Red Imported Fire Ant (Hymenoptera: Formicidae) Mortality Following Exposure to Sodium Hydrogen Carbonate ($NaHCO_3$)[1]

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Abstract Red imported fire ant, *Solenopsis invicta* Buren, worker responses to sodium hydrogen carbonate ($NaHCO_3$) placed on surfaces and in liquid food were evaluated in laboratory bioassays. The median lethal concentration (LC_{50}) of $NaHCO_3$ applied to surfaces on which workers were restricted was 7.11 mg per cm^2 at 7 days after initial exposure. Only 42% of workers feeding on sugar water containing 7.5% $NaHCO_3$ were killed; mortality was not increased with increasing concentration of $NaHCO_3$. Choice tests demonstrated that $NaHCO_3$ did not repel or deter feeding by workers. Whole-body pH of workers not exposed to $NaHCO_3$ was 6.97 (±0.08), while pH of workers exposed to 28 mg $NaHCO_3$ per cm^2 on surfaces was 7.90 (±0.21). This suggests a physiological shift in hydrogen ion concentration of ants exposed to $NaHCO_3$ and perhaps accounts for cause of death.

Key Words Sodium bicarbonate, pH, red imported fire ant

The red imported fire ant, *Solenopsis invicta* Buren, colonizes many different habitats in urban and agricultural settings and, therefore, more than one method of control is needed. The most common methods of fire ant control are insecticidal baits and mound treatments (Sparks 1993, Drees et al. 1998). However, these types of treatments may not be useful or safe in all situations. Additional safe and inexpensive methods of control are needed for fire ant management. For example, fire ants often colonize electric utility boxes, damaging equipment and posing safety problems for utility employees (MacKay et al. 1992). However, extensive use of insecticides in utility boxes would be costly, time consuming, and compromise human safety.

Sodium hydrogen carbonate ($NaHCO_3$), also known as sodium bicarbonate or bicarbonate of soda, is distinct from many other substances in that it is a registered pesticide active ingredient for use against fungal phytopathogens (EPA 1999) and yet is also listed by the USDA National Organic Program as a nonorganic substance allowed as an ingredient in or on processed products labeled as "organic" or "made with organic" (NOP 2003). It is used to control powdery mildew (Horst et al. 1992) and inhibits growth of yeasts and bacteria (Corral et al. 1988). This compound occurs naturally in the environment and is safe for humans (Corral et al. 1988, EPA 1999). It is not known if $NaHCO_3$ would be effective against invertebrate pests such as fire

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ants. The objective of this research was to determine the response of red imported fire ant workers to $NaHCO_3$ in the laboratory.

Materials and Methods

All fire ants used in this study were obtained from field populations in Griffin, GA (Spalding Co.), and were removed from soil using procedures described by Jouvenaz et al. (1977) and maintained in our laboratory. These laboratory colonies were in plastic trays containing artificial nests constructed of 150-mm plastic Petri dishes with dental plaster on the bottom to maintain moisture (Stimac et al. 1993). Fluon® (Northern Products Inc., Woonsocket, RI) was applied to the inside walls of trays to prevent ant escape. Ants were fed foods including 10% sugar water (v/v), tuna in oil, and yellow mealworm, *Tenebrio molitor* L., larvae.

LC_{50} for $NaHCO_3$ on surfaces. Test arenas were prepared by burning a 5-mm diam hole in the bottom of clear 35-ml plastic cups and adding dental plaster to about 10% of total cup volume. Fluon was applied to the inside walls of cups and undersides of lids. A 1.2-cm diam hole in each lid allowed for air exchange. Treatments tested in cups were an untreated control, 0.85, 1.7, 3.5, 7.0, 14.0 and 28.0 mg $NaHCO_3$ per cm^2. The $NaHCO_3$ was spread evenly on the surface of the dental plaster in cups, and ten workers were placed in each container. Sugar water in small containers constructed from the lids of 0.65 ml microcentrifuge tubes (Fisher Scientific, Pittsburgh, PA) was placed in each cup. Cups were placed on a wet foam pad to maintain moisture within cups. Mortality was checked daily for 7 d. Dead ants were removed from cups each day and were kept frozen until the end of each test. Treatments were replicated 10 times in a randomized complete block design (RCBD). These tests were conducted four times between 24 April and 25 September 2002 using workers from four different colonies. Data were subjected to probit analysis (SAS Institute 1985) to obtain estimates of lethal concentrations and associated parameters. Concentration of $NaHCO_3$ was transformed by log (x + 1) prior to regression analysis and graphing of ant mortality data (SPSS Inc. 1998).

Ant pH. After 7 d, the remaining live ants in the LC_{50} cup study were freeze-killed and combined with the ants that died in treatments. All 100 ants from each treatment were placed in a sieve (U.S. Standard Sieve, No. 80, 177 micron opening, W.S. Tyler Co., Cleveland, OH) and rinsed under running tapwater for 60 s. Ants were rinsed again in a 35-ml plastic cup with 20 ml of distilled water by gently shaking for 60 s. Samples were blotted dry on paper towel and then weighed. For each treatment, samples of whole ants weighing 0.04 to 0.07 g were crushed and mixed with 2 ml of distilled water in a 20-ml scintillation vial. An Accumet 1003 pH meter (Fisher Scientific) was standardized with 7.00 and 10.00 pH standard buffers prior to analysis of ant samples. Concentration of $NaHCO_3$ was transformed by log (x + 1) prior to regression analysis and graphing of ant pH data. Analysis of pH was conducted on ants from three of the four bioassay tests that had been conducted to determine LC_{50}.

