Authorized Reprint from
Special Technical Testing Publication 875
Copyright
American Society for Testing and Materials
1916 Race Street, Philadelphia, PA 19103
1985

W. A. Banks,[1] *C. S. Lofgren,*[1] *and D. F. Williams*[1]

Development of Toxic Baits for Control of Imported Fire Ants

REFERENCE: Banks, W. A., Lofgren, C. S., and Williams, D. F., "**Development of Toxic Baits for Control of Imported Fire Ants,**" *Pesticide Formulations and Application Systems: Fourth Symposium, ASTM STP 875,* T. M. Kaneko and L. D. Spicer, Eds., American Society for Testing and Materials, Philadelphia, 1985, pp. 133-143.

ABSTRACT: Toxic baits for control of the red and black imported fire ants, *Solenopsis invicta* Buren and *S. richteri* Forel, respectively, were developed by incorporating an effective toxicant into a liquid food material and absorbing this into a granular carrier for distribution in the field. Screening tests with worker ants and laboratory colonies showed that of more than 4400 chemicals tested only three primary toxicants and four insect growth regulators demonstrated promise for control of field populations of the fire ants. Effective bait formulations that gave good control of the ants were produced by incorporating the amidinohydrazone toxicant, AC-217300, or the insect growth regulator, Prodrone, into soybean oil and impregnating the oil solution onto pregel defatted corn grits.

KEY WORDS: imported fire ant, *Solenopsis invicta*, *Solenopsis richteri*, toxic baits, chemical control, formulations, toxicants, granular carriers, food attractants

The red imported fire ant, *Solenopsis invicta* Buren, and the black imported fire ant, *Solenopsis richteri* Forel, were accidentally introduced into the United States at Mobile, Alabama, approximately 45 and 65 years ago, respectively. Through natural flights and inadvertent transport by man the ants, from this point of entry, have infested about 100 million hectares of land in nine southern states and Puerto Rico. Public demand for relief from the stinging and mound-building habits of the ants prompted the U.S. Congress in 1957 to appropriate funds and authorize the U.S. Department of Agriculture (USDA) to cooperate with the affected states in efforts to control them. Chemical control was begun in the fall of 1957 with large-area applications of the residual chlorinated hydrocarbons heptachlor and dieldrin. A research and methods development laboratory to improve existing or develop new

[1]Insects Affecting Man and Animals Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Gainesville, FL 32604.

methods of control was established at the same time. The development of mirex bait by this laboratory and its extensive use for control of the imported fire ant (IFA) has been well documented [*1–8*] and will not be considered here.

In subsequent years, the discovery that residues of mirex were present in a wide variety of organisms in the environment [*9–12*] and that mirex was highly toxic to estuarine organisms [*13–17*] led the Environmental Protection Agency (EPA) to severely restrict its use. When information became available indicating that mirex was also a potential carcinogen [*18*], the EPA in 1978 cancelled registrations for all products containing mirex. These cancellations left no registered chemicals available for fire ant control except on an individual mound basis; however, this method is too labor intensive and costly for large agricultural areas. The need for suitable control chemicals to replace mirex resulted in intensified efforts by USDA scientists to develop new control agents. Williams [*19*] reported that of more than 4400 primary bait toxicants evaluated subsequent to 1976 only three were sufficiently promising to warrant extensive field testing. Banks et al [*20*] reported that only four of fifty five insect growth regulators (IGR) demonstrated potential for control of IFA. We present here the procedures we have used to develop effective baits using our studies with Amdro® fire ant bait as an example.[2]

Development of Amdro Bait

The design of a toxic bait for area-wide applications requires three basic components: a food or other type attractant, a toxicant, and a granular carrier. Prior studies with food attractants had established that vegetable oils were readily accepted by the worker ants [*1*]. They provide water repellency to the bait formulation, which is a great advantage in large-scale applications, and they are not attractive to most beneficial insects. Soybean oil has been the material of choice since mirex was developed because it is readily available at a moderate price. Because of these many desirable properties, it was selected also as the food attractant for Amdro bait in all laboratory and field tests.

