Water Solutions of Boric Acid and Sugar for Management of German Cockroach Populations in Livestock Production Systems

J. CHAD GORE, LUDEK ZUREK,[1] RICHARD G. SANTANGELO, S. MICHAEL STRINGHAM, D. WES WATSON, AND COBY SCHAL[2]

Department of Entomology, North Carolina State University, Raleigh, NC 27695–7613

J. Econ. Entomol. 97(2): 715–720 (2004)

ABSTRACT Pest management in confinement swine production relies primarily on calendar-based applications of broad-spectrum insecticides. However, regulatory restrictions imposed by the U.S. Food Quality Protection Act of 1996, the large financial obligation of pesticide registration, and development of insecticide resistance have led to a renewed search for alternative control methods. Boric acid dust has long served as an insecticide in urban pest management and has been shown an effective alternative for use in sensitive environments such as swine production. However, dust formulations are difficult to apply and require specialized equipment. The purpose of this study was to evaluate the efficacy of liquid baits containing boric acid for the control of German cockroaches in a commercial swine nursery. Bait, consisting of 1 or 2% boric acid and 0.5 M sucrose, was deployed in 21 bait delivery tubes per room. Results of a 2-yr study showed significant reductions in cockroach populations. When baits were withdrawn in the summer, the cockroach population increased significantly faster than when the baits were removed during the winter. These data indicate that liquid formulations of boric acid effectively reduce the burden of cockroach infestation in swine production. This approach should have applications in structures in other urban and agricultural environments.

KEY WORDS German cockroach, boric acid, insecticide bait, swine production, integrated pest management

IN THE LAST TWO DECADES, traditional pork production has given way to a confinement rearing system in which lactating sows are housed with piglets in individual pens within enclosed, temperature-controlled farrowing rooms. Older piglets are likewise housed in groups in temperature-controlled nurseries. This "urbanization" of swine farming in roughly constructed structures has also led to the appearance and intensification of traditional urban pest problems typically associated with structures. The German cockroach, *Blattella germanica* (L.), is a synanthropic pest clearly recognized as medically and economically important (Schal and Hamilton 1990, Brenner 1995, Rosenstreich et al. 1997), and substantial effort is being expended on developing tactics to mitigate its harmful effects (Arbes et al. 2003, 2004). German cockroaches are intimately associated with swine and have been observed at night on pig manure, feed, and on the animals (Waldvogel et al. 1999). Although cockroaches have not been directly associated with transmission of swine diseases, the potential for such a case certainly exists.

Several features of the swine production system—many of which are integral components of production practices—are highly favorable to the growth of pest populations. Farrowing barns (for birthing and lactation) and nurseries are maintained at relatively high temperatures (≈30°C). Hog feed is always present and serves as an excellent source of nutrients not only for swine but also for insect pests. Drinking spouts and sprinklers that keep sows cool and frequent flushing of the under-floor pits and gutters provide ample water for pests. Furthermore, the roughly constructed buildings provide excellent pest refugia within the walls and other voids. As a result, German cockroach infestations have become a serious problem for swine farms.

Swine are a major agricultural commodity in North Carolina; the 10 million hogs represent more than $1 billion. As in many swine facilities in the United States, North Carolina growers rely largely upon broadcast, calendar-based applications of broad-spectrum synthetic organic insecticides, primarily organophosphates and pyrethroids, for pest management. Such frequent application regimes can lead to the development of insecticide resistance and failure of chemical control measures (Cochran 1995). Furthermore, frequent applications of insecticides may pose an undue health risk to workers, animals, and the consumer, as well as the environment. Regulatory

[1] Current address: Department of Entomology, 123 West Waters Hall, Kansas Sate University, Manhattan, KS 66506–4004.

[2] Corresponding author. E-mail: coby_schal@ncsu.edu.

restrictions imposed by the U.S. Food Quality Protection Act of 1996 and the great financial burden required for registration of insecticides has limited the availability of effective pesticides and their labeling for this environment. Therefore, alternative approaches to calendar-based applications of neurotoxic insecticides, as well as safe, effective, and environmentally sound integrated pest management (IPM) strategies are needed. Waldvogel et al. (1999) showed that proper targeting of pest refugia with a single "clean-out" treatment of cyfluthrin, instead of every 3 wk at the end of each production cycle, could provide significant population reduction and at least 3 mo of residual activity; this would reduce the amount of active ingredient by 98.9%, from 34 kg (AI) to 0.36 kg per farm per year. More "environmentally benign" baits (Maxforce and Avert) provided little long-term control, and their applications were much more labor-intensive and costly.

