Abstract

Alder, Patricia McKeithan. Considerations for Argentine ant management (Under the direction of Dr. Jules Silverman).

This research project investigated various aspects of Argentine ant management in North Carolina. The effects of interspecific competition between the Argentine ant, *Linepithema humile* (Mayr), and a native ant species, *Monomorium minimum* (Buckley), on toxic bait performance were examined. In a laboratory study, we found that *L. humile* diminished the effects of a solid sulfluramid bait against *M. minimum*, while *M. minimum* reduced the performance of a liquid fipronil bait against Argentine ants. Argentine ants were not adversely affected by sulfluramid bait at any time, while *M. minimum* was not affected by fipronil bait until 14 days of exposure. In field studies, *L. humile* visited food stations over an entire 24-hour period, while *M. minimum* was only observed at food stations during daylight hours. In addition, during the afternoon hours *M. minimum* appeared to delay *L. humile* visits to food stations by ca. 30 minutes before ultimately being displaced by *L. humile*.

We compared the variability and time associated with four monitoring methods commonly employed to detect changes in Argentine ant populations: trailing activity, ant counts at baits, sucrose consumption, and pitfall trap collections. Pitfall trapping was both the most variable and time consuming, while the variability of the remaining methods was similar. Deployment of baits required the least time per unit, however, and was therefore recommended as a monitoring tool for Argentine ant populations.

Finally, three field studies were performed to evaluate various insecticides and treatment strategies for use against *L. humile*. In one trial, we compared the efficacy of gel bait or contact granules with that of a combination of the two applications. There were no significant reductions of Argentine ants one week following application. A combination treatment of Deltagard® granules and Maxforce® bait provided a greater,

although not significant, reduction in Argentine ant populations. In a second trial, we evaluated the efficacy of two liquid baits. We found that average Argentine ant reductions following exposure to thiamethoxam bait or Advance™ bait did not differ. In addition, the number of Argentine ants consuming thiamethoxam bait was numerically but not significantly less than the number of ants consuming Advance™ bait. Finally, the effect of liquid fipronil (Termidor®) applied as a barrier around the exterior of homes infested with Argentine ants was measured in a third trial. Houses receiving Termidor® had an average Argentine ant population reduction of 41% two weeks following treatment. Those homes that served as untreated controls had a 62% reduction, a reduction greater than that of our treatment.

CONSIDERATIONS FOR ARGENTINE ANT MANAGEMENT

By

PATRICIA MCKEITHAN ALDER

A Thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

DEPARTMENT OF ENTOMOLOGY

Raleigh

2004

APPROVED BY:

____

Dr. Mike Waldvogel

______________________________ ______________________________

Dr. Edward Vargo

Dr. Jules Silverman, Chair of
Advisory Committee

Biography

Patty McKeithan Alder was born and raised in North Carolina. Her hometown is Waxhaw, a small town located about 30 miles south of Charlotte, North Carolina. She received a Bachelor of Science in biology from the University of North Carolina at Charlotte in 2000 before moving to Raleigh, North Carolina to pursue a Master of Science in entomology with Dr. Jules Silverman. She is currently employed at Clegg's Termite & Pest Control as technical director.

Acknowledgements

I would like to thank my advisor, Jules Silverman, for giving me the opportunity to do this project, for providing valuable guidance, advice and support, and for his kind patience. I am also grateful to my committee, Ed Vargo and Mike Waldvogel, for their assistance and expertise. I would also like to thank Fred Hain for being such an unbelievable and outstanding teacher, and also for providing so much advice, guidance and patience as I wavered back and forth about going on to receive a Ph.D. Finally, I would like to thank Cavell Brownie for statistical support.

My field and laboratory work would have been much tougher without the aid of Adrian Carper. Adrian not only provided help with the physical aspects of the work, but also provided someone fun to chat and laugh with.

My family and friends have been a support group over the past few years and have provided much encouragement. I would like to especially thank my husband, David, for packing up and moving to Raleigh so that I could do this project.

This project was funded by North Carolina State University Blanton J. Whitmire Endowment, North Carolina Pest Control Association, Bayer Environmental Science and Syngenta.

Table of Contents

List of Tables

List of Figures

LIST OF FIGURES, CONT'D

Chapter I

Introduction

Distribution

The Argentine ant, *Linepithema humile* (Mayr), originally from South America, is a worldwide pest in Mediterranean climates (Rust and Knight 1990). This ant has invaded and become established in disturbed areas in Western Australia (Whitehouse 1988, Majer 1994), South Africa (Durr 1952, De Kock and Giliomee 1989), Portugal, France, Germany, Italy, and the United States (Mallis 1942, Knight and Rust 1990, Thompson 1990, Klotz et al. 1995). The Argentine ant is believed to have entered the United States via coffee ships from Brazil and was first recorded in Louisiana in 1891 (Newell and Barber 1913). Within a few years it had spread to parts of Alabama and Mississippi (Newell and Barber 1913) and has since spread to other southern states (Haack and Granovsky 1990). The Argentine ant was first recorded in Hawaii in 1940 (Zimmerman 1941) and isolated infestations have been reported from Arizona, Missouri, Illinois, Maryland, Oregon, and Washington (Mallis 1942). This ant was recorded in California by 1908 (Skaife 1961) where it is now common in urban, agricultural, and disturbed riparian woodlands (Ward 1987). In a more recent survey conducted in California, Holway (1995) found that the Argentine ant occupied a wide variety of habitats not previously occupied, especially along the coast.

Life History and Biology

Argentine ant colonies are polygynous and reproduce by budding, a process in which a group of workers, accompanied by one or more queens, will leave the parent colony to create a new nest (Newell and Barber 1913, Skaife 1961, Hedges 1998). In late winter, large numbers of eggs are laid that give rise to sexual forms (Markin 1970a). The production of males precedes that of queens by ca. two weeks (Passera and Aron 1993). Males are most numerous in the colonies during the spring and are very seldom seen in the summer (Newell and Barber 1913). Shortly after the new queens emerge, mating occurs in the nest after which time females lose their wings (Markin 1970a). In early spring, eggs are laid that give rise to the first worker brood of the season (Markin 1970a). Argentine ant workers are monomorphic, 2.2 - 2.8mm, and vary in color from light brown to blackish brown (Newell and Barber 1913). Under optimal conditions, workers have a life span of 10 – 12 months (Newell and Barber 1913). The average incubation period for eggs is 28 days, for larval development 31 days, and the worker pupal stage lasts an average of 15 days (Newell and Barber 1913).

Nesting Habits and Diet

The Argentine ant is often found in close proximity to water (Ward 1987, Holway 1995) and prefers areas disturbed by human activity where landscapes are mulched and irrigated (Majer 1994, Passera 1994). Argentine ants will nest in a variety of substrates, including leaves, mulch, soil, compost piles, and even trash. In the summer, nests are typically concentrated within the top one to two inches of the soil (Haack and Granovsky 1990). When conditions become unfavorable, a portion of the colony may break off and form a satellite colony (Newell and Barber 1916, Skaife 1961).

The Argentine ant has a high preference for liquid, sugary food such as honeydew or nectar, but will also scavenge for dead insects and arthropods (Markin 1970b). Rust et al. (2000) found that both sucrose and honey solutions as well as a protein-based granular food were readily accepted year round by Argentine ants.

Pest Status and Control Methods

Ecological. The Argentine ant is a serious ecological pest. In areas it invades, this ant displaces native ants as well as other arthropods (Erickson 1972, Ward 1987, Cole et al. 1992, Majer 1994, Human and Gordon 1997, Holway 1998, Suarez et al. 1998, Sanders et al. 2001). As with many other invasive species, Argentine ant colonies are large and expansive, consisting of multiple nests, a condition known as polydomy. Upon its introduction, the Argentine ant is believed to have experienced a population bottleneck, resulting in lower overall allelic diversity (Suarez et al. 1999). As a result, intraspecific aggression is reduced among workers of neighboring colonies in the ant's introduced range as compared to its native range. More recently however, Giraud et al. (2002) suggested that the breakdown in nestmate recognition in much of the ant's introduced range is unlikely to have resulted from genetic bottleneck alone. At any rate, the lack of intraspecific aggression exhibited by introduced populations of the Argentine ant allows workers, queens, and brood to mix freely among multiple nests, permitting colonies to grow to enormous sizes. The high population density of this ant in its introduced range has been shown to contribute to its competitive advantage (Holway 1998, Holway 1999, Human and Gordon 1999).

Agricultural. The Argentine ant is considered an agricultural pest because it tends honeydew-producing insects, causing indirect agricultural damage by interfering with biological control programs in citrus groves and other fruit orchards (Foster 1908, Newell and Barber 1913, Durr 1952, Phillips et al. 1987). Increased densities of the citrus red mite, *Panonychus citri* (McGregor), were positively associated with Argentine ant activity (Haney et al. 1987). In agricultural settings control efforts include incorporation of repellent chemicals, such as farnesol, on sticky tree bands to exclude Argentine ants from citrus trees (Shorey et al. 1996). Phillips et al. (1987) reported that although sticky bands were the most effective treatment among those tested for controlling Argentine ants in a cherimoyas orchard, the bands were impractical because of the extensive labor involved with reapplication. The authors recommended a spot application of Lorsban® (chlorpyrifos) stating that this treatment provided the best combination of efficacy and practicality.

The Argentine ant is one of four ant species in Hawaii sugarcane fields, causing damage to plastic drip tubes of irrigation systems (Chang and Ota 1990). The ants chew through the tube walls, enlarging tube diameter, leading to flooding in the damaged area and poor water distribution.

The Argentine ant is the major ant pest of nursery crops in southern California (Costa and Rust 1999). Liquid sprays are commonly used in nursery settings for Argentine ant control. However, liquid sprays can be diluted or removed from surfaces and broadcast bait formulations may become moldy due to frequent overhead irrigation (Costa et al. 2001). Costa and Rust (1999) found that an alternative control method in which soil was treated with fipronil provided significantly greater Argentine ant mortality than did the control or other treatments. Commercial shipments of plants have contributed to the distribution of the Argentine ant in the United States (Newell and Barber 1913, Smith 1965), necessitating effective Argentine ant control in nursery settings.

Urban. The Argentine ant is a significant urban pest that readily invades homes and other structures (Newell and Barber 1913, Smith 1965, Klotz 1995). This ant is the most common pest ant in and around structures in urban settings in California (Knight and Rust 1990), and has become established in the southern states of the U.S. as well (Smith 1965, Haack and Granovsky 1990). It is also the dominant ant species in disturbed areas in the Mediterranean (Holldobler and Wilson 1990), and southwest Australia (Whitehouse 1988, Holldobler and Wilson 1990).

A common control strategy in the urban landscape is the application of a residual barrier to prevent ants from entering the structure (Haack and Granovsky 1990, Knight and Rust 1990). Rust et al. (1996) reported 80-90% reductions in Argentine ants with barrier treatments of chlorpyrifos, cyfluthrin, and cypermethrin seven days after treatment. However, only chlorpyrifos provided reductions greater than eighty percent 30 days following treatment. Rust and Knight (1990) found that Argentine ants were most successfully controlled when barrier sprays were applied around the perimeter of the property and as spot treatments to nest sites.

Chemical barriers are often ineffective for several reasons. The barrier must be applied thoroughly to ensure complete coverage so that ants cannot access structures through gaps. These barriers can kill or repel workers, but may have little effect on colony reproductives. Barber (1909) observed that one percent or less of the workers comprising a colony can sustain remaining individuals. In addition, barrier treatments may harm beneficial and non-target organisms.

The use of baits for Argentine ant control may minimize insecticide exposure to non-target organisms and the environment. Bait forms include solids, liquids, gels and granules. Klotz et al. (1998) achieved a significant and continuous reduction in Argentine ant numbers of 80% using 0.5% boric acid in 25% sucrose water. Argentine ant foraging activity was reduced by each of three containerized commercial baits within two weeks of exposure in a Georgia field study (Blachly and Forschler 1996). Granular formulations of hydramethylnon and diazinon were reported to provide significant reductions in Argentine ant numbers 60 days after treatment (Knight and Rust 1991). Baits have also been used in natural settings in an attempt to control this ant. Maxforce bait resulted in a reduction of Argentine ant activity an average maximum of 97% in Haleakala National Park, Hawaii, where eradication of this ant is desired.

The use of baits for controlling the Argentine ant has several advantages. Toxicants within a bait matrix have the potential of reaching brood and queens if taken to the nest by foraging workers. Baits can be placed on the exterior of homes quickly and easily, which may be less disruptive for homeowners because pest control operators can remain outdoors. Argentine ants may be less likely to invade homes in search of food if baits are placed on the exterior of homes. Klotz et al. (1998) reported Argentine ant foraging redirected from the inside of buildings to the outside in response to liquid boric acid bait. The efficacy of toxic bait, however, depends on acceptance and amount returned to the colony (Forschler and Evans 1994). Knowing where to place toxic baits and the amount to make available to ants may prove difficult because of the scattered nesting habits and large colony size of Argentine ants. In addition, baits can become moldy in rainy or humid conditions and toxicants may break down from UV radiation, both of which could shorten exposure time. Baits should be replenished as needed to ensure palatability. Placement of baits in locations free of direct sunlight should help avoid toxicant breakdown.

Biological control of the Argentine ant has only recently been investigated. In a study conducted in the ant's native range, Brazil, Orr and Seike (1998) reported that Argentine ants abandoned food resources and returned underground in the presence of *Pseudacteon* fly parasitoids. These responses have lead to the idea that phorid flies may be useful in a biological control program aimed at invasive Argentine ants. However, in a later study, Orr et al. (2001) found that phorids did not locate *L. humile* in North American or morphologically similar ants from Brazil and suggested that these parasitoids are not candidates for biological control of Argentine ants in North America.

References Cited

Blachly, J.S. and B.T. Forschler. 1996. Suppression of late-season Argentine ant (Hymenoptera: Formicidae) field populations using a perimeter treatment with containerized baits. J. Econ. Entomol. 89(6): 1497-1500.

Chang, V. and A.K. Ota. 1990. Ant control in Hawaiin drip irrigation systems. *In* Applied myrmecology, a world perspective. R.K. Vander Meer, K. Jaffe, and A. Cedeno, Editors. Westview Press, Boulder, CO. Pages 708-715.

Cole, F.R., A.C. Medeiros, L.L. Loope, and W.W. Zuehlke. 1992. Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. Ecology 73(4): 1313-1322.

Costa, H.S. and M.K. Rust. 1999. Mortality and foraging rates of Argentine ant (Hymenoptera: Formicidae) colonies exposed to potted plants treated with fipronil. J. Agric. Urban Entomol. 16(1): 37-48.

Costa, H.S., L. Greenberg, J. Klotz, and M.K. Rust. 2001. Monitoring the effects of granular insecticides for Argentine ant control in nursery settings. J. Agric. Urban Entomol. 18(1): 13-22.

De Kock, A.E. and J.H. Giliomee. 1989. A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South African fynbos. J. Entomol. Soc. South. Afr. 52: 157-164.

Durr, H.J.R. 1952. The Argentine ant *Iridomyrmex humilis* (Mayr). Its distribution, harmfulness and life cycle. Farm. S. Afr. 27: 381-390.

Erickson, J.M. 1972. The displacement of native ant species by the introduced Argentine ant *Iridomyrmex humilis* (Mayr). Psyche 78: 257-266.

Forschler, B.T. and G.M. Evans. 1994. Argentine ant (Hymenoptera: Formicidae) foraging activity response to selected containerized baits. J. Entomol. Sci. 29: 209-214.

Foster, E. 1908. The introduction of *Iridomyrmex humilis* (Mayr) into New Orleans. J. Econ. Entomol. 1: 289-293.

Giraud, T., J.S. Pedersen, and L. Keller. 2002. Evolution of supercolonies: the Argentine ants of southern Europe. Proc. Natl. Acad. Sci. 99(9): 6075-6079.

Haack, K.D. and T.A. Granovsky. 1990. Ants. Pages 415-479. *In* A. Mallis, editor. Handbook of pest control. Franzak and Foster, Cleveland, OH.

Haney, P.B., R.F. Luck, and D.S. Moreno. 1987. Increases in densities of the citrus red mite, *Panonychus citri* (Acarina: Tetranychidae), in association with the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in southern California citrus. Entomophaga 32: A.

Hedges, S.A. 1998. Field guide for the management of structure-infesting ants. Second Edition. G.I.E. Publishing, Cleveland, OH.

Holldobler, B. and E.O. Wilson. 1990. The Ants. Harvard University Press, Cambridge, Mass. 732 pages.

Holway, D.A. 1995. Distribution of the Argentine ant (*Linepithema humile*) in northern California. Conserv. Biol. 9(6): 1634-1637.

Holway, D.A. 1998. Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. Oecologia 116: 252-258.

Holway, D.A. 1999. Competitive mechanisms underlying the displacement of native ants by the invasive Argentine ant. Ecology 80(1): 238-251.

Human, K.G. and D.M. Gordon. 1997. Effects of Argentine ants on invertebrate biodiversity in northern California. Conserv. Biol. 11(5): 1242-1248.

Human, K.G. and D.M. Gordon. 1999. Behavioral interactions of the invasive Argentine ant with native ant species. Insect. Soc. 46: 159-163.

Klotz, J.H., J.R. Mangold, K.M. Vail, L.R. David, Jr., and R.S. Patterson. 1995. A survey of the urban pest ants (Hymenoptera: Formicidae) of peninsular Florida. Fla. Entomol. 78(1): 109-118.

Klotz, J.H., L. Greenberg, and E.C. Venn. 1998. Liquid boric acid bait for control of the Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 91(4): 910-914.