Mode of exposure. Fire ant workers were placed in a clear 35-ml plastic cup with 2.25 g of $NaHCO_3$. The cup was turned on its side and rotated so that workers were completely covered with $NaHCO_3$ powder. Ants were then immediately removed from the cup with forceps and placed in untreated test arenas as previously described. A solution was mixed using 2 ml of $NaHCO_3$ and 8 ml of sterile distilled water. Fire ant workers were immersed in the solution and immediately placed in untreated test arenas. For each test, 100 fire ants were kept as untreated controls, 100 were briefly exposed to $NaHCO_3$ powder, and 100 were dipped in the $NaHCO_3$ solution. All ants were placed ten per cup for each treatment, and cups were arranged in a RCBD. Mortality was checked daily for 7 d. Data were analyzed by using the PROC MIXED procedure in SAS (Littell et al. 1996), and means were separated with LSD ($P = 0.05$).

Arena choice tests. A set of test arenas consisted of paired 15.3 cm diam × 6.5 cm tall plastic dishes (Pioneer Plastics, Inc., Dixon, KY) connected to a 4.5 cm diam × 4.0 cm tall Nalgene® container (Fisher Scientific) with 4 mm (inside) diam vinyl tubing (Fig. 1). Fluon was applied to the inside walls of test arenas. Artificial nests

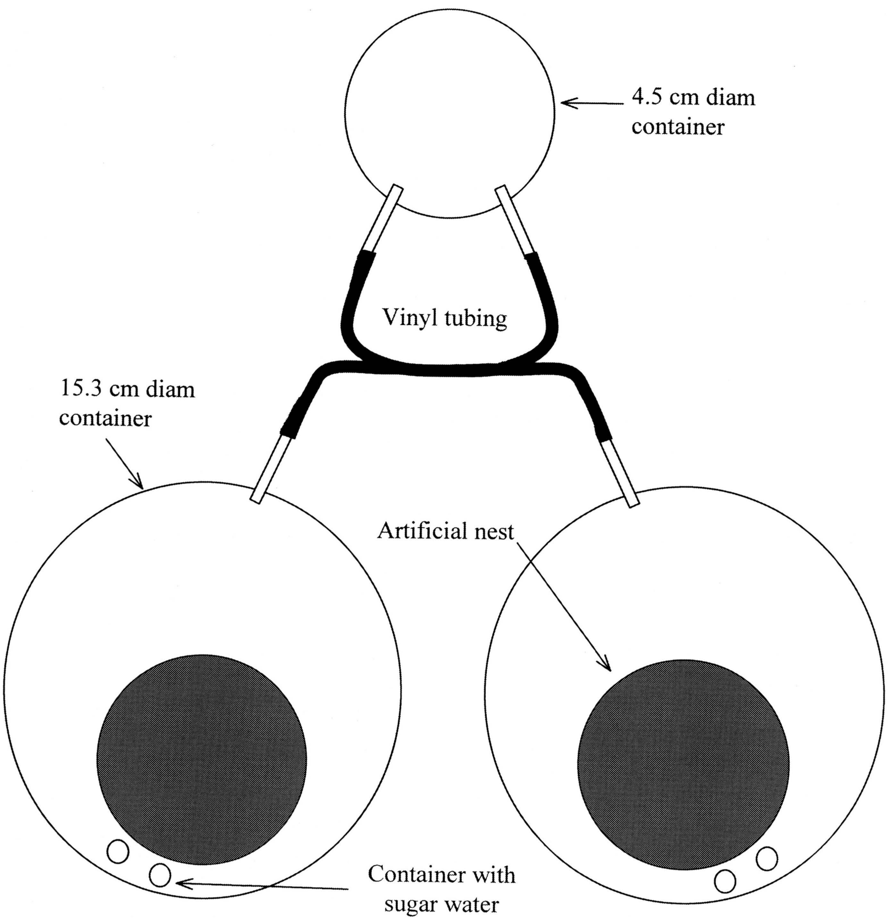

Fig. 1. Diagram of arena set. Entrance hole on left side of small container is connected by a vinyl tube to the entrance hole of the large container on the right. Entrance hole on the right side of small container is connected to the large container on the left. Artificial nests and containers with sugar water were placed within large containers. Ants were added to the small container and could freely move between structures.

