BOLL WEEVIL MORTALITY AND MALATHION RESIDUES ON COTTON LEAVES TREATED BY ERADICATION AIRCRAFT

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ABSTRACT

Malathion at rates of 0.73, 0.88, and 1.17 liters per ha (10, 12, and 16 oz per acre) was aerially-applied to approximately 162 ha (400 acres) of cotton by pilots engaged in boll weevil (*Anthonomus grandis* Boheman) eradication in Mississippi. Leaves from treated fields were collected on the day of application and the next 6 days unless rainfall occurred. Toxicity of the treated leaves was evaluated in the laboratory using a petri dish bioassay. Ethanol rinses of leaf surfaces were analyzed for malathion residues. All three rates resulted in consistently high levels of boll weevil mortality, but mortality tended to occur faster at the higher rates, and high mortality persisted longer as rate increased. As time after treatment increased, malathion residues on leaves declined at rates similar to those seen for mortality. Consequently, greater amounts of malathion persisted on leaves treated with the higher rates at any given time period after treatment. More than 20% of malathion residue was found on the bottom surfaces of treated leaves.

INTRODUCTION

An early study with aerially applied ULV (ultra-low-volume) malathion showed rates of 0.66, 1.02, and 1.31 L per ha (9, 14, and 18 oz. per acre) to be effective against the boll weevil, *Anthonomus grandis* Boheman, and not significantly different from each other (Burgess 1965). Other studies showed no difference in mortality of boll weevils in the field following aerial applications of 0.58, 0.88, and 1.17 L per ha (8, 12, or 16 oz. per acre; Cleveland et al. 1966), and a rate of 0.28 L per ha (4 oz. per acre) was shown to be effective (Hopkins and Taft 1967). In the latter study toxic effects of malathion diminished to unacceptable levels 48 hours after application or following rainfall of 12.7 mm (0.5 inches). Nemec and Adkisson (1969) also reported significant reductions in toxicity of ULV malathion to boll weevils following 25.4 mm (1") of simulated rainfall and slight reductions in toxicity of plants subjected to dew. A more recent study showed no significant dew-related differences in either malathion residues or boll weevil mortality following aerial applications of 0.88 L per ha (Kirk et al. 1997).

Malathion is the most costly item required for eradication. Currently, each 0.15 L per ha (2 oz. per acre) reduction in malathion rate reduces costs about 74 cents per ha (30 cents per acre) per application. With many applications over millions of ha, substantial savings to boll weevil eradication can be realized with small reductions in rate. The potential for such savings prompted additional studies in the mid 1990's to determine if the standard boll weevil eradication rate of 1.17 L per ha (16 oz. per acre) could be lowered. Results indicated that boll

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weevil mortality resulting from 0.88 L of malathion per ha (12 oz. per acre) compared favorably to that of 1.17 L per ha (Mulrooney et al. 1995, Mulrooney et al. 1996, Jones et al. 1996, Villavaso et al. 1996). As a result of these studies and the need to reduce the cost of eradication, the 0.88 L per ha rate of malathion was widely accepted as adequate for eradication (in Texas, Louisiana, and Arkansas, for example). To further reduce eradication costs and thereby make boll weevil eradication more palatable to Mississippi producers, the Mississippi Boll Weevil Management Corporation adopted a rate of 0.73 L per ha (10 oz. per acre) in 1997.

The objective of this study was to compare three rates of malathion (0.73, 0.88, and 1.17 L per ha) applied to commercially grown cotton by aerial applicators contracted by the Mississippi boll weevil eradication managers. Comparisons were made using bioassay and chemical analyses. The effect of rainfall was also measured.

MATERIALS AND METHODS

Test Insects. The majority of boll weevils tested were reared from egg to adult at the Gast Insect Rearing Laboratory, USDA, ARS, Mississippi State, MS on the artificial larval diet of Lindig (1979) with Pharmamedia (Trader's Protein, Fort Worth, TX) substituted for cottonseed meal. After emergence, adults were fed wax-coated cylinders (8 mm [dia.] X 10-40 mm) of the same diet until treatment. Mixed sex, 5-7 d old weevils were used.

Native weevils were also tested. They were obtained from fields of commercially-grown cotton by 3 methods: 1) collecting cotton squares (flower buds) that contained immature stages and holding them in computer-controlled environmental chambers that simulated daylength and average temperature for Stoneville, MS over a 15 year period (temperature was adjusted every 15 minutes; humidity was not strictly controlled, but damp sponges were supplied to keep moisture at a high level; see Wagner and Villavaso 1999 for details); 2) collecting adults from open white blooms; and 3) collecting adults captured in pheromone traps (Dickerson 1986).

Malathion Treatments. Three replications of the three malathion (FYFANON® ULV: 95%; 1.17-kg per L; CHEMINOVA, Lemvig, Denmark) treatments (0.73, 0.88, and 1.17 L per ha = 10, 12, and 16 oz. per acre, respectively) were aerially-applied randomly to 9 fields of commercially grown cotton near Starkville, MS. Plots were whole fields, and field size ranged from 23 to 103 ha (4 to 64 acres). Total test area was approximately 162 ha (400 acres). Aircraft (Cessna 188 Ag Truck) and pilots under contract by the Mississippi Boll Weevil Management Corporation were used to apply malathion. The aircraft sprayed a 23 m (75') swath at 194 kph (120 mph) at a pressure of 262 kPa (38 lbs per in^2). Thirteen 8002 nozzles were used to apply 1.17 L per ha (16 oz per acre), and 10 and 8 nozzles, respectively, to apply the 0.88 (12 oz.) and 0.73 (10 oz.) rates. Each treatment was applied 7 times to 3 fields on August 7, 13, 17, 22, and 28 and September 5 and 11. Heavy rains that occurred during the August 13 application prevented its completion and washed the insecticide from the plants in the few fields where it was applied. That partially aborted application was not included in this study, and we report here only the results of the other 6 applications.