Knight, R.L. and M.K. Rust. 1990. The urban ants of California with distribution notes of imported species. Southwest. Entomol. 15: 167-178.

Knight, R.L. and M.K. Rust. 1991. Efficacy of formulated baits for control of Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 84(2): 510-514.

Majer, J.D. 1994. Spread of Argentine ants (*Linepithema humile*), with special reference to western Australia. Pages 163-173. *in* D.F. Williams, editor. Exotic ants: biology, impact, and control of introduced species. Westview, Boulder, Colorado, USA.

Mallis, A.M. 1942. Half a century with the successful Argentine ant. Sci. Mon. 55(6): 536-545.

Markin, G.P. 1970a. Foraging behavior of the Argentine ant in a California citrus grove. J. Econ. Entomol. 63: 740-744.

Markin, G.P. 1970b. The seasonal life cycle of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in southern California. Ann. Entomol. Soc. Amer. 63(5): 1238-1242.

Newell, M.S. and T.C. Barber. 1913. The Argentine ant. USDA Bulletin No. 122.

Orr, M.R. and S.H. Seike. 1998. Parasitoids deter foraging by Argentine ants (*Linepithema humile*) in their native habitat in Brazil. Oecologia 117: 420-425.

Orr, M.R., S.H. Seike, W.W. Benson, and D.L. Dahlsten. 2001. Host specificity of *Pseudacteon* (Diptera: Phoridae) parasitoids that attack *Linepithema* (Hymenoptera: Formicidae) in South America. Environ. Entomol. 30(4): 742-747.

Passera, L. and S. Aron. 1993. Social control over the survival and selection of winged virgin queens in an ant without nuptial flight: *Iridomyrmex humilis*. Ethology 93: 225-235.

Passera, L. 1994. Characteristics of tramp species. Pages 23-43. *in* D.F. Williams, editor. Exotic ants: biology, impact, and control of introduced species. Westview, Boulder, Colorado, USA.

Phillips, P.A., R.S. Bekey, and G.E. Goodall. 1987. Argentine ant management in cherimoyas. California Agriculuture. March – April 1987: 8-9.

Rust, M.K. and R.L. Knight. 1990. Controlling Argentine ants in urban situations. *In* Applied myrmecology, a world perspective. R.K. Vander Meer, K. Jaffe, and A. Cedeno, Editors. Westview Press, Boulder, CO. Pages 663-670.

Rust, M.K., K. Haagsma, and D.A. Reierson. 1996. Barrier sprays to control Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89(1): 134-137.

Rust, M.K., D.A. Reierson, E. Paine, and L.J. Blum. 2000. Seasonal activity and bait preferences of the Argentine ant (Hymenoptera: Formicidae). J. Agric. Urban Entomol. 17(4): 201-212.

Sanders, N.J., K.E. Barton, and D.M. Gordon. 2001. Long-term dynamics of the distribution of the invasive Argentine ant, *Linepithema humile*, and native ant taxa in northern California. Oecologia 127: 123-130.

Shorey, H.H., L.K. Gaston, R.G. Gerber, C.B. Sisk and D.L. Wood. 1996. Formulating farnesol and other ant-repellent semiochemicals for exclusion of Argentine ant (Hymenoptera: Formicidae) from citrus trees. Environ. Entomol. 25(1): 114-119.

Skaife, S.H. 1961. The study of ants. Spottiswoode, Ballantyne and Co. Ltd., London and Colchester.

Suarez, A.V., D.T. Bolger, and T.J. Case. 1998. Effects of fragmentation and invasion on native ant communities in coastal southern California. Ecology 79(6): 2041-2056.

Suarez, A.V., N.D. TsuTsui, D.A. Holway, and T.J. Case. 1999. Behavioral and genetic differentiation between native and introduced populations of the Argentine ant. Biological Invasions 1: 43-53.

Smith, M. 1965. House-infesting ants of the eastern United States. USDA Agricultural Research Service Bulletin 1326.

Thompson, C.R. 1990. Ants that have pest status in the United States. *In* Applied myrmecology, a world perspective. R.K. Vander Meer, K. Jaffe, and A. Cedeno, Editors.Westview Press, Boulder, CO. Pages 51-67.

Ward, P.S. 1987. Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the lower Sacramento valley and its effects on the indigenous ant fauna. Hilgardia 55(2): 1-16.

Whitehouse, S. 1988. A review of Argentine ant control in Western Australia. The Agricultural Protection Board, Perth, Australia.

Zimmerman, E.C. 1941. Argentine ant in Hawaii. Proceedings of the Hawaiian Entomol. Soc. 11: 108.

Chapter II

Effects of interspecific competition between two urban ant species,

Linepithema humile and *Monomorium minimum*, on toxic bait performance

Abstract

We evaluated the effects of interspecific competition on ant bait performance using two urban pest species, the Argentine ant, *Linepithema humile* (Mayr), and the little black ant, *Monomorium minimum* (Buckley). In a laboratory study, *L. humile* diminished the effects of a solid sulfluramid bait against *M. minimum*, while *M. minimum* reduced the performance of a liquid fipronil bait against Argentine ants. Argentine ants were not adversely affected by sulfluramid bait at any time, while *M. minimum* was not affected by fipronil bait until 14 days of exposure.

In field studies measuring diel foraging activity, *M. minimum* appeared to delay *L. humile* foraging to food stations by ca. 30 minutes during the summer of 2001. However, *L. humile* subsequently recruited to food stations in very high numbers, thereby displacing *M. minimum*. *Linepithema humile* visited food stations over an entire 24-hour period, while *M. minimum* was only observed visiting food stations during daylight hours. Adjusting the timing of bait placement in the field may minimize any negative effects of interspecific competition between these two species on toxic bait performance.

Introduction

The Argentine ant, *Linepithema humile* (Mayr), and the little black ant, *Monomorium minimum* (Buckley), are urban pest ants that are sympatric through parts of their range (Newell and Barber 1913, Smith 1965). The Argentine ant is a serious introduced urban, agricultural, and ecological pest (Holway 1998, Markin 1970a, Knight and Rust 1990), while the little black ant is an occasional invader of human dwellings (Smith 1965). Both species mass-recruit (Baroni-Urbani and Kannowski 1974, Adams and Traniello 1981, Jones and Phillips 1990) and can dominate clumped food resources (Adams and Traniello 1981, Human and Gordon 1996, Holway 1999). In addition, their foraging activity patterns and food preferences overlap to some degree (Newell and Barber 1913, Smith 1965, Markin 1970b, Claborn and Phillips 1986, Stein and Thorvilson 1989). Therefore, we predict that these species will compete for limited resources where their niches overlap.

Toxic baits are commonly used in urban pest ant management programs. We predict that the same factors important in diet partitioning during interspecific encounters may also reduce the level of toxicant received by a target ant species, thereby compromising bait performance. Therefore, we conducted laboratory experiments to evaluate the effect of interspecific competition on the performance of two ant bait formulations. The species we selected may serve as a model for other ant species' interactions at baits.

The structure of ant communities can be affected in part by diel and/or seasonal foraging patterns (Baroni-Urbani and Kannowski 1974, Lynch, et al. 1980, Sanders and Gordon 2000). Furthermore, competitive tradeoffs may permit species co-existence (Lynch et al. 1980, Fellers 1987, Perfecto 1994, Morrison 1996). For example, ant species that find baits quickly and feed before other ants discover the bait (exploitative competitors) may co-exist with interference competitors, which take longer to discover resources but dominate them following discovery. *Monomorium minimum* excels at interference competition (Baroni-Urbani and Kannowski 1974, Adams and Traniello 1981), thereby dominating food resources. Argentine ants, on the other hand, appear to be removed from the exploitative-interference tradeoff, both finding food quickly and dominating it once discovered (Holway 1999). We examined the diel activity of *L. humile* and *M. minimum* in the field, both in areas where the species' boundaries overlapped and were separated, in an effort to identify mutually exclusive foraging periods. This information may be used to adjust the timing of bait placement thereby ensuring that the target ant receives an effective toxicant load.

Materials and Methods

Effects of competition on bait performance. We conducted a laboratory study to determine the effects of competition on toxic bait performance. *Linepithema humile* were field-collected from a residential neighborhood in Chapel Hill, North Carolina while *M. minimum* were collected from the J.C. Raulston Arboretum at North Carolina State University, Raleigh, North Carolina. Following collection, ants and substrate material were taken to the laboratory, placed in plastic trays (53 x 39 x 13cm) lined with Fluon® (Northern Products Inc., Woonsocket, RI) to prevent ant escape, and provided a nest. Nests consisted of glass tubes (10 x 75mm for *M. minimum* and 25 x 150mm for *L. humile*) filled ca. 1/4 with water and plugged with cotton. To keep nest interiors dark, glass tubes were covered with aluminum foil. Ants were fed 25% sucrose solution, freshly killed cockroaches (*Blattella germanica*), and artificial diet (Bhatkar and Whitcomb 1970) ad libitum, and maintained at 27±2°C and 50±10% RH.

Experimental colonies. Colony fragments consisting of 500 workers, 50 brood, and 1 queen of *L. humile* and *M. minimum* were paired and given access to a common arena (Figure 1). Each colony was placed in a plastic tray (24 x 17 x 11cm) and provided a nest, which consisted of a glass test tube filled ca. 1/4 with water and plugged with cotton. *Monomorium minimum* were housed in 10 x 75mm glass tubes while *L. humile* were housed in 25 x 150mm glass tubes. The glass tubes were covered with aluminum foil so the interior remained dark. Each colony had access to an alternate food arena and the central arena through a clear plastic tubing connection (17cm in length x 0.8cm dia). All trays (24 x 17 x 11cm) were lined with Fluon® to prevent ant escape. Ants were allowed to acclimate for 5-7 days during which time access to the CA was blocked, thereby preventing species interaction. During the acclimation period, and throughout the entire experiment, each colony was provided 25% sugar water, artificial diet (Bhatkar and Whitcomb 1970) and freshly killed *Blattella germanica* in the AFA.

After the acclimation period, the tubing leading to the CA was unblocked and a glass tube (6 x 50 mm) containing 25% sucrose solution was placed in the central arena. The small opening in the tube facilitated interactions between the two ant species during feeding. The sucrose remained in the central arena for 3 days during which time the ants could interact as well as establish territories and develop foraging strategies. Following this 3-day period, the sugar water was replaced with toxic bait, either 5×10^{-4}% fipronil in 25% sucrose solution or Raid® Double Control ant bait (0.5% N-ethyl Perfluorooctanesulfonamide, SC Johnson), a solid matrix. Based on the diet breadth of *L. humile* and *M. minimum*, we expected that both baits would be accepted by each species. Baits were placed in a small (6 x 50mm) glass tube to facilitate contacts between the species when feeding. The ants had access to the toxic bait for two weeks. Dead ants were counted and removed from all trays daily. Dead ants inside the tubing connecting arenas were also counted daily but were not removed until the end of the experiment to ensure minimal disturbance.

Treated controls (no competition in the presence of toxic bait) consisted of 500 workers, 50 brood, and 1 queen of each species placed in a nest tray connected to two foraging arenas (Figure 2). Untreated controls, with and without competition for each species were prepared as described above, however, ants were not exposed to toxic bait. Each treatment, treated control, and untreated control was replicated 5 times.

Seasonal and diel activity. Knowledge of the foraging activities and interactions of co-existing ant species can influence toxic bait placement (timing and location) decisions. Therefore, we monitored the daily foraging activity of co-occurring and isolated field colonies of *L. humile* and *M. minimum* during different seasons. From June through September 2001, we loaded each of ten plastic petri dish bases (8.5 cm dia.) with ca. 1.5g of apple jelly on one half and ca. 1g of cooked canned tuna on the other half. We placed the dishes at 30 cm intervals in a 2 x 5 array at each of three sites: a) site containing both *L. humile* and *M. minimum*; b) site containing *L. humile* only and; c) site containing *M. minimum* only. All sites were chosen based on preliminary mapping of ants using jelly and tuna baits. The site containing both *L. humile* and *M. minimum* as well as the *L. humile* only site were located in a residential neighborhood in Chapel Hill, North Carolina. The *L. humile* only site was located in a resident's front yard on a section of grass adjacent to the road, while the site containing both species was located on a section of grass ca. one meter wide that separated the sidewalk from the road. The two sites were ca. 4.5 meters apart and separated by a paved road. The *M. minimum* only site was located at the J.C. Raulston Arboretum at North Carolina State University. The site within the arboretum contained cone flowers (*Echinacea* spp.) and the ground was covered with wood mulch. Ants were counted on each food type every 30 minutes during 3 time periods: (a) 06:00 – 08:00, (b) 14:00 – 17:00, and (c) 22:00 – 24:00. Counts at each time period (morning, afternoon, and evening) were replicated 5 times at all sites. On each of the five days, we made ant counts on each of ten baits every 30 minutes for a total of four counts per bait for each time period.

Field counts at baits were also examined at all three sites during the fall of 2001 (October – November) as well as in the spring (May) and summer (July - September) of

2002 from 14:00 – 16:00. We did not examine morning and evening periods during these remaining seasons because little black ant activity was not evident at the sites containing both *L. humile* and *M. minimum* during these cooler times of the day during the summer of 2001.

Field observations led us to suspect that Argentine ants were successful in displacing *M. minimum* from baits, in part due to their numerical dominance at our site. Initially, little black ants persisted at baits for some time and were generally not displaced until Argentine ants recruited in large numbers. To determine the outcome of individual encounters between Argentine ants and little black ants, we recorded 20 one-on-one interactions between *L. humile* and *M. minimum* in the laboratory. Ants were placed in a 5mL glass vial, the walls of which were coated with Fluon®. We observed the ants every 30 minutes for 90 minutes and recorded which individuals, if any, were dead or dying at 90 minutes.

Data analysis. For the laboratory experiments, we determined cumulative daily mortality for both species during two time periods: (a) Period 1 (days 0-3), when access was allowed between all containers and sucrose solution was provided in the central arena and; (b) Period 2, beginning on day 3 when the sucrose solution was removed and toxic bait was added to the central arena, ending 2 weeks later (day 17). Daily mortality during Period 1 measured mortality due to competition. Daily mortality during Period 2 measured the effect of competition on toxic bait performance. Mortality comparisons of each species were made between conditions of species competition and toxic bait presence. A 3-factor (species, bait, competition) analysis of variance was performed (PROC GLM) with protected least significant difference (LSD) means separation (SAS Institute 1990). For our field studies, the average number of ants present at baits for each species was determined for each season. The data were square root transformed and the association of ant activity and temperature was determined with analysis of variance. The percentage of ants feeding on each food type (jelly or tuna) during each season was compared using analysis of variance (PROC GLM) and protected LSD means separation (SAS Institute 1990). A t-test was used to compare the number of ants present on occupied baits at each site containing only one species with the site containing both species (Minitab 2000).

Results

Effects of competition on bait performance. During the acclimation period, before central arenas were accessible, ants of both species suffered some mortality, however, mortality rates were generally the same for both species (8.3±2.7% and 9±1.8% for *L. humile* and *M. minimum*, respectively.

Ants exposed to Raid® Double Control ant bait (sulfluramid):

Many workers of both species were killed during the three days prior to bait placement (Period 1, Table 1). After this time, bait caused significant mortality to *M. minimum*, but not to *L. humile* (Period 2, Table 1). The bait x competition effect for *M. minimum* through day seven probably included residual mortality from fights with *L. humile*. By day ten (seven days after bait placement) no bait x competition effect was evident. However, when assessed across the 14 days that bait was provided, average daily *M. minimum* mortality increased when *L. humile* was absent (Table1), suggesting that *L. humile* somehow restricted *M. minimum* access to the bait (Figure 3b).

Ants exposed to fipronil bait:

In the three days prior to the introduction of liquid fipronil bait, both species suffered significant daily mortality when barriers between colonies were removed (Period 1, Table 2). Liquid fipronil bait caused high daily *L. humile* mortality within four days (day 7), however effects of this bait on *M. minimum* were not evident until 14 days post-treatment (Table 2). From one week after liquid fipronil bait placement through the remainder of the experiment, the average daily mortality for Argentine ants alone was significantly greater than those in arenas with *M. minimum* (Table 2), suggesting that access to bait by *L. humile* was impeded by *M. minimum* (Figure 4a). There was no effect of competition on the performance of liquid fipronil bait against *M. minimum* (Table 2, Figure 4b).

Seasonal and diel activity. During the summer of 2001, Argentine ants may have reduced the foraging of little black ants at food baits in the morning hours. At the site occupied solely by *M. minimum*, workers occupied baits as early as 7:30 a.m., but they were not at the site where the two species co-occurred (Figure 5). *Monomorium minimum* appeared to delay *L. humile* foraging by ca. 30 minutes during the afternoon. Up to one hour following bait placement, significantly fewer Argentine ants were present on food baits at the site where the two species occurred together ($t=7.92$, $df=53$, $p<0.05$) (Figure 6). *Monomorium minimum* workers were ultimately displaced by Argentine ants during the afternoon (Figure 6). In a typical encounter with Argentine ants, most little black ants would remain at the food and raise their gasters. Many Argentine ants would subsequently flee the food and/or vigorously rub their antennae and heads, presumably responding to an irritating chemical released by *M. minimum*. However, ca. one hour following food placement, Argentine ants began recruiting to the food in very large numbers and ultimately displaced *M. minimum*. In fact, 90 minutes following bait placement (beginning at 15:30) and throughout the remainder of the afternoon, Argentine ants had a significant impact on the numbers of little black ants present at food baits ($t=4.86$, $df=32$, $p<0.05$) (Figure 6). Only Argentine ants were observed foraging at night during the summer of 2001 (Figure 7).