The toxicant in Amdro fire ant bait is American Cyanamid AC 217300, (tetrahydro-5,5-dimethyl-2(1*H*)-pyrimidinone, (3-[4-(trifluoromethyl)phenyl]-1-(2-[4-trifluoromethyl)phenyl]ethenyl)-2-propenylidene)hydrazone). It was the most effective of a group of nine similar amidinohydrazones [*21*], exhibiting delayed toxicity at 0.1 and 1.0% in laboratory tests (Table 1). Activity of the chemical was initially hampered by its poor solubility in soybean oil (ca. 1.0% or less); however, it was determined that addition of oleic or linoleic acid at 50% of the toxicant concentration increased solubility without

[2]This paper reports the results of research only; mention of pesticides in this paper does not constitute a recommendation for use by the U.S. Department of Agriculture nor does it imply registration under FIFRA as amended. Also, mention of a commercial or proprietary product does not constitute an endorsement of this product by the USDA.

TABLE 1—*Effectiveness of AC 217300 against red imported fire ant workers (average of 9 replications with 20 workers each replication).*

Chemical	Concentration, %	Percent Mortality on Indicated Day						
		1	2	3	6	8	10	14
AC 217300	0.01	1	1	1	2	5	7	7
	0.1	1	1	4	49	68	73	82
	1.0	19	63	87	100			
Mirex (standard)	0.01	1	1	1	11	28	50	67
	0.1	0	2	45	84	91	93	100
	1.0	3	71	96	100			
Soybean oil (check)	...	0	1	1	3	4	5	7

seriously reducing acceptability of the oil solution to the ants at concentrations up to 5.0%. The oil-cosolvent solutions of AC 217300 were very effective in tests against whole laboratory colonies [*19*] (Table 2), causing high level worker mortality and death of the queen in all colonies treated at concentrations of toxicant in the solution of 2.5, 5.0, and 10.0%. Colonies treated at 20% concentration survived due to apparent repellency of the higher concentration.

Initial field tests with AC 217300 were conducted with the toxicant-soybean oil bait impregnated on corn cob grits (CCG). This carrier had proven very successful with mirex, since it was readily available, the particles were easily sized and durable, and the final formulations could be applied with ground or aerial equipment. The test formulations were made by dissolving the toxicant at a concentration of 4.0% in the soybean oil-cosolvent system and impregnating it on the CCG at 15% by weight of the formulation to produce a 0.6% bait. (This is the maximum absorption capacity of the grits.) The bait was applied at the rate of 3.7 kg/ha (22.2 g/ha active ingredient (AI)) with tractor-mounted granular application equipment to 2.0 ha plots in nongrazed permanent pasture. Three 0.16 ha circular subplots were established in each treatment plot for pre- and posttreatment evaluation of ant activity. Each mound within the subplots was examined at each interval and rated as alive or active if 20 or more live ants were present.

The initial tests were disappointing (Table 3), with a maximum kill of only 34% versus 96% for the mirex standard. Since the oil solutions containing AC 217300 had given good results in laboratory tests, we concluded that insufficient toxicant was reaching the ants in the field colonies because of the low absorption rate on CCG. We reasoned that more oil-toxicant could be delivered to the ants by increasing toxicant concentration in the soybean oil, increasing the bulk rate of application of bait, or using a more absorptive carrier that would carry and deliver more oil-toxicant per particle than the 15% possible with CCG.

TABLE 2—*Mortality in laboratory colonies of the red imported fire ant treated with indicated concentrations of AC 217300 in soybean oil baits.*[a]

Concentration, %, AC 217300 in Soybean Oil	Percent Mortality in Each Colony at Indicated Number of Weeks Posttreatment[b]							
	1	2	3	4	8	16	20	24
			Gulfport, Mississippi					
2.5	90QD	98	100					
5.0	80	100QD						
10.0	90	90	100QD					
20.0	75	75	85	CN				
			Gainesville, Florida					
2.5	58	88	90	93QD	95	97	98	100
5.0	50	73	75	79QD	91	95	100	
10.0	30	55	64	66QD	66	75	80	100
20.0	10	13	18	20CN				

[a] Tests at Gulfport, Mississippi, were with colonies with 10 000 to 20 000 workers and 10 to 20 mL of brood; tests at Gainesville, Florida, were with colonies with 60 000 to 120 000 workers and 50 to 60 mL of brood.

[b] QD = queen dead; CN = colony normal (queen alive with eggs and all stages of brood); colonies receiving only soybean oil and either cosolvent or untreated checks remained normal throughout the test.

TABLE 3—*Effectiveness of corncob grit-soybean oil baits containing AC 217300 against natural infestations of red imported fire ants.*

Toxicant and Percent Concentration	Rate of Application		Pretreatment Count of Active IFA Colonies	Percent Reduction in Active Colonies After Indicated Weeks[a]		
	Bait, kg/ha	Toxicant, g/ha		4	9	15
AC 217300, 0.6%	3.7	22.2	39	34	27	34
Mirex 10-5, 0.1%	4.6	4.6	33	51	93	96
Check	...	...	33	17	8	3

[a] Corrected for check mortality by Abbott's formula.