Boric acid (H_2BO_3) dust, a nonvolatile, slow-acting inorganic insecticide, has long been used in cockroach management (Ebeling 1995). It has a favorable safety profile with negligible absorption through unbroken skin (Pfeiffer 1951, Valdes-Dupena and Arey 1962, Fail et al. 1998). We have recently shown that boric acid dust can be used as an effective alternative to cyfluthrin for the management of German cockroach infestations in farrowing rooms (Zurek et al. 2003). Nevertheless, dust formulations are difficult to apply, require specialized equipment and can only be applied when pigs are removed from the room at the end of each production cycle. Liquid formulations of boric acid have previously been shown effective against other insect pests (Klotz and Moss 1996; Klotz et al. 1997a,b, 1998) and our recent laboratory evaluations of three borates and various sugars in liquid baits have shown potential for control of German cockroaches (Gore and Schal 2004). Water solutions of the disaccharides maltose and sucrose at 0.01–0.5 M and 0.5 or 1.0% boric acid provided the best results.

In this study, we evaluate the efficacy of water solutions containing boric acid and sucrose as bait against German cockroaches in a commercial swine nursery in eastern North Carolina.

Materials and Methods

Farm. Trials were conducted in the nursery of a commercial farm located in Duplin County, North Carolina. The nursery consisted of four 37.9-m^2 rooms, housing ≈80 piglets. Each room was on a 6-week production cycle at the end of which it was vacated, washed at high pressure, and disinfected before being repopulated with a new lot of piglets.

Monitoring. A 7-person-min (i.e., 7 min by one observer, 3.5 min by each of two observers) visual inspection of the perimeter of each room was used for cockroach monitoring. Monitoring was consistently conducted by the same personnel and involved daytime counting of all visible cockroaches along the walls and within cracks and crevices with the aid of a flashlight and a mechanical counter. Individual cockroaches were counted when numbers were low, but in heavily infested rooms cockroaches were counted by fifties. Our previous research (unpublished data) has shown a close correlation between visual counts and overnight trap catches. These counts represented relative measures of population size and they were conducted immediately before treatments and again each time bait stations were refilled.

Treatments. Bait dispensers were constructed from 30 by 3.12-cm-o.d. thin-walled polyvinyl chloride (PVC) tubes connected with two PVC Ell (L) connectors to form a U-shaped feeder (Fig. 1A). A rubber stopper (#8, Fisher Scientific, Pittsburgh, PA) was fitted at the top end of the long tube, and a cotton plug at the other end served as a drinking surface for cockroaches (Fig. 1B). Each bait tube was filled with ≈500 ml of fresh bait solution of 1 or 2% boric acid and 0.5 M sucrose and changed every 2–3 wk. Twenty-one baits were placed in each of the four rooms; four vertically oriented dispensers per corner, one vertically oriented dispenser on each of two sidewalls, one vertically oriented dispenser on each of two door frames, and one horizontally oriented on the upper frame of an outward swinging door. Bait placement was based upon locations of cockroach aggregations and where baits were inaccessible to piglets.

Because of concerns about disease transmission and other biosecurity issues, this research was restricted to a single farm. However, modern confinement swine production farms are extremely similar in design and production practices. Treatments were replicated over time by sequentially imposing a pesticide treatment and then removing the treatment to allow the pest population to increase. Each of the four rooms in the nursery represented a replicate.

Data Analysis. To compare the results of different trials in the presence of the baits, cockroach counts were converted to percentages of the pretreatment (day 0) counts and analyzed by repeated-measures analysis of variance (ANOVA) (PROC GLM) in SAS 8.2 (SAS Institute 2001). To compare the increase in the cockroach population after baits were removed in three trials, cockroach counts at each census were square root-transformed and analyzed by repeated-measures ANOVA. Comparisons of means were conducted with Tukey's studentized range test ($\alpha = 0.05$).

Results

Interviews with farmworkers indicated that they were most bothered when the infestation corresponded to counts >1,000 cockroaches per room in farrowing barns (unpublished data). Based upon this census, a count of 1000 cockroaches per room was used as the treatment threshold. Nursery rooms are considerably smaller than farrowing rooms, but in each case, we began our studies with populations that substantially exceeded this threshold.