Ant activity for both species declined in the fall of 2001; neither species appeared to impact the foraging activity of the other during this time (Figure 8). During the spring and summer of 2002, *M. minimum* discovered and recruited to baits at the *M.m.* site, however, only Argentine ants were found at the site where the two species had occurred together during the summer and fall of 2001.

Linepithema humile and *M. minimum* activity at food stations generally increased with increasing temperature across all seasons (Figures 9, 10a and 10b). Temperature played a role in Argentine ant activity across seasons, however, could not solely explain activity ($F=18.82$, $df=3$, $p<0.0001$). Other factors such as day length, amount of precipitation, and colony needs probably affect Argentine ant activity across seasons. Temperature was directly associated with Argentine ant activity within seasons ($F=6.93$, $df=1$, $p=0.0135$). During the summer of 2001, Argentine ants were most active during the afternoon when temperatures were highest ($F=44.04$, $df=1$, $p=0.0003$). *Monomorium minimum* presence at the food stations was directly associated with temperatures across seasons ($F=23.28$, $df=1$, $p<0.0001$) (Figures 10a and 10b). Little black ant activity was highest in the spring and summer when afternoon temperatures were highest. *M. minimum* activity during summer 2001 was also associated with temperature ($F=98.5$, $df=1$, $p<0.0001$); the greatest activity occurred during the afternoon when temperatures were highest.

Linepithema humile preferred jelly over tuna within each season with the exception of summer 2002 (Figure 11). Approximately 59% and 76% of Argentine ants across all stations fed on jelly in the summer and fall of 2001, respectively (Figure 11). In the spring, however, significantly more Argentine ants (56%) fed on tuna (Figure 11). Greater than 75% of *M. minimum* were present on the jelly during all seasons (Figure 12).

In a separate study performed in the laboratory to determine the outcome of competition between individual *L. humile* and *M. minimum* workers, Argentine ants were killed in 70% of the one-on-one interactions, while little black ants were either killed or injured in only 20% of the interactions.

Discussion

We recognize that Argentine ants generally dominate native ant species in invaded habitats and therefore strategies targeting *L. humile* will usually not be undermined by the activities of one or more sympatric species. Nevertheless, *M. minimum* does co-exist with *L. humile* in some urban locations and the potential for competition interfering with control measures exists. More importantly, when the entire complex of urban ants is considered, we have demonstrated that bait performance against a target ant can be diminished by interspecific competition and we infer that timing of bait placement can reduce the impact of competition. Over the course of 14 days, *M. minimum* had a measurable effect on the performance of liquid fipronil bait against *L. humile,* while *L. humile* reduced sulfluramid bait performance against *M. minimum*. Although we did not observe competitive interactions and feeding each day, bait was made available for fourteen days. Therefore, it is unlikely that one species could simply remove bait before the other had the opportunity to feed. Instead, decreased bait performance appears to be the result of interspecific competition. Competing ants probably avoided the central foraging arena where toxic bait was located, and as a result would have ingested less toxicant.

Bait performance depends, in part, on bait base acceptance. Low *M. minimum* mortality after exposure to liquid fipronil bait may have resulted from low bait acceptance. This was surprising since *M. minimum* workers visit floral and extrafloral nectaries of plants, and tend some honeydew-producing insects (Smith 1965). Therefore, we would have expected better acceptance of our sugar-based liquid bait. Perhaps the presence of alternate food resulted in low bait intake. Alternatively, the concentration of the active ingredient may have been somewhat repellent to *M. minimum* workers. Compared to the liquid fipronil bait, the solid sulfluramid bait produced significant *M. minimum* worker mortality, a possible consequence of high bait acceptance. *Monomorium minimum* readily feeds on non-toxic food baits relatively high in protein, including peanut butter (Urbani and Kannowski 1974, Glancey et al. 1976, Jones and Phillips 1990). Perhaps the sulfluramid bait contained levels of protein that stimulated feeding. The sulfluramid bait performed poorly against *L. humile,* possibly due to low bait consumption. In laboratory trials, Knight and Rust (1991) recorded lower Argentine ant mortality from sulfluramid than most other toxicants tested. The authors did not mention that lower mortality resulted from low bait consumption or from the delayed action of the active ingredient. Of the toxicants available for urban pest ant control, sulfluramid generally took longer to reduce ant populations (Reid and Klotz 1992, Forschler and Evans 1994). In our study, fipronil in sucrose solution reduced *L. humile* worker numbers by over 50%, which may reflect high bait consumption. This is not surprising considering that Argentine ants prefer liquids with high sugar content (Markin 1970b, Baker et al. 1985). Hooper-Bui and Rust (2000) also reported significant mortality in Argentine ants exposed to sucrose solution containing fipronil, the most efficacious compound of those tested.

Our findings in the field were similar to those of Markin (1970b) and Baker et al. (1985) in that Argentine ants had an overall preference for jelly over tuna, a high-protein food. Even though Argentine ants preferred jelly overall, a higher percentage of Argentine ants fed on tuna in the spring, which could reflect seasonal changes in the colony's nutritional requirements. Krushelnycky and Reimer (1998) reported an increase in the intake of a protein-based bait in the spring and summer and stated that the increased intake of protein may be important at this time when egg production and larval growth increase. Furthermore, Rust et al. (2000) report an increase in the amount of protein taken by Argentine ants in the spring and summer. *Monomorium minimum* had an overall preference for jelly across all seasons. Seasonal food preferences by ants may be an important consideration in toxic bait acceptance.

Results of one-on-one encounters between individual *L. humile* and *M. minimum* workers might suggest *M. minimum* could dominate food resources, however, *L. humile* displaced *M. minimum* from food dishes in the field. Most likely, numerical advantages contributed to the dominance of the Argentine ant over *M. minimum* as reported for other native ants (Holway 1996, Human and Gordon 1999). Numerical advantages over native ants may also be important in the success of other economically important ant species, such as the red imported fire ant (*Solenopsis invicta*) (Phillips et al. 1986, Morrison 2000).

Resource distribution should affect food or bait retrieval efficiency by competing ant species. For example, Adams and Traniello (1981) reported that individual *M. minimum* workers retrieved small food particles (<1mg). However, as food items became too large for a single worker to carry, *M. minimum* experienced a much greater chance of interference by other ant species, although large food clumps were frequently dominated by *M. minimum*. Argentine ants are efficient exploitative and interference competitors, dominating both dispersed and clumped resources (Human and Gordon 1999). Unless foods (or bait) of equal palatability are placed in close proximity to a *M. minimum* nest they will most likely be removed by *L. humile*.

Our diel forgaging patterns are consistent with those reported elsewhere, with *L. humile* active both day and night during the summer of 2001 (Markin 1970b, Human et al. 1998), and *M. minimum* active only during the day (Urbani and Kannowski 1974, Glancey et al. 1976, Claborn and Phillips 1986). Knowledge of the activity pattern of a target ant(s) prior to toxic bait placement is necessary to better ensure that the targeted species finds the bait.

During the summer of 2001, Argentine ants depressed *M. minimum* numbers at food stations. While *M. minimum* recruited to several food stations during the afternoon of summer 2001, they were ultimately displaced by *L humile.* Holway (1999) reported that Argentine ants both found baits more quickly and dominated those baits more consistently than native ant species, including a related *Monomorium* species, *M. ergatogyna*. In our study, *M. minimum* appeared to delay Argentine ant foraging by about 30 minutes before displacement occurred. Adams and Traniello (1981) reported that chemical interference by little black ants delays invasion of food resources by competitors and that *M. minimum* may be able to better withstand higher temperatures and direct sunlight than other ant species. The findings of Howard and Oliver (1979) were similar to our field results in that *M. minimum* was able to repel individual *Solenopsis invicta* workers from baits for some time, presumably using chemical defense, before eventually being displaced by the latter. Urbani and Kannowski (1974) reported that *M. minimum* was almost always successful in competition with *S. invicta* if the interactions took place in direct sunlight. Other authors have reported the persistence of *M. minimum* in areas invaded by *S. invicta* (Stein and Thorvilosen 1989, Porter and Savignano 1990). Perhaps chemical interference coupled with an ability to tolerate greater temperatures enabled *M. minimum* to feed at food baits for some time before ultimately being displaced by Argentine ants.

The absence in 2002 of *M. minimum* at the site shared with *L. humile* in 2001 suggests that *M. minimum* was displaced by *L. humile*, however, further surveys would be required to confirm this observation. Ward (1987) reported that *M. minimum* occurred in five of ten sites without Argentine ants, but only two of ten sites with Argentine ants.

The foraging activity of Argentine ants in our study shows a clear seasonal pattern, similar to that reported by Krushelnycky and Reimer (1998) in that peak numbers of foragers occurred in the spring and summer. However, in a study conducted in Hawaii, Krushelnycky and Reimer (1998) found that high numbers of foragers persisted into October. We observed a decline in Argentine ant activity by October similar to that reported by Rust et al. (2000). Markin (1970a) reported an association between temperature and Argentine ant activity, with optimum foraging occurring between 15° and 30°C.

Using *L. humile* and *M. minimum*, we demonstrated that toxic bait performance can be compromised by interspecific competition. Adjusting the timing of bait placement or changing the bait base could minimize the negative effects of interspecific competition on toxic bait performance. Depending on bait acceptance, foraging behaviors, and the interactions of co-existing ants, interspecific competition between other ant species may also diminish the effects of toxic bait. By considering food preference, colony boundaries, and diel activity patterns, it may be possible to effectively manage a particular species without interference from non-target ants.

References Cited

Adams, E.S. and J.F.A. Traniello. 1981. Chemical interference by *Monomorium minimum* (Hymenoptera: Formicidae). Oecologia 51: 265-270.

Baker, T.C., S.E. Van Vorhis Key, and L.K. Gaston. 1985. Bait-preference tests for the Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 78: 1083-1088.

Bhatkar, A. D. and W. H. Whitcomb. 1970. Artificial diet for rearing various species of ants. Fla. Entomol. 53: 229-232.

Claborn, D.M. and S.A. Phillips, Jr. 1986. Temporal foraging activities of *Solenopsis invicta* (Hymenoptera: Formicidae) and other predominant ants of central Texas. Southwest. Nat. 31(4): 555-557.

Fellers, J.H. 1987. Interference and exploitation in a guild of woodland ants. Ecology 68(5): 1466-1478.

Forschler, B.T. and G.M. Evans. 1994. Argentine ant (Hymenoptera: Formicidae) foraging activity response to selected containerized baits. J. Entomol. Sci. 29(2): 209-214.

Glancey, B.M., D.P. Wojcik, C.H. Craig, and J.A. Mitchell. 1976. Ants of Mobile County, Alabama, as monitored by bait transects. J. Georgia Entomol. Soc. 11(3): 191-197.

Holway, D.A. 1995. Distribution of the Argentine ant (*Linepithema humile*) in northern California. Conservation Biology 9(6): 1634-1637.

Holway, D.A. 1998. Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. Oecologia 116: 252-258.

Holway, D.A. 1999. Competitive mechanisms underlying the displacement of native ants by the invasive Argentine ant. Ecology 80(1): 238-251.

Hooper-Bui, L.M. and M.K. Rust. 2000. Oral toxicity of abamectin, boric acid, fipronil, and hydramethylnon to laboratory colonies of Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 93(3): 858-864.

Howard, F.W. and A.D. Oliver. 1979. Field observations of ants (Hymenoptera: Formicidae) associated with red imported fire ants, *Solenopsis invicta* Buren, in Louisiana pastures. J. Georgia. Entomol. Sci. 14(3): 255-258.

Human, K.G. and D.M. Gordon. 1996. Exploitation and interference competition between the Argentine ant, *Linepithema humile*, and native ant species. Oecologia. 105: 405-412.

Human, K.G. and D.M. Gordon. 1997. Effects of Argentine ants on invertebrate biodiversity in northern California. Conserv. Biol. 11(5): 1242-1248.

Human, K.G., S. Weiss, A. Weiss, B. Sandler, and D.M. Gordon. 1998. Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera: Formicidae). Environ. Entomol. 27(4): 822-833.

Human, K.G. and D.M. Gordon. 1999. Behavioral interactions of the invasive Argentine ant with native ant species. Insect. Soc. 46: 159-163.

Jones, S.R. and S.A. Phillips, Jr. 1990. Resource collecting abilities *Solenopsis invicta* (Hymenoptera: Formicidae) compared with those of three sympatric Texas ants. Southwest. Nat. 35(4): 416-422.

Knight, R.L. and M.K. Rust. 1990. The urban ants of California with distribution notes of imported species. Southwest. Entomol. 15(2): 167-178.

Knight, R.L. and M.K. Rust. 1991. Efficacy of formulated baits for control of Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 84(2): 510-514.

Krushelnycky, P.D. and N.J. Reimer. 1998. Bait preference by the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Hawaii. Environ. Entomol. 27(6): 1482-1487.

Majer, J.D. 1994. Spread of Argentine ants (*Linepithema humile*), with special reference to western Australia. Pages 163-173. *in* D.F. Williams, editor. Exotic ants: biology, impact, and control of introduced species. Westview, Boulder, Colorado, USA.

Markin, G.P. 1970a. The seasonal life cycle of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in southern California. Annals of the Entomological Society of America 63(5): 1238-1242.

Markin, G.P. 1970b. Foraging behavior of the Argentine ant in a California citrus grove. J. Econ.Entomol. 63: 740-744.

MINITAB Statistical Software. 2000. Release 13. User's guide 2: data analysis and quality tools. Minitab, Inc., USA.

Morrison, L.W. 1996. Community organization in a recently assembled fauna: the case of Polynesian ants. Oecologia 107: 243-256.

Morrison, L.W. 2000. Mechanisms of interspecific competition among an invasive and two native fire ants. Oikos 90: 238-252.

Newell, W. and T.C. Barber. 1913. The Argentine ant. USDA Bureau of Entomology Bulletin 122.

Perfecto, I. 1994. Foraging behavior as a determinant of asymmetric competitive interaction between two ant species in a tropical agroecosystem. Oecologica 98: 184-192.

Phillips, S.A., S.R. Jones, and D.M. Claborn. 1986. Temporal foraging patterns of *Solenopsis invicta* and native ants in central Texas. Pages 114-122. *in* C.S. Lofgren and R.K. Vander Meer, editors. Fire ants and leaf-cutting ants: biology and management. Westview, Boulder, Colorado, USA.

Porter, S.D. and D.A. Savignano. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community. Ecology 71(6): 2095-2105.

Reid, B.L. and J.H. Klotz. 1992. Oral toxicity of abamectin, dechlorane, and sulfluramid to free-foraging workers of *Camponotus pennsylvanicus* (Hymenoptera: Formicidae). J. Econ. Entomol. 85(5): 1822-1829.

Rust, M.K., D.A. Reierson, E. Paine, and L.J. Blum. 2000. Seasonal activity and bait preferences of the Argentine ant (Hymenoptera: Formicidae). J. Agric. Urban Entomol. 17(4): 201-212.

Sanders, N.J. and D.M. Gordon. 2000. The effects of interspecific interactions on resource use and behavior in a desert ant. Oecologia. 125: 436-443.

SAS Institute. 1990. Version 6, 4th Ed. Vol. 2. pp. 891-1686. SAS Institute, Cary, NC.

Smith, M. 1965. House-infesting ants of the eastern United States. USDA Agricultural Research Service Bulletin 1326.

Stein, M.B. and H.G. Thorvilson. 1989. Ant species sympatric with the red imported fire ant in southeastern Texas. Southwest. Nat. 14(3): 225-231.

Urbani, C.B. and P.B. Kannowski. 1974. Patterns in the red imported fire ant settlement of a Louisiana pasture: some demographic parameters, interspecific competition and food sharing. Environ. Entomol. 3(5): 755-760.

Ward, P.S. 1987. Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the lower Sacramento valley and its effects on the indigenous ant fauna. Hilgardia 55(2): 1-16.

Table 1. Analysis of variance table for the effects of competition on sulfluramid bait performance as measured by worker mortality.

	F	*P*	Average Daily Mortality C[a]	N[b]
Period 1 (Days 0 - 3): No bait present; ants interacting				
Day 3				
Competition	189.94	<.0001		
Species*Competition	3.51	.0714		
Competition for *L.humile*		<.0001	34.62a	3.84b
Competition for *M.minimum*		<.0001	45.75a	5.28b

	F	*P*	B[c]	Con[d]	B/C[e]	B/N[f]	Con/C[g]	Con/N[h]
			Average Daily Mortality					
Period 2 (Days 3 - 17): Bait introduced and remained								
Days 3 - 7								
Bait	.01	.9057						
Bait*Species	3.72	.0641						
Bait*Species*Competition	2.23	.1462						
Bait *L. humile*		.1588	2.58a	5.32a				
Bait *M. minimum*		.2115	7.7a	5.28a				
Bait*Competition *L. humile*	.15	.7005			3.10a	2.06a	7.56	3.08
Bait*Competition *M. minimum*	7.32	.0115			11.32a	4.08b	6.62	3.94
Days 3 - 10								
Bait	.76	.3915						
Bait*Species	4.67	.0394						
Bait*Species*Competition	.14	.7105						
*L.humile**Bait		.3693	2.02a	7.77a				
*M.minimum**Bait		.0409	8.26a	3.87b				
Bait*Competition for *L.humile*	.04	.8496			2.29a	1.74a	5.19	2.58
Bait*Competition for *M.minimum*	.38	.5444			9.15a	7.37a	4.70	3.04
Days 3 - 17								
Bait	3.39	.0762						
Bait*Species	5.56	.0255						
Bait*Species*Competition	1.39	.2481						
*L.humile**Bait		.7169	1.58a	2.55a				
*M.minimum**Bait		.0061	11.19a	3.35b				
Bait*Competition for *L.humile*	0.00	.9493			1.70a	1.46a	2.95	2.14
Bait*Competition for *M.minimum*	4.22	.0494			7.35a	15.02b	4.21	2.49

Means in the same row followed by the same letter are not significantly different (P = 0.05, LSD)

[a] C = Competing ants
[b] N = Non-competing ants
[c] B = Bait present (competing + non-competing ants)
[d] Con = Control (competing + non-competing ants)
[e] B/C = Bait present (competing ants)
[f] B/N = Bait present (non-competing ants)
[g] Con/-C = Control (competing ants)
[h] Con/N = Control (non-competing)

Table 2. Analysis of variance table for the effect of competition on fipronil bait performance as measured by worker mortality.