were constructed of 150-mm Petri dishes as previously described, and one was placed inside each of the large plastic containers. $NaHCO_3$ was evenly spread on the bottom of treated nests and large containers at a rate of 18.0 mg per cm^2. The area under nests was left untreated. This rate was selected based on preliminary results from LC_{50} bioassays and had potential for causing relatively high levels of mortality in fire ants. Dental plaster in artificial nests was moistened with sterile distilled water prior to the beginning of tests, and water was added each day as needed. Two lids cut from 1.5-ml microcentrifuge tubes were filled with sugar water and were placed opposite entrance holes of the large containers. In one set of arenas, both large containers received $NaHCO_3$. In another set of arenas, both large containers were left untreated. In remaining arena sets, one large container was treated with $NaHCO_3$ and the other large container in the pair was left untreated. Tubing allowed workers to freely move between containers. In the first test, there were five sets of arenas in which only one container was treated with $NaHCO_3$ and the other was left untreated. There was also an arena set in which both containers were untreated (control), and one arena set had both containers treated with $NaHCO_3$. In subsequent tests, there were two sets of arenas in which either the left or right container was treated with $NaHCO_3$, while the other was left untreated. Two other arena sets had both containers untreated (control), or both containers treated with $NaHCO_3$. These tests were conducted a total of three times between 11 June and 21 August 2002 using workers from three different colonies. Experimental design was a RCBD. Each test began with the addition of 100 workers to the small untreated container. Mortality and number of live ants in large containers and artificial nests were recorded; dead individuals were removed each day for 6 d. Live ant data for the arena pairs with treated and untreated areas were pooled and analyzed by using the PROC MIXED procedure to determine any differences between treatment effects over 6 d. These data were also analyzed separately by container and by date using one-way analysis of variance (Analytical Software 1992); means were separated with LSD (P = 0.05). Mortality data for arena sets with treated and untreated areas, arena sets with both containers left untreated, and arena sets with both containers treated with $NaHCO_3$ were analyzed using the PROC MIXED procedure. Means were separated with LSD (P = 0.05).

$NaHCO_3$-sugar water tests. Test arenas were prepared with 35-ml clear plastic cups as previously described. Ten workers were placed in each container. Sugar water treatments were pipetted into 0.65 ml microcentrifuge tube lids and individually placed on the dental plaster in cups. Treatments were sugar water (untreated control) and a range of concentrations of $NaHCO_3$ in sugar water (Table 1), and were replicated 10 times in a RCBD. Mortality was checked daily for 10 d. Dead ants were removed from cups each day. These tests were conducted four times between 09 January and 16 February 2003 using ants from four different colonies. Data were analyzed by using the PROC MIXED procedure, and means were separated with LSD (P = 0.05).

Food choice tests. Test arenas were prepared using 35-ml clear plastic cups as previously described. Ten workers were placed in each container. Sugar water treatments were pipetted into 0.65 ml microcentrifuge tube lids and individually placed on the dental plaster in cups. Treatments were sugar water (untreated control), 10% $NaHCO_3$ in sugar water (v/v), and sugar water in a container next to a container with 10% $NaHCO_3$ in sugar water. The 10% $NaHCO_3$ in sugar water treatment was prepared by mixing 1.07 g (1 ml) of $NaHCO_3$ with 9 ml of sugar water. Mortality was checked daily for 6 d. Dead ants were removed from cups each day. Treatments were

Table 1. Cumulative mortality for *S. invicta* (n = 100 per treatment per test) provided sugar water and $NaHCO_3$

Food treatment	Mean # dead (day 10)
Untreated	3.75 ± 1.03a
1.0%-0.10 ml $NaHCO_3$ in 9.90 ml sugar water	7.50 ± 3.67a
5.0%-0.50 ml $NaHCO_3$ in 9.50 ml sugar water	26.00 ± 12.19b
7.5%-0.75 ml $NaHCO_3$ in 9.25 ml sugar water	44.00 ± 8.91c
10.0%-1.00 ml $NaHCO_3$ in 9.00 ml sugar water	32.50 ± 11.45bc
15.0%-1.50 ml $NaHCO_3$ in 8.50 ml sugar water	35.50 ± 11.39bc
20.0%-2.00 ml $NaHCO_3$ in 8.00 ml sugar water	41.00 ± 13.31c

Means (±SEM) followed by same letter are not significantly different (LSD, $P > 0.05$).

replicated 10 times in a RCBD. These tests were conducted four times between 18 June 2002 and 19 March 2003 using workers from four different colonies. Data were analyzed by using the PROC MIXED procedure and means were separated with LSD ($P = 0.05$).

$NaHCO_3$ on surfaces and in sugar water. Fluon was applied to the inside walls of arenas that were 15.3 cm diam × 6.5 cm tall. An artificial nest was placed inside each of the plastic arenas. Dental plaster of nests was moistened prior to the beginning of tests, and water was added each day as needed. $NaHCO_3$ was evenly spread on the bottom of treated nests and containers at a rate of 18.0 mg per cm^2. A 1.5-ml microcentrifuge tube lid was placed on the bottom of each arena with untreated arenas receiving sugar water only, and treated arenas receiving 7.5% $NaHCO_3$ in sugar water (v/v). Arenas were paired, but not connected, and treatments were randomly assigned to one arena in each of four arena sets. The other arena in each pair served as an untreated control. Tests began with addition of 30 workers to each arena. Mortality was recorded, and dead individuals were removed each day for 6 d. These tests were conducted four times between 18 to 31 March 2003 using workers from three different colonies. Data were analyzed by using the PROC MIXED procedure, and means were separated with LSD ($P = 0.05$).

Results

LC_{50} for $NaHCO_3$ on surfaces. A significant positive linear relationship ($R^2 = 0.2322$; $F_{1,278} = 80.05$; $P < 0.0001$) occurred between $NaHCO_3$ concentration on surfaces and fire ant mortality (Fig. 2). Probit analysis of the concentration-mortality response of fire ant workers 5 d after exposure to $NaHCO_3$ yielded an LC_{50} of 9.66 mg per cm^2 (Table 2). After 7 d of exposure, the calculated LC_{50} for fire ants was 7.11 mg $NaHCO_3$ per cm^2. Mean cumulative mortality for fire ants exposed to 28.00 mg $NaHCO_3$ per cm^2 was 68.50% on day 7.

