1990

Evaluation of Chlorpyrifos-Methyl and Chlorpyrifos-Methyl plus Methoprene as Protectants of Stored Corn: Small Bin Tests

Frank H. Arthur
USDA-ARS, frank.arthur@ars.usda.gov

James E. Throne
USDA-ARS, Manhattan, KS, james.throne@ars.usda.gov

Richard A. Simonaitis
USDA-ARS

James M. Zehner
USDA-ARS

Evaluation of Chlorpyrifos-Methyl and Chlorpyrifos-Methyl plus Methoprene as Protectants of Stored Corn: Small Bin Tests

FRANK H. ARTHUR, JAMES E. THRONE, RICHARD A. SIMONAITIS, AND JAMES M. ZEHNER

Stored-Product Insects Research and Development Laboratory, USDA–ARS, Savannah, Georgia 31403

J. Econ. Entomol. 83(3): 1114–1121 (1990)

ABSTRACT Chlorpyrifos-methyl applied at 6 ppm and a combination of 6 ppm chlorpyrifos-methyl + 1 ppm methoprene were evaluated as protectants of stored corn (*Zea mays* L.) against a standard malathion application of 8 ppm and an untreated control. Corn was treated in October 1987, placed in 10-, 19-, and 76-bu bins, and infested at selected intervals with red flour beetle, *Tribolium castaneum* (Herbst); flat grain beetle, *Cryptolestes pusillus* (Schönherr); maize weevil, *Sitophilus zeamais* Motschulsky; and Indianmeal moth, *Plodia interpunctella* (Hübner). Indianmeal moths did not establish populations on treated or untreated corn. Beetle populations in untreated controls were not abundant until June 1988 (8 mo after application). After 12 mo, red flour beetle and flat grain beetle populations were significantly greater in corn treated with malathion than in corn treated with either chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene. Maize weevil populations were not significantly different among the three chemical treatments. Moisture content was not significantly different between treated and untreated corn or among the chemical treatments. Dockage and weight loss were significantly greater in untreated than in treated corn after 8 mo. After 12 mo, weight loss was significantly greater in malathion-treated corn than in corn treated with either chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene. Insect population levels or insect damage did not differ significantly between the latter two treatments.

KEY WORDS Insecta, insecticides, corn, stored-product insects

CHLORPYRIFOS-METHYL is an insecticide labeled as a protectant for stored barley, oats, rice, sorghum, and wheat. It is applied at the rate of 6 ppm as the crop is loaded into storage. However, this insecticide has not been properly evaluated as a protectant of stored corn, which is also an important commodity. The only published reports are a laboratory study (LaHue 1976) and a simulated field test in Kansas with an application rate of 6.7 ppm (LaHue 1977). In that field test, bags of treated corn were held 4 mo under ambient conditions in warehouses, collected, and stored in a cold room for 8 mo, then returned to the warehouses for another 4 mo to simulate a second storage season. The treated corn was exposed to insect attack for a comparatively short period, and no attempt was made to maintain a constant infestation pressure. Residue degradation, temperature and grain moisture content, which determine the rate of degradation, were not monitored.

Methoprene, an insect growth regulator (IGR) acting as a juvenile hormone mimic, is toxic to many insect species that infest stored corn, although it may be less active against internal feeders such as *Sitophilus* spp. (McGregor & Kramer 1975). The Environmental Protection Agency has set the tolerance for methoprene residues in stored commodities at 5 ppm. Some of the concerns about the use of methoprene in pest management programs include the increased cost compared with traditional chemicals and the continued feeding of adults and larvae until the immatures die as pupae, which causes some damage to the commodity. These concerns might be alleviated by reducing the application rate of methoprene and combining it with an insecticide protectant such as chlorpyrifos-methyl. This combination may lengthen residual control and reduce costs.

Monitoring techniques for evaluating the effectiveness of insecticide treatments in stored grain are not fully developed. The most common method is to collect samples of the treated commodity and count live insects and damaged kernels. Sample methods that are either more accurate or less laborious would be an asset to pest management programs. Pitfall traps efficiently sample insects in bulk grain (Loschiavo 1975), but they have not been used in insecticide tests. Indirect methods of assessing insect damage in treated commodities, such

This paper reports the results of research only. Mention of a pesticide or a commercial or proprietary product does not constitute a recommendation or endorsement by the U.S. Department of Agriculture.

as weight loss, amount of dockage, and changes in moisture content of grain have not been investigated.

The objectives of our test were: to determine if chlorpyrifos-methyl applied at the labeled rate for small grains (6 ppm) would protect corn stored for up to 1 yr in the southeastern United States; to evaluate a combination treatment of 6 ppm chlorpyrifos-methyl + 1 ppm methoprene; and to assess insect infestations and insect damage using pitfall traps to monitor insect populations and determine damage by monitoring dockage, weight loss, and moisture content of the corn.