	F	*P*	Average Daily Mortality C[a]	Average Daily Mortality N[b]
Period 1 (Days 0 - 3): No bait present; ants interacting				
Day 3				
Competition	42.53	<.0001		
Species*Competition	1.38	.2498		
Competition for *L.humile*		<.0001	31.05a	3.38b
Competition for *M.minimum*		.0008	24.05a	4.83b

	F	*P*	Average Daily Mortality					
			B[c]	Con[d]	B/C[e]	B/N[f]	Con/C[g]	Con/N[h]
Period 2 (Days 3 - 17): Bait introduced and remained								
Days 3 - 7								
Bait	21.19	<.0001						
Bait*Species	11.71	.0019						
Bait*Species*Competition	.11	.7418						
*L.humile**Bait		<.0001	22.18a	1.98b				
*M.minimum**Bait		.4104	7.38a	4.40a				
Bait*Competition for *L.humile*	3.45	.0738			17.50a	26.85a	2.90	1.05
Bait*Competition for *M.minimum*	.09	.7604			6.60a	8.15a	7.55	1.25
Days 3 - 10								
Bait	39.61	<.0001						
Bait*Species	21.43	<.0001						
Bait*Species*Competition	.19	.6633						
*L.humile**Bait		<.0001	19.90a	1.39b				
*M.minimum**Bait		.2493	5.83a	3.01a				
Bait*Competition for *L.humile*	4.86	.0360			16.17a	23.64b	1.87	.91
Bait*Competition for *M.minimum*	.26	.6148			4.96a	6.69a	4.87	1.15
Days 3 - 17								
Bait	88.92	<.0001						
Bait*Species	40.56	<.0001						
Bait*Species*Competition	2.77	.1070						
*L.humile**Bait		<.0001	14.59a	.89b				
*M.minimum*Bait		.0391	4.71a	2.06b				
Bait*Competition for *L.humile*	17.87	.0002			10.92a	18.26b	1.02	.75
Bait*Competition for *M.minimum*	.03	.8653			4.56a	4.86a	2.82	1.29

Means in the same row followed by the same letter are not significantly different (P = 0.05, LSD)

[a] C = Competing ants
[b] N = Non-competing ants
[c] B = Bait present (competing + non-competing ants)
[d] Con = Control (competing + non-competing ants)
[e] B/C = Bait present (competing ants)
[f] B/N = Bait present (non-competing ants)
[g] Con/-C = Control (competing ants)
[h] Con/N = Control (non-competing)

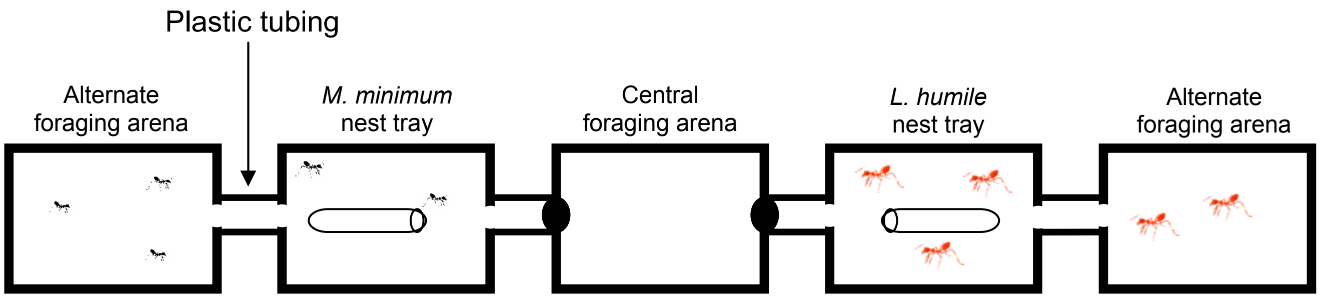

Figure 1. Experimental arrangement for measuring the effect of ant species' interaction on toxic bait performance.

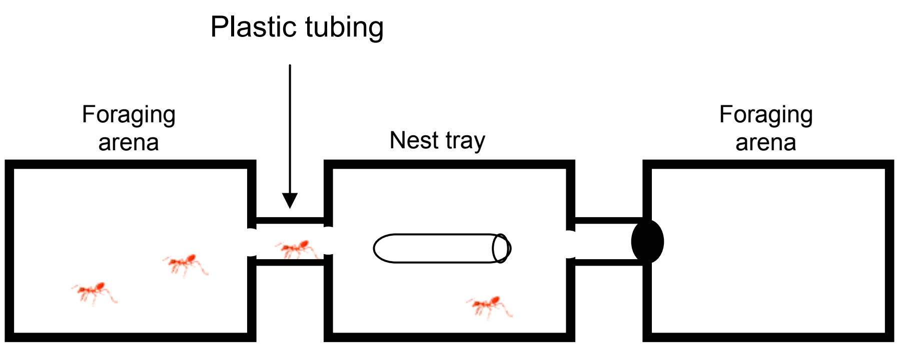

Figure 2. Experimental arrangement for treated and untreated controls for ants in the absence of competition.

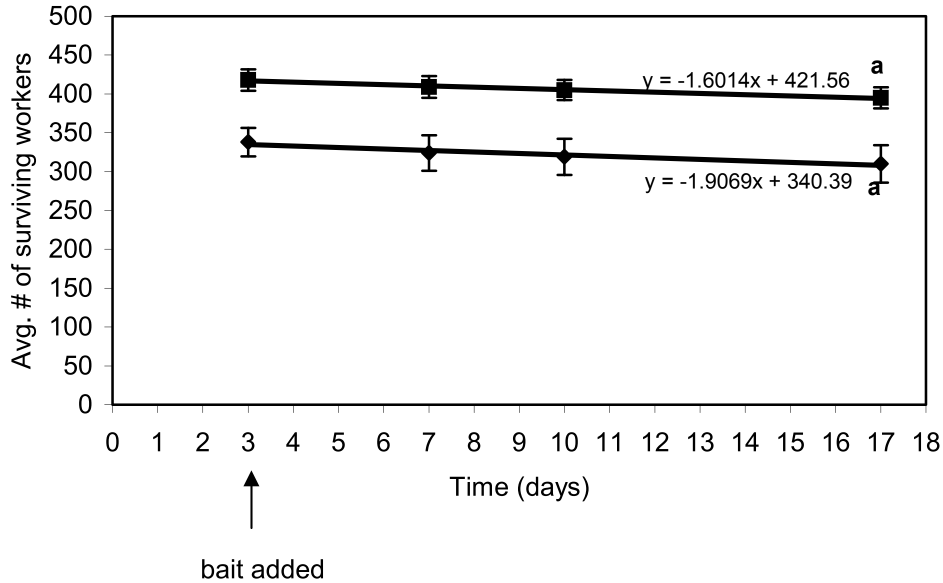

Figure 3a. Average number (± SEM) of surviving *L. humile* exposed to sulfluramid bait. Diamonds = competing ants. Squares = non-competing ants. There was no difference between slopes whether ants in the presence or absence of competition (F=0.14, df=1, p=0.9493, LSD).

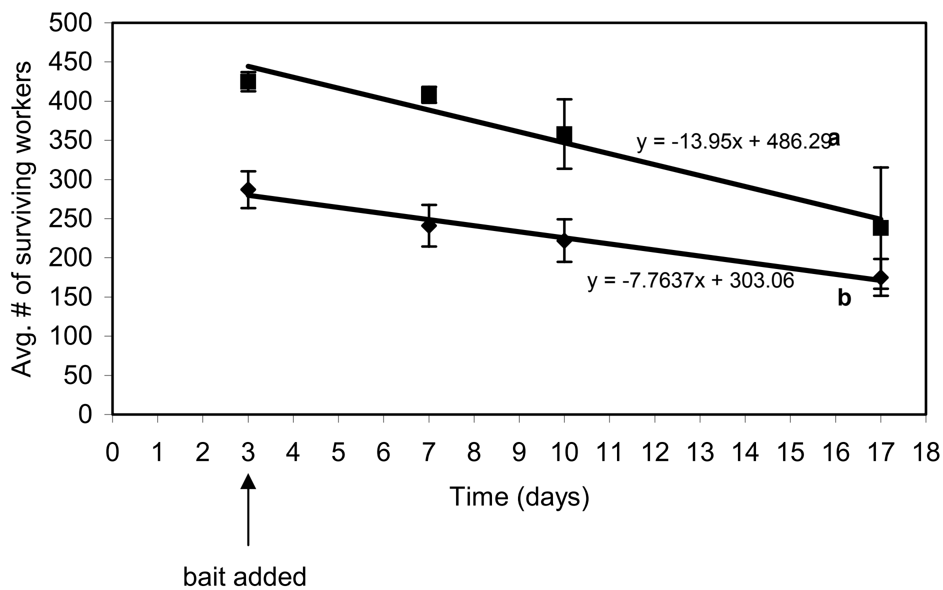

Figure 3b. Average number (± SEM) of surviving *M. minimum* exposed to sulfluramid bait. Diamonds = competing ants. Squares = non-competing ants. Slope for non-competing ants was significantly different from that of competing ants (F=4.22, df=1, p=0.05, LSD).

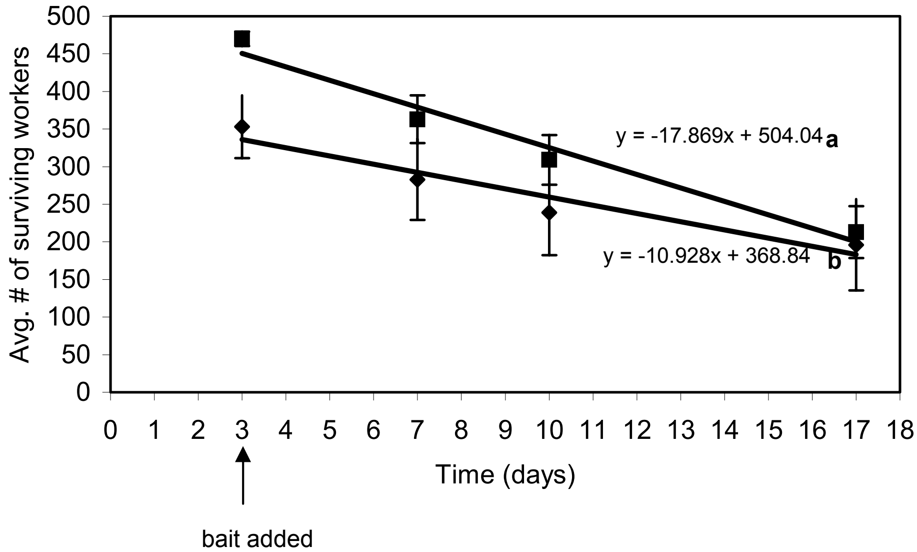

Figure 4a. Average number (± SEM) of surviving *L. humile* exposed to fipronil bait. Diamonds = competing ants. Squares = non-competing ants. Slope for non-competing ants was significantly different from that of competing ants (F=17.87, df=1, p=0.0002, LSD).

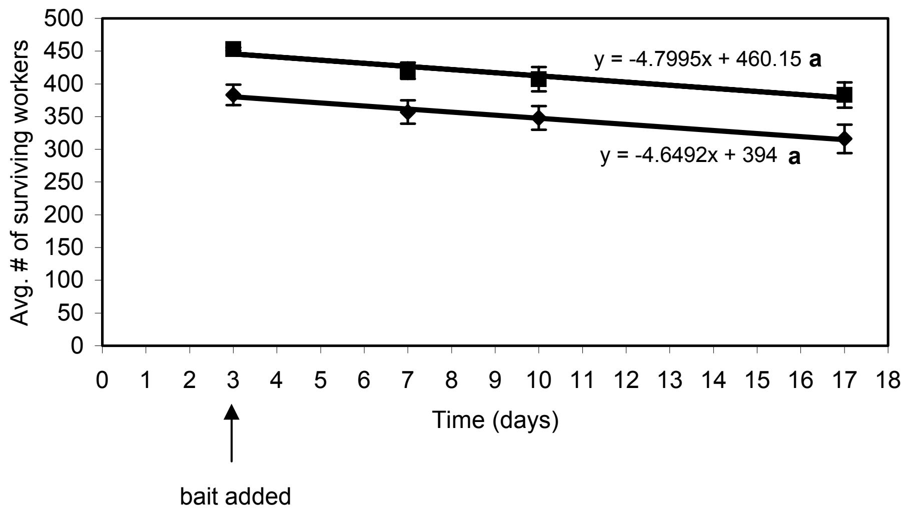

Figure 4b. Average number (± SEM) of surviving *M. minimum* exposed to fipronil bait. Diamonds = competing ants. Squares = non-competing ants. There was no difference between slopes whether ants in the presence or absence of competition (F=0.22, df=1, p=0.8653, LSD).

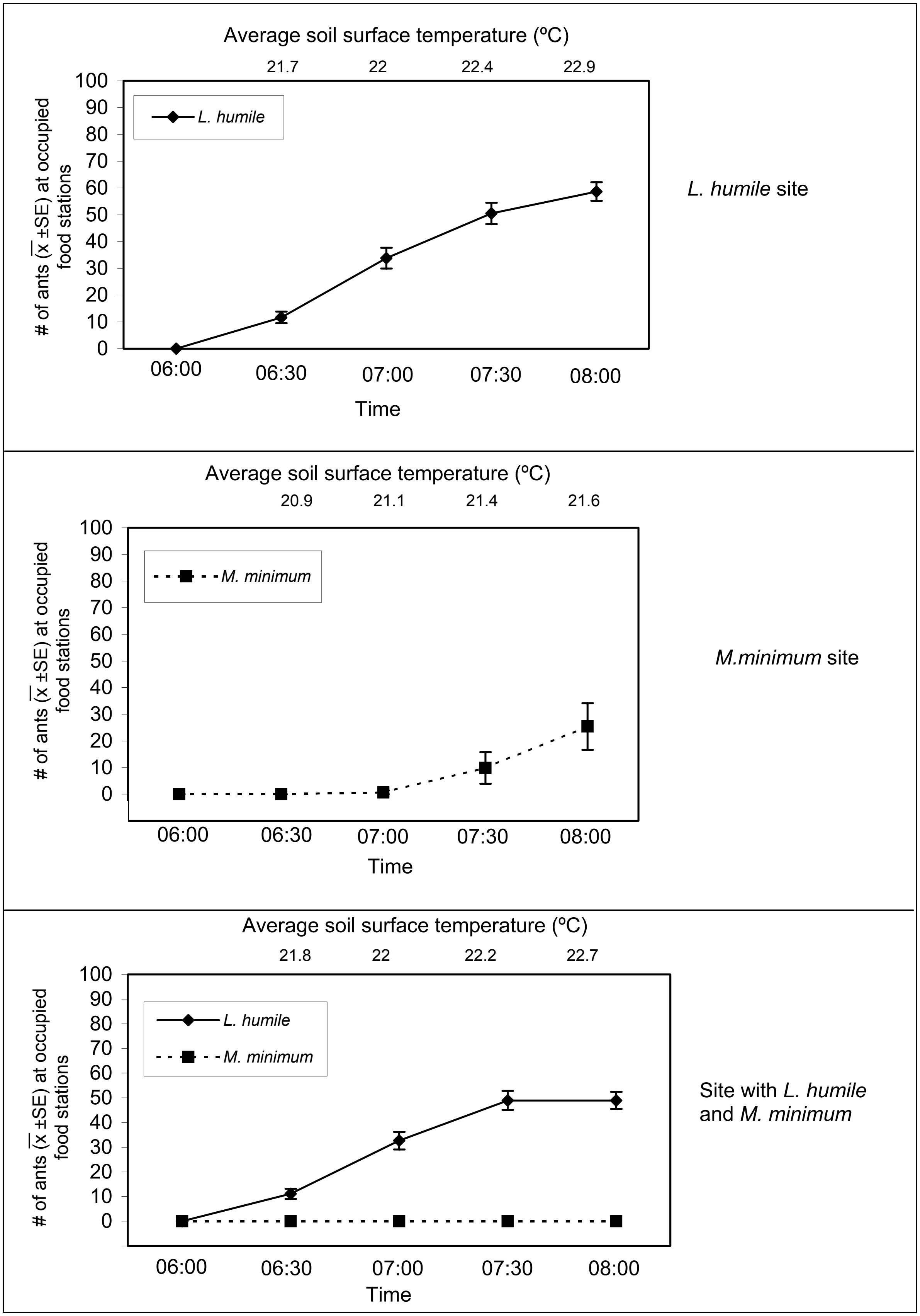

Figure 5. *Linepithema humile* and *M. minimum* visits to food stations from 06:00 - 08:00 June through September 2001.