Ant pH. A significant positive linear relationship ($R^2 = 0.2853$; $F_{1,19} = 7.59$; $P = 0.0126$) also was observed between $NaHCO_3$ concentration and whole-body pH of fire ants (Fig. 3). Mean pH of untreated fire ants was 6.97 (±0.08). The mean pH of ants exposed to $NaHCO_3$ ranged from 7.34 (±0.39) in the 0.85 mg per cm^2 treatment to 7.90 (±0.21) in the 28.00 mg per cm^2 treatment.

Mode of exposure. After 7 d, only two fire ants in the $NaHCO_3$ powder treatment

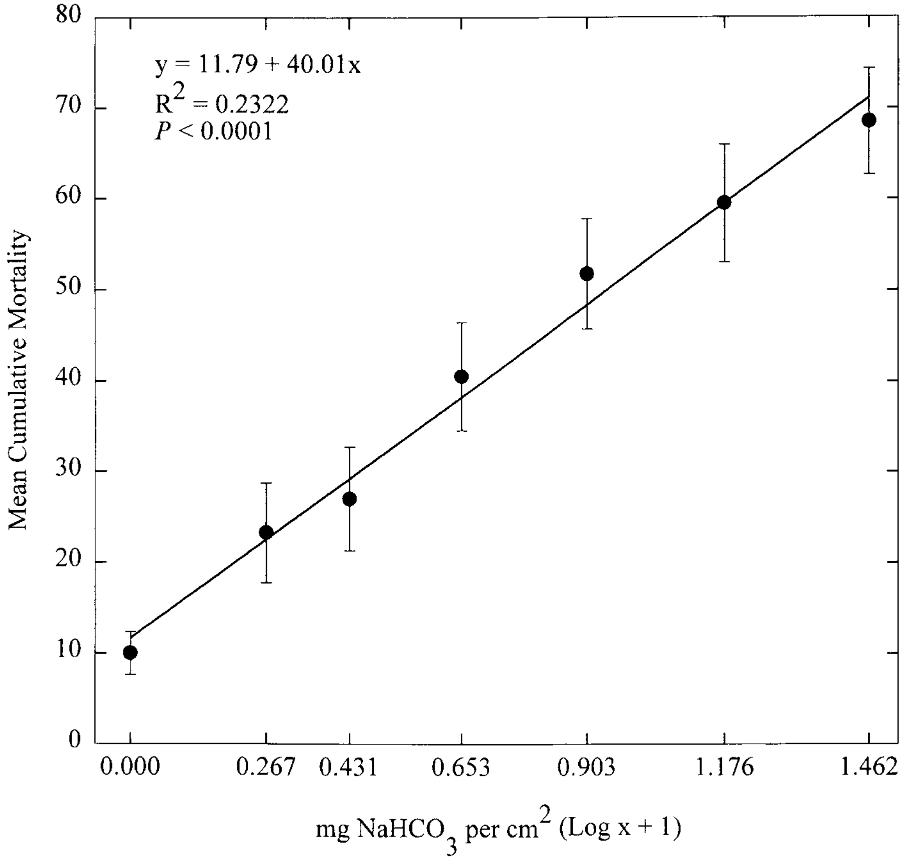

Fig. 2. Linear regression for $NaHCO_3$ concentration effects on *S. invicta* mortality in test cups (Day 7). Vertical lines represent ± SEM. Treatments were an untreated control, 0.85, 1.70, 3.50, 7.00, 14.00 and 28.00 mg $NaHCO_3$ per cm^2. Concentration of $NaHCO_3$ was transformed by log (x + 1) prior to regression analysis and graphing of ant mortality data.

had expired. None of the fire ants immersed in the $NaHCO_3$ solution died during this period. Mortality of ants kept as untreated controls was 3.0%. Mortality for untreated ants did not differ significantly ($F = 1.52$; df = 2,6; $P = 0.2371$) from mortality for ants briefly exposed to $NaHCO_3$ powder or $NaHCO_3$ in solution.

Arena choice tests. When live ant data observed in the large containers and nests were pooled, there was no significant ($F = 1.12$; df = 1,7; $P = 0.3253$) difference between treated and untreated areas of arena sets over the 6 days of the test. On the first and second days following addition of ants to the small containers, only one treated container of one arena set of nine was totally devoid of fire ants. In all of the other arena sets with treated and untreated containers, there was a minimum of three worker ants in the treated container or nest.

Table 2. Concentration-mortality response of *S. invicta* workers to $NaHCO_3$ exposure for 5 to 7 d (n = 400 in each treatment)

Day	LC_{50} (95% CL)*	LC_{95} (95% CL)**	Slope ± SE	χ^2	$P > \chi^2$
5	9.66 (8.21-11.59)	1.15 (0.61-2.61)	0.792 ± 0.052	228.2	0.0001
6	8.16 (7.02-9.61)	0.81 (0.45-1.68)	0.825 ± 0.052	246.8	0.0001
7	7.11 (6.16-8.30)	0.65 (0.38-1.30)	0.839 ± 0.052	255.8	0.0001

* mg per cm^2.
** g per cm^2.