All three approaches had merit, so we decided to investigate all. The first two were accomplished easily; however, a search for more absorptive carriers proved to be more difficult. Our studies with mirex had shown that a completely inert carrier was needed to reduce the potential for the soybean oil to become rancid. Rancidity could have two undesirable effects: reduced feeding by the ants and breakdown of the chemical toxicant. Of all the material tested, only puffed cereal-type pellets of corn, rice, or wheat consistently satisfied these requirements, absorbed 30% or more oil, and flowed readily through application equipment. Baits were thus formulated on extruded corn pellets (ECP), with 30% soybean oil containing 1.25, 2.5, 5.0, and 10% AC 217300 producing baits containing 0.375, 0.75, 1.5, or 3.0% AI. Formulations on CCG for comparison were made with 15% oil containing the same toxicant concentrations, but produced baits containing 0.1875, 0.375, 0.75, and 1.5% AI. The CCG baits were applied at rates ranging from 2.8 to 8.07 kg/ha (5.25 to 121.0 g/ha AI) and the ECP baits at rates ranging from 1.4 to 4.03 kg/ha (5.25 to 121.0 g/ha AI). Application and evaluation techniques were the same as for the initial tests, except plots were 1.2 ha in size with 0.15 ha evaluation subplots. Results from these tests were somewhat better (Table 4) than in the initial tests although quite erratic. When data from all the tests were combined it was seen (Fig. 1) that 10 to 15 g AI/ha was the optimum dosage and at those rates the corn pellet bait was decidedly superior to the CCG baits. No consistent correlation between application rate and control was discernible.

Further tests were considered necessary to fully determine the best carrier and formulation; thus larger-scale tests were conducted in Alabama, Louisiana, and Texas. It became apparent as these tests were planned that the ECP used in the previous tests would no longer be available and an alternative material would be necessary. Therefore studies were conducted to compare the ECP with defatted and degermed corn grits, a new type of carrier produced as a byproduct of the cereal industry (Lauhoff Grain Company, Danville, Illinois). All the formulations contained 2.5% toxicant in the oil solution which was applied to the carriers at 30% by weight of the formulation. The baits were applied with fixed-wing aircraft to 40.5 ha plots on noncultivated areas. Since the earlier laboratory and field tests had shown evidence of eliminating the queens even though all workers in the colonies were not killed, a new system of evaluating the treatments was developed that took into account effects of the toxicants other than total colony mortality. In this new system, circular subplots were established, as previously, the entire area within each subplot was searched, and each nest found was opened with a spade and examined carefully. A nest rating of 1 to 10 was assigned as shown in Table 5.

The interaction of population density and colony class was then used to establish a population index that can be expressed mathematically by

$$\text{Population index (PI)} = \sum_{K=1}^{10} K(N_k)$$

where N_k is the number of ant colonies in a given area comprised of colony classes having the value of K, where $(10 \leq K \geq 1)$.

The changes in population indices offered a more realistic means of assessing effects of the chemical. Comparison of the reductions in population indices obtained in the aerial treatment tests showed that all the baits were 80 to 90% effective in reducing populations of the ants (Table 6). The formulations

TABLE 4—*Effectiveness of baits containing AC 217300 for control of red imported fire ants (each test consisted of three replications at three sites).*

Formulation (Carrier and Toxicant Concentration)	Application Rate		% Control Obtained[a]	
	Bait, kg/ha	Active Ingredient, g/ha	Test 1	Test 2
		Corncob Grits		
0.1875%	2.8	5.25	...	52
	5.6	10.5	...	67
0.375%	2.8	10.5	...	45
	4.03	15.1	33	...
	5.6	21.0	...	72
	8.07	30.2	55	...
0.75%	2.8	21.0	...	63
	4.03	30.2	51	...
	5.6	42.0	...	70
	8.07	60.5	56	...
1.5%	4.03	60.5	39	...
	8.07	121.0	47	...
		Extruded Corn Pellets		
0.375%	1.4	5.25	...	66
	2.8	10.5	...	87
0.75%	1.4	10.5	...	79
	2.02	15.1	84[b]	...
	2.8	21.0	...	82
	4.03	30.2	47[b]	...
1.5%	1.4	21.0	...	72
	2.02	30.2	55[c]	...
	2.8	42.0	...	71
	4.03	60.5	55[c]	...
3.0%	2.02	60.5	49[c]	...
	4.03	121.0	57[c]	...
Mirex (standard), 0.1%	1.12	1.12	97	...
On corncob grits	1.37	1.37	...	86