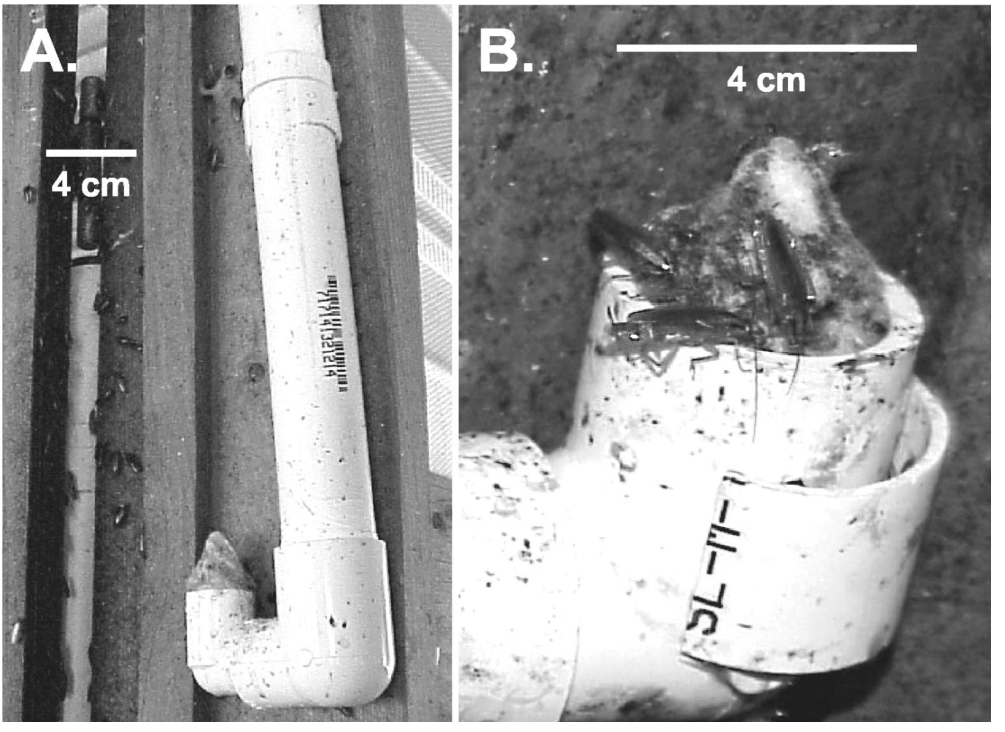

Fig. 1. Bait dispenser for delivery of the boric acid-sucrose solution to cockroaches. (A) A bait dispenser positioned on a door frame. (B) German cockroaches feeding from the cotton plug on a bait dispenser.

In the first trial, baits containing 1% boric acid and 0.5 M sucrose were introduced in the summer, when counts averaged 3,625 cockroaches per room, and remained deployed for 62 d (Fig. 2A). Cockroach counts were significantly reduced by 69 ± 17% (SEM) (Tukey's test, df = 30, $P < 0.05$) within 20 d of introducing the baits to the four rooms of the nursery and subsequently remained below the threshold while the baits were present. Sixty-two days after the start of the first trial, when baits were removed from the nursery, cockroach counts had been reduced by 94 ± 3%. However, 43 d after the baits were removed cockroach counts significantly increased to 2,150 ± 480 per room, or 29 ± 17-fold (Tukey's test, df = 30, $P < 0.05$) relative to the counts on day 62 (Fig. 2A). Furthermore, the cockroach counts on day 105 also correspond to a return to levels not significantly different from those at day 0.

The second trial, with the same boric acid-sucrose bait solution, began in October and immediately followed the first trial when mean cockroach counts per room were 3,225. As in the first trial, a significant decline in cockroach counts was evident 26 d after bait application (71 ± 12%; Tukey's test, df = 42, $P < 0.05$); counts remained below the threshold while baits were in place (Fig. 2B). The bait dispensers were removed in late December (70 d after their first introduction), when cockroach counts had been reduced by 90 ± 2%, to 330 cockroaches. Counts slowly increased after bait removal, but only by 10 ± 2.9-fold through the winter. It took 144 d after the baits were removed before cockroach counts were significantly greater than the counts on day 70 (Tukey's test, df = 42, $P < 0.05$). Nonetheless, only 98 d after bait removal, cockroach counts had increased to a level not significantly different from the pretreatment (day 0) counts.

