for survival than other insects (Delaplane and La Fage 1989).

Because subterranean termites lose water more readily from their integument rather than from respiration (Collins 1969), it is imperative that the moisture content of the ambient air is very high. If the surrounding air is too dry, subterranean termites must leave that area in search of water; otherwise they will die (Collins 1969). If the relative humidity is near 100%, then the termites can survive and will continue to feed (Forschler 1999). In laboratory studies, Delaplane and LaFage (1989) found that subterranean termites showed a distinct preference for moister wood. To maintain this moisture, termites will bring moisture from their water source, such as soil, or deposit fecal material into the galleries (Collins 1969).

Although subterranean termites typically obtain their moisture from the soil, they are capable of forming aerial nests, with no ground contact. If the moisture content of wood above ground level is high enough, subterranean termites can survive and multiply for an indefinite

period with no soil contact (Potter 2004). For example, an intact colony of *R. flavipes* was found infesting a floating lake house and a houseboat in Kentucky, both completely suspended over water with no soil connection (Potter et al. 2000 and 2001). Aerial infestations of *C. formosanus* account for about 25% of structural infestations in Florida (Su and Scheffrahn 1986) and 50% of high rise buildings in Honolulu, Hawaii (Tamashiro et al. 1987). Because these two species are subterranean termites, they do require a source of moisture in order to survive. The moisture source can be from faulty plumbing, leaky roofs, condensation, or others.

The relative humidity (RH) of the ambient air plays a large role in subterranean termite survival. Other termite species, such as the drywood termite, *Cryptotermes brevis* (Walker), obtain the majority of its moisture from the ingested wood. The rectal pads in these species are more developed than those found in subterranean termites, allowing drywood termites to reabsorb most of the water from their feces (Collins 1969). When exposed to highly humid environments, however, they become progressively more bloated and die of “water poisoning” (Buxton 1932). Subterranean termites do not have rectal pads as specialized as drywood termites and depend on water from their food and environment.

Other insects depend on the relative humidity of their environment, as well. The stored product beetles *Sitophilus granary* (Linnaeus), and *S. zeamais* (Motschulsky) both showed highest survival at 100% RH, compared to $\leq 95\%$ RH. Other beetles, such as the *Tenebriodes mauritanicus* (Linnaeus), however, had peak survival at RH between 65 and 80% (Khan 1983). The cat flea, *Ctenophelides felis* (Bouche), is unable to live as a larva when RH is <45 or $>95\%$ (Bruce 1948). It has also been reported that in the desert fleas, *Xenopsylla ramesis* (Rothschild) and *X. conformis* (Wagner), humidity was the most important factor in determining survival. Low humidities cause a lower lifespan in these species, decreased larval activity, and soften

cocoons. Subterranean termites are also dependent on RH and so have developed ways to sustain the RH in aerial infestations.

Subterranean termites are able to utilize a nesting building material known as carton, consisting of soil and masticated wood cemented together with saliva and excrement, which allow them to sustain aerial nests. This nest carton, which helps retain and conserve water, can be found along walls, attics, or roofs of termite-infested buildings. These nests provide termites with moisture, food, and protection away from the soil with no ground contact. Flat roofs are ideal locations for termites to start an aerial colony because of water pools in low areas, giving termites the moisture they need to sustain a colony (Su et al. 1990). Just as soil tubes are used as a guide to find active subterranean termite colonies, tubes can also be formed by termites living in an aerial nest. Because termites found in aerial infestations have no soil contact, these tubes will contain little to no soil and the majority of it will consist of saliva, feces, and masticated wood (Blasingame 1987).

In urban southeastern Florida, 25% of all *C. formosanus* infestations are aerial. In Honolulu, Hawaii, 50% of all *C. formosanus* infestations are found in high-rise buildings in Honolulu, Hawaii (Su and Scheffrahn 1987). These infestations can be started by alates which find a suitable area above ground to start a colony. Another way aerial infestations can be formed is from a colony that is initially underground. Sometimes, worker termites will forage into an above ground area and find it more suitable than the original nest. In this situation, workers will transport the king and queen to the location above ground and the connection to the ground is severed. The third way aerial infestations can form is from secondary reproductives that get separated from the rest of the colony and are cut off from the ground. These secondary reproductives are sexually mature males and females. When they are separated from their

original colony, sometimes from pesticide applications, male and female secondary reproductives start new colonies by budding (Blasingame 1987; Su and Scheffrahn 1987).

Wood moisture content plays a large role in colony survival (Delaplane and La Fage 1989). When wood is of lower moisture content, termites will rely on external sources of moisture. These external moisture sources allow subterranean termites to be able to survive in wood with moisture content less than 14.8% (Blasingame 1988). However, too much water can be lethal to termites resulting in reduction of foraging populations or cause termites to enter a state of quiescence for several hours (Potter 2004). If the wood containing termites is above 15% WMC, the interstitial air space occupied by the termites is believed to be near 100% relative humidity (Sponsler and Appel 1990). This relative humidity level should protect termites from cuticular desiccation.

Depending on termite species, wood moisture content can be the factor determining whether or not termites can sustain activity. The subterranean termites *Odontotermes sp.* are known to survive best at 96% RH but can restore their moisture from the timber on which they are feeding (Milner et al. 1997). In a choice test of wood moisture preference, *R. flavipes* did not prefer moist wood over dry wood as long as they had a source of external moisture. However, *C. formosanus* preferred moist wood over drier wood, even if there was an available external source of moisture (Delaplane and La Fage 1989).

According to Forschler (1998), wood moisture readings above 15% could indicate conditions suitable enough to support subterranean termite activity with no external water sources. Wood moisture content below 15% would be unsuitable for the termites and would result in death by cuticular water loss, if no external source of moisture was available. Because termites can be found infesting wood at 15% moisture content, subterranean termites do not

necessarily have to be in fully saturated wood in order to survive and continue to feed on the structure. Wood fiber saturation does not occur until the wood reaches 25-30% moisture content (Carll and Highly 1999). At WMC above 25-30% wood is to be above saturation point and free water is available for termites. Little research exists on wood moisture content required in order sustain aerial infestations without an external source of moisture (Potter 2004).

Delaplane and La Fage (1989) showed that damp wood in buildings are more prone to sustain aerial termite infestations and that bait blocks should have higher moisture content in order to increase its effectiveness. McManamy et al. (2008) conducted a wood moisture experiment and concluded that wood moisture content needed to be at least 30% WMC in order for eastern subterranean termites to be able to survive more than six months. McManamy et al. (2008) also stated that wood moisture content $\leq 24\%$ was not enough to sustain an aerial infestation, but did not measure whether relative humidity had an effect. These authors also measured body weight and concluded that termite mortality drastically increased once termites dropped 30-40% of their body weight. Sponsler and Appel (1990) obtained similar results and found that water loss at time of death was an average of 50.5% for *C. formosanus* and 53.5% for *R. flavipes*.

This study was conducted to determine effects of wood moisture content on subterranean termites. Two types of wood, northern red oak (NRO) and southern yellow pine (SYP), and two species of termites, *C. formosanus* and *R. flavipes*, were used. My first objective was to determine the air relative humidity of a void inside the wood moistened at 5-35% and compare our results between a hard wood, NRO, and a soft wood, SYP. My second objective was to determine the wood moisture content (WMC) needed for long-term subterranean termite survival with no soil contact. For this experiment, two species of termites and the two species of wood

were compared and determine the wood-moisture death kinetics for subterranean termites. Using these results, I attempted to correlate air relative humidity and subterranean termite mortality. Finally, I wanted to determine what percent body water loss that resulted in subterranean termite death, and to compare the results for the two termite species living on the two wood species.

CHAPTER 2 MATERIALS AND METHODS

Insects

Three colonies of *Reticulitermes flavipes* (Koller), separated by more than 1.5 km, were collected in Gainesville, FL as described by Tucker (2004). Briefly, termites were field-collected in 6-L plastic buckets inserted in the ground and covered with a lid accessible just above the soil surface. Two rolls of corrugated cardboard were inserted into the buckets and were checked every 7-10 days. At those times, cardboard rolls infested with termites were replaced with new rolls and infested rolls were taken back to the lab for termite removal. The termites were removed from cardboard rolls and placed on moist corrugated cardboard sheets and reared at room temperature (~23°C) in plastic containers (27.0 by 19.0 by 9.5 cm) for ≤ 1 wk before used in experiments.

Coptotermes formosanus Shiraki were collected from the Audubon Zoo in New Orleans, LA. Termites were collected from monitoring traps stocked with cylindrical pieces of wood. Infested wood was placed in 20-L plastic buckets and driven to the University of Florida in Gainesville, FL. Termites in infested wood were then kept in 30.5 by 14.0 by 20.3 cm Sterilite® Show Offs™ (Sterilite Corporation, Townsend, MA) containers with 0.95 L builder sand at approximately 10% moisture. Termites collected from different collection sites in the New Orleans Zoo were kept in separate containers and assumed to represent different colonies. These containers were stored in a lit room at room temperature (~23°C) for later use.

Wood Blocks for Termite Bioassay

Northern red oak (NRO) boards and southern yellow pine (SYP) stakes were cut into small blocks (7 by 4 by 2 cm). Three adjoining holes (1 cm deep) were drilled using a 1.9 cm Forstner bit on one side of each block to produce a void (5 by 1.9 by 1 cm). A separate hole, (0.5

cm diam. by 1 cm deep) was drilled into the corner of each block 0.5 cm from one of the corners to allow moisture replacement. Blocks were oven-dried at 60°C for 48 hr to remove any water from the wood. Each block was then weighed and dry weights were recorded.

Relative Humidity Experiment

To measure the relative humidity in the air space surrounding moist wood, a device was constructed to simulate the use of a sling psychrometer. A small fan, connected to either a 9V battery or electrical outlet, was placed in the center of a five-sided 15.3 by 8.8 by 7.0 cm wooden box. This fan moved the air and created the drying effect necessary to measure a differential of temperature between a dry and a wet thermocouple. The wooden box was placed in a 1.9-L Glad® Gladware container (The Clorox Company, Oakland, CA).

To create the wooden boxes, NRO boards or SYP stakes were cut into five 11.3 by 3.5 by 2.0 cm (long blocks) and four 8.8 by 3.5 by 2.0 cm (short blocks). Each block had a 0.8 cm deep and 2.5 cm wide drilled void to create blocks that were similar to the ones described above which were used in moisture experiments with termites. The void was drilled so that it started 1.5-2 cm from one end of the block and continued to the opposite end. Wood blocks were placed in a 60°C oven for 48 hr to dry and were then moistened to 5-35% WMC by weight in increments of 5%. Wood blocks were then individually placed in 0.5-L Ziploc® bags which were placed into 3.8-L Ziploc® bags to prevent moisture loss. Blocks were kept in plastic bags for 36-48 hr to allow water to completely disperse within the wood block before blocks were used for experiments. One hour before the blocks were used for experiments, water was added to replace any evaporated water and reestablish the desired WMC.

Nine wood blocks with the same WMC were used to create a five-sided 15.3 by 8.8 by 7.0 cm wooden box. Blocks were positioned so the side with the void faced inward in the box. The length of the box consisted of two stacked long blocks and the width consisted for two

stacked short blocks. The bottom of the box was a single long block, with the void facing upward. Size-16 rubber bands were used to secure the box. Formed and secured wooden boxes were placed open side up in the center of the 1.9-L Glad Gladware[®] plastic containers, which were sealed with their plastic lids. Wooden boxes and containers remained in at room temperature for the remainder of the experiment.