[a] Data corrected for untreated check mortality by Abbott's formula.
[b] Data for one replicate.
[c] Data for two replicates.

on pregel defatted corn grits were slightly more effective than those on pregel degermed corn grits. The data obtained in these studies provided the basis for conditional registration by the EPA of AC 217300 in a pregel defatted corn grit formulation under the trade name Amdro. This bait has gained good acceptance by the homeowner and is being widely used for IFA control on lawns, playgrounds, and other areas frequented by people. It can also be used for IFA control in pastures, range grass, and nonagricultural land.

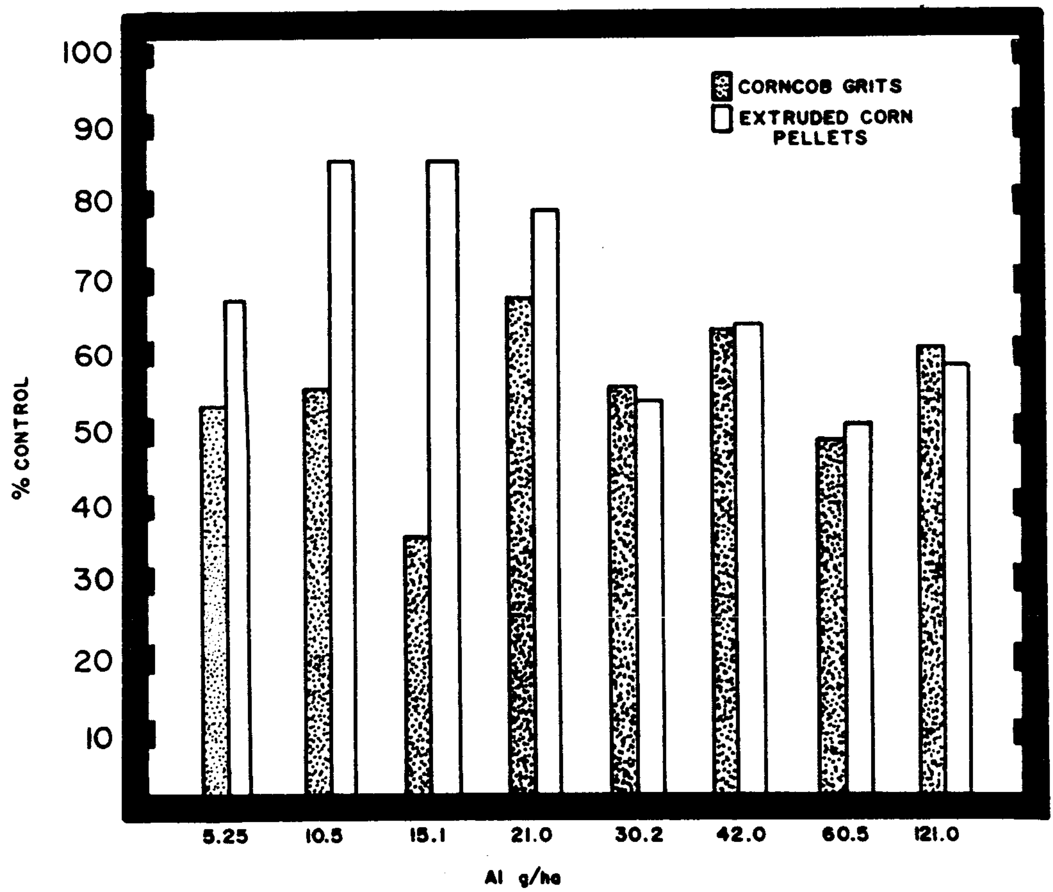

FIG. 1—*Comparative effectiveness of indicated g/ha of AC 217300 in corn cob grit or extruded corn pellet bait in controlling red imported fire ants.*

TABLE 5—*Nest ratings.*

	Colony Classes	
No. of Worker Ants	Without Worker Brood	With Worker Brood
<100	1	6
100 to 1000	2	7
1000 to 10 000	3	8
10 000 to 50 000	4	9
>50 000	5	10