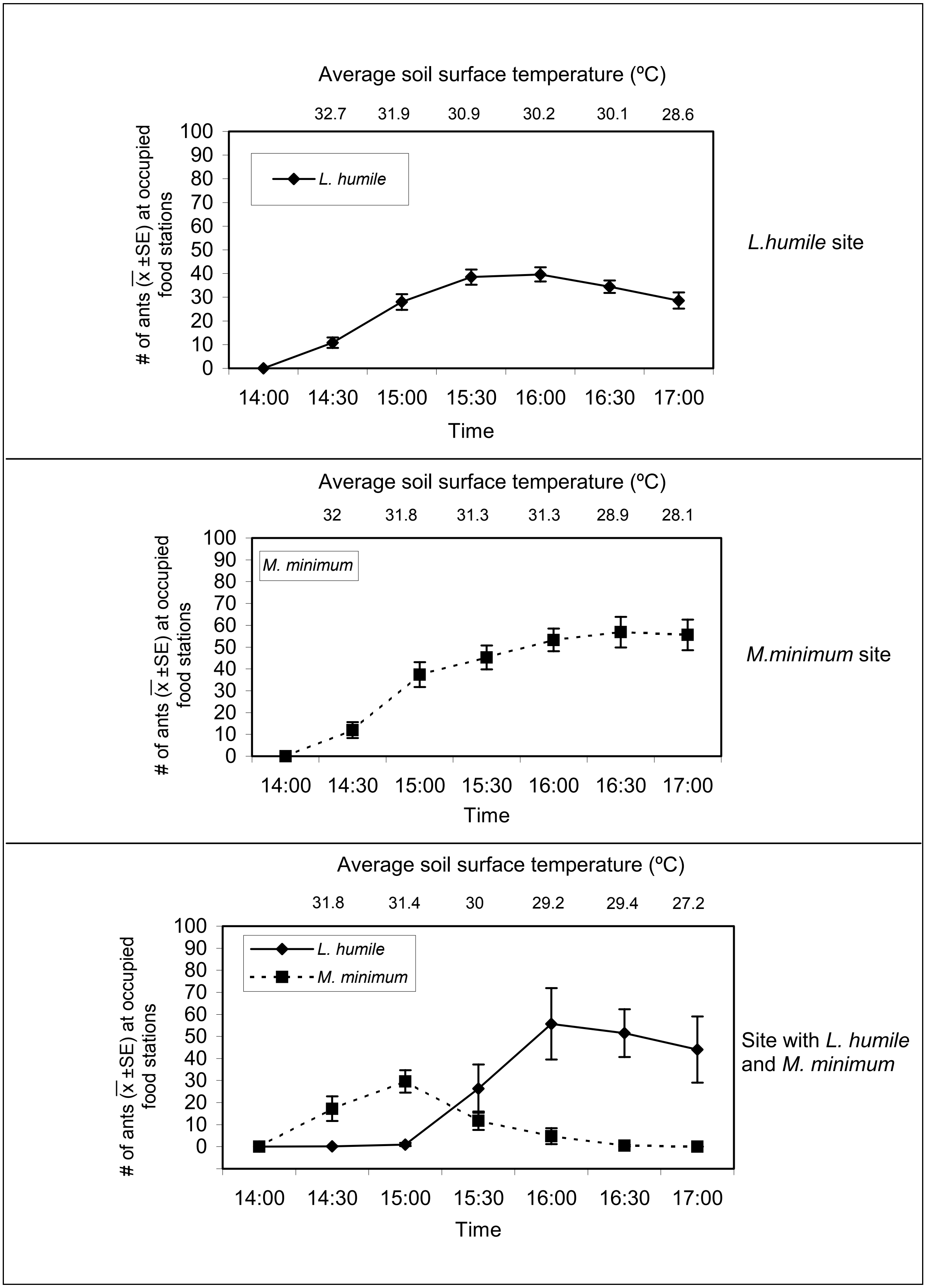

Figure 6. *Linepithema humile* and *M. minimum* visits to food stations from 14:00 - 17:00 June through September 2001.

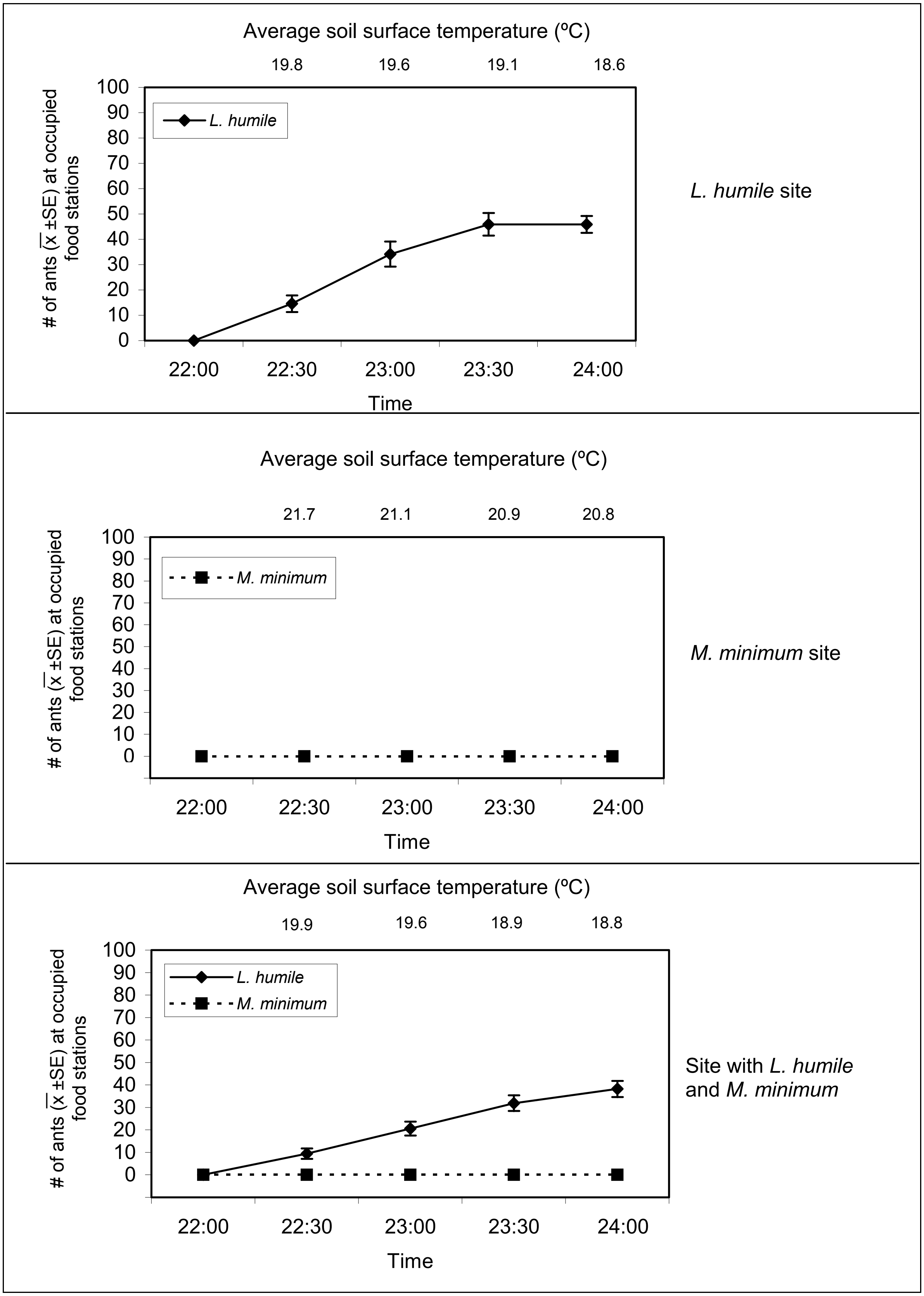

Figure 7. *Linepithema humile* and *M. minimum* visits to food stations from 22:00 - 24:00 June through September 2001.

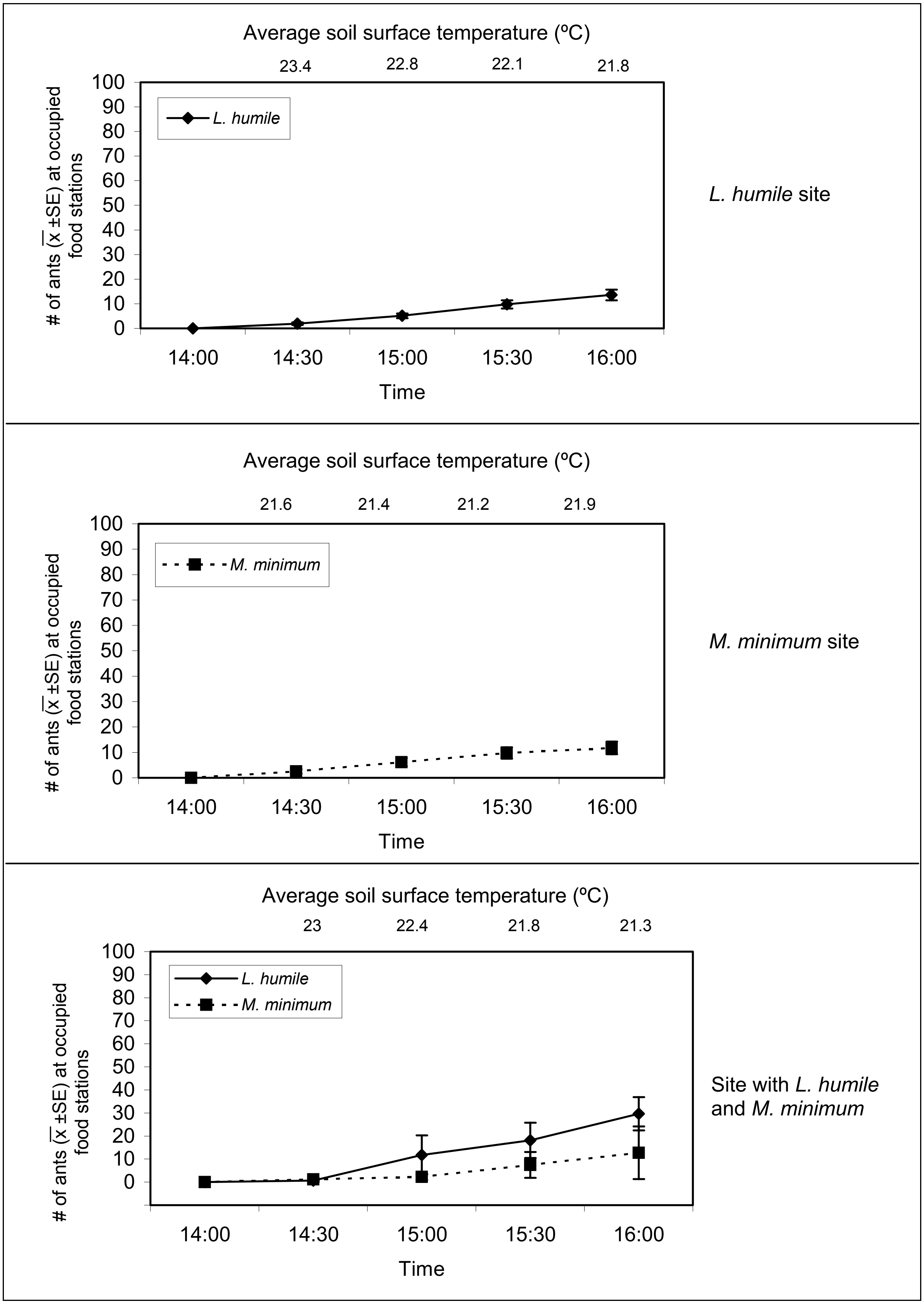

Figure 8. *Linepithema humile* and *M. minimum* visits to food stations from 14:00 – 16:00 October through November 2001.

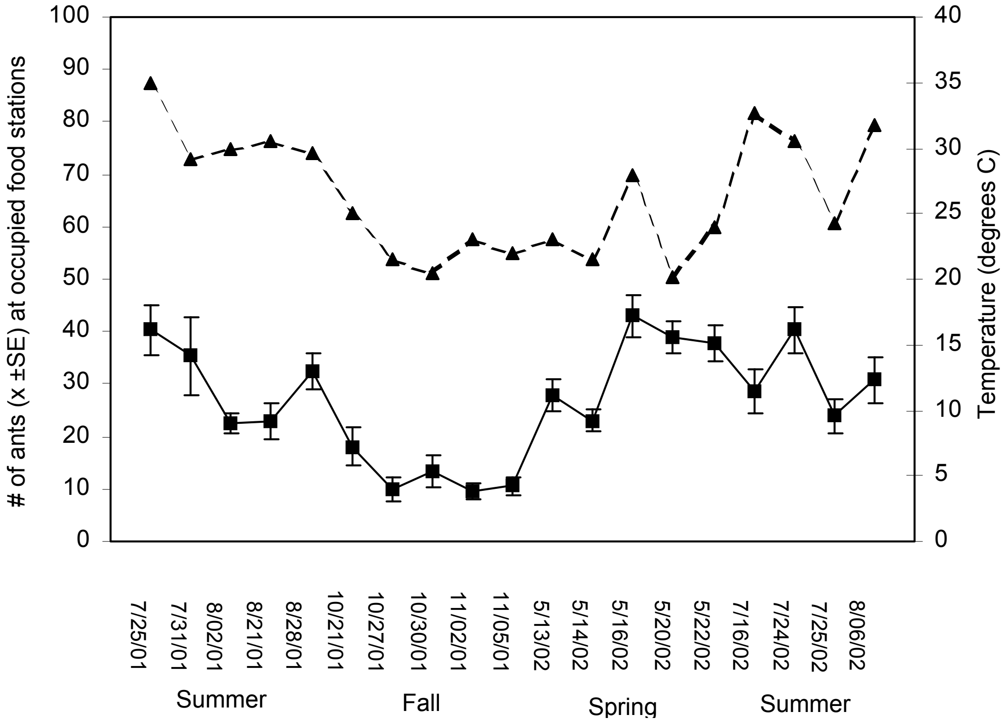

Figure 9. Average seasonal foraging activity of *L. humile* (*L.h.* only and site containing both *L. humile* and *M. minimum* combined). Data represents five afternoon (2:00p.m. - 5:00p.m.) readings per season. Squares = ant counts; triangles = temperature.

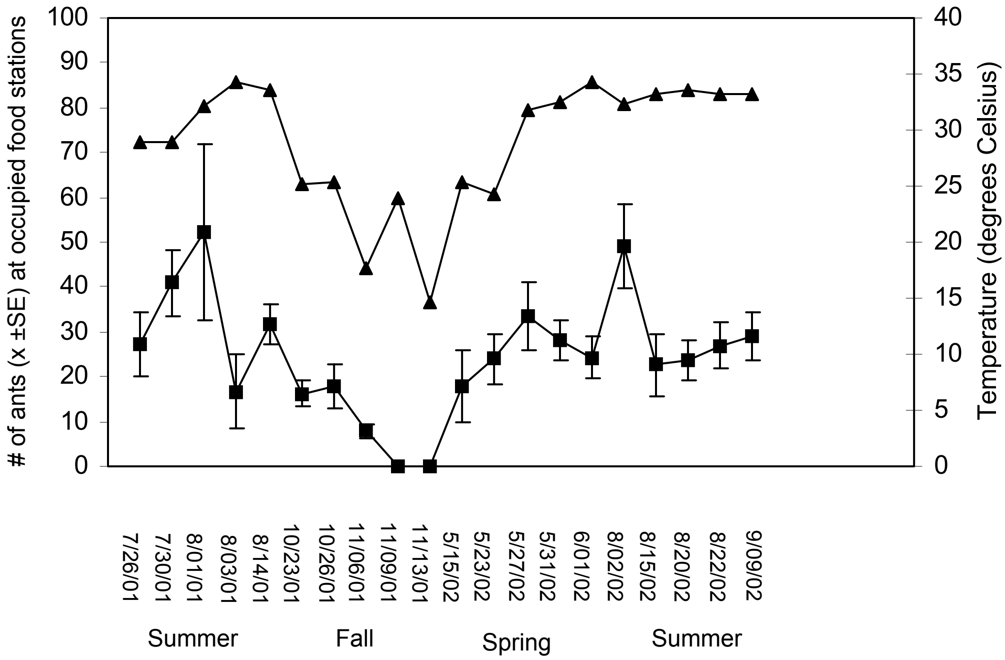

Figure 10a. Average seasonal foraging activity of *M. minimum* (*M.m.* site). Data represents five afternoon (2:00p.m. - 5:00p.m.) readings per season. Squares = ant count; triangles = temperature.