Materials and Methods

This test was conducted at the USDA Stored-Product Insects Research and Development Laboratory, Savannah, Ga., using 'Pioneer 3320' field corn that had been cleaned and fumigated with phosphine. The moisture content of the corn was 14.3 ± 0.09%. Chlorpyrifos-methyl applied at 6 ppm and the combination of 6 ppm chlorpyrifos-methyl + 1 ppm methoprene were evaluated against a standard malathion application (8 ppm) and an untreated control. Chlorpyrifos-methyl (Gustafson, Plano, Tex.) was formulated from a 43.2% emulsion (E) (4 lb [AI]/gal), methoprene (Gustafson) was formulated from a 65.7% E (5 lb [AI]/gal), and malathion (American Cyanamid, Princeton, N.J.) was formulated from a 57.7% emulsifiable concentrate (5 lb [AI]/gal). The insecticides were applied 5–8 October 1987 at the rate of 94.6 ml of formulated spray per 5 bu of corn. This rate is proportional to the field spray rate of 5 gal/1,000 bu. Controls were sprayed with 94.6 ml of distilled water. The corn was sprayed with the insecticide formulations as it fell from a conveying system into a hopper-bottom cart; the sprayed corn then was mixed by transferring the corn from one cart to another three times.

All treatments were made inside an enclosed warehouse. The corn was then carried outside and conveyed into bins. Four 10- and four 19-bu fabricated bins and four standard 2,727.3-kg (3-ton) bins were used to store the treated corn (12 bins total). Each of the four treatments was replicated in the three bin sizes. The 10-bu (272.7 kg corn) and 19-bu (518.2 kg corn) bins were filled to capacity and 76 bu (2,072 kg corn) were loaded into the 2,727.3-kg bins (hereafter referred to as "76-bu bins"). After the 10- and 19-bu bins were filled, they were placed in the rear of a shed with an open front. The 76-bu bins were placed in front of the shed.

One week after insecticide application, insects commonly associated with stored corn in the southeastern United States (Horton 1982) were introduced into the bins. Species introduced were adult red flour beetle, *Tribolium castaneum* (Herbst); adult maize weevil, *Sitophilus zeamais* Motschulsky; adult flat grain beetle, *Cryptolestes pusillus* (Schönherr); and eggs of Indianmeal moth, *Plodia interpunctella* (Hübner). Two hundred individuals of each species were placed in each 10-bu bin; 400 individuals of each species in each 19-bu bin; and 800 maize weevils and 1,600 individuals of each of the other three species in each 76-bu bin. All insects were obtained from colonies susceptible to pesticides and maintained in the laboratory. Three weeks after insects were introduced, two plastic pitfall traps (34.3 by 1.9 cm, Grain Guard, Verona, Wis.) were placed in the top center and bottom center of each 10 bu bin (depths of 5 and 60 cm from the top surface). Three traps were placed in the top center, middle center, and bottom center of each 19-bu bin (5, 60, and 120 cm from the top surface); and five traps were placed in each 76-bu bin. Three were 5 cm from the top surface at SW, S, and NE coordinates, one was in the middle center, and one was in the bottom center (60 and 135 cm from the top surface, respectively). Four rolled cardboard pupation traps for moth larvae were embedded just below the top surface of the bulk corn in each 10- and 19-bu bin. Eight traps were placed below the top surface in each 76-bu bin.

After 1 wk, traps were removed and the number of live insects of each species was recorded. The corn was then sampled using a 38.1 cm deep grain probe (Seedburo Equipment Company, Chicago) that removed 240–250 g per sample. Four top (5 cm depth) samples and one bottom (60 cm) sample were removed from each 10-bu bin. Four top, four middle (60 cm), and one bottom (120 cm) sample were removed from each 19-bu bin. Eight top, four middle, and one bottom (135 cm) samples were removed from each 76-bu bin. Each sample was processed by removing insects and dockage using a U.S. standard no. 6 sieve (3.35-mm openings). Moisture content was measured with a Burrows DMC-700 moisture (Chicago, Il.) computer. Finally, 250 ml of the corn was weighed.

After the samples from each bin were processed, approximately 250 g from each level (top, middle, and bottom) were collected for insecticide residue analysis. The test was repeated with samples taken again at 2, 4, 6, 8, 10, and 12 mo after insecticide application. Insects were introduced into the bins 4 wk before sampling (1 wk, 1, 3, 5, 7, 9, and 11 mo after insecticide application), and plastic pitfall and cardboard traps were inserted into the bins after 3 wk. The corn was sampled 1 wk later as described above. The controls were not sampled after 10 mo because they were heavily infested.