Development of Other Baits

Concurrent with the studies on Amdro other ongoing laboratory studies showed that six other chemicals were effective in reducing the size of, or eliminating, laboratory colonies; however, for various reasons only three of these

TABLE 6—*Effectiveness of AC 217300 baits against red imported fire ants in large-area tests (results from three tests).*

Application Rate		Percent Reduction after 22 weeks in[a]	
Bait, kg/ha	Active Ingredient, g/ha	No. of Active Nests	Population Index
	0.75% Pregel Defatted Corn Grits		
0.84	6.3	73.6	82.1
1.40	10.5	78.1	84.9
1.96	14.7	87.6	91.6
	0.75% Pregel Degermed Corn Grits		
0.84	6.3	73.6	81.5
1.40	10.5	83.0	87.8
1.96	14.7	80.6	85.8
	0.75% Extruded Corn Pellets[b]		
1.40	10.5	72.9	86.5

[a] Results corrected with Abbott's formula for check mortality.
[b] Results from two tests.

materials are being considered for development. Two of these materials are IGRs, one of which, Prodrone® (1-(8-methoxy-4,8-dimethylnonyl)-4-(1-methylethyl)benzene), was recently granted conditional registration by EPA. The other IGR, Maag Ro 13-5223 (ethyl[2-(*p*-phenoxyphenoxy)ethyl] carbamate), and the third chemical, Avermectin B_1, are currently being used in field tests against red imported fire ants. All these materials are very effective against laboratory colonies (Table 7) and have shown good effectiveness against field populations (Table 8). The latter two materials have been evaluated in both pregel defatted corn grit baits containing 30% soybean oil and in expanded corncob grit bait containing 15 or 25% soybean oil. The latter carrier is made from regular corn cob grits by a procedure that expands their porosity, thus increasing absorption capacity. Maag Ro 13-5223 is the only chemical we have tested that gives good control of the IFA with the expanded corn cob grit bait, but results have been somewhat poorer than with the pregel defatted formulations. Field tests of avermectin B_1 and Maag Ro 13-5223 are continuing, with anticipated registration by EPA for IFA control within the next one to two years.

The results obtained in all these studies emphasize the importance of the formulation. The need for cosolvents to increase solubility of toxicants in soybean oil and the absorption capacity of the carrier are good examples of the special requirements needed. In addition, the final formulation must retain its attractiveness to the IFA. Unless all these factors are evaluated carefully, an effective formulation can not be developed.

TABLE 7—*Effects of Avermectin B_1, Maag Ro 13-5223, and Prodrone on laboratory colonies of red imported fire ants.*

Chemical	Dosage, mg/colony	No. of Colonies Tested	Percent Reduction in Workers or Brood after Indicated Week										Fate of Colonies[a]
			Workers					Brood					
			1	4	8	16	32	1	4	8	16	32	
Avermectin B_1	50.0	6	41	64	72	100		5	88	100			D
	25.0	2	25	35	50	88		5	85	100			D
	12.5	2	30	55	80	90		15	95	100			D
	5.0	2	45	65	80	100		23	100				D
	1.25	4	39	73	96	100		4	100				D
Ro 13-5223	10.0	3	0	6	18	30	53	0	100	100	86	26	1D,2S
	5.0	3	0	13	25	44	50	0	100	100	100	78	2D,1S
Prodrone	10.0	6	0	5	30	45	60	0	50	100	100	75	5D,1S
	5.0	6	0	0	20	38	52	0	30	100	100	66	4D,2S

[a] D = colony dead or queen dead or sterile, S = survived.

TABLE 8—*Effectiveness of Avermectin B_1, Maag Ro 13-5223, and Prodrone baits against natural infestations of red imported fire ants.*

Formulation[a]	Application Rate: Bait, kg/ha	Application Rate: Active Ingredient, g/ha	Percent Reduction in Population Index[b]
		Avermectin B_1	
0.0055% PDCG	1.0 kg	0.055	96
0.011% PDCG	1.12	0.123	96
0.0055% CCG	1.12	0.062	64
0.011% CCG	1.12	0.123	82
		Maag Ro 13-5223	
1.0% PDCG	1.12	11.2	99
1.0% ECG	1.12	11.2	97
		Prodrone[c]	
1.2% PDCG	0.98	11.9	96

[a] PDCG = pregel defatted corn grits, CCG = corncob grits, ECG = expanded corncob grits.

[b] Population index calculated on basis of procedure described by Lofgren and Williams [*22*].