Two 3-mm holes, 1.0 cm apart, were created at the center of the lid of the plastic container to allow two thermocouples to be inserted through the top of the lid. One of the two thermocouples was wrapped with a wet sponge (~0.4 cm in diam. and 1.5 cm long). Size-4 cotton thread was used to secure the sponge on the thermocouple with several knots. An additional hole was placed on the lid of the container to insert a disposable pipette. Tap water was placed in the pipette and the pipette was placed so its tip was touching the sponge-wrapped thermocouple to allow water replenishment of the sponge throughout the experiment. Temperature measurements from both dry and wet thermocouples were taken with an EasyView[®] Dual Input Thermometer (Extech Instruments Corp., Waltham, MA) at 15-min increments until temperatures stabilized (3-4 hr). Using an online psychrometric calculator (<http://www.sugartech.co.za/psychro/index.php>), wet bulb and dry bulb temperature values were used to compute the relative humidity within the wooden boxes constructed with wood at different WMC levels.

Moisture Experiments

Immediately after the wood blocks were oven-dried, water was added to the large void of the wood blocks to achieve 5, 10, 15, 20, 25, 30, and 35% (wt/wt) WMC. Moistened blocks were placed into individual 0.5-L Ziploc[®] bags (S.C. Johnson and Son, Inc, Racine, WI), which were kept in larger 3.8-L Ziploc[®] bags to further help prevent moisture absorption or loss for 36-

48 hours until added water was evenly distributed throughout the wood block. After this period, blocks were weighed and moist weight was recorded.

Termite Mortality at Various Wood Moisture Contents

Four separate experiments were conducted with *R. flavipes* or *C. formosanus* placed on NRO or SYP using the following procedure. Termites were separated and counted to result in 101 *R. flavipes* or 110 *C. formosanus* individuals in order to mimic natural field ratios of 1 soldier for 100 workers for *R. flavipes* and 10 soldiers for 100 workers for *C. formosanus*. After separation from the colony, termites were chilled over ice for ~1 min to slow the termites so they could be placed into the large void in the wood blocks without escaping. Clear acetate paper (7.0 by 4.0 cm) was hot-glued over the opening of the block void to prevent termite escape and allow for an enclosed air space. The total weight of the blocks, including termites, acetate paper and hot glue, was recorded immediately after setup, and blocks were sealed back into individual 0.5-L Ziploc[®] bags. Bags with wood blocks were then placed in larger 3.8-L Ziploc[®] bags and kept at room temperature (~23°C) for the duration of the experiment. Water was added every 7 days throughout the experiments to the moisture reservoirs to maintain initial weight and WMC.

Termite Body Water Content at Various Wood Moisture Contents

Blocks were prepared for destructive sampling at 1, 2, 3, 5, 7, 10, and 14 days. At each sampling day, total block weights were recorded to allow an estimation of the amount of WMC that had been retained. Termite mortality was determined and all the surviving termites were weighed together, then killed and dried at 60°C for 30 minutes, and re-weighed to a 0.01-mg precision. Percent body water content (BWC) was calculated by subtracting the termite dry mass from the initial mass of the living termites and dividing the result by the initial mass. Mass loss was assumed to be entirely from water loss.

Data Analysis

Relative humidity was not measured directly from the wood blocks in which the termites were placed, but rather from a separate wooden box comprised of blocks of wood moistened at WMC levels 5, 10, 15, 20, 25, 30, or 35% as described before. It was assumed that relative humidity in the air space of the wood blocks to which termites were exposed was the same as that within the wooden boxes used to measure relative humidity for each WMC. Death and survivorship curves were calculated for WMC 5-25% because it was at those levels that significant mortality in termites was observed, whereas no significant termite mortality occurred at 30 and 35% WMC.

For the relative humidity experiment, a completely random design was conducted, using two wood species and 7 moisture levels. Each experimental unit consisted of a wooden box built with nine blocks of wood placed in a plastic Gladware container with a psychrometer. There were three replicates totaling 42 experimental units. One-way ANOVA was conducted to determine effects of wood species on ambient wood relative humidity.

Using statistical analytical software (SAS Institute 2007), termite mortality and percent BWC were arcsine-square-root transformed. A randomized complete block design was used for the termite mortality experiment. Three replications, from different termite colonies, with 100 termite workers plus soldiers for each termite species, *C. formosanus* and *R. flavipes*, were used. Using destructive sampling, termites were exposed to seven different WMC levels (5, 10, 15, 20, 25, 30, and 35%) and mortality was observed every 1, 2, 3, 5, 7, 10, and 14th day. At each sampling date for each WMC level, BWC for remaining living termites was measured. Significant differences were determined by graphically comparing standard error bars surrounding the means. One way analysis of variance was used to view significance differences between treatments and significance of day and moisture within treatments. Separation of means

was conducted using student Neumann keuls. A t-test was conducted to measure significant differences between termite species and wood species.

The fundamental empirical model used to estimate thermal mortality kinetics (Johnson et al. 2009, Wang et al. 2002, Alderton and Snell 1970) was used to determine the effect of WMC on termite mortality. Time was measured in days in order to estimate kinetics of termite mortality when insects were exposed to different levels of WMC. Termite survival at each WMC was plotted against exposure days, and survival curves were obtained for each WMC by linear regression. A WMC death curve was obtained by plotting the observed minimum time in days [Log (time) plotted on y-axis] needed to obtain 100% termite mortality at the different WMC (x-axis). Plots were obtained with kinetic orders 0, 0.5, 1, 1.5, and 2 following the methods described by Wang et al. (2002). Coefficients of determination (r^2) were calculated for each curve. Based on these coefficients, the kinetic order equations that best fitted the survival data were selected. Parameters for kinetic orders 0 and 0.5 order equations were used to determine the effect of WMC on termite mortality. These kinetic orders were chosen based on the best combination of coefficient of determinations, comparing all kinetic orders.

Slope and intercept from the regression equations were used to estimate the number of days to 100% mortality at different WMC for each of four treatments (*C. formosanus* on SYP, *C. formosanus* on NRO, *R. flavipes* on SYP, and *R. flavipes* on NRO). Estimated time to cause 100% termite mortality according to these curves were plotted against WMC. Confidence intervals (95%) of slope and intercept were used to compare significance in the regressions lines for each treatment.

To determine the accuracy of these estimates, another WMC death curve was obtained plotting WMC against the number of days (LOG) where 100% mortality was actually observed

in the wood blocks. Confidence intervals (95%) of slope and intercept were used to compare regressions lines obtained for each termite species/wood type combination. Differences between treatments were determined to be significant when confidence intervals did not overlap.

Termite BWC for each of the 7 sampling dates (1, 2, 3, 5, 7, 10, and 14 d) was graphed for each WMC level (5, 10, -35%) . Significant differences between BWC within treatments were determined by comparing standard error values; means with overlapping standard errors were considered not significantly different and means with standard errors that did not overlap were considered significantly different. The percent BWC relationship to survival of the termites was measured by comparing the amount of termites that survived at certain BWC levels. Termite BWC was grouped into increments of 5%. Number of surviving termites measured at specific BWC was graphed.

CHAPTER 3 RESULTS

Relative Humidity

Relative humidity (RH) in the air surrounding the wood box arenas showed a significant increase with an increase in WMC, reaching at plateau at 25% WMC for both NRO and SYP (Fig. 3-1). There was no significant difference in RH between the two types of wood ($df=1$; $F=0.10$; $P=0.7583$). At WMC levels $\geq 25\%$, RH values were $>90\%$, however no RH values above 98% were measured using the methods in these studies. Relative humidities for 25, 30 and 35% WMC were not significantly different on NRO or SYP.

Termite Mortality at Different Wood Moisture Content Levels

An increase in WMC yielded a decrease in termite mortality and increase in longevity for both *R. flavipes* and *C. formosanus* on NRO and SYP (Table 3-1). Termite mortality was significantly lower at higher WMC for all treatments (Table 3-2). Analysis of variance showed a significant relationship between WMC and termite mortality, representing a significant decrease in mortality with increase in WMC. Neither species of termites were able to sustain activity longer than 7 d in arenas where surrounding air was $\leq 90\%$ RH.

Mortality of *R. flavipes* on NRO (Fig. 3-2A) decreased with an increase in WMC yet a minimum of 25% WMC was required to yield some survival for the 14-day duration of the experiment. Rapid mortality occurred at 5-20% WMC within the first 7 days. By 7 d, all termites had died at up to 15% WMC. At 20% WMC, termite mortality was $<10\%$ within the first 5 d but increased to 72% by 7 d. There was a slight increase in mortality at 25% WMC on 10 d but no significant differences, with less than 10% mortality, occurred between 25, 30, and 35% WMC at 14 d for *R. flavipes* on NRO ($df=2$; $F=2.00$; $P=0.2160$).

Similarly, *R. flavipes* on SYP at 5-15% WMC (Fig. 3-2B) were not able to survive longer than 7 d. At 20% WMC, rapid mortality occurred between 3 and 10 d with an average of 89% population mortality. *R. flavipes* mortality at 25% was not observed until after 7 d, averages for mortality were 0.3% at 7 d, 19.8% at 10 d, and 43.2% at 14d. There were no significant differences in mortality between sampling days at 30% ($df=6$; $F=0.35$; $P=0.8953$) or 35% ($df=6$; $F=0.80$; $P=0.5890$) WMC, both with <3 mortality throughout the experiment.

Coptotermes formosanus on NRO (Fig. 3-2C) were not able to survive 5-15% WMC longer than 7 d. At 20% WMC, termites had <20% mortality for the first seven days but at 10 d, mortality was 100%. At 25% WMC, mortality slowly increased from 8.5% at 7 d, to 11.2% at 10d, and rapidly increased to 41.2% at 14 d. At 30 and 35% WMC, mortality maintained below 10% and showed no significant differences between sampling days (30% WMC: $df=6$; $F=0.43$; $P=0.8447$; 35% WMC: $df=6$; $F=0.77$; $P=0.6029$)

Coptotermes formosanus on SYP at 5-15% WMC (Fig. 3-2D) were also unable to survive past 7 d. When termites were placed in SYP at 20% WMC, *C. formosanus* mortality began to increase rapidly from 5 to 10 d to an average of 72%. On SYP at $\leq 20\%$ WMC, *C. formosanus* SYP were unable to survive 14 d. At 25% WMC, the majority of mortality for *C. formosanus* was observed between 7 and 14 d with an average of 53% mortality. *C. formosanus* mortality on SYP at 25% WMC slowly increased from 5.45% at 7 d to 10.91% at 10 d and increased to 61.82% at 14 d. There was significant mortality at 30% WMC and at 35% WMC at 14 d. However, there was no significant difference between 30 and 35% WMC mortalities at 14 d.

One way analysis of variance showed significant differences in mortality between treatments ($df=3$; $F=4.64$; $P=0.0033$). Separation of means showed no significant differences between *C. formosanus* on SYP, *R. flavipes* on NRO, and *R. flavipes* on SYP. However, *C.*

formosanus on NRO did have significantly lower mortality. There were no significant differences in mortality between the two termite species ($df=559$; $T=-1.47$; $P=0.1416$). However mortality was significantly greater on SYP than NRO ($df=559$; $T=-2.73$; $P=0.0064$).

For *R. flavipes* at 5% WMC on NRO, the air RH was 54% which lead to 11% termite mortality by 1 d, 96% by 2 d, and 100% mortality by 3 d (Table 3-1). A 5% increase in WMC increased air RH to 75% at 10% WMC, which caused 98% termite mortality by 3 d and 100% by 5 d. At 15% WMC, air RH in wooden boxes had increased to 85% though it was not enough to allow termites to survive beyond 7 d. Mortality at 10 d for *R. flavipes* on NRO was 96% at 20% WMC and 1.3% at 25% WMC, though air RH for both test arenas were estimated to be 95% (Table 3-1). Wooden NRO boxes with 30 and 35% WMC were measured to have 97% air RH and resulted in <2% termite mortality throughout the 2-week period (Table 3-1).