Temperature in the untreated corn and corn treated with chlorpyrifos methyl alone was monitored with an Omnidata Easy Logger (Omnidata International, Logan, Utah). This system has a capacity of 26 probes, which were placed into positions corresponding with the sampling points as follows: top side (5 cm), top center (5 cm), and bottom (60 cm) in the 10-bu bins; top side, top center, middle center (60 cm) and bottom center (120 cm) in the 19-bu bins; and top side, top midcenter, top center, middle side (120 cm), middle center (135 cm), and bottom center (135 cm) in the 76-bu bins. Temperature at these points was scanned at 5-min intervals and the average recorded hourly for the duration of the test.

On each sample date, data from pitfall traps were combined into one value per bin for each beetle species. Moth data from the cardboard traps also were combined into one value per bin per sample date. The amount of dockage (ground corn) in probe samples, moisture content, and the weight of a 250-ml subsample from each probe sample were analyzed statistically to determine differences between chemical treatments and bin sizes. The GLM procedure (SAS Institute 1987) was used. Live beetles in the probe samples were combined into one value per bin for each species. Insect data from the probe traps were analyzed by linear contrasts. Data from the temperature recorder were summarized by computing daily averages.

Chlorpyrifos-methyl residues were analyzed using a procedure described by Arthur et al. (1988a). Methoprene residues were analyzed by extraction with acetonitrile, cleanup through florisil and C-18 PrepSep columns, and analysis by HPLC. The conditions for HPLC were: Zorbax C-18 column, mobile phase = 87% acetonitrile/water (vol/vol), flow rate = 1 ml/min, and UV detector = 265 nm.

Results

When the bins were sampled after 1 mo (November 1987), the total number of adult red flour beetles recovered in pitfall traps from untreated corn in the 10-, 19-, and 76-bu bins was 18, 81, and 161, respectively (Fig. 1A). Few adults were collected from these bins during the winter, and populations did not increase beyond the levels found after 1 mo until June 1988 (8 mo). By August (10 mo), the untreated corn was heavily infested; 579, 225, and 1,225 live adults were collected from the 10-, 19-, and 76-bu bins, respectively. Large numbers of live adults were not detected in corn treated with malathion until August; 2 mo later, numbers of red flour beetles in the malathion treatment began approaching the levels detected in the control bins at 10 mo (August). No live adults were collected from corn treated with either chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene until August; even then, no more than five were collected from any bin. Significantly fewer adults were collected from these bins at 12 mo than were collected from the malathion bins ($F = 15.32$; df = 1, 6; $P = 0.008$), but numbers of adults did not differ between chlorpyrifos-methyl and chlorpyrifos-methyl + methoprene ($F = 0.00$; df = 1, 6; $P = 0.9631$).

No more than 11 live adult flat grain beetles were collected in pitfall traps from untreated controls on any sample date until June 1988 (Fig. 1B). By August, populations in these bins were well established, particularly in the 76-bu bin. No more than 3 live adults were found in the malathion bins on any sample date until 12 mo, when the number collected in the 10-, 19-, and 76-bu bins had increased to 197, 277, and 320, respectively. No live adults were found in corn treated with either chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene until 12 mo, when the numbers ranged from 6 to 52. Significantly fewer adults were collected from these bins at 12 mo compared with the malathion bins ($F = 79.97$, df = 1, 6; $P = 0.0001$), but again no difference was apparent between chlorpyrifos-methyl and chlorpyrifos-methyl + methoprene ($F = 0.01$; df = 1, 6; $P = 0.9112$).

Maize weevil populations in untreated corn increased at a very slow rate during summer 1988 (Fig. 1C). The number of adults collected in pitfall traps from untreated corn at 10 mo was low compared with numbers of red flour beetles and flat grain beetles collected at the same time. No live adults were collected from corn treated with either chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene until 12 mo; no more than three were collected from any one bin. Significantly fewer adults were collected from these bins at 12 mo compared with the malathion bins ($F = 8.08$; df = 1, 6; $P = 0.0295$), but no difference was detected between chlorpyrifos-methyl and chlorpyrifos-methyl + methoprene ($F = 0.01$; df = 1, 6; $P = 0.9083$).

Live Indianmeal moths were not detected in cardboard traps from untreated corn after December 1987, and no live moths were collected from any 10-bu bin containing treated corn (Fig. 1D). In June 1988, 41 and 28 moths were collected from the 76-bu malathion and chlorpyrifos-methyl bins, respectively. Two months later, 217 moths were collected from the 19-bu malathion bin, but these were the only times that substantial numbers of moths were found.

None of these beetle species were detected in large numbers in probe samples from untreated corn until 10 mo (Fig. 2). No live beetles were ever found in probe samples from corn treated with chlorpyrifos-methyl. One red flour beetle and one flat grain beetle were found in probe samples from the 19-bu chlorpyrifos-methyl + methoprene bin, but no live beetles were found in the other two bins containing this treatment. Live beetles were found in probe samples from corn treated with malathion only at 12 mo. Total numbers of each species found in the 10-, 19-, and 76-bu bins were red flour beetle, 0, 2, and 9, respectively; maize weevil, 0, 3, and 0, respectively; and flat grain beetle, 3, 8, and 12, respectively.