[c] Data for Prodrone are two applications at indicated rate six months apart.

References

[*1*] Lofgren, C. S., Bartlett, F. J., and Stringer, C. E., *Journal of Economic Entomology*, Vol. 54, 1961, pp. 1096-1100.

[*2*] Lofgren, C. S., Stringer, C. E., and Bartlett, F. J., *Journal of Economic Entomology*, Vol. 55, 1962, pp. 405-407.

[*3*] Lofgren, C. S., Bartlett, F. J., and Stringer, C. E., *Journal of Economic Entomology*, Vol. 56, 1963, pp. 62-66.

[*4*] Lofgren, C. S., Bartlett, F. J., and Stringer, C. E., *Journal of Economic Entomology*, Vol. 57, 1964, pp. 601-602.

[*5*] Lofgren, C. S., Bartlett, F. J., Stringer, C. E., and Banks, W. A., *Journal of Economic Entomology*, Vol. 57, 1964, pp. 695-698.

[*6*] Alley, E. G., *Journal of Environmental Quality*, Vol. 2, 1973, pp. 52-61.

[*7*] Banks, W. A., Glancey, B. M., Stringer, C. E., Jouvenaz, D. P., Lofgren, C. S., and Weidhaas, D. E., *Journal of Economic Entomology*, Vol. 66, 1973, pp. 785-789.

[*8*] Banks, W. A., Hicks, D. M., Plumley, J. K., Jouvenaz, D. P., Wojcik, D. P., and Lofgren, C. S., *Journal of Economic Entomology*, Vol. 69, 1976, pp. 465-467.

[*9*] Markin, G. P., Ford, J. H., Hawthorne, J. C., Spence, J. H., Davis, J., Collins, H. L., and Loftis, D. C., "The Insecticide Mirex and Techniques for Its Monitoring," U.S. Animal and Plant Health Inspection Service Report 81-3, Washington, DC, 1972, 19 pp.

[*10*] Markin, G. P., Collins, H. L., and Davis, J., *Pesticide Monitoring Journal*, Vol. 8, 1974, pp. 131-134.

[*11*] Markin, G. P., Hawthorne, J. C., Collins, H. L., and Ford, J. H., *Pesticide Monitoring Journal*, Vol. 7, 1974, pp. 139-143.

[*12*] Baetcke, K. P., Cain, J. D., and Poe, W. E., *Pesticide Monitoring Journal*, Vol. 6, 1972, pp. 14-22.

[13] Bookhout, C. G., Wilson, A. J., Jr., Duke, T. W., and Lowe, J. I., *Water, Air and Soil Pollution*, Vol. 1, 1972, pp. 165-180.
[14] Bookhout, C. G., and Costlow, J. D., Jr., *Water, Air and Soil Pollution*, Vol. 4, 1975, pp. 113-126.
[15] Bookhout, C. G., and Costlow, J. D., "Effects of Mirex, Methoxychlor, and Malathion on Development of Crabs," U.S. Environmental Protection Agency, Office of Research and Development Report EPA-600/3-76-007, Washington, DC, 1976, 85 pp.
[16] Lowe, J. I., Wilson, P. D., and Davison, R. B., "Effects of Mirex on Crabs, Shrimp, and Fish," U.S. Department of Interior Circular No. 335, Washington, DC, 1970, pp. 22-23.
[17] Lowe, J. I., Parrish, P. R., Wilson, A. J., Jr., Wilson, P. D., and Duke, T. W., in *Transactions*, North American Wildlife and Natural Resources Conference No. 36, Portland, OR, sponsored by Wildlife Management Institute, Washington, DC, 1971, pp. 171-186.
[18] Ulland, B. M., Page, N. P., Squire, R. A., Weisburger, E. K., and Cypher, R. L., *Journal of the National Cancer Institute*, Vol. 58, No. 1, 1977, pp. 133-140.
[19] Williams, D. F., *The Florida Entomologist*, Vol. 66, No. 1, 1983, pp. 166-172.
[20] Banks, W. A., Miles, L. R., and Harlan, D. P., *The Florida Entomologist*, Vol. 66, No. 1, 1983, pp. 172-181.
[21] Williams, D. F., Lofgren, C. S., Banks, W. A., Stringer, C. E., and Plumley, J. K., *Journal of Economic Entomology*, Vol. 73, 1980, pp. 798-802.
[22] Lofgren, C. S., and Williams, D. F., *Journal of Economic Entomology*, Vol. 75, 1982, pp. 798-803.