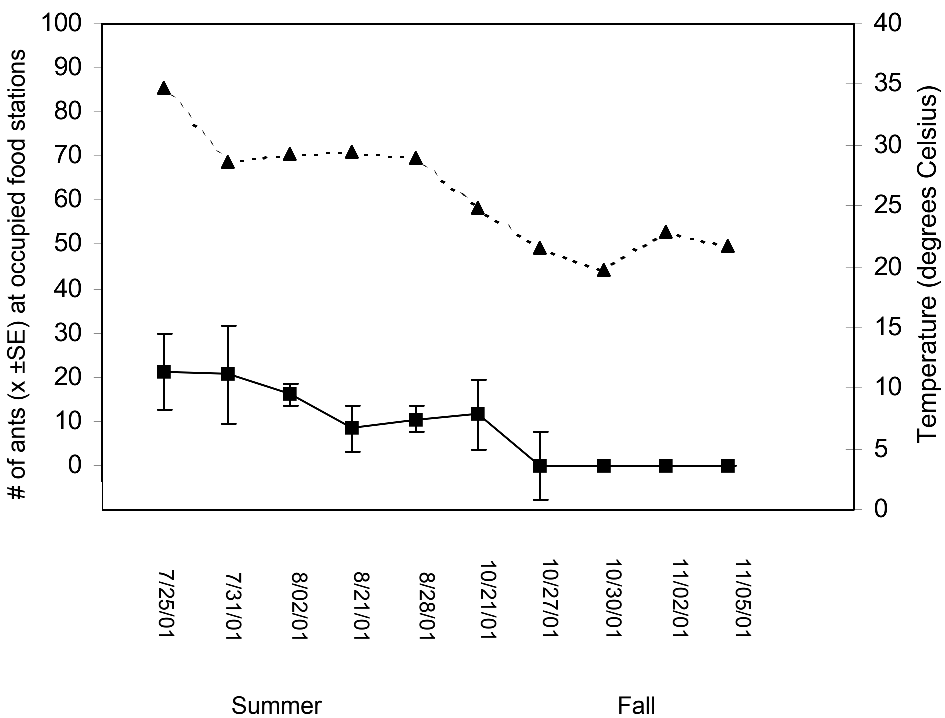

Figure 10b. Average seasonal foraging activity of *M. minimum* (site containing both *L. humile* and *M. minimum*). Data represents five afternoon (2:00p.m. - 5:00p.m.) readings per season. Squares = ant count; triangles = temperature.

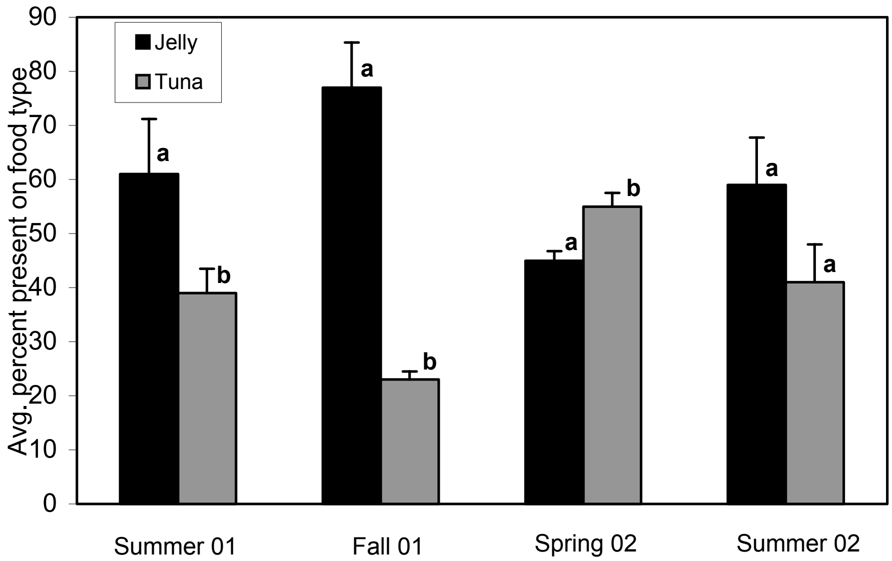

Figure 11. Average percentage of Argentine ants present on jelly and tuna across seasons.

Within seasons, the different letters indicate significant difference ($p<0.05$, chi-square test).

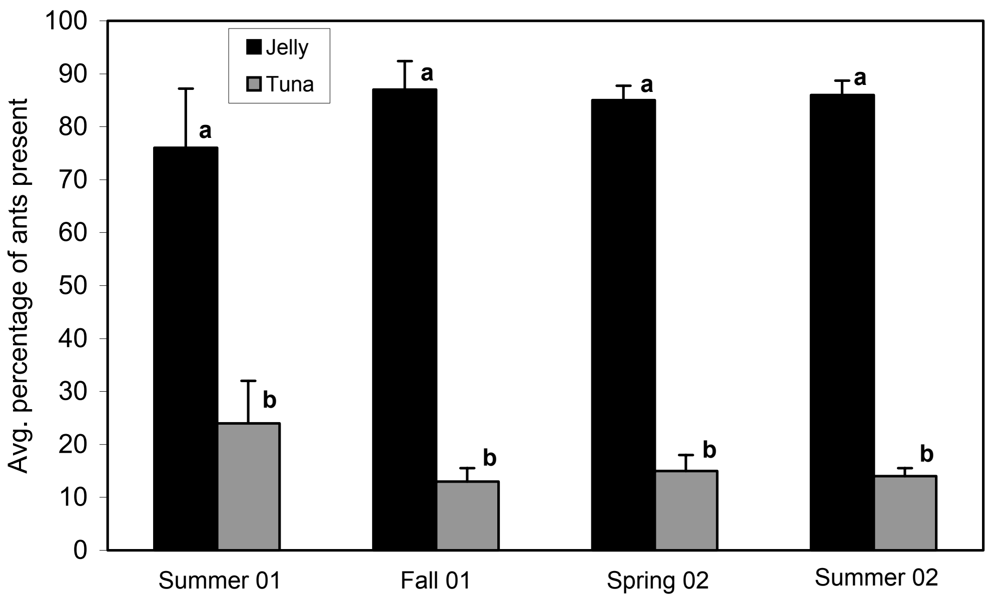

Figure 12. Average percentage of little black ants present on jelly and tuna for each season.

Within seasons, the different letters indicate significant difference ($p<0.05$, chi-square test).

Chapter III

A comparison of monitoring methods used to detect changes in Argentine ant (Hymenoptera: Formicidae) populations

Abstract

Investigators have employed a variety of sampling procedures to assess changes in Argentine ant numbers during treatment regiments. We compared the variability and time associated with four monitoring methods commonly employed to detect changes in Argentine ant populations: trailing activity, ant counts at baits, sucrose consumption, and pitfall trap collections. We found pitfall trapping to be both the most variable and time consuming. The variability of the remaining methods was similar, however, deployment of baits required the least time per unit and is therefore recommended as a monitoring tool for estimating changes in Argentine ant populations.

Introduction

The Argentine ant, *Linepithema humile* (Mayr), is a significant urban pest, invading residential and commercial structures in California (Knight and Rust 1990) and the southeastern United States (Newell and Barber 1913, Smith 1965). Consequently, novel insecticide formulations and treatment strategies are continuously being developed to control this pest. A variety of monitoring techniques are employed to detect changes in Argentine ant activity following treatments. One involves counting the number of ants present at non-toxic baits such as honey, jelly or tuna (Blachly and Forschler 1996, Forschler and Evans 1994a, Klotz et al. 1998, Krushelnycky and Reimer 1998). Typically, these food baits are placed in areas near Argentine ant nests and/or foraging trails, and the number of ants present at each bait is determined at various intervals. This is accomplished by counting the number of ants on baits at the site, or alternatively, ants may be trapped and counted at a later time. The use of food baits for monitoring Argentine ant populations requires only one site visit per evaluation period, however the food bait must be attractive to ensure recruitment.

Another monitoring method often employed involves locating pre-existing Argentine ant trails and counting the number of ants crossing an imaginary line or walking over a piece of twine for one to two minutes (Moreno et al. 1987, Rust et al. 2000, Shorey et al. 1992, Shorey et al. 1996). This method requires only one site visit but requires the presence of pre-existing ant trails.

Finally, the amount of sucrose water consumed by Argentine ants has been used to estimate changes in activity (Reierson et al. 1998, Klotz et al. 2000, Suoja et al. 2000). This method exploits a favored food source of the Argentine ant (Markin 1970a), however sucrose water is typically left out overnight to ensure that ants have ample time to feed, and therefore requires two site visits.

Pitfall trapping is employed in ecological studies to investigate Argentine ant abundance and species richness in habitats invaded by Argentine ants (Ward 1987, Human and Gordon 1996, Holway 1998), although currently not used in monitoring insecticide efficacy. No studies have been conducted to directly compare the utility of the above methods. Therefore, we compared the variability and time required of these four methods, emphasizing counting consistency and time required to deploy each sampling method.

Materials and Methods

Study site. Our study site was located in a residential neighborhood in Chapel Hill, North Carolina with an Argentine ant population established more than five years ago. Experimental units were single-family homes on ca. 0.1 hectare lots. Homes selected for the study had at least five exterior pre-existing Argentine ant trails. A total of five homes was selected and each method was assessed at these same homes.

Estimating sampling variation. We compared four monitoring methods, each at five sampling periods: (a) trailing activity, (b) ant counts on baits, (c) consumption of sucrose water by ants, and (d) number of ants in pitfall collections. All methods were deployed sequentially. For a given method, sampling was performed at the same time of day and only on days that did not receive rainfall to minimize possible diel variation in ant activity. All sampling was performed between 14 June 2002 and 22 July 2002 to reduce seasonal variation in ant foraging. The average mean daily temperature (±SE) for sampling periods was 24.9±0.7°C, 27.5±1.3°C, 24.4±1.4°C, and 27.3±0.5°C for trailing activity, ant counts on baits, sucrose consumption by ants, and pitfall trap collections, respectively, and were not significantly different from one another ($F=2.26$, $df=16$, $p=0.121$, ANOVA)

Trailing activity. At each sampling period on separate days at ca. 9:00 a.m., we counted the number of ants crossing a defined point during one minute on each of five trails per home. We sampled in the morning because Argentine ants were most active at this time when temperatures were cooler and where most trails were not in direct sunlight; average temperature when ant counts were taken was 24.9±0.7°C. Four of the five homes had one trail that disappeared after the first or second sampling day. Trails that disappeared were included in the data analysis as zeros if no ants were present on a sampling day.

Baits. We placed eight plastic petri dishes (8.5 cm in dia.) containing ca. 1.5g of apple jelly (Harris Teeter brand) at each home; two baits on each side directly against the base of the foundation and no closer than three meters from one another. We used eight jelly baits per home to increase the chance for discovery and recruitment. Baits were placed in the morning between 08:00 and 09:00 when temperatures were cooler. Approximately 45 minutes after bait placement, we recorded the number of ants feeding at each of the baits. Each bait was placed in the same location on each sampling day.

Argentine ants recruited to some baits in very high numbers, making it difficult to accurately count the number of ants. This difficulty could create observer bias, inflating or deflating the numbers of ants relative to those actually present on baits. To determine count accuracy, we performed a separate experiment in which Argentine ants were allowed to recruit to eight baits. Approximately 45 minutes after placement, the number of ants present at each bait was counted and recorded by two individuals. Each bait was then covered with parafilm, returned to the laboratory, and the trapped ants were frozen so that the actual number of ants could be determined.

Consumption of sucrose solution. Fifty mL plastic centrifuge containers (Corning) were filled with ca. 35 mL of 25% sucrose. The containers were plugged with cotton so that ants could consume the sucrose water without drowning. The containers were capped and ants were allowed access to the sucrose water through a hole (ca. 0.5 cm dia.) in the center of the cap. Eight containers were fastened to the outside foundation of each home with Velcro®, two containers on each side, ca. 30.5 cm from the ground and no closer than three meters from one another. We also placed two containers at each home as described above, except the containers were screened to exclude ants, thereby serving as evaporation controls. Each container was placed in the same location on each sampling day. The containers were put out at ca. 4:00 p.m. and collected the following morning ca. 9:00 a.m. Sucrose water consumed by Argentine ants was determined from container pre-weight minus post-weight. Weight loss was corrected for evaporation and the presence of drowned ants, which was determined based on an individual worker weight of 0.3mg. The number of ants that visited each container was calculated based on 0.3mg of sugar water consumed/worker/visit (Reierson et al. 1998).

Pitfall collections. Eight pitfall traps were set at each home, two on each side, directly against the structure and no closer than three meters from one another. Each trap was placed at the same location on each sampling day, with the top rim of the trap set flush with the ground. Traps were clear plastic cups (10 cm high, 8 cm dia.) filled ca. 3/4 with soap solution. The traps were put out at ca. 4:00 p.m. and collected ca. 24 h later. Most traps contained numbers of ants that could be counted quickly and accurately. However, some traps contained thousands of ants that could not be counted directly in the trap. These ants were extracted from the soap water, rinsed with alcohol, and placed in plastic petri dishes. The dishes were held in a fume hood until the ants were dry. The ants were then weighed and an estimation of the number of ants was made based on the weight of an individual ant (0.31mg).

Time considerations for sampling methodologies. In a separate study, which took place in August 2002, we calculated the time required to prepare, deploy, and process sampling procedure units. A unit refers to a single jelly bait, ant trail, pitfall trap, or sucrose container. Travel to and from field sites, which is required once for monitoring with jelly baits and ant trails, but twice for sucrose water and pitfall sampling was not measured in our study because distances to different investigators' field sites will vary.

Trailing activity. The time to locate ten exterior ant trails across five homes was determined. For each home, we started recording time the moment we reached the front door. After locating a trail and counting ants for one minute, we stopped recording the time. We started recording the time from that trail location before searching for the next trail. All homes had a minimum of one trail, with two of the homes containing three trails.

Baiting. For each of 20 apple jelly baits, we recorded the time for the following: (1) placement of jelly in each petri dish; (2) placement of each bait in the field, beginning at the front of each home and working counterclockwise around the home; (3) counting the number of ants on each bait; (4) retrieval of baits; and (5) removal of any ants from the baits, which was necessary since we recycled bait dishes. We placed four baits against the foundation of five homes, one on each side.

In a separate experiment, we recorded the time required to trap and count ants at baits that were later frozen (-20°C). After ca. 45 minutes of recruitment time (not included in the time calculation), we quickly placed a lid on the baited petri dish and wrapped parafilm around the edge to prevent ants from escaping.

Sucrose consumption. We determined the initial preparation time for each of 20 sucrose containers, which included drilling holes in the caps, placing mesh on six of the caps (evaporation controls) and adhering Velcro® to the containers. We recorded the time required to fill each container with sucrose solution, plug it with cotton, and weigh it. We then recorded the time required for: (1) placement, which included physically walking to the location and attaching the container to the home, again beginning at the front of each home; (2) collection; (3) removal of any ants from the containers; (4) weighing the returned containers; and finally (5) processing each sample (estimating the number of ants that visited each container based on sucrose weight loss). Four containers were placed at each of five homes, one on each side.

Pitfall collections. We recorded the time required for each of the following: (1) digging the hole required for each trap, (2) placement of soap solution in each trap, (3) placement of each trap into the ground, (4) retrieval of each trap, and (5) counting the number of ants present in each trap. Four pitfall traps were placed at each of five homes; one trap on each side, for a total of 20 traps.

Data analysis. To measure average within-unit variability for each method over the five sampling days, we used the coefficient of variation [CV=(standard deviation/mean)]. The CV value for each unit was calculated from mean ant counts for that unit across the five sampling days. The CV value for jelly baits was based on live ant counts. Analysis of variance and least squares mean comparison (PROC GLM, SAS Institute 1990) were computed on the log of the average CV values for each monitoring method. We used analysis of variance (SAS Institute 1990) to compare the average time requirement per unit for each monitoring method. To compare ant counts made by two individuals with those of the actual number present, analysis of variance was performed on square root transformed ant counts.

Results and Discussion

Sampling variability. The methods we compared varied in the period of time ants were exposed to each. In addition, two of the methods, jelly baits and sucrose containers, actually attracted Argentine ants. As a result, the average number (±SEM) of ants estimated by each monitoring method varied greatly (trails = 32.4±7.76; jelly baits = 41.1±6.21; pitfall traps = 297.5±135.35; sucrose containers = 38655.5±3308.56). However, CV calculation allows for direct comparison across different treatment counts.

All the monitoring methods used to estimate Argentine ant populations had average CV values greater than 0.5, indicating relatively high day-to-day variation in ant activity within units. This could reflect movement patterns of Argentine ants in response to disturbance (Newell and Barber 1913) or a change in the distribution of food resources (Silverman and Nsimba 2000, Holway and Case 2000). Pitfall traps had significantly greater CV than the other methods (ANOVA; df=3,144; p<0.001) (Figure 1). The average number of ants (±SEM) caught in pitfall traps was relatively low on the first sampling day (21±16), increasing to 463±202 by day five, with fluctuations across sampling days. Greenslade (1973) reported the opposite effect with high catches of ants (other than *L. humile*) immediately after traps were set followed by a decline ("digging-in effect"). Explanations for the "digging-in effect" include population depletion, traps being placed between trails to and from food/water sources, and learned avoidance.

Ant counts at baits obtained in the field by one of the two observers were significantly less than actual numbers of ants present (ANOVA; df=2,23; p=0.001), but were not different from one another (Table 1).

Time considerations for sampling methodologies. Total time to monitor with jelly baits was the shortest followed by trailing activity, sucrose consumption, and pitfall trapping (Figure 2). Ant counts on jelly baits required about the same time per unit whether handled in the field (66.1±6.01 sec) or trapped and counted in the laboratory (82.7±6.28 sec). The time required to collect data from pitfall traps was quite variable due to the large range in the numbers of ants caught. Five of the 20 (25%) pitfall traps required an average of 552±176.4 seconds per trap, while 15 of the 20 traps (75%) contained small numbers of ants, requiring an average of 18.7±2 seconds per trap.