Moisture content, dockage, and weight loss of corn were not significantly different among bins containing the same treatment. Moisture content was not significantly different among treatments ($F = 2.12$; df = 3, 6,441; $P = 0.0961$), and remained constant throughout the 12-mo test period. Average moisture content ($\pm$ SEM) of all samples ($n = 648$) was 14.4 $\pm$ 0.02%. The amount of dockage was not significantly different among treatments for the

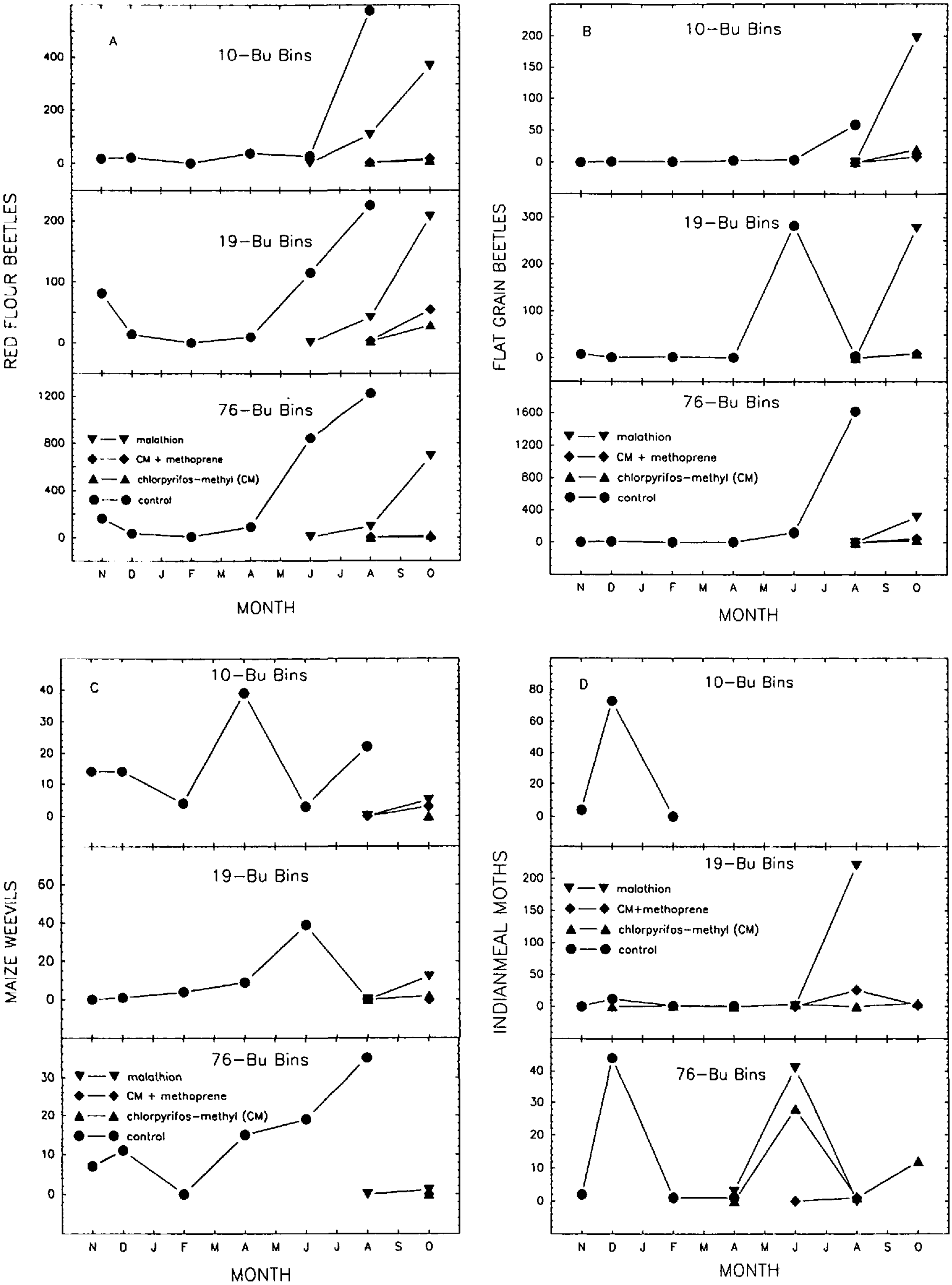

Fig. 1A–D. (A) Live adult red flour beetle, (B) adult flat grain beetle, (C) adult maize weevil, and (D) Indianmeal moth larvae and pupae collected after 1, 2, 4, 6, 8, 10, and 12 mo from untreated corn and corn treated with 6 ppm chlorpyrifos-methyl, 6 ppm chlorpyrifos-methyl + 1 ppm methoprene, or 8 ppm malathion.