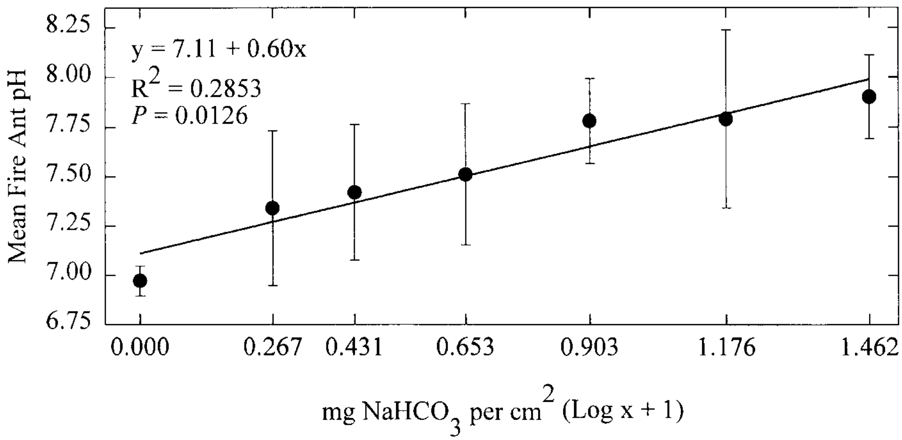

Fig. 3. Linear regression for $NaHCO_3$ concentration effects on whole-body pH of *S. invicta*. Vertical lines represent ± SEM. Treatments were an untreated control, 0.85, 1.70, 3.50, 7.00, 14.00 and 28.00 mg $NaHCO_3$ per cm^2. Concentration of $NaHCO_3$ was transformed by log (x + 1) prior to regression analysis and graphing of ant pH data.

Live ants preferred to reside in nests regardless of treatment, rather than outside nests in large containers, or in the untreated small containers and tubes (Table 3). However, each day there were usually 1 to 3 workers foraging outside nests. The number of workers residing in both treated and untreated areas of arena sets declined over time. Mean number of workers in untreated nests on day 6 was less than half the number residing in those same nests on day 1.

Cumulative fire ant mortality in arena sets in which both containers and respective nests were untreated was significantly ($F = 22.44$; df = 2,5; $P = 0.0001$) lower than for arena sets in which one or both containers plus nests were treated with $NaHCO_3$ (Fig. 4). There was no significant ($P > 0.05$) difference between mean percent mortality for arena sets in which both containers plus nests were treated with $NaHCO_3$ and mortality in arena sets with only one treated container plus nest. Fire ant mortality in arena sets in which both containers plus nests were untreated was 25% at 6 d. Following correction for control mortality (Abbott 1925), fire ant mortality in arena sets in which

Table 3. Comparison of mean number of live *S. invicta* in small containers, artificial nests, and large containers within arena sets in which one large container + nest was treated with $NaHCO_3$. The other large container + nest was untreated. Tubing allowed workers (n = 100) to freely move between containers in an arena set

Day	Small container and hoses	Artificial nests untreated	Artificial nests treated	Large containers untreated	Large containers treated
1	1.44 ± 0.58a	53.00 ± 11.59b	34.11 ± 9.30b	3.22 ± 1.65a	3.44 ± 1.48a
2	1.56 ± 0.75a	38.89 ± 11.72b	24.22 ± 6.89b	3.78 ± 1.45a	2.22 ± 0.88a
3	0.00 ± 0.00a	30.79 ± 11.58b	14.11 ± 3.98a	0.67 ± 0.44a	0.44 ± 0.18a
4	0.00 ± 0.00a	27.89 ± 11.28b	5.78 ± 2.41a	1.33 ± 0.50a	0.33 ± 0.24a
5	0.00 ± 0.00a	17.00 ± 10.07b	11.44 ± 6.56ab	1.00 ± 0.44a	0.33 ± 0.24a
6	0.67 ± 0.24a	21.00 ± 10.05b	2.33 ± 1.24a	0.78 ± 0.32a	0.89 ± 0.54a

Means (±SEM) within rows followed by same letter are not significantly different (LSD, $P > 0.05$).

both containers plus nests were treated with $NaHCO_3$ was 77.78% at 6 d (Fig. 4, non-corrected mortality). Corrected mortality of fire ants in arena sets in which only one of the two containers plus nests was treated with $NaHCO_3$ was 65.04%.

$NaHCO_3$-sugar water tests. Cumulative mortality for fire ants provided untreated sugar water was 3.75% at 10 d and was significantly ($F = 8.98$; df = 6,9; $P = 0.0001$) lower than for the five concentrations of $NaHCO_3$ in sugar water. The highest corrected mortality was 41.82% in the 7.5% $NaHCO_3$-sugar water treatment at 10 d (Table 1, non-corrected mortality). However, this was not significantly ($P > 0.05$) different from ant mortality for three higher concentrations of $NaHCO_3$ in sugar water. Corrected mortality for the three higher concentrations of $NaHCO_3$ in sugar water was 29.87 to 38.70%.

Food choice tests. Cumulative mortality for fire ants provided untreated sugar water was 13% at 6 d and was significantly ($F = 16.00$; df = 2,5; $P = 0.0001$) lower than mortality for ants provided $NaHCO_3$ in sugar water, and for ants that had a choice between feeding on $NaHCO_3$ in sugar water or untreated sugar water. Corrected mortality for fire ants provided sugar water with $NaHCO_3$ was 43% at 6 d and did not differ significantly ($P > 0.05$) from mortality for ants that could feed on $NaHCO_3$ in sugar water or untreated sugar water (Fig. 5, non-corrected mortality). Corrected mortality for ants provided $NaHCO_3$ in sugar water and untreated sugar water was 34% at 6 d.