On SYP, RH's of the air surrounding wood at 5-15% WMC were not significantly different from air RH's surrounding NRO at similar WMC (Table 3-1), yet *R. flavipes* mortalities were significantly higher on SYP than on NRO. On SYP at 5% WMC, air RH was 52% and resulted in 78% mortality at 1 d and 100% mortality by 2 d. On SYP at 10% WMC, air RH in wood boxes was 73% which resulted in 25% *R. flavipes* mortality on 1 d, 64% at 2 d, 99% at 3 d, and 100% by 5 d. At 25% WMC, RH was 95% and <2% termite mortality was observed until 14 d when there was 43% mortality (Table 3-1).

Coptotermes formosanus on NRO were not able to survive >10 d when the RH in the air surrounding the wood was assumed to be $\leq 90\%$ from the RH data at <20% WMC (Table 3-1). When the RH was 95% (20% WMC), *C. formosanus* mortality reached 100% at 10 d. Relative humidity was not significantly different between 20 and 25% WMC on NRO however, termite

mortality was significantly lower at 25% WMC than 20% WMC. At 98% RH (35% WMC on NRO), *C. formosanus* mortality was $\leq 5\%$ throughout the two-week period.

For *C. formosanus* on SYP at 25% WMC, though the air RH in the arenas was measured in wooden boxes to be 95%, as was seen in NRO, 64% mortality occurred at 14 d (Table 3-1). At 20 and 25% WMC (97% RH), mortality slowly increased to 13% by 14 d at 30% WMC, and to 18% at 14 d at 35% WMC.

Kinetics of Wood Moisture Effects on Termite Survival

Daily mortality rates for both termite species on both wood species at 30 and 35% WMC were not estimated because the estimated slopes for the mortality lines were not different from 0.

Coefficients of determinations (r^2) were determined to choose the best kinetic model for death curve estimates (Table 3-3). The 0.5-order kinetic model (Wang et al. 2002) were used for *R. flavipes* on NRO (Fig. 3-3). At 5% WMC, mortality was estimated to begin to occur before 1 d and to reach 100% at 3 d, increasing at a rate of 45.4% per day. For 10% WMC, mortality was also estimated to begin before 1 d and to reach 100% at 4.6 d. At 10% WMC, live populations were estimated to decrease by 24.5% per day. When NRO had 15% WMC, mortality was estimated to begin at 1.1 d and to reach 100% at 9.5 d, with populations decreasing by 11.9% a day. At 20% WMC, mortality was estimated to begin at 4.4 d, and to reach 100% mortality by 10 d, with the population decreasing 16.4% per day. For wood at 25% WMC, mortality was estimated to begin at 4.8 d. Populations were not estimated to reach 100% mortality until 52.3 d and were estimated to reach 19% mortality at 14 d, increasing at a rate of at 2.1% per day.

The 0-order kinetic model was used for *R. flavipes* on SYP and *C. formosanus* on NRO and SYP (Fig. 3-4, 3-5 and 3-6). Survivorship curves for all three treatments showed a decrease in their rate of mortality with an increase in WMC. For *R. flavipes* on SYP (Fig. 3-4), at 5% WMC, mortality was estimated to begin within the first day and reach 100% by 2 d. At 15%

WMC, mortality was estimated to begin before 1 d and to reach 100% by 7 d, with populations decreasing at 16.8% per day. With 20% WMC, mortality was estimated to begin at 1.3 d and to reach 100% mortality by 12 d, decreasing 8.9% a day. At 25%, mortality was estimated to begin at 6.9 d and to reach 43% at 14 d. Using this death curve, it was estimated that *R. flavipes* at 25% WMC in SYP would reach 100% mortality by 23.3 d, with a mortality rate of 6.1 % per day.

The wood-moisture death kinetics for *C. formosanus* on NRO (Fig. 3-5) estimated that termites started dying before 1 d at 5% WMC and that mortality reached 100% mortality at 2 d, with populations decreasing 68.7% per day. At 10% WMC, mortality was estimated to begin before 1 d and reach 100% at 4.5 d. Populations of *C. formosanus* are estimated to decrease by 22.7% per day when placed on NRO at 10% WMC. At 15% WMC, *C. formosanus* were estimated to start dying at 1.9 d and to reach 100% mortality by 6.9 d, with populations decreasing by 19.7% per day. When *C. formosanus* termites were placed in NRO at 20% WMC, mortality was estimated to begin at 4.7 d and reach 100% mortality 10.6 d, with populations decreasing by 17.1% per day. At 25% WMC, mortality was estimated to begin at 6.1 d and reach 38% mortality at 14 d. Using this curve, 100% mortality was estimated to occur at 26.8 d.

When *C. formosanus* was placed in SYP (Fig. 3-6) at 5% WMC, mortality was estimated to begin before 1 d and 100% mortality was estimated to occur by 2.7 d. Populations were estimated to decrease at a rate of 29.8% per day when placed in 5% WMC. At 10% WMC, mortality was estimated to start before 1 d and reach 100% by 4.2 d, with populations decreasing by 18.8% per day. At 15% WMC, mortality was estimated to start before 1 d and reach 100% at 6.8 d, with populations decreasing by 14.4% per day. For 20% WMC, the wood moisture death curve estimated mortality to begin at 1.2 d and reach 100% by 11.0 d, with mortality rates of

10.2% per day. At 25% WMC, mortality was estimated to begin at 4.8 d and reach 62% at 14 d. When the SYP was 25% WMC, mortality for *C. formosanus* was not estimated to reach 100% at 19.7 d.

The WMC death curves plotted using the slopes and intercepts from the model-estimated survival curves (Fig. 3-7) showed that there were no significant differences in kinetics of WMC-effects between *R. flavipes* and *C. formosanus* on NRO. On SYP, *R. flavipes* was estimated to survive longer than *C. formosanus* for each respective WMC. The 95% CI for the wood moisture death curves generated with the observed data on time to reach 100% mortality (Fig. 3-8) showed that survival of both termite species on SYP and NRO were not significantly different. A comparative graph was made combining death curves from the model-estimated survival curves and death curves generated with observed data (Fig. 3-9). No differences were observed between mortality estimates based on model-estimated kinetics and actual mortality data.

Body Water Content

Body water content (BWC) in termites started to decrease within the first day for all treatments at all WMC levels (Fig. 3-10). Termites confined to blocks with higher WMC lost BWC at a slower rate. The average initial BWC for *R. flavipes* was 77%. On NRO, termite mortality for WMC 5-20% occurred rapidly after termite BWC decreased to an average of 40% (Fig. 9A).

In SYP at 5% WMC (Fig. 3-10B), *R. flavipes*'s lowest BWC measurement was 39% at 1 d. On SYP, termites decreased to a BWC average of 38% when placed on wood at 5-20% WMC before reaching 100% mortality. There were only two remaining live termites after 3 d from one rep at 10% WMC which were measured to have reduced their BWC to 22% before reaching 100% mortality. At 30 and 35% WMC, termite BWC reached levels ~70% before recovering previously lost BWC.

Coptotermes formosanus initial average BWC was 71%. The lowest BWC measurement of live termites on NRO between 5, 10, and 15% WMC was between 40 and 50% (Fig. 3-10C) before all termites in the treatment died. Termites reached an average of 39% BWC before reaching 100% mortality at 5-20% WMC. Live termites on wood at 25-35% WMC did not replenish all the BWC lost and were measured to have an average BWC of 54% at 14 d.

On SYP, *C. formosanus* BWC decreased on the first day for all WMC levels (Fig. 3-10D). The lowest BWC recorded for termites at 5, 10, and 20% WMC was ~45%. Four remaining surviving termites subjected to 15% at 5 d were measured to have 31.63%. *C. formosanus* BWC had decreased to an average of 41% for insects on wood at 5-20% WMC before reaching 100% mortality. After 14 d, termites in 25-35% WMC had an average of 52% BWC. Standard error differentiation showed these values to be significantly lower than initial BWC.

There was a positive correlation between termite BWC and survival for all treatments (Fig. 11). Survival of *R. flavipes* on NRO (Fig. 3-11A) was highest when BWC was 51-55%. For this treatment, there was an increase of 49% in survival between 36-40% and 41-45% BWC. For *R. flavipes* on SYP, (Fig. 3-11B), termite survival increased more gradually with increase in BWC, however, <50% of termites were able to survive at BWC lower than 41-45%. Similarly, with *C. formosanus* on NRO (Fig. 3-11C), an average of 44% of termites were able to survive when BWC was 41-45% or less. *C. formosanus* survival on NRO was highest when BWC was 51-55% and greater. For *C. formosanus* on SYP (Fig. 3-11D), survival also showed a gradual increase with an increase in termite BWC. *C. formosanus* survival on SYP was >50% when BWC was 36-40% and 68% survival was observed in termites with 41-45% BWC. When BWC was above 50%, termite mortality became minimal (89% survival or higher).

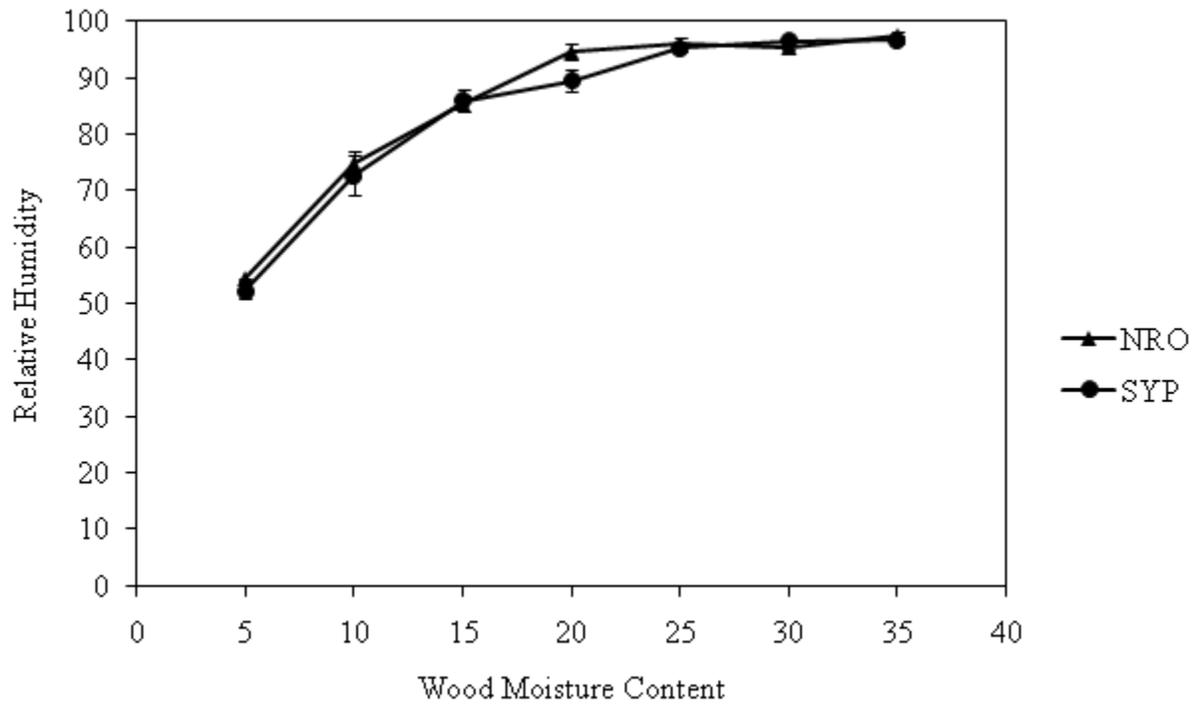


Figure 3-1. Percent relative humidity (RH) of space enclosed by Southern Yellow Pine (SYP) and Northern Red Oak (NRO) at 5, 10, 15, 20, 25, 30, and 35% wood moisture content (WMC).