Table 1. Average weight, in grams (± SEM) of dockage and 250 ml of corn from samples taken from untreated corn and corn treated in October 1987 with 6 ppm chlorpyrifos-methyl, 6 ppm chlorpyrifos-methyl + 1 ppm methoprene, or 8 ppm malathion (n = 27 for each chemical)

Treatment	Month						
	Nov.	Dec.	Feb.	April	July	Aug.	Sept.
	Weight of dockage, g						
Control	0.17 ± 0.02a	0.14 ± 0.01a	0.14 ± 0.01a	0.16 ± 0.02a	0.36 ± 0.09a	0.62 ± 0.09a	—
Chlorpyrifos-methyl (CM)	0.14 ± 0.01a	0.12 ± 0.01a	0.14 ± 0.02a	0.14 ± 0.02a	0.10 ± 0.00b	0.13 ± 0.01b	0.15 ± 0.02a
CM + methoprene	0.14 ± 0.01a	0.12 ± 0.01a	0.11 ± 0.01a	0.13 ± 0.01a	0.10 ± 0.01b	0.13 ± 0.02b	0.15 ± 0.01a
Malathion	0.14 ± 0.01a	0.12 ± 0.01a	0.14 ± 0.02a	0.14 ± 0.02a	0.11 ± 0.01b	0.16 ± 0.02b	0.21 ± 0.03a
	Weight of 250 ml, g						
Control	203.8 ± 0.4a	202.4 ± 0.4a	201.9 ± 0.4a	202.0 ± 0.4a	199.2 ± 0.6b	192.6 ± 1.4b	—
Chlorpyrifos-methyl (CM)	204.0 ± 0.5a	203.6 ± 0.3a	202.1 ± 0.3a	202.2 ± 0.3a	201.1 ± 0.4a	198.9 ± 0.8a	195.1 ± 0.7a
CM + methoprene	202.7 ± 0.4ab	202.5 ± 0.3a	202.3 ± 0.4a	201.7 ± 0.3a	200.6 ± 0.4ab	198.1 ± 0.5a	198.1 ± 0.5a
Malathion	202.1 ± 0.4b	202.6 ± 0.4a	201.3 ± 0.4a	201.1 ± 0.4a	200.3 ± 0.6ab	197.9 ± 0.9a	196.1 ± 0.8b

Means within columns followed by the same letter are not significantly different ($P = 0.05$; Duncan's multiple range test [PROC GLM, SAS Institute 1987]).

first 6 mo of the test (Table 1). Dockage in samples of untreated corn increased to 0.36 ± 0.087 and 0.62 ± 0.087 g in June and August, respectively, and was significantly greater than dockage in the chemical treatments. No differences among the three chemical treatments were significant at any time. The weight of 250 ml of corn from each sample was not significantly different among treatments for the first 6 mo (Table 1). In August, untreated corn weighed significantly less than treated corn; after 12 mo corn treated with malathion weighed less than corn treated with chlorpyrifos-methyl or chlorpyrifos-methyl + methoprene. Whether chlorpyrifos-methyl was applied alone or with methoprene, residues were not significantly different ($F = 0.03$; df = 1, 110; $P = 0.8700$). Therefore, data were combined for further analysis.

Insecticide residues were not significantly different either within bins (chlorpyrifos-methyl: $F = 1.13$; df = 2, 109; $P = 0.3262$; methoprene: $F = 0.57$; df = 2, 53; $P = 0.5671$; malathion: $F = 1.63$; df = 2, 53; $P = 0.2063$) or among bins (chlorpyrifos-methyl: $F = 0.300$; df = 2, 109; $P = 0.7394$; methoprene: $F = 3.09$; df = 2, 53; $P = 0.537$; malathion: $F = 0.48$; df = 2, 53; $P = 0.6219$). The actual concentrations ($\bar{x}$ ± SEM) of malathion and chlorpyrifos-methyl after application were 10.8 ± 2.81 and 6.0 ± 0.47 ppm, respectively. After 6 mo, residue levels for both chemicals were equal and remained so throughout the test (Fig. 3). At the conclusion of the test, malathion and chlorpyrifos-methyl residues were 8.1 and 11.7%, respectively, of the original levels. In contrast, methoprene was more stable than either chlorpyrifos-methyl or malathion. Actual residue after application was 0.7 ± 0.07 ppm, and 33.9% remained after 12 mo.

Temperature data for the bins containing untreated corn and corn treated with chlorpyrifos methyl alone are presented in Fig. 4. Temperature did not differ between treatments for the first 6 mo of storage, and fluctuations were less severe in the 76-bu bins compared with the smaller ones. After beetle populations began increasing in untreated controls, temperatures in these bins ranged from 5 to 10°C higher than temperatures at the corresponding positions in the chlorpyrifos methyl bins.