The most time consuming step in measuring worker trailing activity was locating the trails (Figure 2). Once trails were located, this method took relatively little time (one to two minutes per trail). Although counting ants on trails was not very labor intensive, this method is limited by the availability of visible trails. In our study, we selected homes that contained visible trails during the pre-treatment period, however many of the homes within our study site revealed no trails despite the presence of ants in the area. In locations where there are numerous persistent ant trails, such as citrus groves with many trees (Moreno et al. 1987, Rust et al. 2000, Shorey et al. 1992, Shorey et al. 1996), then counting ants on trails could be quite efficient. For demployment of sucrose containers and jelly baits, preparation was the most time consuming step, followed by collection of the containers and baits, because this sometimes required the removal of ants (Figure 2). We reused our bait dishes; consequently, removing ants was a necessary step in this method. Bait dish disposal would minimize the time required for this sampling method. Removal of ants from each sucrose container was necessary because we were measuring weight loss. Processing each pitfall trap required the most time, followed by trap placement (Figure 2).

While counts on baits or trails are based on short-term observations, pitfall trapping and sucrose consumption over periods up to 24 hours can account for variation in diel foraging activity. However, the longer sucrose solution is left outdoors the more susceptible it is to non-target scavengers, evaporative water loss, or dilution due to precipitation. Pitfalls may trap non-target epigaeic organisms thereby complicating the processing and counting of Argentine ants. In addition, pitfall trapping removes ants from the population, which may affect later trapping.

Based on sampling consistency and effort, we recommend worker counts on food baits to monitor Argentine ants in the urban environment. Furthermore, to reduce observer bias while counting very high numbers of ants in the field, we recommend the procedure of Knight and Rust (1991) and Rust et al. (1996), of returning baits with ants to the lab to be counted at a later time. Since worker counts on baits were made over a relatively short period, sampling when Argentine ants are most active will facilitate this procedure.

References Cited

Blachly, J.S. and B.T. Forschler. 1996. Suppression of late-season Argentine ant (Hymenoptera: Formicidae) field populations using a perimeter treatment with containerized baits. J. Econ. Entomol. 89(6): 1497-1500.

Forschler, B.T. and G.M. Evans. 1994a. Argentine ant (Hymenoptera: Formicidae) foraging activity response to selected containerized baits. J. Entomol. Sci. 29(2): 209-214.

Forschler, B.T. and G.M. Evans. 1994b. Perimeter treatment strategy using containerized baits to manage Argentine ants, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae). J. Entomol. Sci. 29(2): 264-267.

Greenslade, P.J.M. 1973. Sampling ants with pitfall traps: diggin-in effects. Insect. Soc. 20(4): 343-353.

Holway, D.A. 1998. Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. Oecologia 166: 252-258.

Holway, D.A. and T.J. Case. 2000. Mechanisms of dispersed central-place foraging in polydomous colonies of the Argentine ant. Anim. Behav. 59: 433-441.

Human, K.G. and D.M. Gordon. 1996. Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. Oecologia 105: 405-412.

Klotz, J., L. Greenberg, and E.C. Venn. 1998. Liquid boric acid bait for control of the Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 91(4): 910-914.

Klotz, J., L. Greenberg, and G. Venn. 2000. Evaluation of two hydramethylnon granular baits for control of Argentine ant (Hymenoptera: Formicidae). Sociobiology 36(1): 201-207.

Knight, R.L. and M.K. Rust. 1990. The urban ants of California with distribution notes of imported species. Southwest. Entomol. 15(2): 167-178.

Knight, R.L. and M.K. Rust. 1991. Efficacy of formulated baits for control of Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 84(2): 510-514.

Krushelnycky, P.D. and N.J. Reimer. 1998. Efficacy of maxforce bait for control of the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Maui, Hawaii. Environ. Entomol. 27(6): 1473-1481.

Markin, G.P. 1970a. Foraging behavior of the Argentine ant in a California citrus grove. J. Econ. Entomol. 63(3): 740-744.

Markin, G.P. 1970b. The seasonal life cycle of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in southern California. Ann. Entomol. Soc. Amer. 63(5): 1238-1242.

Newell, M.S. and T.C. Barber. 1913. The Argentine ant. USDA Bulletin No. 122.

Reierson, D.A., M.K. Rust, and J. Hampton-Beesley. 1998. Monitoring with sugar water to determine the efficacy of treatments to control Argentine ants, *Linepithema humile* (Mayr). In: Proceedings of the National Conference on Urban Entomology, pp. 78-82, San Diego, CA.

Rust, M.K., K. Haagsma, and D.A. Reierson. 1996. Barrier sprays to control Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89(1): 134-137.

Rust, M.K., D.A. Reierson, E. Paine, and L.J. Blum. 2000. Seasonal activity of bait preferences of the Argentine ant (Hymenoptera: Formicidae). J. Agric. Urban Entomol. 17(4): 201-212.

SAS Institute. 1990. Version 6, 4th Ed. Vol. 2. pp. 891-1686. SAS Institute, Cary, NC.

Shorey, H.H., L.K. Gaston, R.G. Gerber, P.A. Phillips, and D.L. Wood. 1992. Disruption of foraging by Argentine ants, *Iridomyrmex humilis*, (Mayr) (Hymenoptera: Formicidae), in citrus trees through the use of semiochemicals and related chemicals. J. Chem. Ecol. 18(11): 2131-2143.

Shorey, H.H., L.K. Gaston, R.G. Gerber, C.B. Sisk, and P.A. Phillips. 1996. Formulating farnesol and other ant-repellent semiochemicals for exclusion of Argentine ant (Hymenoptera: Formicidae) from citrus trees. Environ. Entomol. 25(1): 114-119.

Silverman, J. and B. Nsimba. 2000. Soil-free collection of Argentine ants (Hymenoptera: Formicidae) based on food-directed brood and queen movement. Fla. Entomol. 83(1): 10-16.

Smith, M. 1965. House-infesting ants of the eastern United States. USDA Agricultural Research Service Bulletin 1326.

Southwood, T.R.E. 1978. Ecological methods. Chapman and Hall, London. 524pp.

Suoja, S., S. Garcia-Rubio, G. Chow, and V. Lewis. 2000. Ant behavior impacts barrier efficacy. Pest Control 69: 65-72.

Ward, P.S. 1987. Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the lower Sacromento valley and its effects on the indigenous ant fauna. Hilgardia 55(2): 1-16.

Table 1. Argentine ant worker counts in the field at each of eight bait stations by two different observers along with actual count.

Bait	Observer 1	Observer 2	Actual Count
1	153	264	339
2	272	325	500
3	228	312	464
4	149	135	151
5	132	110	135
6	178	171	285
7	131	145	156
8	186	251	161
Mean count	179a	214ab	274b

Means sharing the same letter are not significantly different (p=0.05; LSD).

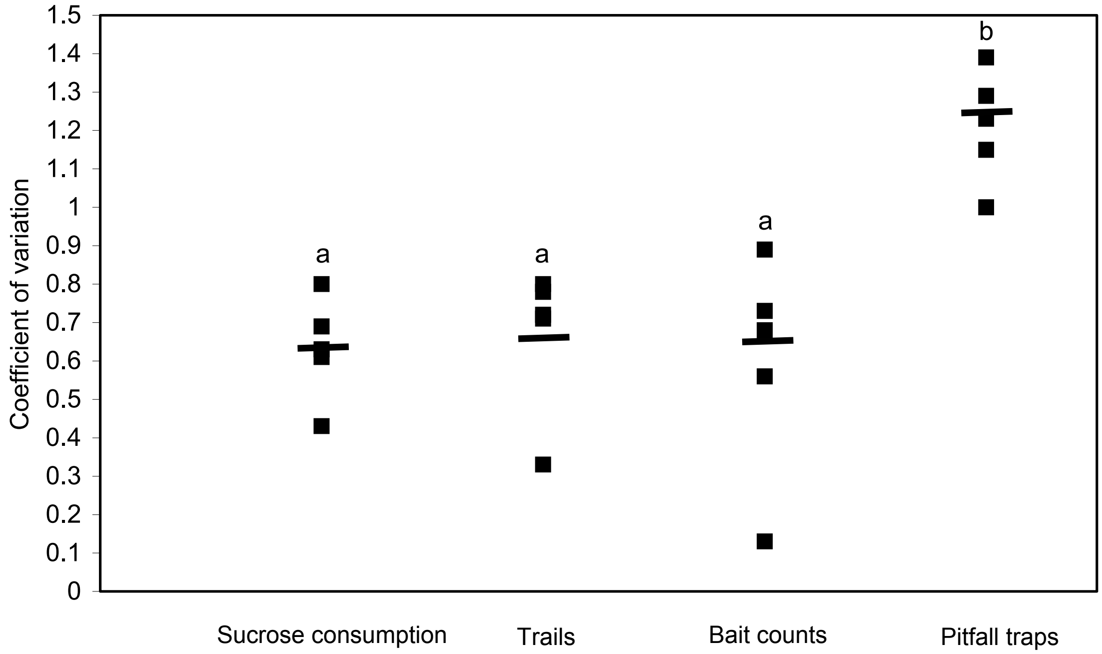

Figure 1. Coefficient of variation (CV) for each Argentine ant sampling procedure. Each point represents the average CV of all units of a house sampled over five days. Bar = mean.
Means sharing common letters are not significantly different (p=0.05; LSD).

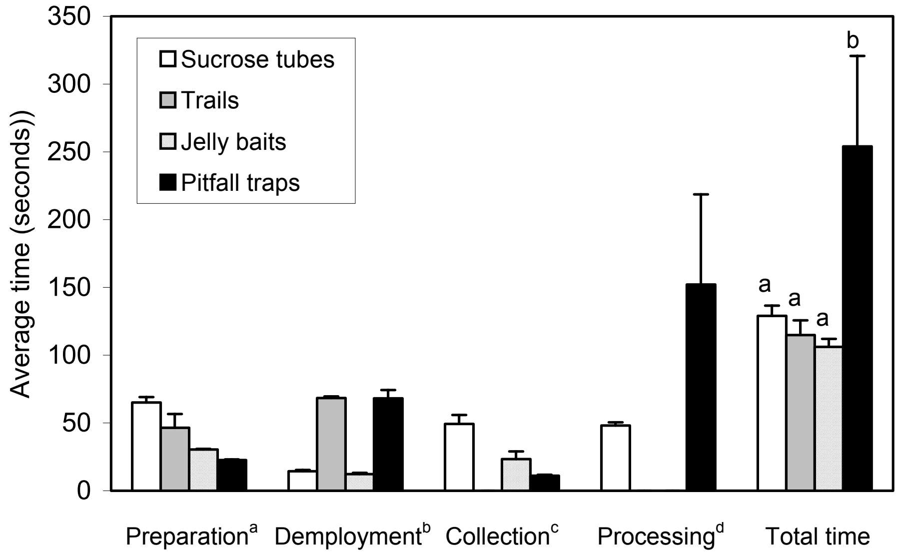

Figure 2. Average time requirement per unit step for monitoring methods used to estimate Argentine ant populations.
Columns sharing the same letter are not significantly different (p=0.05,LSD).

[a] preparation time per unit
[b] time to place unit in the field
[c] time to collect unit
[d] time to calculate number of ants

Chapter IV

Evaluation of Argentine ant insecticidal control strategies

Abstract

We performed three field studies to evaluate various insecticides and treatment strategies. In one trial, we compared the efficacy of gel bait or contact granules with that of a combination of the two applications. There were no significant reductions of Argentine ants one week following application. We found for combined weeks 2-5 the bait plus granular treatment provided a greater reduction than either bait or granules used singly. A combination treatment of Deltagard® granules and Maxforce® bait provided a greater, although not significant, reduction in Argentine ant populations. In a second trial, we evaluated the efficacy of two liquid baits. We found that average Argentine ant reduction following exposure to thiamethoxam bait or Advance™ bait did not differ, whether bait was in place for seven days or 21 days. The estimated number of Argentine ants consuming thiamethoxam bait was numerically but not significantly less than the number of ants consuming Advance™ bait, both 7 and 21 days following placement. Finally, in another trial we measured the effect of liquid fipronil (Termidor®) applied as a barrier around the exterior of homes infested with Argentine ants. Houses receiving Termidor® had an average Argentine ant population reduction of 41% two weeks following treatment. Those homes that served as untreated controls had a 62% reduction, a reduction greater than that of our treatment.

Introduction

The Argentine ant, *Linepithema humile* (Mayr), is a serious urban pest that invades homes and other structures (Newell 1909, Smith 1965, Klotz 1995). It is the dominant ant species in disturbed areas in California, the Mediterranean (Holldobler and Wilson 1990), and southwest Australia (Whitehouse 1988, Holldobler and Wilson 1990). Argentine ants were the most abundant ants in residential and commercial buildings in California (Knight and Rust 1990), and consequently are the focus of many control efforts. These control measures generally provide limited benefit. In a California study, pest control operators received callbacks from 40% of homes treated (Knight and Rust 1990). In a study conducted by Rust et al. (1996), Argentine ants began re-entering homes treated with cypermethrin and permethrin 30 days after treatment, necessitating re-treatment.

In an effort to identify new insecticides and treatment strategies, we performed three separate insecticide efficacy trials. The efficacy of perimeter sprays or baits for controlling the Argentine ant has been investigated (Forschler and Evans 1994, Knight and Rust 1991, Rust and Knight 1990, Rust et al. 1996), however efficacy studies of combined treatment strategies for control of the Argentine ant have not been reported. In one trial, we compared the efficacy of gel bait or contact granules with that of a combination of the two applications.

In a second trial, the efficacy of two liquid baits was evaluated. Toxic baits offered in a sweet sucrose-type solution may be better accepted by Argentine ants than some other bait types since these ants prefer sugary liquids (Markin 1970, Baker et al. 1985). These liquid baits can be placed on the exterior of homes quickly and easily, which may be less disruptive to homeowners because pest control operators can remain outdoors. Argentine ants may be less likely to invade homes in search of food if baits are placed on the exterior of homes. The use of baits may also minimize the uptake of insecticide by non-target organisms as well as minimize insecticide exposure to the environment.

Finally, we measured the effect of liquid fipronil (Termidor®) applied as a barrier around the exterior of homes infested with Argentine ants. Termidor® was recently registered for use against ants outdoors. Fipronil is capable of producing high mortality in Argentine ant populations and/or significantly reducing foraging rates of Argentine ants. Hooper-Bui and Rust (2000) found that low levels of fipronil (1×10^{-4} and 1×10^{-5}%) in 25% sucrose solution produced total mortality of Argentine ant workers and queens regardless of exposure periods. Broadcast applications of fipronil granules provided almost complete mortality of Argentine ant workers by week five in a study conducted by Costa and Rust (1999). Costa and Rust (2001) also found that a broadcast application of fipronil granules reduced Argentine ant foraging activity in two commercial greenhouses.

Materials and Methods

Each study was conducted in a residential neighborhood located in Chapel Hill, North Carolina with a history of problems with Argentine ants. We conducted door-to-door house visits and those homeowners agreeing to cooperate were included in at least one of the three studies.

For all trials, we used sucrose consumption by Argentine ants before and after treatments to determine Argentine ant percent reductions. For each monitoring period, we placed four 50 mL plastic centrifuge tubes (Corning) containing ca. 35 mL of 25% sucrose solution at each home monitored. One tube was attached vertically (with Velcro) to each side of a house. The tube was plugged with cotton so that ants could consume the liquid without drowning. Ants were allowed access to the sucrose water through a hole (ca. 0.5 cm dia.) in the tube cap. At each house we also placed two tubes as described except a screen was glued over the hole in the tube cap to exclude ants. These tubes served as controls for water loss due to evaporation. Amount of sucrose water consumed by Argentine ants was determined using the weight loss of each sucrose tube. Weight loss was corrected for evaporation and any ants left in the tubes. Using the corrected weight loss of each tube, we determined the average amount of sucrose consumed at each house for each treatment. Argentine ants consume an average of 0.3mg of sugar water per visit (Reierson et al. 1998). To determine the number of ants that visited each tube, we divided the total amount of sucrose consumed per tube by 0.3mg. This gave an estimate of the average number of ants that visited each house at each monitoring period. Efficacy of treatments was determined based on average percent reduction in Argentine ant activity for each monitoring period [(pre-count - post count/pre-count)(100)].

Trial 1: Comparison of combination treatments. On 29 July 2002, the average amount of sucrose consumed by Argentine ants at each home was determined and the homes were ranked from most to least sucrose consumed. The homes with the four highest means were assigned treatments as follows: a.) bait plus granule, b.) granule only, c.) bait only, d.) untreated control. This process was repeated until all homes were assigned treatments, thereby ensuring that treatments were partitioned equally. Each treatment was replicated six times and five homes served as an untreated control.

Treatments were applied two days following the pre-treatment count. Treatments were Deltagard® granules (0.1% deltamethrin, Bayer CropScience), applied at a rate of 0.13 AI lbs/acre in a three-foot wide band around the exterior of homes using a granule spreader; Maxforce® brand ant bait (30g tube) (0.001% fipronil, Bayer CropScience) applied to the exterior of homes at the base of the foundation directly above the ground in bands ca. 6 cm in length at ca. six locations and a combination of Deltagard® granules and Maxforce® bait, each applied as described above. Post-treatment counts were conducted using sucrose consumption to estimate Argentine ant worker numbers one, two, three, and five weeks after treatment. A weekly survey was also conducted, whereby all participating homeowners were asked whether or not Argentine ants were present inside their homes.