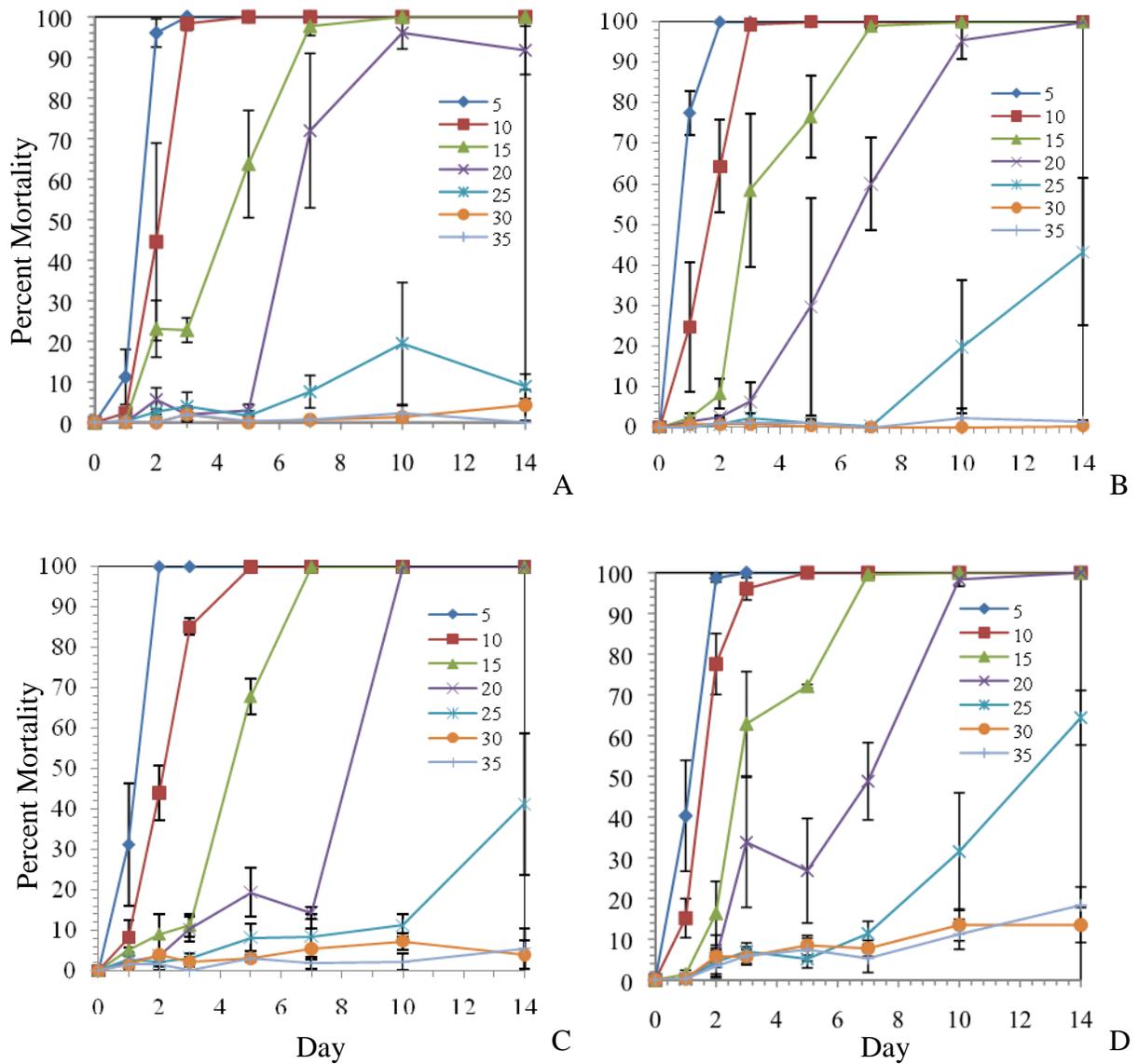


Figure 3-2. Effect of wood moisture on mortality of *Reticulitermes flavipes* and *Coptotermes formosanus* placed in southern yellow pine (SYP) and northern red oak (NRO) wood blocks with 5, 10, 15, 20, 25, 30 and 35% moisture contents: A) *R. flavipes* on NRO; B) *R. flavipes* on SYP; C) *C. formosanus* on NRO; D) *C. formosanus* on SYP.

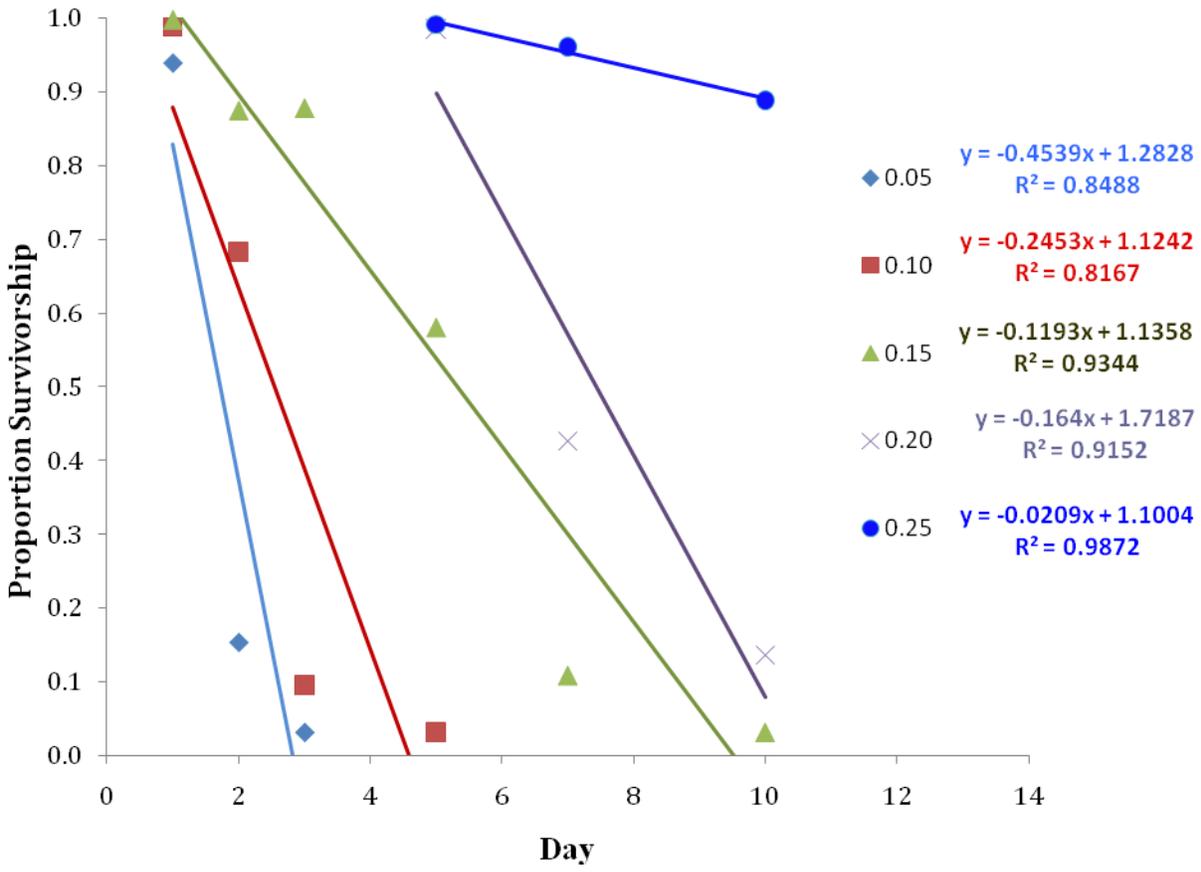


Figure 3-3. Survival curves of *Reticulitermes flavipes* placed in northern red oak moistened at 5, 10, 15, 20, and 25% moisture contents.

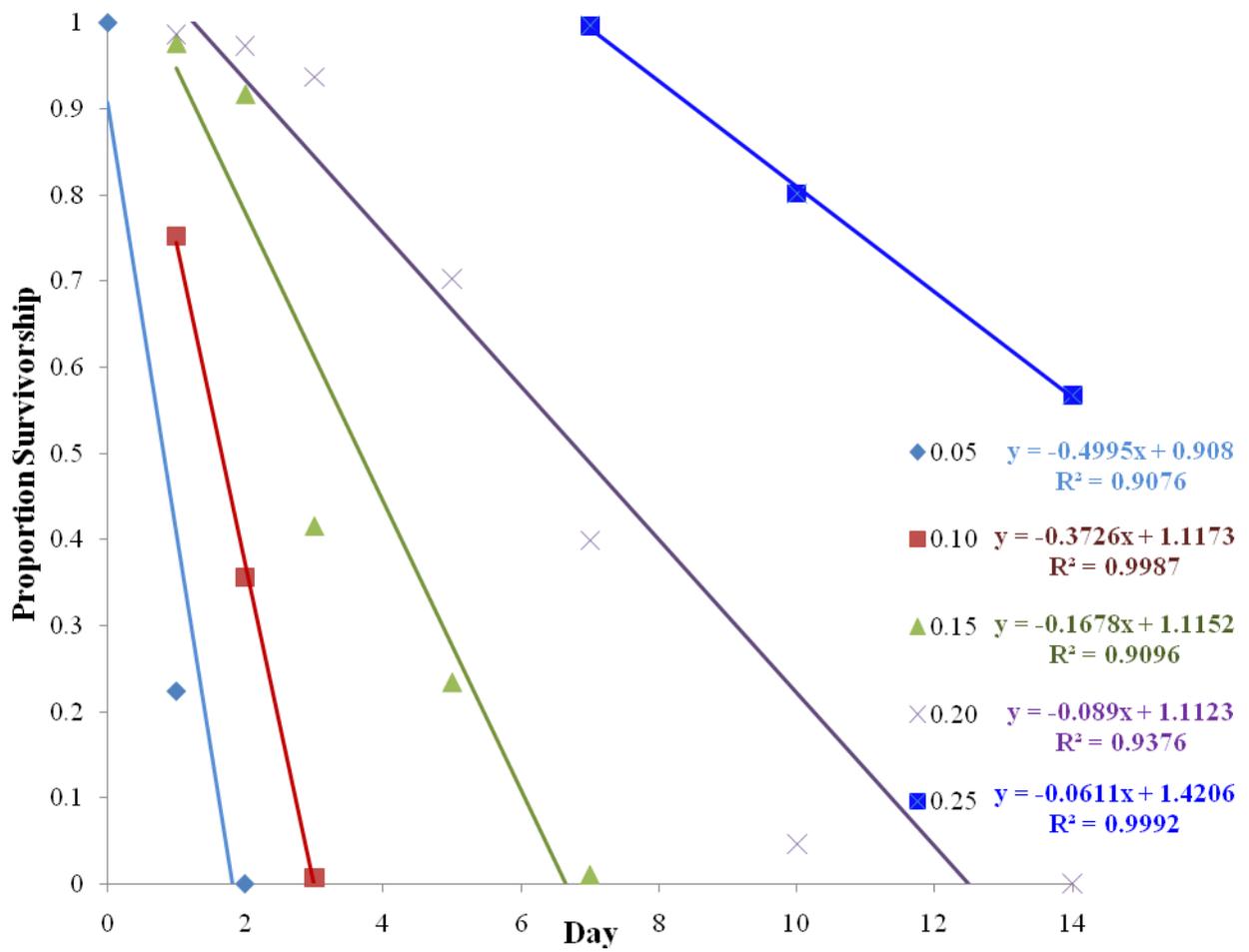


Figure 3-4. Survival curves of *Reticulitermes flavipes* placed in southern yellow pine moistened at 5, 10, 15, 20, and 25% moisture contents.