Discussion

The temperature of the corn rarely exceeded 20°C for the first 6 mo of storage, which probably limited insect growth and development in the untreated corn. Lower developmental temperature limits for red flour beetle, flat grain beetle, *Sitophilus* spp. and Indianmeal moth are 22, 22, 17, and 18°C, respectively (Howe 1965). When temperatures rose and conditions for development became more favorable, red flour beetles and flat grain beetles may not have immediately increased because they are secondary feeders that have diffi-

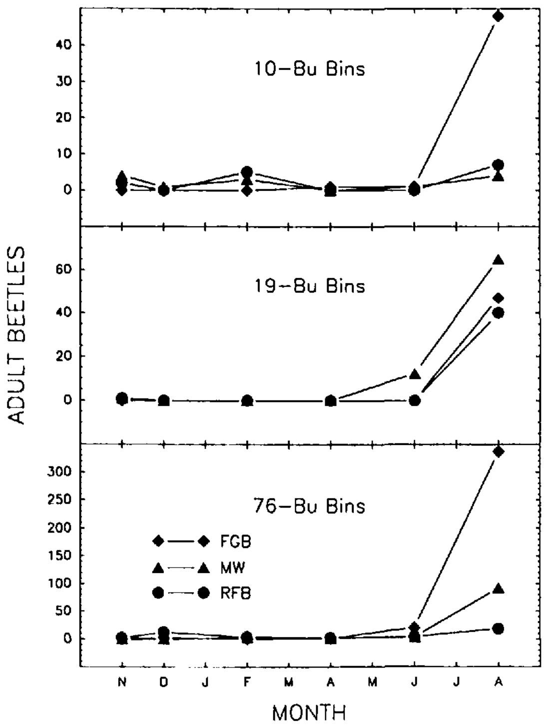

Fig. 2. Live red flour beetles (RFB), flat grain beetles (FGB), and maize weevils (MW) found in probe samples from untreated corn after 1, 2, 4, 6, 8, 10, and 12 mo.

culty feeding on whole corn (LeCato 1975a,b). A primary feeder such as the maize weevil is required to break the kernels into particulate matter that can be ingested by secondary feeders. Once red flour beetles and flat grain beetles became established, they could inhibit Indianmeal moth development by preying on eggs (LeCato & Flaherty 1973). Both predation and mechanical damage from maize weevil feeding (Chesnut & Douglas 1971) could be responsible for the fact that no Indianmeal moths were collected from untreated controls after 2 mo of storage.

As expected, chlorpyrifos-methyl applied at the rate labeled for small grains was more effective than malathion. Similar results were obtained in a previous evaluation of chlorpyrifos-methyl as a protectant of stored peanuts (Arthur et al. 1988a). Red flour beetles and Indianmeal moths from peanut storage facilities are highly resistant to malathion (Zettler 1982, Arthur et al. 1988b, Halliday et al. 1988), and data from a South Carolina study show widespread malathion resistance in red flour beetles from stored grain, but no resistance in maize weevils (Horton 1984). The latter study is the only published report concerning malathion resistance in corn stored in the southeastern United States, but studies by Beeman et al. (1982) and Haliscak & Beeman (1983) document malathion resistance in the north-central United States. If chlorpyrifos-methyl were labeled for stored corn, it would be

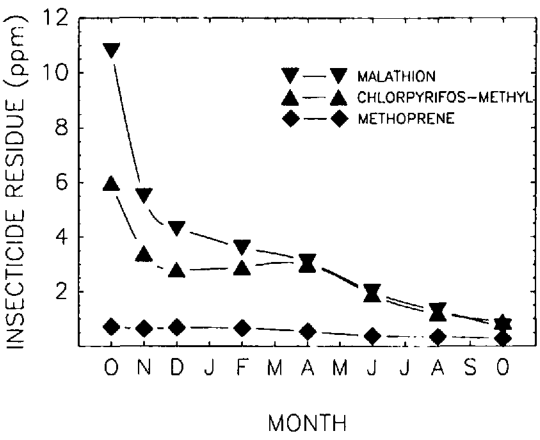

Fig. 3. Chlorpyrifos-methyl, methoprene, and malathion degradation during storage.

an asset to pest management programs and could replace malathion in areas where malathion resistance is a problem. The chlorpyrifos-methyl + methoprene treatment was no more effective than chlorpyrifos-methyl used alone, and use of this combination would be feasible only if the rate of chlorpyrifos-methyl were reduced or if chlorpyrifos-methyl resistance were to develop.

Most of the live beetles collected in our test were caught in pitfall traps, probably because these traps were put in the bins 1 wk before probe sampling. This test was not designed to measure the efficiency of pitfall traps versus probe samples as a means of estimating insect populations, therefore the two methods cannot be directly compared. We had expected pitfall trap catch to be lower than probe sample counts during the cooler months of the year, but few live beetles were found in pitfall traps or probe samples when temperatures were low. The results of our test indicate that pitfall traps can be used in insecticide evaluation studies in stored grain or to monitor insect populations after insecticide treatment.