A comparison of these two trials showed a significant effect of the bait over time ($F_{1,39} = 16.01$; $P = 0.0004$). The declines in cockroach counts in the two trials relative to the respective pretreatment counts were not significantly different from each other (Fig. 2A and B).

The third trial began in mid-June with a cockroach count of ≈2,300 per room. We doubled the boric acid concentration to 2% in an effort to induce faster declines in the cockroach population, and the baits were left in place for ≈10 mo to evaluate their long-term efficacy. Although the visual counts declined below threshold (62 ± 21.1%) within 42 d after the baits were installed (Fig. 2C), the rate of this decline was not significantly different from the first two trials despite doubling of active ingredient. During the 10-mo evaluation the cockroach counts were reduced by 90–99%, and maintained well below the threshold level of 1000 cockroaches per room. Baits were removed in April, 307 d after the start of trial 3, because cockroach counts stabilized at a low level. A significant increase of 53 ± 17-fold (Tukey's test, df = 54, $P < 0.05$) in cockroach counts was first evident 113 d after baits were withdrawn, at which time the counts were not different from the pretreatment counts.

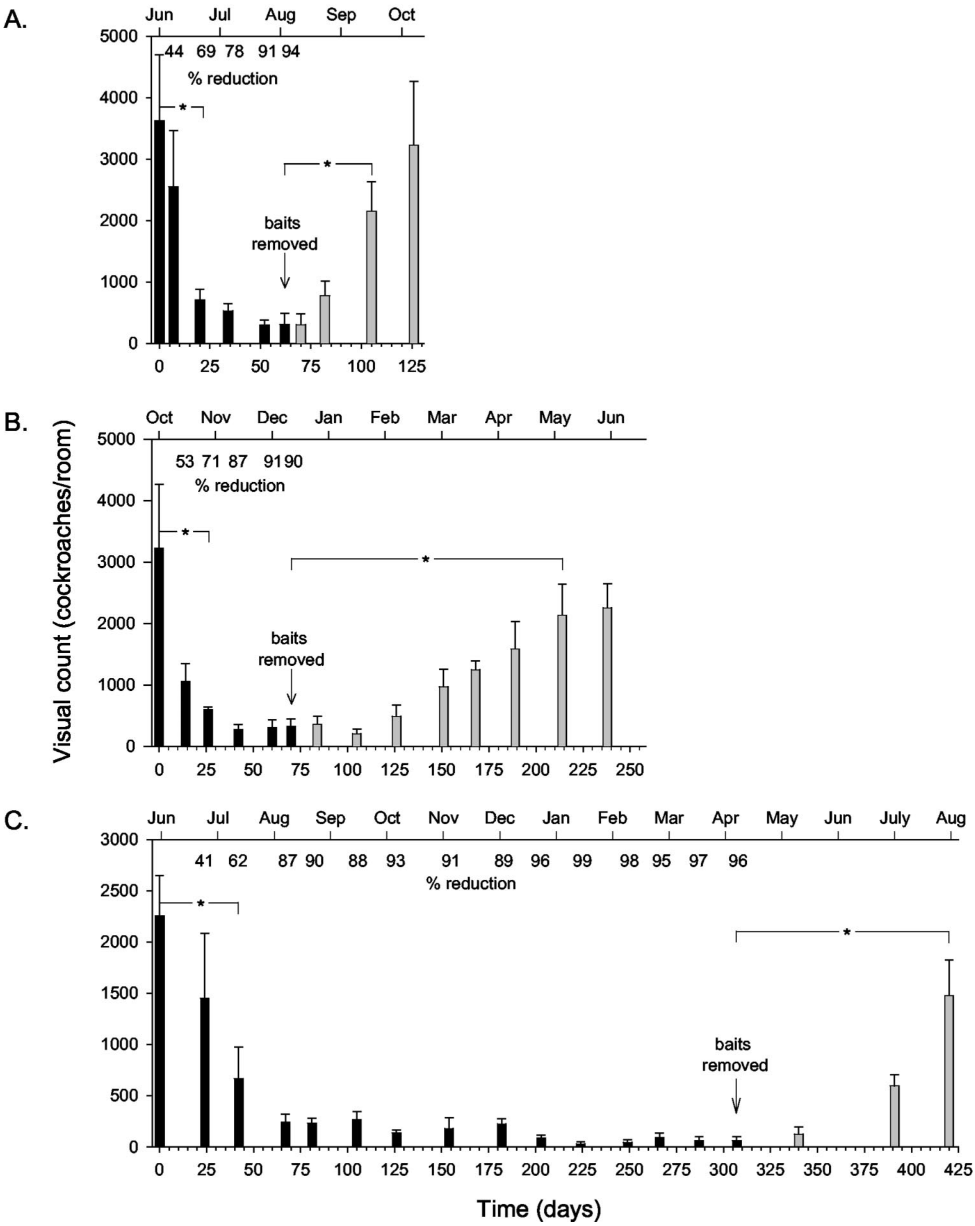

Fig. 2. Three trials documenting the efficacy of boric acid-sucrose solutions on cockroach populations in four nursery rooms of a confinement swine farm. (A) Trial 1 from summer to fall (126 d). (B) Trial 2 from fall to summer (238 d). (C) Trial 3 from summer to summer (420 d). Each trial was initiated immediately after the conclusion of the previous trial. Bait for trials one and two consisted of 1% boric acid and 0.5 M sucrose; 2% boric acid and 0.5 M sucrose was used for trial 3. Baits were deployed on day 0 and replenished every 2–3 wk. The baits were removed after 62, 70, or 307 d, respectively, and growth of the cockroach population was monitored for several months. Percentage reduction is the mean of four rooms, calculated for each visual count relative to the respective day 0 count. The first * in each trial represents the first occurrence of a significant decrease in cockroach counts relative to introduction of baits (day 0), whereas the second * represents the first occurrence of a significant increase in cockroach counts relative to the day when baits were removed. Error bars represent SEM.

A comparison of the three trials after the removal of the baits showed a significant effect of trial ($F_{2,67} = 6.13$; $P = 0.0354$) and time after baits were removed ($F_{1,67} = 133.11$; $P < 0.0001$), indicating a seasonal effect upon the return of suppressed populations to the respective pretreatment levels.

Discussion