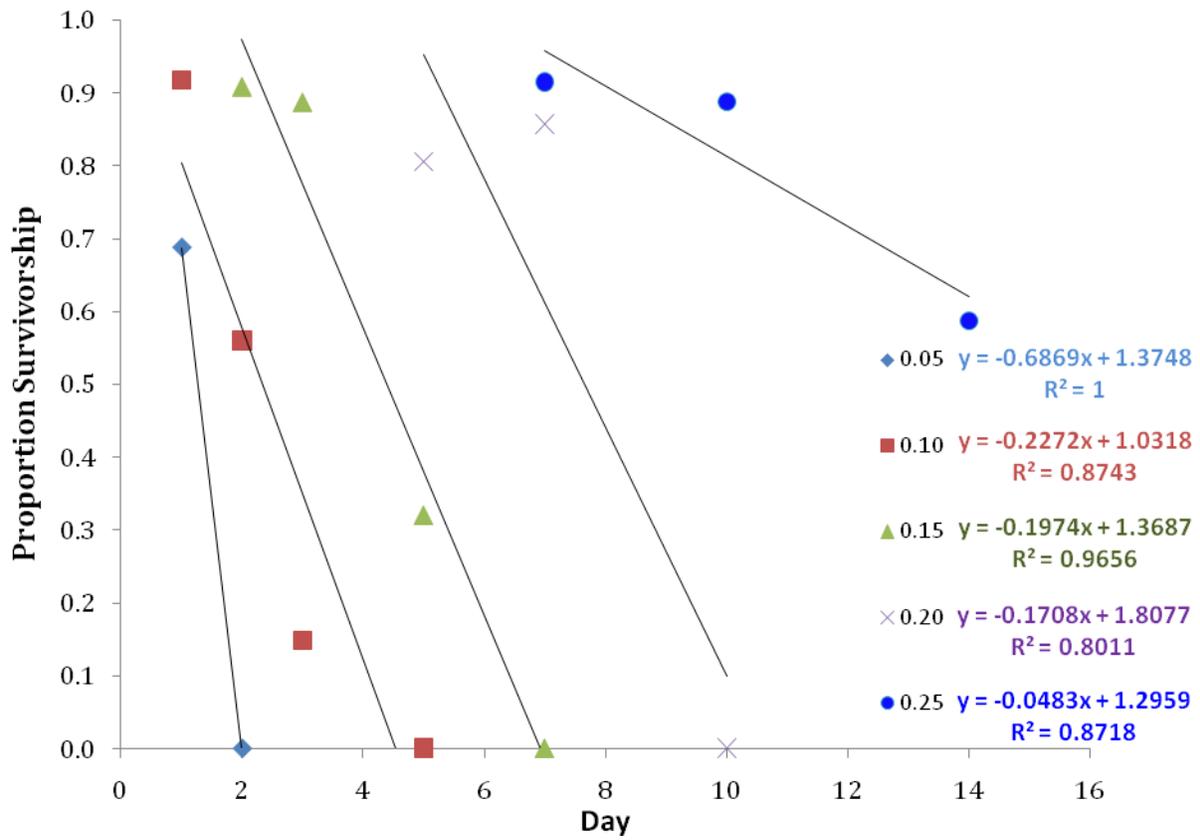


Figure 3-5. Survival curves of *Coptotermes formosanus* placed in northern red oak moistened at 5, 10, 15, 20, and 25% moisture contents.

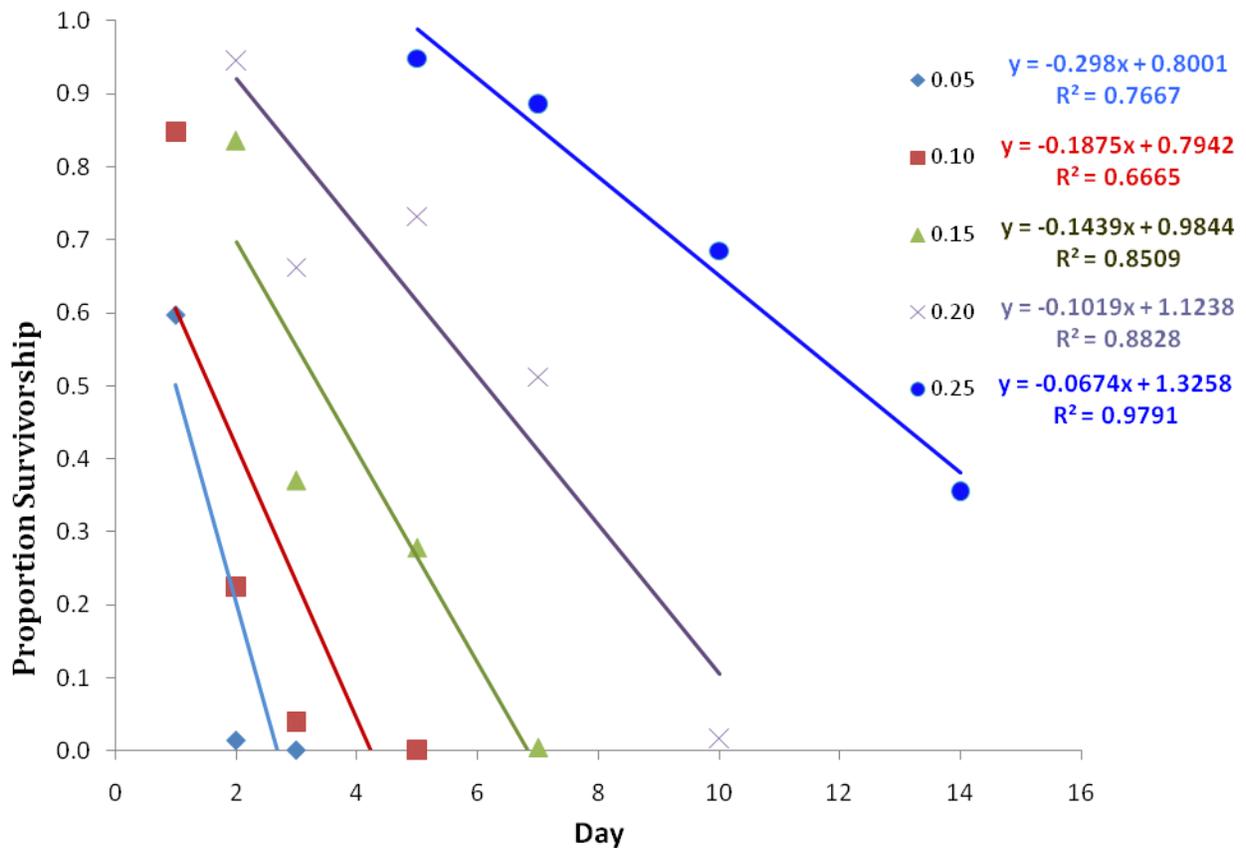


Figure 3-6. Survival curves of *Coptotermes formosanus* placed in southern yellow pine moistened at 5, 10, 15, 20, and 25% moisture contents.

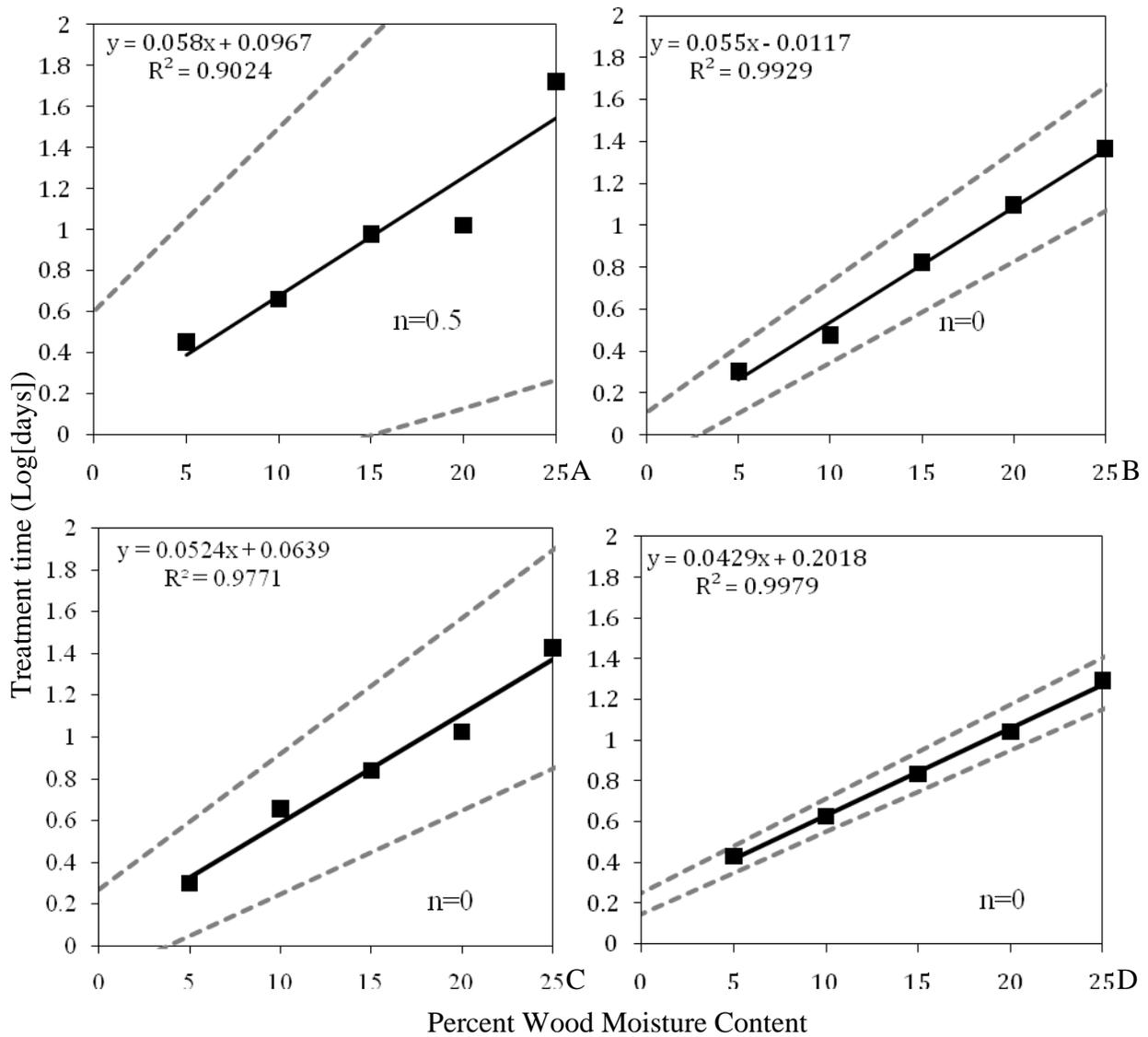


Figure 3-7. Death curve using the kinetic order model (n) representing LOG of days to reach 100% mortality of *Reticulitermes flavipes* and *Coptotermes formosanus* placed in southern yellow pine (SYP) and northern red oak (NRO) blocks with 5, 10, 15, 20, and 25% wood moisture contents (WMC), dotted lines represent 95% confidence interval of regression line: A) *R. flavipes* on NRO, B) *R. flavipes* on SYP, C) *C. formosanus* on NRO, D) *C. formosanus* on SYP.