Adams (1976) reported that feeding by maize weevil produced a measurable weight loss in individual kernels; therefore we expected a given volume of infested corn to weigh less than the same volume of undamaged corn. Infested and uninfested corn did not differ until after 6 months of storage, possibly because the secondary feeders (red flour beetles and flat grain beetles) were much more abundant in the untreated corn than were maize weevils. The increased dockage and elevated temperatures in untreated corn during the latter months of the test indicated the severity of the infestation, and damaged kernel counts may have shown a clearer distinction between both the chemical treatments and untreated controls and the chlorpyrifos-methyl and malathion treatments.

One of the major concerns in stored-grain management in the southeastern United States is that warm fall and winter temperatures may increase

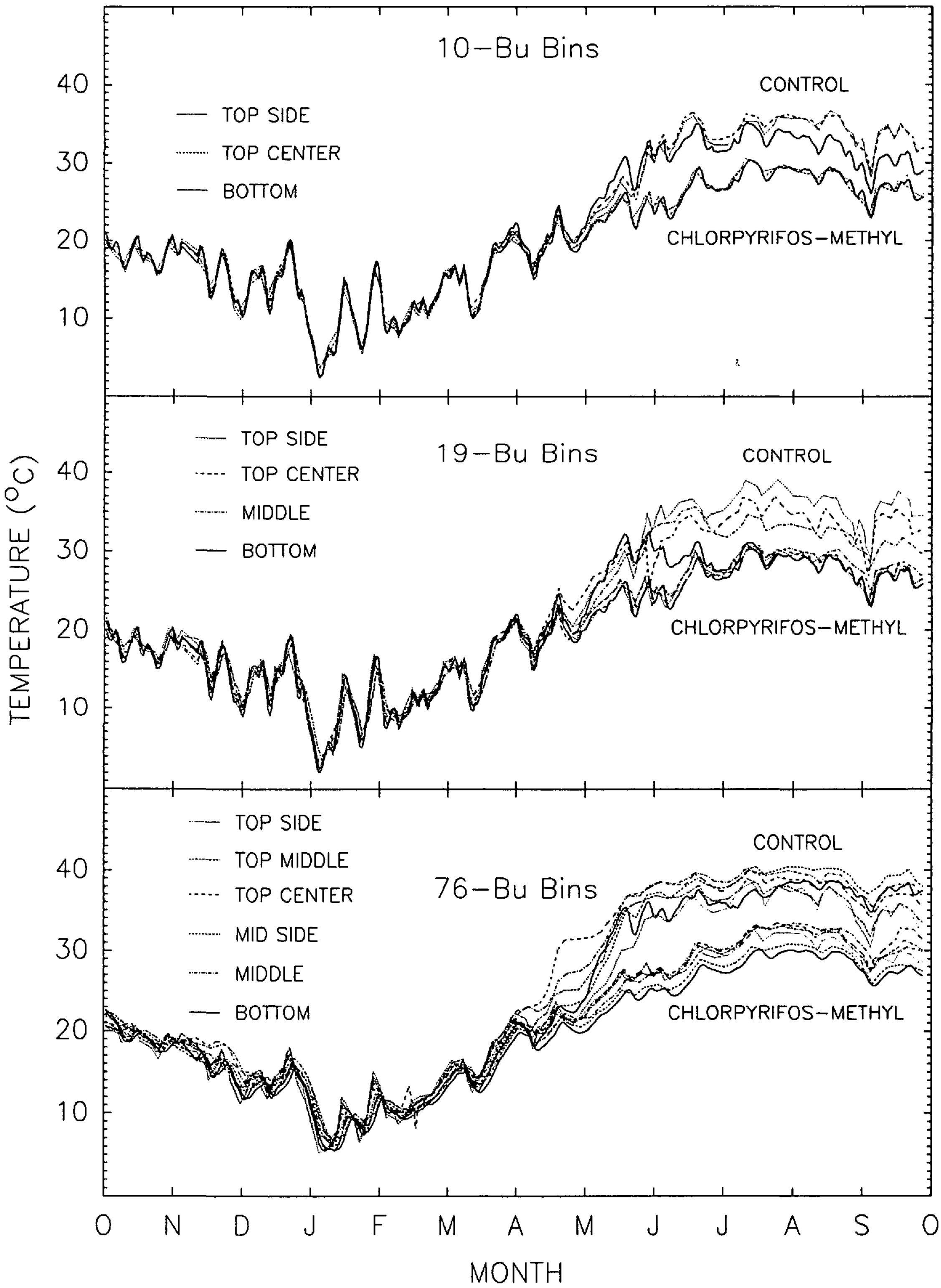

Fig. 4. Temperature profiles during storage in untreated corn and corn treated with 6.0 ppm chlorpyrifos-methyl. Legend denotes positions of temperature probes.

the risk of insect infestation early in the storage season. Our test began in early October, and for the first 6 mo, storage temperatures ranged from 3 to 22°C. Insect development during that time was severely limited. Further reduction of the risk of damage by aerating and cooling grain stored in the Southeast may be possible. Aeration reduces insect pest populations in on-farm storages in Oklahoma (Cuperus et al. 1986), which has a climate similar to much of the Southeast.