Boric acid is an inexpensive inorganic insecticide with a favorable safety record and no known cases of resistance in arthropods. Various boric acid formulations have been used for more than a century for effective management of German cockroach infestations (Ebeling 1995). However, its use has declined in the last several decades primarily because much faster acting organic insecticides are preferred by consumers and pest management professionals.

Nonetheless, the insecticidal and toxicological profiles of boric acid are highly favorable in the agricultural structural environment because its slow insecticidal activity is not a major constraint, numerous wall voids can be treated, unsightly dust formulations are more tolerated, and dusting can be integrated into the animal production schedule. Indeed, the efficacy of boric acid dust is comparable with that of residual pyrethroid formulations in highly infested confinement livestock production barns (Zurek et al. 2003). But use of the dust formulation is limited by certain technical, managerial, and health constraints. For example, insecticide applications occur shortly after a thorough high-pressure washing of farrowing or nursery rooms, and the bioavailability of the dust would be reduced on wet surfaces. Also, whereas farrowing cycles are short (≈22 d), nursery cycles last up to 45 d, during which dust cannot be used around the piglets. It was therefore necessary to consider alternative boric acid formulations.

Recently, laboratory studies showed that boric acid, admixed with sugar and water as a liquid bait, effectively killed cockroaches (Gore and Schal 2004). Dose-mortality studies with three borates and various sugars indicated that 0.5–2% boric acid and 0.5 M sucrose resulted in the fastest kill under rigorous conditions where cockroaches had access to clean water and food. Ready availability of both bait ingredients and likely acceptance of this approach by growers prompted us to test this concept under field conditions.

The results of the present 2-yr study in a swine nursery corroborated the laboratory results. Cockroach populations in the nursery were significantly reduced by >90% within 1–2 mo (i.e., within one production cycle) and maintained below threshold levels as long as the baits were deployed (Fig. 2). However, the initial declines in visual counts were more variable than in farrowing rooms after either boric acid dust or cyfluthrin treatments (Zurek et al. 2003). This is likely attributable to physical and cultural differences between the farrowing and nursery rooms. When a nursery room reaches the end of its production cycle, approximately every 6 wk, it is vacated and disinfected. This disturbance can cause cockroaches to redistribute to adjacent rooms through loosely constructed walls with large voids, open flooring, and an attic. With no residual insecticides to intercept the moving cockroaches, this redistribution can result in transient increases and decreases in the visual counts. Overall, however, it is clear that multiple placements of water-based baits containing boric acid and sucrose were highly effective in the field, as they were in the laboratory.