$NaHCO_3$ on surfaces and in sugar water. Fire ant mortality in untreated arenas was 9% at 6 d and was significantly ($F = 95.86$; df = 1,15; $P = 0.0001$) lower than mortality for arenas with $NaHCO_3$ in sugar water on the bottom surfaces of containers and nests. Corrected fire ant mortality in treated arenas was 78% at 6 d (Fig. 6, non-corrected mortality).

Discussion

The mode of action for $NaHCO_3$ against imported fire ant workers is unclear, but results from the tests in which workers were immersed in $NaHCO_3$ powder or solution

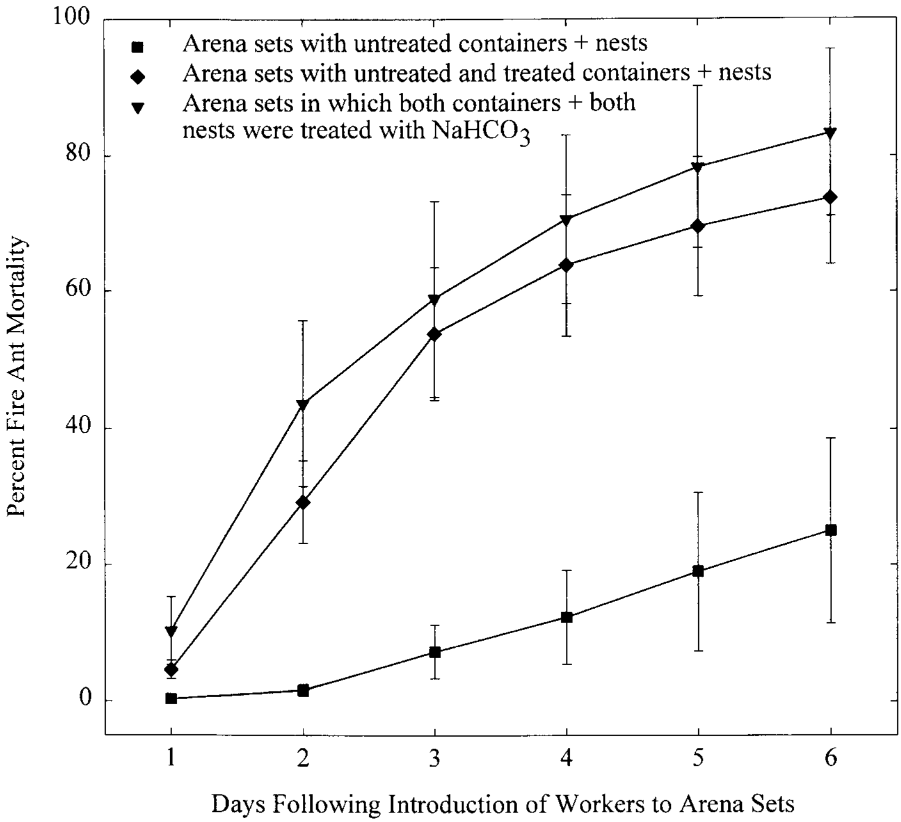

Fig. 4. Percent cumulative mortality of *S. invicta* in treated and untreated arena sets. Ants (n = 100) were added to small containers, and could freely move between containers within arena sets. Large containers in arena sets were both untreated (control), both treated with $NaHCO_3$, or only one was treated with $NaHCO_3$.

containing $NaHCO_3$ suggest that brief exposure to the agent is not sufficient to noticeably impact fire ant health. In bioassays to determine the dose-mortality response of fire ant workers to $NaHCO_3$, the median lethal concentration (LC_{50}) of $NaHCO_3$ decreased as the interval of time from exposure to evaluation increased. Further, fire ant worker mortality increased following 2 to 3 d of exposure to $NaHCO_3$ on surfaces or in baits. Many of the ants surviving exposure to $NaHCO_3$-treated containers were sluggish, but foraging behavior did not totally cease. Some ants were motionless and appeared to be dead, but would move appendages after being prodded with forceps. These ants usually expired within 24 h.

These results are similar to those of Arthur (2000) in his study of red flour beetle, *Tribolium castaneum* (Herbst), and confused flour beetle, *T. confusum* (DuVal), responses to diatomaceous earth exposure interval. Carlson and Ball (1962) attributed the efficacy of diatomaceous earth against stored-grain insect pests to the action of