In conclusion, residue levels from an application of 6 ppm chlorpyrifos-methyl should control insect pests in stored corn for at least 8 to 10 mo. Plastic pitfall traps can be used to monitor infestations in stored corn following treatment, but indirect techniques of assessing insect damage may not be as accurate as the standard method of examining individual kernels. Future research should include the development of an integrated pest management system for grain stored in the southeastern United States; such a system would include chemical and nonchemical controls, and a monitoring program to accurately determine insect infestations in large bulk storage facilities.

Acknowledgment

We thank J. E. O'Bryan for his excellent technical assistance. We thank K. P. Burnham for statistical assistance, and also thank J. E. Baker, C. M. Christensen, G. W. Cuperus, H. H. Highland, and J. L. Zettler for reviewing the manuscript. Gustafson, Inc. (Plano, Tex.) provided the corn and the insecticide used in this experiment.

References Cited

Adams, J. M. 1976. Weight loss caused by development of *Sitophilus zeamais* Motsch. in maize. J. Stored-Prod. Res. 12: 269–272.

Arthur, F. H., L. M. Redlinger & R. A. Simonaitis. 1988a. Chlorpyrifos methyl as a protectant of farmers stock peanuts. Peanut Sci. 15: 15–18.

Arthur, F. H., J. L. Zettler & W. R. Halliday. 1988b. Insecticide resistance among populations of almond moth and Indianmeal moth (Lepidoptera: Pyralidae) in stored peanuts. J. Econ. Entomol. 81: 1283–1287.

Beeman, R. W., W. E. Speirs & B. A. Schmidt. 1982. Malathion resistance in Indianmeal moths (Lepidoptera: Pyralidae) infesting stored corn and wheat in the north-central United States. J. Econ. Entomol. 75: 950–954.

Chesnut, T. L. & W. A. Douglas. 1971. Competitive displacement between natural populations of the maize weevil and the Angoumois grain moth in Mississippi. J. Econ. Entomol. 64: 864–868.

Cuperus, G. W., C. K. Prickett, P. D. Bloome & J. T. Pitts. 1986. Insect populations in aerated and unaerated stored wheat in Oklahoma. J. Kans. Entomol. Soc. 59: 620–627.

Haliscak, J. P. & R. W. Beeman. 1983. Status of malathion resistance in five genera of beetles infesting farm-stored corn, wheat, and oats in the United States. J. Econ. Entomol. 76: 717–722.

Halliday, W. R., F. H. Arthur & J. L. Zettler. 1988. Resistance status of red flour beetle (Coleoptera: Tenebrionidae) infesting stored peanuts in the Southeastern United States. J. Econ. Entomol. 81: 74–77.

Horton, P. M. 1982. Stored-product insects collected from on-farm storage in South Carolina. J. Ga. Entomol. Soc. 17: 485–491.

1984. Evaluation of South Carolina field strains of certain stored-product Coleoptera for malathion resistance and pirimiphos-methyl susceptibility. J. Agric. Entomol. 1: 1–5.

Howe, R. W. 1965. A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. Stored-Prod. Res. 1: 177–184.

LaHue, D. W. 1976. Grain protectants for seed corn. J. Econ. Entomol. 69: 652–654.

1977. Grain protectants for seed corn: field test. J. Econ. Entomol. 70: 720–722.

LeCato, G. L. 1975a. Species composition influencing insect population growth and weight loss of stored rice, wheat, and corn. J. Kans. Entomol. Soc. 48: 224–231.

1975b. Interactions among four species of stored-product insects in corn: a multifactorial study. Ann. Entomol. Soc. Am. 68: 677–679.

LeCato, G. L. & B. R. Flaherty. 1973. *Tribolium castaneum* progeny production and development on diets supplemented with eggs or adults of *Plodia interpunctella*. J. Stored-Prod. Res. 9: 199–203.

Loschiavo, S. R. 1975. Field tests of devices to detect insects in different kinds of grain storages. Can. Entomol. 107: 385–389.

McGregor, H. E. & K. J. Kramer. 1975. Activity of insect growth regulators, hydroprene and methoprene, on wheat and corn against several stored-grain insects. J. Econ. Entomol. 68: 668–670.

SAS Institute. 1987. SAS/STAT guide for personal computers, version 6 ed. SAS Institute, Cary, N.C.

Zettler, J. L. 1982. Insecticide resistance in selected stored-product insects infesting peanuts in the southeastern United States. J. Econ. Entomol. 75: 359–362.

Received for publication 2 May 1989; accepted 7 August 1989.