This study reveals interesting comparisons between summer and winter pest populations. Lower winter temperatures in some sections of the nursery cause cockroaches to aggregate in fewer favorable areas that are relatively accessible and easy to target with baits. Surprisingly, however, the rate of decline of the cockroach population was similar in summer and winter (Fig. 2A and B), suggesting that proper placement of multiple bait dispensers can effectively target even highly scattered and rapidly reproducing cockroaches in summer. However, the increase in the cockroach population after removal of the boric acid baits was much faster in summer (Fig. 2A and C) than in winter (Fig. 2B). This most likely resulted from cooler winter temperatures that slowed cockroach development within refugia, despite the warm ≈30°C ambient temperature near the piglets. A similar trend was observed in a comparison of cyfluthrin sprays and boric acid dust treatments (Zurek et al. 2003). These results indicate that removal of the baits, as is sometime necessary for farm maintenance, would be least disruptive to pest management if done in winter.

Doubling the boric acid concentration to 2% failed to accelerate the rate of decline of the pest population (Fig. 2C). This confirms laboratory findings that at moderate molar concentrations of sugar (0.1–0.5 M) no significant differences were observed between 1 and 2% boric acid solutions. Moreover, at high sugar concentrations, boric acid tends to precipitate out of the sugar solution, and it may physically interfere with cockroaches feeding on the bait. Similar laboratory results have been shown with house flies; ≥2.25% boric acid mixed with sucrose became repellent and increasingly less efficient (Hogsette and Koehler 1994). Nonetheless, our laboratory results indicated no repellent activity with 2.0% boric acid in a 0.5 M sucrose solution. In the end, low levels of boric acid in liquid baits make this a low cost and environmentally benign approach compared even with solid baits of boric acid, which usually contain 30–50% (AI) (Appel 1990, 1992; Waldvogel et al. 1999).

The third trial also documented that when the baits were deployed continuously for ≈10 mo the cockroach counts in the nursery declined by 90–99% and were maintained well below the threshold level for 9 of the 10 mo (Fig. 2C). Although some aggregations of cockroaches are difficult to target with this approach (e.g., within metal crates, feeders, under the slotted floor), this relatively low-cost and low-input pest management tactic clearly reduced the overall pest population. Moreover, similar mixtures kill house flies in the laboratory (Hogsette and Koehler 1994), and flies were routinely observed to feed upon the sugar-based liquid baits. This has important implications to farm biosecurity, prevention of disease transmission, and dramatic reductions in worker exposure to cockroaches and possibly flies.

A similar approach needs to be tested against German cockroaches in residential and other structural environments. Solid bait formulations of boric acid have generally been less effective than similar formulations of other insecticides, such as hydramethylnon (Appel 1990, 1992). However, because gels tend to outperform solid formulations, it is likely that water is a major limiting resource for pest cockroaches and that water-based formulations may more effectively target cockroaches. Aqueous solutions of boric acid have been shown to be effective against other structural pests, including *Monomorium pharaonis* (L.) (Klotz et al. 1997a), *Linepithema humile* (Mayr) (Klotz et al. 1996, 1998), *Camponotus abdominalis floridanus* (Buckley) (Klotz and Moss 1996), and *Solenopsis invicta* Buren (Klotz et al. 1997b).

Acknowledgments

We thank workers and management of a commercial farm (Smithfield Foods) for assistance and access to facilities. We also thank C. Brownie for statistical guidance. This study was supported by grants from USDA–PMAP (9804680), and USDA–SRIPM (2001-34103–10533), Urban Entomology scholarships from the North Carolina Pest Control Association and Pi Chi Omega to J.C.G., and the Blanton J. Whitmire Endowment at North Carolina State University.

References Cited

Appel, A. G. 1990. Laboratory and field performance of consumer bait products for German cockroach (Dictyoptera: Blattellidae) control. J. Econ. Entomol. 83: 153–159.

Appel, A. G. 1992. Performance of gel and paste bait products for German cockroach (Dictyoptera: Blattellidae) control: laboratory and field studies. J. Econ. Entomol. 1176–1183.