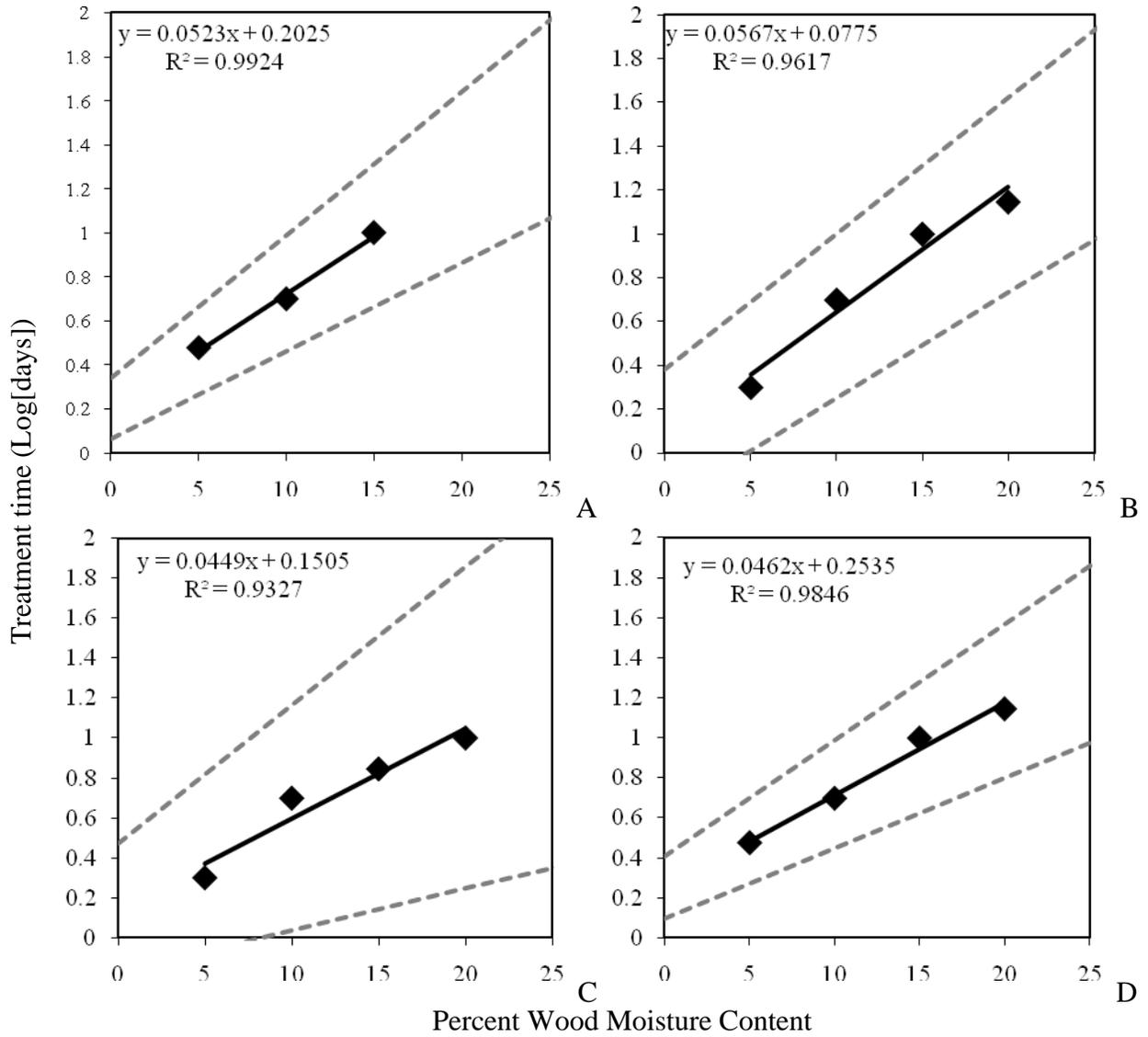


Figure 3-8. Death curves representing observed time (Log[days]) and wood moisture content (WMC) combinations in *Reticulitermes flavipes* and *Coptotermes formosanus* yielding 100% mortality, dotted lines represent 95% confidence interval of regression line: A) *R. flavipes* on NRO; B) *R. flavipes* on SYP; C) *C. formosanus* on NRO; D) *C. formosanus* on SYP.

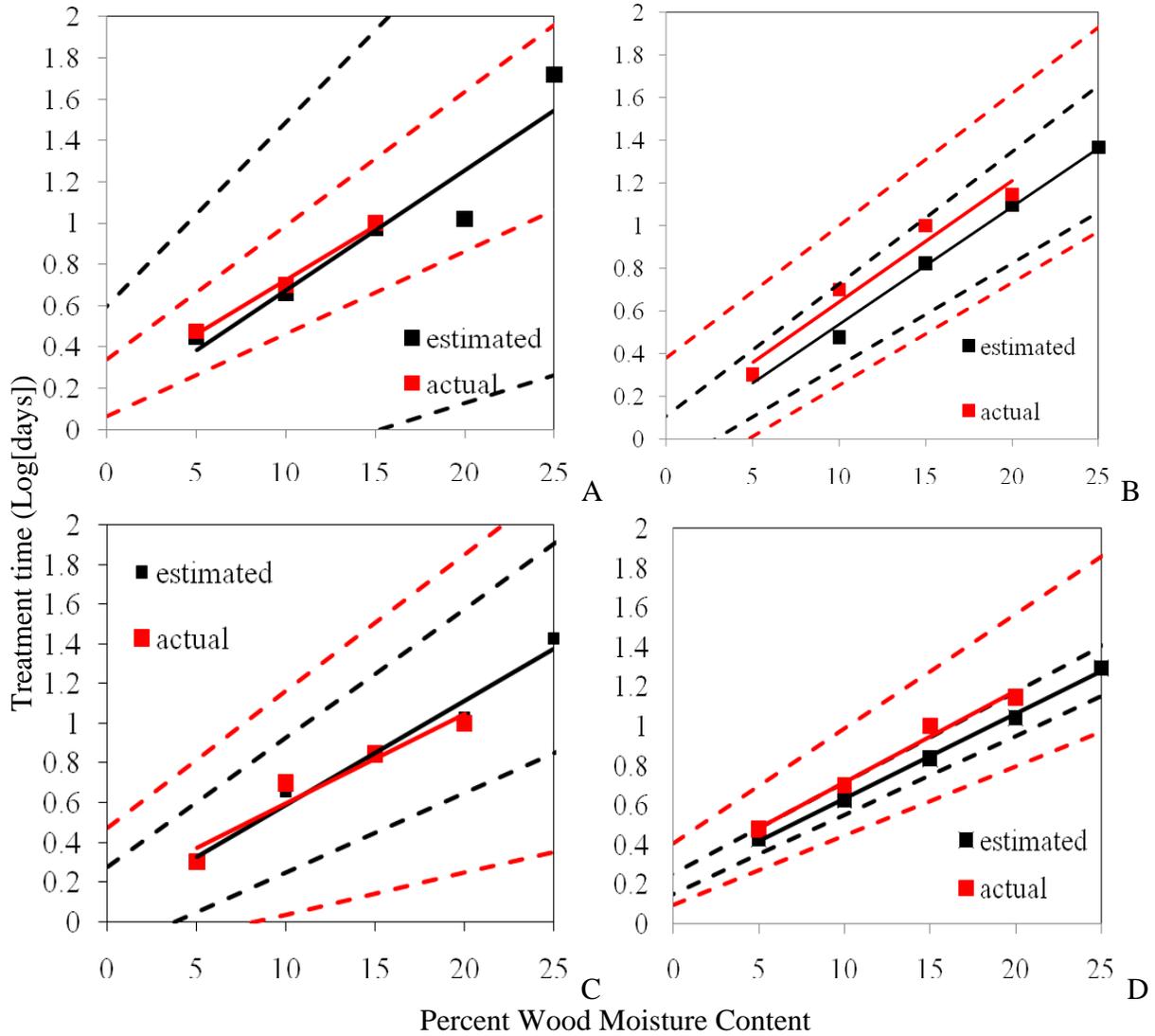


Figure 3-9. Comparison of estimated (Fig. 3-7) and actual (Fig. 3-8) death curves representing time (Log[days]) and wood moisture content (WMC) combinations in *Reticulitermes flavipes* and *Coptotermes formosanus* yielding 100% mortality, dotted lines represent 95% confidence interval of regression line. A) *R. flavipes* on NRO; B) *R. flavipes* on SYP; C) *C. formosanus* on NRO; D) *C. formosanus* on SYP

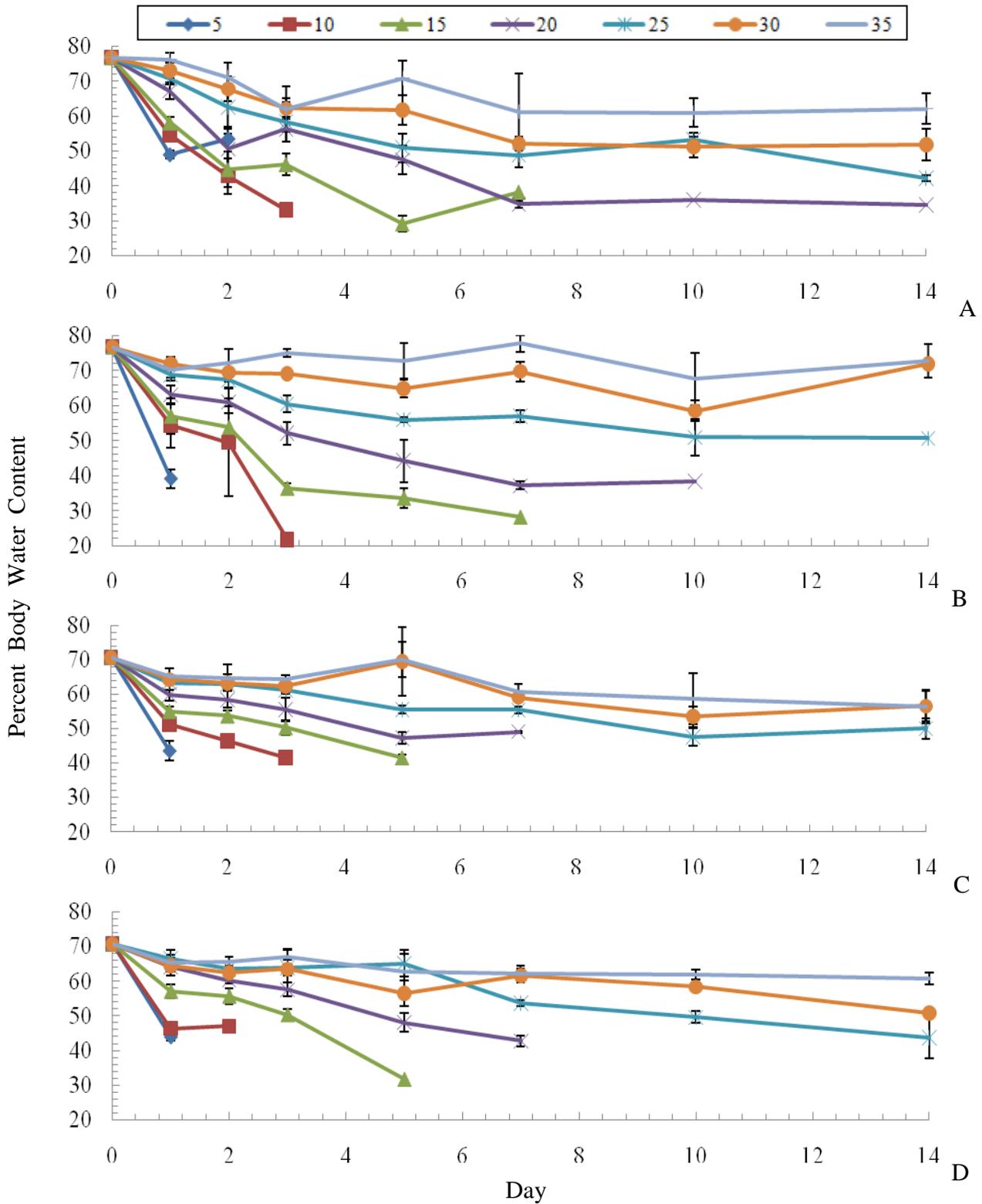


Figure 3-10. Effect of wood moisture on body water content of *Reticulitermes flavipes* and *Coptotermes formosanus* placed in southern yellow pine (SYP) and northern red oak (NRO) wood blocks with 5, 10, 15, 20, 25, 30 and 35% moisture contents: A) *R. flavipes* on NRO, B) *R. flavipes* on SYP, C) *C. formosanus* on NRO, D) *C. formosanus* on SYP.