Trial 2: Evaluation of liquid ant baits. On 4 September 2002, we conducted a pre-treatment count at each house used in the study using sucrose consumption by Argentine ants to estimate ant activity, and treatments were allocated as described above. Treatments were 100 ppm thiamethoxam (Syngenta) experimental liquid ant bait left in place 2, 7 or 21 days, Advance™ liquid ant bait (1.0% orthoboric acid, Whitmire Micro-Gen) left in place 7 or 21 days, or a control (thiamethoxam experimental bait formulation minus the toxicant) present 21 days. Baits were placed the varying time lengths to determine the effects of different exposure periods on population reductions. Each treatment was replicated five times; five homes served as untreated controls, for a total of 30 homes. For each treatment, ca. 35 mL of liquid ant bait was placed in 50 mL plastic centrifuge tubes (Corning brand). The tube was plugged with cotton so that ants could consume the bait without drowning. Ants were allowed access to the bait through a hole (ca. 0.5 cm in dia) in the tube cap. The exterior of each home was examined for the presence of Argentine ant trails and six tubes containing bait were placed upright together at this single location, attached with Velcro. Two of the tubes containing bait were screened to exclude Argentine ants, thereby serving as water evaporation controls. To determine percent reduction following bait placement, counts were made 7 days and 21 days following bait placement using sucrose consumption to estimate Argentine ant numbers. Eight tubes containing sucrose solution were placed at each house at ca. 4:00p.m. and collected ca. 16 hours later. Amount of sucrose water consumed by Argentine ants was determined using the weight loss of each tube. Weight loss was corrected for evaporation and any ants left in the tubes. We determined the average amount of sucrose consumed at each house for each treatment using the corrected weight loss of each tube. Argentine ants consume an average of 0.3mg of sugar water per visit (Reierson et al. 1998). We divided the total amount of sucrose consumed per tube by 0.3mg to determine the number of ants that visited each tube. This gave an estimate of the average number of ants that visited each house at each monitoring period. Efficacy of treatments was determined based on average percent reduction in Argentine ant activity for each monitoring period [(pre-count - post count/pre-count)(100)].

We also determined the amount of toxic bait consumed by Argentine ants using the pre-weight and post-weight of tubes containing bait. Finally, we examined and counted the number of ants present on the caps of all bait tubes at 1 hour, 1 day, 2 days, 7 days, and 21 days after bait placement to determine the effects of different exposure periods on Argentine ant reductions.

Trial 3: Evaluation of Termidor® liquid insecticide. On 8 October 2002, we conducted a pre-treatment count at each house used in the study using sucrose consumption to estimate Argentine ant activity. The homes with the two highest means were assigned Termidor®; the home with the next highest mean served as an untreated control. This process was repeated until all homes were assigned treatments. Twenty-two homes received Termidor® (9.1% fipronil) and 10 served as untreated controls. Termidor® was prepared according to label instructions (0.8 fluid oz/gallon water) to provide a final concentration of 0.057% fipronil. Approximately 1.25 liters were applied in a two-foot wide band around the exterior of each home, and also one foot up the foundation using a backpack sprayer. A post-treatment count was made two weeks following treatment.

Data analysis. We compared average percent reduction of each treatment for each monitoring period in trial 1 using analysis of variance (SAS Institute 1990). For trial 3, we compared the average percent reduction between treatments and controls using a Mann-Whitney test (SAS Institute 1990).

For Trial 2, we compared average percent reduction of Argentine ant populations for each treatment seven days and 21 days following bait placement using a Kruskal-Wallis test (Minitab 2000). We compared the amount of toxic bait consumed by ants for seven days with a Mann-Whitney test (Minitab 2000), and for 21 days, including a sugar water control, with a Kruskal-Wallis test (Minitab 2000). The number of ants present on the caps at each bait tube 1 hour, 1 day, 2 days, 7 days, and 21 days following placement was compared with a Kruskal Wallis test (Minitab 2000).

Results and Discussion

Trial 1: Comparison of combination treatments. There were no significant reductions of Argentine ants among treatments after one week (Table 1). Low overnight temperature at the one-week monitoring time period may have depressed normal Argentine ant activity, giving the impression that populations declined due to treatment effects. The minimum temperature at the one-week monitoring period was around 14°C, while the minimum temperature at our pre-treatment monitoring period was ca. 24°C. At the one-week monitoring period we noticed a trail of Argentine ants foraging past one monitoring tube at two of the homes that served as untreated controls. These monitoring tubes failed to pick up Argentine ant activity at these homes. This could obviously lead to misleading results. It is not clear why Argentine ants would fail to visit and take advantage of such a favored food resource (Markin 1970). Klotz et al. (2000) also monitored Argentine ant activity using consumption of sucrose water, however, they placed monitoring tubes at eye level and then sprayed a trail of 25% sucrose water from the ground to each tube to help the ants find the tubes. We did not spray a sucrose trail from the ground to our monitoring tubes, however, our tubes were placed very close to the base of the homes where Argentine ants were seen foraging. Perhaps the migrating ants were moving to a new nest site or had found an alternate food or water source.

At those homes receiving gel bait only, Argentine ant populations actually increased at weeks two, three, and five following treatment (Table 1). The amount of gel bait we used may not have been sufficient to cause a reduction in Argentine ant activity since ants were present in such high numbers.

By averaging data across weeks 2, 3, and 5, the percent reduction for the bait plus granule treatment was significantly greater than that of the control (97.44% versus 66.64%; p=0.0097; Mann-Whitney test) and the granule only treatment (55.03%; p=0.0148; Mann-Whitney test).

As indicated by our weekly survey, the percentage of homes where Argentine ants were observed inside by homeowners was high regardless of treatment (Table 2). No treatment completely excluded Argentine ants from the interior of homes. Interestingly, those homes receiving only Maxforce® bait had a lower percentage of Argentine ants indoors than those homes receiving other treatments even though there was a large population increase at those homes receiving Maxforce® bait only. It would seem logical that more Argentine ants would invade homes because there was such an increase in activity at these homes. The bait was placed outside and was attractive to ants; perhaps this kept the ants foraging outside. However, the bait was consumed within a few days after which time the ants may have been more likely to invade homes in search of food.

In this trial, treatments were applied once. Argentine ants occur at this study site in very large numbers. Perhaps if a second application had been applied there would have been a greater reduction in Argentine ant populations. Irrigation was not conducted following application of granules, on the recommendation of the manufacturer. Irrigation may have led to greater dispersion of the granules, which may have provided a more complete barrier and subsequently a greater reduction in Argentine ant populations at those homes receiving granules.

In summary, we found that a combination treatment of Deltagard® granules and Maxforce® bait provided a greater reduction in Argentine ant populations than did granules only or bait only 2, 3, and 5 weeks after treatment, however, this difference was not significant. For the average of post-treatment counts for weeks 2, 3, and 5, the reduction for the bait plus granule treatment was significantly greater than that of the control and the granule only treatment. Therefore, the use of the two treatments in combination may be efficacious, although none of our treatments completely excluded Argentine ants from invading homes in this study.

Trial 2: Evaluation of liquid baits. Argentine ant activity increased at those homes where thiamethoxam bait was available for two days (Table 3). However, the overall increase seen following this treatment was due to only one home. All other homes where thiamethoxam bait was present for two days actually had population reductions greater than 60% (average percent reduction=82.3±10.2) seven days following bait placement and greater than 85% (average percent reduction=95.2±3.0) twenty-one days following bait placement.

Average Argentine ant percent reductions exposed to thiamethoxam bait or Advance™ did not differ, whether bait was in place for seven days (H=2.07, df=5, p=0.839) or 21 days (H=6.05, df=5, p=0.301) (Table 3). Treatments were not significantly different from untreated controls, therefore the depressed activity of Argentine ants observed following some of the treatments was probably due to factors other than the bait. This study was conducted relatively late in the season (September), which may account for the overall depressed Argentine ant activity seen with most treatments and untreated controls.

Those homes that had Advance™ bait in place for 21 days had population reductions greater than 95% one week after bait placement (Table 3). However, two of the five homes had an increase in Argentine ants 21 days following placement, accounting for the overall increase in ant activity seen with this treatment at the 21-day monitoring period.

At those homes where thiamethoxam bait was available for 21 days, Argentine ant populations were reduced by greater than 65% at four of the five homes treated one week following bait placement. One home had a substantial increase in Argentine ant activity accounting for the overall increase seen for this treatment 21 days after bait placement (Table 3). Conditions and/or resources may have changed at these homes, attracting Argentine ants thereby causing the increased activity. Perhaps the activities of the homeowners, such as lawn watering or disposing of food, altered the condition or resources available to Argentine ants. We noticed no such change in condition or resources, however we could not monitor all homeowner activity.

The estimated number of Argentine ants consuming thiamethoxam bait was less than the number of ants consuming Advance™ bait both 7 and 21 days following placement (Table 3). Perhaps Advance™ was more attractive to Argentine ants or that the thiamethoxam bait was repellent, or both. The thiamethoxam bait used in this study was experimental; perhaps other concentrations would be less repellent. The average number of Argentine ants consuming bait was significantly greater at those tubes containing only sugar water vs. tubes containing thiamethoxam ($p=0.0122$, Mann-Whitney test) when made available for 21 days (Table 3), suggesting that the concentration of thiamethoxam used in this study may have been repellent to Argentine ants. The average number of ants present at bait tube caps did not differ at any time point examined ($p=0.823$ for 1hr; $p=0.128$ for 24hr; $p=0.452$ for 2d; $p=0.132$ for 7d; $p=0.157$ for 21d), suggesting that that Argentine ant populations did not decline.

Trial 3: Evaluation of Termidor® insecticide. Houses receiving Termidor® had an average Argentine ant population reduction of 41% two weeks following treatment. With one exception, all treated homes had a reduction in Argentine ant activity, and over half of treated homes (59%) had a 100% reduction in Argentine ant activity (Table 4). However, those homes that served as untreated controls had a 62% reduction, a reduction greater than that of our treatment. Forty percent of the homes that served as controls had a 100% reduction in Argentine ant activity, however two homes actually had an increase in Argentine ant activity (Table 4). Interestingly, when the one treated house that experienced an increase in ant activity was excluded from the data, our treatment showed an 86% reduction in Argentine ant activity, a reduction greater than that of the control.

This study was conducted late in the season and it is possible that depressed ant activity at our monitoring tubes may have been due in part to cooler temperatures at pre-count vs. post-count periods. Perhaps if this study were conducted earlier in the summer under warmer conditions, we would have seen a greater reduction in Argentine ant activity due to Termidor®.

Our control efforts offered limited success, as is sometimes the case with Argentine ants (Knight and Rust 1990, Rust et al. 1996). Several factors may contribute to the difficulty in controlling these ants. Argentine ants will abandon nests if conditions become unfavorable (Newell and Barber 1913). The Argentine ant is unicolonial with multiple nests that contain thousands of workers and hundreds of queens (Newell and Barber 1913). As a result, nests are difficult to locate and treat. Also, chemical barriers can kill or repel workers, but have little effect on the reproductive success of the colony. Barber (1909) observed that one percent or less of the workers comprising a colony can sustain remaining individuals. Toxicants placed in bait material have the potential of reaching brood and queens if taken to the nest by foraging workers. However, the efficacy of toxic bait depends on acceptance of the bait and the amount returned to the colony (Forschler and Evans 1994). Knowing where to place toxic baits and the amount to make available to ants may prove difficult because of the scattered nesting habits and large colony size of Argentine ants.

All of the factors mentioned above may have contributed to the limited success of control measures used in our studies. Argentine ants occurred at our site in such high numbers; the amount of insecticide used may not have been sufficient to provide significant mortality and/or reduced foraging activity. A more aggressive treatment may be necessary at this site. A more rigorous treatment could be achieved with multiple applications of treatments or by making more insecticide available to Argentine ants if treatments are to be applied once.

References

Baker, T.C., S.E. van Vorhis Key, and L.K. Gaston. 1985. Bait-preference tests for the Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 78: 1083-1088.

Costa, H.S. and M.K. Rust. 1999. Mortality and foraging rates of Argentine ant (Hymenoptera: Formicidae) colonies exposed to potted plants treated with fipronil. J. Agric. Urban Entomol. 16(1): 37-48.

Costa, H.S., L. Greenberg, J. Klotz, and M.K. Rust. 2001. Monitoring the effects of granular insecticides for Argentine ant control in nursery settings. J. Agric. Urban Entomol. 18(1): 13-22.

Forschler, B.T. and G. M. Evans. 1994. Argentine ant (Hymenoptera: Formicidae) foraging activity response to selected containerized baits. J. Entomol. Sci. 29(2): 209-214.

Holldobler, B. and E.O. Wilson. 1990. The ants. Harvard University Press, Massachusetts. 732pp.

Hooper-Bui, L.M. and M.K. Rust. 2000. Oral toxicity of abamectin, boric acid, fipronil, and hydramethylnon to laboratory colonies of Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 93(3): 858-864.

Klotz, J., J.R. Mangold, K.M. Vail, L.R. Davis, and R.S. Patterson. 1995. A survey of the urban pest ants (Hymenoptera: Formicidae) of Peninsular Florida. Florida Entomol. 78(1): 109-118.

Klotz, J., L. Greenberg, and G. Venn. 2000. Evaluation of two hydramethylnon granular baits for control of Argentine ant (Hymenoptera: Formicidae). Sociobiology 36(1): 201-207.

Knight, R.L. and M.K. Rust. 1990. The urban ants of California with distribution notes of imported species. Southwest. Entomol. 15(2): 167-178.

Markin, G.P. 1970. Foraging behavior of the Argentine ant in a California citrus grove. J. Econ. Entomol. 63: 740-744.

MINITAB Statistical Software. 2000. Release 13. User's guide 2: data analysis and quality tools. Minitab, Inc., USA.

Newell, W. 1909. Measures suggested against the Argentine ant as a household pest. J. Econ. Entomol. 2: 324-332.

Newell, W. and T.C. Barber. 1913. The Argentine ant. USDA Bulletin No. 122.

Reierson, D.A., M.K. Rust, and J. Hampton-Beesley. 1998. Monitoring with sugar water to determine the efficacy of treatments to control Argentine ants, *Linepithema humile* (Mayr).). In: Proceedings of the National Conference on Urban Entomology, pp. 78-82, San Diego, CA.

Rust, M.K., K. Haagsma, and D.A. Reierson. 1996. Barrier sprays to control Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89(1): 134-137.

SAS Institute. 1990. Version 6, 4th Ed. Vol. 2. pp. 891-1686. SAS Institute, Cary, NC.

Smith, M.R. 1965. House-infesting ants of the eastern United States. USDA Technical Bulletin No. 1326.

Whitehouse, S. 1988. A review of Argentine ant control in western Australia. In: Heptachlor use for the control of Argentine ants, Bulletin No. 325. The Agriculture Protection Board, Perth, Western Australia.

Table 1. Field efficacy of gel bait and granules against Argentine ants.

Treatment	Estimated average no.	% reduction (±SE) at week			
	Pre-count	1	2	3	5
Maxforce® gel	264,884	77.8±13.76a	-24.5±109.25a	-4.1±76.07a	-246.5±308.14a
Deltagard® granules	431,969	76.7±18.36a	47.7±31.62a	11.1±42.14a	33.6±31.47a
Maxforce® + Deltagard®	396,118	77.1±19.22a	86.8±10.42a	70.8±20.81a	68.7±25.74a
Untreated control	261,148	91.7±3.36a	74.8±12.17a	24.6±27.99a	20±28.71a

[a] estimate based on consumption of 25% sucrose solution
Columns containing the same letter are not significantly different (Mann-Whitney Test; p=0.05)

Table 2. Argentine ant sitings by residents indoors following insecticide treatment.

Treatment	Percentage of respondents reporting ants			
	Week 1	Week 2	Week 3	Week 5
Maxforce® gel	67	75	80	60
Deltagard® granules	100	83	100	100
Maxforce® + Deltagard®	67	100	100	75
Untreated control	75	67	100	100

Table 3. Efficacy of liquid baits against Argentine ants.

Treatment	Exposure time	% reduction (±SE) at day		estimated # of ants (±SE) consuming bait[a]	avg. # ants on cap at time				
		7	21		1 h	1 d	2 d	7 d	21 d
Thiamethoxam	2d	-1613±1695	-794±890	875±486	4	2	4	--	--
Thiamethoxam	7d	75±17	84±14	1025±627A	3	0.8	0	0	--
Advance	7d	61±12	91±9	35432±21204A	1	17	19	6	--
Thiamethoxam	21d	26±66	-3±70	3225±1365a	0	0	2	0	1
Advance	21d	96±2	-1664±1676	19969±13564ab	0	0	0	0	6
Control	21d	74±24	69±27	59598±20694b	1	20	9	3	8

[a] estimate based on consumption of 25% sucrose solution
Numbers followed by different letters are significantly different ($p<0.05$). A Kruskal-Wallis test was used to compare numbers of ants consuming bait when made available 21 days; a Mann-Whitney test was used to compare numbers of ants consuming bait when made available 7 days.

Table 4. Efficacy of Termidor® against Argentine ants.

House	estimated# ants at pre-count[a]	estimated# ants at post-count	% reduction
Treated			
A	22	0	100
B	68	17	75
C	31	0	100
D	33	5	85
E	102	45	56
F	11227	136	99
G	70	0	100
H	25	0	100
I	67	0	100
J	69	41	41
K	2586	0	100
L	12	4	67
M	84	852	-914
N	40	20	50
O	3756	0	100
P	49	0	100
Q	10275	0	100
R	4371	0	100
S	20312	0	100
T	9372	0	100
U	1808	0	100
V	44	29	34
Treatment mean (±SE)	**3065.7±1126.8**	**53.3±38.6**	**40.8±45.7**
Controls			
AA	6991	1707	76
BB	116	23	80
CC	73	105	-44
DD	3564	2388	33
EE	18	21	-17
FF	66	0	100
GG	58	0	100
HH	1736	72	96
II	120	0	100
JJ	8415	32	100
Control mean (±SE)	**2115.7±952.3**	**434.8±259.7**	**62.4±16**

[a] estimate based on consumption of 25% sucrose solution