Arbes, Jr., S. J., M. Sever, J. Archer, E. H. Long, J. C. Gore, C. Schal, M. Walter, B. Nuebler, B. Vaughn, H. Mitchell, et al. 2003. Abatement of cockroach allergen (Bla g 1) in low-income, urban housing – a randomized controlled trial. J. Allergy Clin. Immunol. 112: 339–345.

Arbes, Jr., S. J., M. Sever, J. Mehta, J. C. Gore, C. Schal, B. Vaughn, H. Mitchell, and D. C. Zeldin. 2004. Abatement of cockroach allergens (Bla g 1 and Bla g 2) in low-income, urban housing: Month 12 continuation results. J. Allergy Clin. Immunol. 113: 109–114.

Brenner, R. J. 1995. Economics and medical importance of German cockroaches, pp. 77–92. *In* M. K. Rust, J. M. Owens, and D. A. Reierson [eds.], Understanding and controlling the German cockroach. Oxford University Press, New York.

Cochran, D. G. 1995. Insecticide resistance. *In* M. K. Rust, J. M. Owens, and D. A. Reierson [eds.], Understanding and controlling the German cockroach. Oxford University Press, New York.

Ebeling, W. 1995. Inorganic insecticides and dusts, pp. 193–230. *In* M. K. Rust, J. M. Owens, and D. A. Reierson [eds.], Understanding and controlling the German cockroach. Oxford University Press, New York.

Fail, P. A., R. E. Chapin, C. J. Price, and J. J. Heindel. 1998. General, reproductive, developmental, and endocrine toxicity of boronated compounds. Reprod. Toxicol. 12: 1–18.

Gore, J. C., and C. Schal. 2004. Laboratory evaluation of boric acid-sugar solutions as baits for management of German cockroach infestations. J. Econ. Entomol. 97: 581–587.

Hogsette, J. A., and P. G. Koehler. 1994. Repellency of aqueous solutions of boric acid and polybor 3 to house flies (Diptera: Muscidae). J. Econ. Entomol. 87: 1033–1037.

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

Klotz, J. H., and J. I. Moss. 1996. Oral toxicity of a boric acid-sucrose water bait to Florida carpenter ants (Hymenoptera: Formicidae). J. Entomol. Sci. 31: 9–12.

Klotz, J. H., D. H. Oi, K. M. Vail, and D. F. Williams. 1996. Laboratory evaluation of a boric acid liquid bait on colonies of *Tapinoma melanocephalum* Argentine ants and Pharaoh ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89: 673–677.

Klotz, J. H., K. M. Vail, and D. F. Williams. 1997a. Liquid boric acid baits for control of structural infestations of Pharaoh ants (Hymenoptera: Formicidae). J. Econ. Entomol. 90: 523–526.

Klotz, J. H., K. M. Vail, and D. F. Williams. 1997b. Toxicity of a boric acid-sucrose water bait to *Solenopsis invicta* (Hymenoptera: Formicidae). J. Econ. Entomol. 90: 488–491.

Pfeiffer, C. C. 1951. Is boric acid harmless? Modern Hospital 74: 106–142.

Rosenstreich, D. L., P. Eggleston, M. Kattan, D. Baker, R. G. Slavin, P. Gergen, H. Mitchell, K. McNiff-Mortimer, H. Lynn, D. Ownloy, et al. 1997. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N. Engl. J. Med. 336: 1356–1363.

SAS Institute 2001. SAS/STAT user's guide, version 8.2, Cary, NC.

Schal, C., and R. L. Hamilton. 1990. Integrated suppression of synanthropic cockroaches. Annu. Rev. Entomol. 35: 521–551.

Valdes-Dupena, M. A., and J. D. Arey. 1962. Boric acid poisonings. J. Pediat. 61: 531–546.

Waldvogel, M. G., C. B. Moore, G. W. Nalyanya, S. M. Stringham, D. W. Watson, and C. Schal. 1999. Integrated cockroach (Dictyoptera: Blattellidae) management in confined swine production, pp. 183–188. *In* W. H. Robinson, F. Rettich, and G. W. Rambo, [eds.], Proceedings of the 3rd International Conference of Urban Pests, Graficke Zavody Hronov, Prague, Czech Republic.

Zurek, L., J. C. Gore, M. S. Stringham, D. W. Watson, M. G. Waldvogel, and C. Schal. 2003. Boric acid dust as a component of an integrated cockroach management program in confined swine production. J. Econ. Entomol. 96: 1362–1366.

Received for publication 3 September 2003; accepted 10 October 2003.