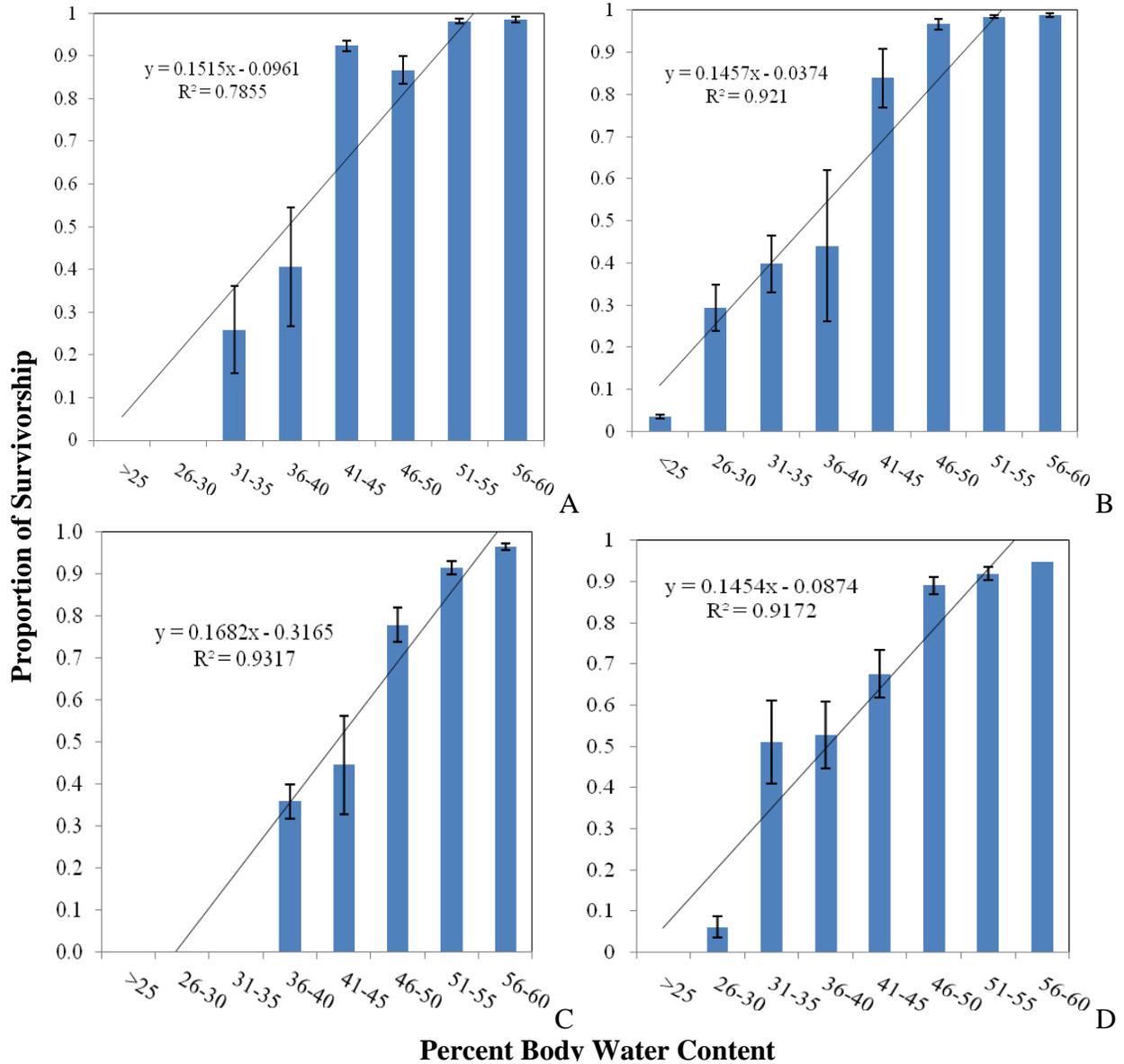


Figure 3-11. Relationship between classes of percent body water content (BWC) and survivorship of *Reticulitermes flavipes* and *Coptotermes formosanus* confined to wood at different WMC. A) *R. flavipes* on NRO; B) *R. flavipes* on SYP; C) *C. formosanus* on NRO; D) *C. formosanus* on SYP.

Table 3-1. Effect of WMC, and estimated relative humidity, on the mortality of *Reticulitermes flavipes* and *Coptotermes formosanus* over 14 d in northern red oak (NRO) and southern yellow pine (SYP)

wood species	% WMC	Estimated % Relative Humidity	<i>Reticulitermes flavipes</i> Days							<i>Coptotermes formosanus</i> Days						
			1	2	3	5	7	10	14	1	2	3	5	7	10	14
NRO	5	54	11	96	100	-	-	-	-	31	100	-	-	-	-	-
	10	75	2	45	98	100	-	-	-	08	44	85	100	-	-	-
	15	86	0	23	23	64	98	100	-	05	09	11	68	100	-	-
	20	95	0	06	02	03	72	96	100	02	04	1	19	14	100	-
	25	96	0	03	04	02	08	19	09	03	02	03	08	08	11	41
	30	95	0	0	02	0	01	01	04	01	04	02	03	05	07	04
	35	98	0	0	02	0	01	02	0	01	01	0	03	02	02	05
SYP	5	52	78	100	-	-	-	-	-	4	99	100	-	-	-	-
	10	73	25	64	99	100	-	-	-	15	78	96	100	-	-	-
	15	86	02	08	58	77	99	100	-	01	16	63	72	99	100	-
	20	90	01	03	06	3	6	95	100	0	05	34	27	49	98	100
	25	95	0	01	02	01	0	2	43	0	04	07	05	11	31	64
	30	97	01	01	01	0	0	0	0	0	06	06	08	08	13	13
	35	97	0	01	01	01	0	02	01	0	03	06	07	05	11	18

Table 3-2. Analysis of Variance results for termite mortality in 5-35% wood moisture content for different treatments ($\alpha=0.05$)

Treatment	DF	MS	F-value	P-value
R. flavipes on NRO	6	6.51	33.45	<0.0001
R. flavipes on SYP	6	7.77	50.39	<0.0001
C. formosanus on NRO	6	1.79	12.96	<0.0001
C. formosanus on SYP	6	6.38	32.82	<0.0001

Table 3-3. Coefficients of determination (r^2) used to determine N (kinetic orders) used for survivorship curves to estimate termites mortality at any given wood moisture content. Highlighted values represent those used to develop death curves

Treatment	N	Wood Moisture Content						
		5	10	15	20	25	30	35
<i>R. flavipes</i> NRO	0	1	0.8743	0.9656	0.8011	0.8718	0.2763	1
	0.5	1	0.979	0.9505	0.8204	0.8306	0.3027	1
	1	1	0.933	0.8067	0.8357	0.8521	0.3312	1
	1.5	1	0.8066	0.7035	0.8413	1	0.3621	1
	2	1	0.7755	0.6854	0.842	0.8379	0.3951	1
<i>R. flavipes</i> SYP	0	0.7667	0.6665	0.8509	0.8828	0.9791	0.843	0.9992
	0.5	0.8089	0.7984	0.9388	0.8193	0.9808	0.8398	0.9998
	1	0.8909	0.9201	0.9646	0.7151	0.7158	0.8366	1
	1.5	0.946	0.9469	0.8972	0.6542	0.1016	0.8335	0.9998
	2	0.9608	0.9493	0.8571	0.6432	0.0342	0.8303	0.999
<i>C. formosanus</i> NRO	0	0.7829	0.7753	0.9122	0.8678	0.9944	0.9301	0.1263
	0.5	0.8488	0.8167	0.9344	0.9152	0.9872	0.9265	0.1241
	1	0.9684	0.8701	0.9010	0.9665	0.9778	0.9229	0.1219
	1.5	0.9970	0.8872	0.8549	0.9846	0.9666	0.9192	0.1197
	2	0.9777	0.8893	0.8444	0.9867	0.9543	0.9155	0.1175
<i>C. formosanus</i> SYP	0	1.0000	0.9987	0.9096	0.9376	0.9992	1.0000	0.2500
	0.5	1.0000	0.9728	0.9629	0.9520	1.0000	1.0000	0.2421
	1	0.7500	0.8426	0.8755	0.8980	0.9995	1.0000	0.2344
	1.5	0.7500	0.8706	0.6943	0.8371	0.9975	0.8176	0.2267
	2	0.7500	0.8842	0.6346	0.9268	0.7784	0.8176	0.2192

CHAPTER 4 DISCUSSION

Though studies have been conducted demonstrating that wood moisture content needs to be high in order for termites to be able to sustain activity, the exact wood moisture content needed, without external moisture sources was unknown. My study aimed at determining the wood moisture content effects on termite survival and body water content. Previous studies have shown that termites prefer moist wood over dry wood (Delaplane and La Fage 1989), even if given an additional source of water. However, these authors did not examine the effects the lower moisture wood had on subterranean termites.

WMC affects the relative humidity in the ambient environment around the block of wood. Though it has been noted that termites are able to survive in wood as long as the moisture content is >16% (Forschler 1999), my data suggests otherwise. It has been suggested that when wood has >16% WMC, the relative humidity in the interstitial spaces is at or near 100% and, therefore, termites should not die from water loss through the cuticle. However, my results show that even in cases where the wood is >16% WMC, and even at 25% WMC, termites still lose body water.

I estimated the relative humidity of the air within 15% WMC blocks to be <90%, which explains why termites were unable to survive for a week at 15% WMC or below. At 20% WMC, neither *R. flavipes* nor *C. formosanus* were able to survive longer than 10 days, where relative humidity was lower than that found at 25% WMC. This suggests that relative humidity needs to be >95% in order for termites to sustain activity as shown before. McManamy *et al.* (2008) found that WMC had to be >24% in order to sustain subterranean termite aerial infestations with no soil contact. However, the authors assumed that the relative humidity within the wood was at or near 100% based on Forchler's review (1999). Our results suggest that relative humidity may be lower

than previously expected when the wood has >24% WMC, therefore, termites can lose cuticular body water.

Relative humidity results peaked to 98% relative humidity at 25% WMC and there was no significant difference between the relative humidity in the area surrounding wood boxes moistened to 30 and 35% WMC. I was unable to obtain a relative humidity value of 100% when wood was moistened at a point higher than saturation. This may have occurred because tap water was used to wet the wood blocks. Wood saturation with distilled water may have given a close relative humidity of 100% (Almeida and Hernandez 2005). Tap water may have contained dissolved salts which prevented measurements of ambient environment from reaching 100%. Studies have shown that tap water contains higher fluoride content than distilled water (Lalumandier et al. 2000).