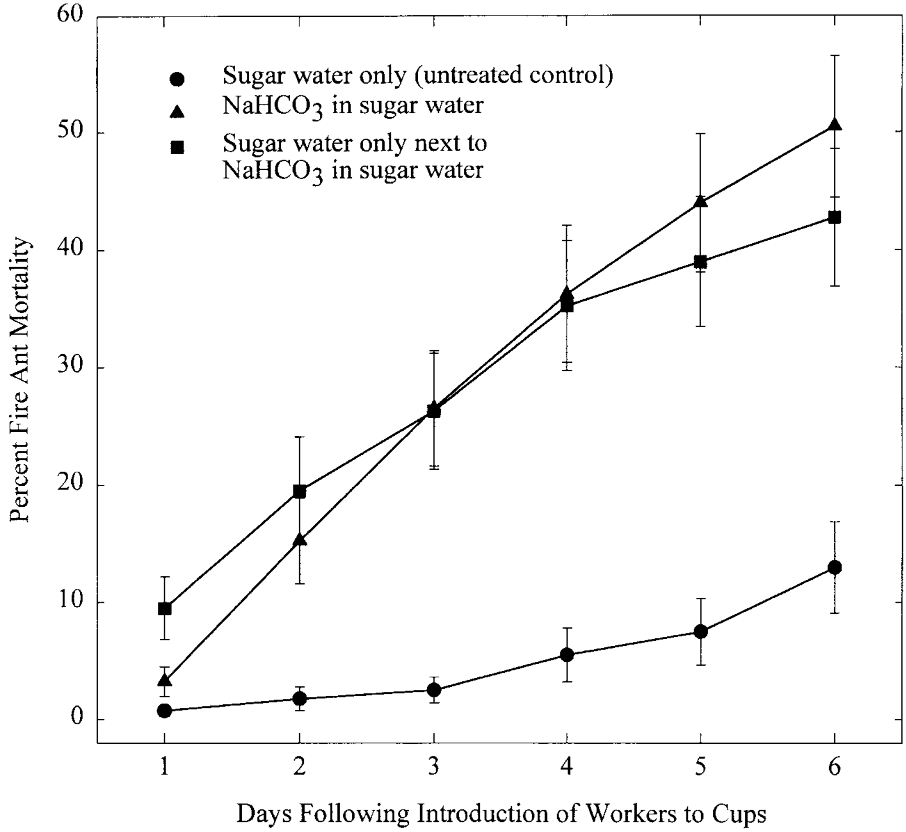

Fig. 5. Percent cumulative mortality of *S. invicta* provided untreated sugar water (control), $NaHCO_3$ in sugar water, or untreated sugar water in a container next to a container with $NaHCO_3$ in sugar water.

desiccation and abrasion, but it is not known whether those factors caused fire ant mortality in our study. In fact, Brinkman and Gardner (2001) observed only 29% mortality of fire ant workers exposed to diatomaceous earth for 10 d. Stimac et al. (1993) observed almost twice this level of fire ant mortality after 22 to 30 d of exposure to diatomaceous earth. Interestingly, Stringer et al. (1964) described a method of using talc to prevent escape of fire ants from containers and warned against using too much because "ants are easily killed by it, especially in the absence of moisture or if they are in a weakened condition." However, they did not elaborate on the possible reasons for the activity of talc against fire ants. Boric acid has been tested against *S. invicta* (Klotz et al. 1997); its mode of action is not fully understood (Klotz et al. 2002). A liquid bait containing boric acid increased passage of liquid feces by the Florida carpenter ant, *Camponotus abdominalis floridanus* (Buckley); foragers also spent more time at these baits than at others not containing boric acid (Klotz and Moss 1996). They concluded that carpenter ants that had imbibed the boric acid bait were

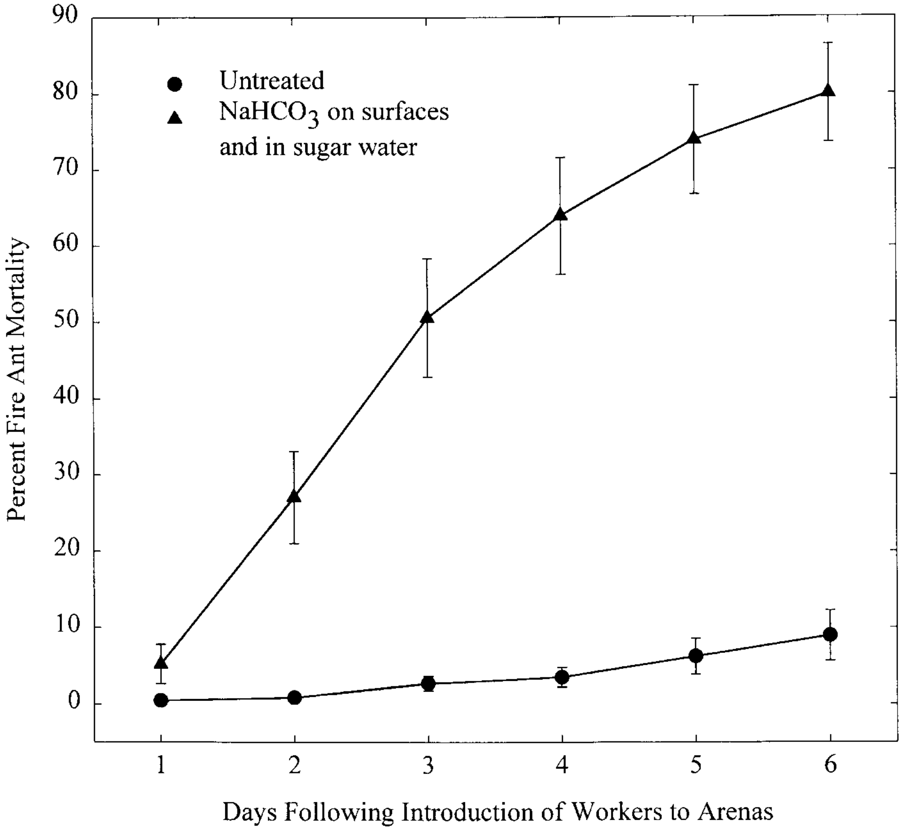

Fig. 6. Percent cumulative mortality of *S. invicta* in untreated arenas (control), and exposed to $NaHCO_3$ in arenas, artificial nests, and in sugar water.

dehydrated from disruption of water regulation. Klotz et al. (2002) found extensive damage to cells and microvilli of the midguts of Argentine ants, *Linepithema humile* (Mayr), following consumption of boric acid.

Although workers could avoid dishes and nests containing $NaHCO_3$ in our study, they freely colonized treated nests and were observed foraging in treated containers. This suggests that $NaHCO_3$ is not repellent (Dethier et al. 1960) to *S. invicta*. There may have been some degree of preference for untreated nests; however, the reduced presence of live ants in treated nests was more likely due to mortality caused by treatments rather than potential repellency of $NaHCO_3$. Mortality was relatively high in arena choice tests even though the concentration of $NaHCO_3$ was 64% less than the highest concentration tested in the LC_{50} bioassays. Ants in LC_{50} bioassay cups had no choice in avoiding treated areas. The higher mortality in the arena choice tests than in the LC_{50} bioassays could be attributed to the larger-sized containers used for the choice tests. Perhaps this larger foraging area allowed for more foraging activity, resulting in increased exposure to $NaHCO_3$. In dose-mortality bioassays, fire ants were agitated for about 30 min following introduction to a cup. Activity soon declined, and workers would congregate in stationary groups. In arena choice tests, workers also would aggregate in groups in the artificial nests, but much more foraging was observed in the large containers, whether treated or untreated, than that observed in the bioassay cups.

A range of concentrations of $NaHCO_3$ mixed in sugar water was tested, yet the greatest mortality was observed in the 7.5% $NaHCO_3$-sugar water treatment. A concentration-dependent relationship did not occur beyond this level because the solubility of $NaHCO_3$ in water is 10 g per 100 ml at 25°C. Thus, in higher concentrations, excess $NaHCO_3$ settles out of solution and is not available for ant consumption. While direct observations of ant feeding were not made, mortality of ants provided a choice between sugar water without $NaHCO_3$ and sugar water containing $NaHCO_3$ was higher than for ants provided only sugar water. These results suggest that ants were not deterred (Dethier et al. 1960) by $NaHCO_3$ in sugar water and were killed following ingestion. Results from tests in which a range of concentrations of $NaHCO_3$ was mixed with sugar water further support nonrepellency of $NaHCO_3$. These tests were conducted with 10 ants per cup with adequate food available for each ant. In the $NaHCO_3$-sugar water tests and food choice tests, maximum corrected mortality was 43%. It is not known if higher mortality levels could be achieved by using $NaHCO_3$ in a different carrier. However, honeydew, nectar, and plant sap are natural liquid foods for *S. invicta* (Tennant and Porter 1991); sucrose is a major constituent of each. Additionally, sugar water has been used as a bait carrier for boric acid against fire ants (Klotz et al. 1997) and Argentine ants (Klotz et al. 2002). If $NaHCO_3$ can be distributed by trophallaxis throughout an ant colony before causing mortality, it may be useful as an active ingredient in an ant baiting control strategy (Klotz et al. 1997). In the tests in which fire ants were exposed to $NaHCO_3$ on surfaces and in sugar water at the same time, there was relatively high mortality, but this mortality was similar to that observed in the arena choice tests in which both containers were treated with $NaHCO_3$. We saw no advantage to combining surface treatments of $NaHCO_3$ and mixing $NaHCO_3$ in sugar water food over simply treating surfaces with $NaHCO_3$.

Organisms occupy habitats over a wide pH range, but intracellular pH usually approaches neutrality (pH 7) (Brock 1979). Consoli and Vinson (2002) found the pH of fire ant hemolymph to range from 6.40 to 7.01, depending on gender and stage of development. In our study, the whole-body pH of untreated workers fell within that range. Worker pH became more basic with exposure to increasing levels of $NaHCO_3$, suggesting that $NaHCO_3$ was incorporated into the fire ant body. Ants frequently clean appendages; this behavior may have facilitated *per os* entry of $NaHCO_3$. Sodium hydrogen carbonate contributes OH^- to solution; large amounts would increase internal pH (Tortora and Grabowski 1996). There was nearly a 10-fold difference in H^+ between untreated ants and those exposed to the highest concentration of $NaHCO_3$. Corral et al. (1988) and Horst et al. (1992) attributed the antimicrobial activity of $NaHCO_3$ to bicarbonate ions and elevation in pH. Changes in pH can modify the structure of enzymes, and strongly alkaline solutions can denature enzymes (Conn and Stumpf 1976). Additionally, the pH range in which enzymes exhibit maximum activity is narrow (Chapman 1982), and departure from narrow limits of normal H^+ and OH^- concentrations disrupts body functions (Stryer 1995, Tortora and Grabowski 1996). Because fire ant pH increased with concentration of $NaHCO_3$, enzymatic dysfunction is the most plausible explanation for the majority of the fire ant deaths observed in this study.

Based upon these results, sodium hydrogen carbonate shows promise as a method for killing fire ants. Although fire ants are not repelled by $NaHCO_3$, potential exists for use of $NaHCO_3$ in electric utility boxes to prevent colonization by fire ants. Our results suggest that it may take less than 113 g of $NaHCO_3$ to treat the floor of a 7,871 cm^2 electrical utility box at a cost of $0.16.

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