Sponsler and Appel (1990) exposed termites to conditions of very low relative humidity (0-2%). Our results show that termites were able to lose more BWC throughout time than previous studies before death occurred. The longer survival observed in my studies may have been a result of moisture from wood maintaining a higher ambient relative humidity for a longer period of time. A higher relative humidity would have allowed termites to retain their BWC for a longer time, maintaining BWC above a critical level at which death occurs.

Relative humidity and the temperature to which termites are exposed cause changes in termite BWC which determine survivorship of the insect. Previous studies have also shown that *R. flavipes* will live 5.1 hr at 30°C and 0-2% RH, with 53.5% BWC at time of death, and *C. formosanus* will live 7.1 hr, with 50.5% BWC at time of death (Sponsler and Appel 1990). Collins (1969) showed that *R. flavipes* workers were able to live 3.0-6.2 hr and drop to 56.5% BWC before 100% mortality in 34-35°C and 0-4% relative humidity conditions.

Although a surviving *R. flavipes* termite on SYP at 10% WMC was measured as having 21.7% BWC, termites began to die rapidly at approximately 35-49% body weight loss in my experiment, which is lower than the BWC observed at time of death by Collins (1969) and Sponsler and Appel (1990). McManamy et al. (2008) found similar results where 20% WMC caused termites to drop approximately 40% body weight which led to rapid mortality.

In addition to ambient relative humidity, temperature also has an effect on termite mortality. Our experiment were maintained at room temperature (23°C), contrary to those in previous mentioned experiments (Collins 1969; Sponsler and Appel 1990) where termites were held in $\geq 30^\circ\text{C}$. Lower temperatures may have had an effect on the length of time it took to reach 100% termite mortality, allowing termites to survive longer.

Unlike Collins (1969) who exposed termites to high temperatures (30°C) and low relative humidities (0-2%), my experiment maintained termites at room temperature and relative humidities $\geq 60\%$. Lower temperatures and higher relative humidities may have allowed termites to decrease their BWC over a longer time before reaching 100% mortality. My experiment showed that even though BWC decreased, termites were able to survive longer than 24 hr with ambient relative humidity $< 60\%$. As shown by Mellanby (1939), termites were able to lower their BWC and still be able to sustain activity.

My results showed that even though there was no significant difference between termite mortality at 30, and 35% WMC, mortality was significantly greater at 25% WMC for termites in SYP. McManamy *et al.* (2008) reported that wood moisture content needed to be at least 30% in order for subterranean termites to sustain an aerial infestation. Wood fiber saturation does not occur until the wood reaches 25-30% moisture content (Carll and Highly 1999); any moisture content above that is free water in the wood. This suggests that termite mortality is not only dependent on

ambient relative humidity but also require access to free water. Both *R. flavipes* and *C. formosanus* on NRO showed no significant difference in mortalities between 25 and 30% WMC at the end of the experimental period.

Insects are able to draw upon their hemolymph as a liquid reserve without impairing their locomotion or respiration (Mellanby 1939). Termites are able to do this and have been seen walking after substantial hemolymphic fluid loss following flattening of the abdomen (Collins 1969). By flattening their abdomens, termites were able to sustain more body water weight loss while being exposed to lower relative humidities. This explains why termites in my experiments were able to live for days at lower relative humidities.

Another source of moisture when stressed for water may be the feces of the subterranean termite. Subterranean termite feces is usually a muddy texture, with no solid shape, unlike drywood termite feces. Nakayama et al (2004) suggested that when subterranean termites become stressed for moisture, they will excrete liquid feces to increase ambient relative humidity. Contrary to these reports, solid pellets of feces were found in blocks with WMC <25% in my experiments (Fig. 4-1). Similar observations were made where species of Kalotermitidae showed a plug of hard material protruding from the anus following experimental drying (Collins 1969). This suggests that, when stressed for moisture, subterranean termites may be able to absorb extra moisture from their feces. McManamy *et al.* (2008) suspected termites to be losing water through their feces, which would be minimized if termites were excreting solid feces, as I observed. Dead termites exposed to low relative humidities died from desiccation. A closer observation to those termites showed pellets of feces protruding from their anus (Fig. 4-2). This proves that when stressed for moisture, subterranean termites will try to retain as much moisture as possible from their feces.

Additionally, termites may have better access to moisture depending on the type of wood they are feeding on. *C. formosanus* prefers hard wood over southern yellow SYP (Morales-Ramos and Rojas 2001), however *R. flavipes* has not shown to have any preference. Feeding preference in previous studies may have been affected by the way water is retained in wood. Though hardwoods have tighter wood fibers than soft woods, hard woods contain vesicles which are able to retain more isolated amounts of water, allowing termite access to more water (Manchester 1996). This fact would further explain why both termite species were able to survive in NRO at lower wood moisture contents than SYP.

Using the thermal kinetic method was an effective way to estimate termite mortality. Slopes for all estimated survival curves using the kinetic equations decreased with an increase in wood moisture content for all treatments. This shows that, with an increase in wood moisture content, termites are able to survive longer. This occurs because, with an increase in wood moisture content, there is an increase in water uptake as termites consume the wood. The more water they are able to consume, the longer they are able to survive, decreasing the slope of the survival curve. At 30-35 WMC, termite life span is not limited by lack of moisture and termite colonies should be able to sustain an aerial infestation without other water sources.

Another factor that affects termite survival is group size. Studies have shown that termites exposed to dry conditions will live longer if tested in groups rather than individually (Collins 1969). Different amounts of total insects were used per wood block per species; 101 *R. flavipes* and 110 *C. formosanus*. This could explain why *C. formosanus* on NRO showed lower mortality rates than all other treatments. In our experiments, because 101-110 termites were used in each individual block, mortality in block with WMC at 30 and 35% may have been caused by cannibalism, mold (which was formed in the wood), or other natural causes. In field settings, termites have the ability to move

from an area heavily infested with mold. However in my experiments, termites were confined to an area where mold may have affected the longevity of the termites. Also, because both termite species were field collected and age was not determined, that may have had an effect on termite mortality.

Wood moisture content is a very important factor in determining whether or not a termite colony is able to survive in aerial infestations without soil contact or other water sources. Because these infestations have no soil contact, it is imperative that that moisture content of the nest and relative humidity within the nest are high enough to sustain the colonies. My research shows that relative humidity needs to be <95% in order to sustain long term termite survival in wood with no external source of moisture. Furthermore, termites seem to need free water in the wood to be able to survive, requiring WMC to be >25%. Termites in wood with low WMC were probably not able to obtain enough water to replace water they were losing through the cuticle due to low ambient relative humidities. My experiments showed that when subterranean termites are stressed for moisture, they are capable of conserving water by reabsorbing it from their feces, forming pellets. However, once their BWC lowers to ~35-45%, subterranean termites cannot survive and rapid mortality occurs. For this reason, termites rely greatly on external sources of moisture such as leaky roofs, faulty plumbing, or excess rain water to live long term in aerial infestations.

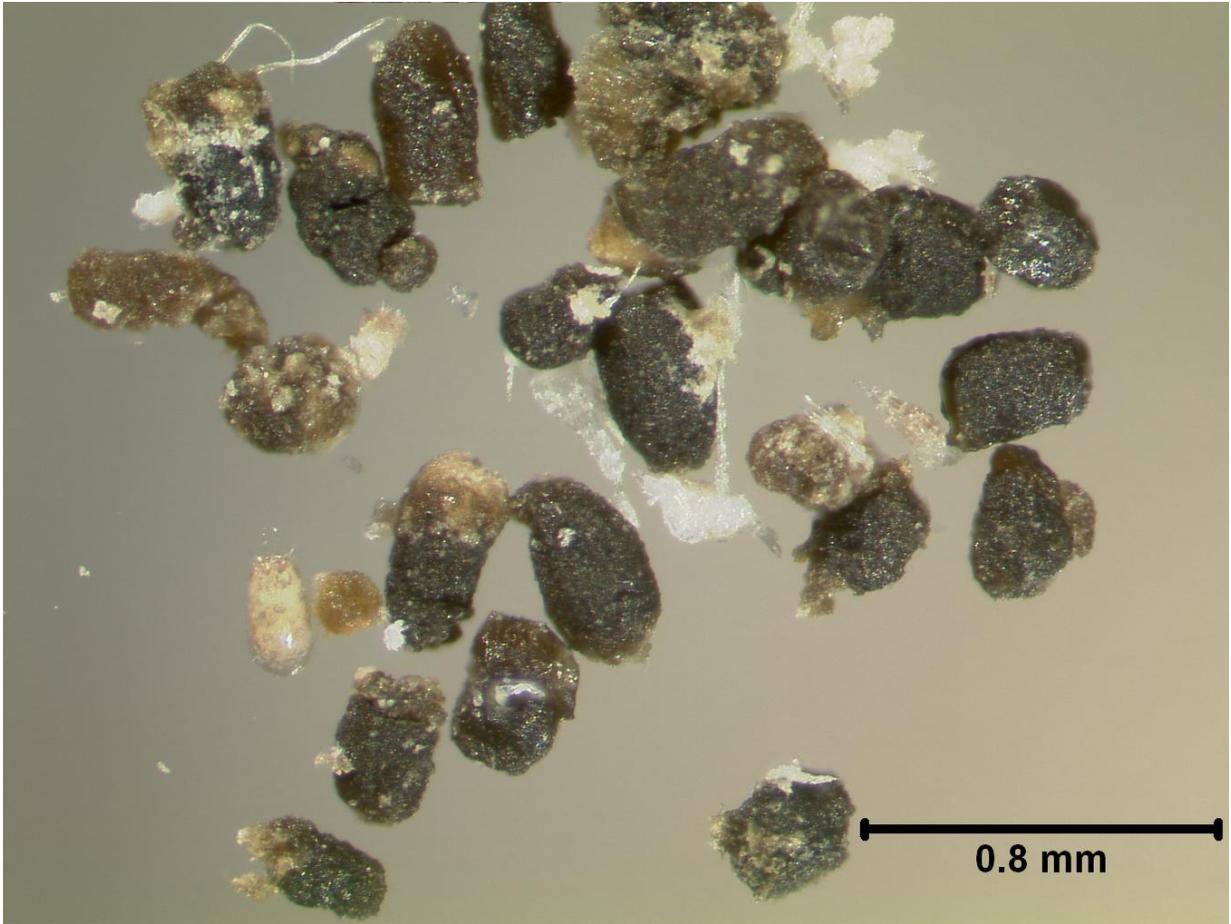


Figure 4-1. Dry fecal pellets obtained from *Reticulitermes flavipes*.



Figure 4-2. Desiccated *Reticulitermes flavipes* worker with dried fecal pellet protruding from anus

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BIOGRAPHICAL SKETCH

Wai-Han Chan grew up in Miami, FL. She is the second of four daughters to Man Tat Chan and Leyon Chan. She attended Gulliver Preparatory for high school. Upon graduation in 2003, she attended Purdue University where she obtained her Bachelor of Science in entomology in 2007. While studying at Purdue University, she was chosen for the Pat Baker/pow Pest Control, Inc. Memorial Scholarship in 2005 and the Oser Family Scholarship for entomology in 2007. She then earned her Master of Science in agricultural and life sciences in urban entomology Summer of 2010 from the University of Florida under the mentorship of Dr. Philip Gene Koehler and Dr. Roberto Manoel Pereira. While obtaining her research degree studying the wood moisture effects on subterranean termites, she had the opportunity to give six professional presentations at annual meetings including the Entomological Society of America, Florida Pest Management Association, Southeastern pest management conference, and the Florida Entomological Society where she won 2nd place in a student paper competition. In 2008, she was elected president of Urban Entomological Society while being a member of the Entomological Society of America and Florida Entomological Society. Upon graduating from the University of Florida, she has completed six publications in Florida Pest Pro magazine, University of Florida Featured Creatures, and Pests in and Around the home.

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