Bioassay. Malathion toxicity to boll weevils was evaluated by petri dish bioassay. Leaves were collected from treated cotton plants and put into 15 mm (ht) by 100 mm (dia) petri dishes to which boll weevils were added -- 1 leaf per dish, 1 weevil per leaf. Between August 17 and September 8, ten groups of control weevils were tested. The first group was put on leaves collected from the test fields after a heavy rainfall, and subsequent groups were put on leaves collected from the greenhouse. Dishes were held at approximately 27°C, and 20 weevils per replicate were used to determine each observation of percent mortality noted.

Mortality for the 3 Treatments. Leaves were collected on the day of malathion application and each day thereafter unless rainfall occurred. At first, mortality was recorded at 24 and 48 h of weevil exposure to treated leaves in the petri dishes; however, during the period following the first 3 malathion treatments, casual observations of mortality were made at times other than 24 and 48 h. These observations indicated that mortality occurred more slowly in weevils exposed to leaves treated at the lower rates. So, beginning with the third application, mortality was recorded more frequently.

Mortality Following Short Term Exposure to Treated Leaves. Leaves were collected from each of the 3 treatments on the day malathion was applied. Laboratory-reared weevils were allowed to remain in the dishes containing the leaves for 0.5, 1, 2, or 4 h. They were then removed from the treated leaves and placed in clean dishes with untreated greenhouse leaves. Mortality was recorded 24 and 48 h after the initial placement on leaves.

Mortality of Weevils of Different Ages. Squares containing boll weevil immature stages were collected from the field and placed in environmental chambers simulating the day length and historical average temperatures occurring at Stoneville, MS for the period of incubation (see *Test Insects* above and Wagner and Villavaso 1999). Weevils were collected on the day they emerged and fed squares (flower buds) until treatment. Weevils of 4 ages -- newly emerged, and 1, 2, and 3-d-old -- were placed in petri dishes with leaves collected from the 0.73 L per ha treatment on the day of malathion application. Percent mortality for each treatment was recorded 1, 2, 4, 8, 18, and 24 h later.

Mortality of Weevils Collected from Field Blooms. Weevils feeding on white blooms in the field were collected and placed in petri dishes with leaves collected from each of the 3 treatments. Although we judged the majority of these weevils to be young (less than 2 d old) based on their soft exoskeleton and color, we could not be certain of their ages. Mortality was recorded 2, 4, 8, and 20 h after they were placed in the dishes.

Mortality of Native Weevils from a Variety of Sources. Native weevils were obtained from fields of commercially-grown cotton by collecting cotton squares containing immature stages and holding them in environmental chambers until emergence, by collecting adults from open white blooms, and by collecting adults captured in pheromone traps (Dickerson 1986). Twenty-four groups of native weevils were collected from 4 locations: Washington (Stoneville), Sunflower (Indianola), and Coahoma County, MS and Marianna, AR. Weevils were placed in petri dishes on leaves collected from the 0.73 L per ha treatment between 0 and 5 d following malathion application. Mortality was recorded 24 and 48 h later.

Chemical Assay of Malathion Residues. Malathion residues were washed from 5.06 cm^2 areas of the top and bottom surfaces of 2 samples of 5 leaves for each day-treatment combination. Each surface was rinsed with 3 ml of 100% ethanol with modified Dual Side Leaf Washers (Carlton 1992). Aliquots (2 ml) were placed in auto-sampler vials for analysis by gas chromatography. A Hewlett-Packard 5890 gas chromatograph equipped with a flame photometric detector, an auto-sampler, and ChemStation (Hewlett-Packard) software was used to quantitate malathion residues.

The parameters of our residue analyses method were as follows: Injector temperature, 200° C; oven program, 120° C initial temperature with a 25° C per min increase to 250° C for 1 min, then a 25° C per min increase to 280° C for 4 min. A Hewlett-Packard Ultra-1 cross-linked methyl silicone gum phase column (25 m by 0.32 by 0.52 μm) with a 2.65 ml per min flow of helium was used. Retention time of malathion was 5.597 min. The leaf-washing procedure removed about 60% of the malathion on the leaf surfaces (J. E. M. unpublished) so the data from GC analysis was divided by 0.6 to estimate the actual amount on the leaf surfaces.

Malathion residues for top, bottom, and combined surfaces were averaged by day and treatment for up to 6 days following treatment. Plots of malathion residue versus day after treatment were calculated using Sigma Plot® 5.0 (SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Mortality for the 3 Treatments. Average mortality by treatment and day following treatment is shown in Fig. 1. For leaves collected on days 0, 1, and 2 following malathion application, mortality of weevils held for 24 h on treated leaves in petri dishes was 89-98%, 96-99%, and 98-100% for the 0.73, 0.88, and 1.17 L per ha treatments, respectively. By 48 h mortality had equalized over treatment with 100, 100, and 99% mortality occurring in each treatment for days 0, 1, and 2, respectively. For days 3-6 following treatment, 24 h mortality for the 1.17 L per ha treatment averaged no lower than 90%, but during that period, the lowest observed mortalities in the 0.88 and 0.73 L per ha treatments were 75 and 63%, respectively. After 48 h in the petri dishes, mortality in the 1.17 L per ha group for days 3-6 following malathion application remained near 100%, the lowest being 96% on day 5. Mortalities of the 0.88 and 0.73 L per ha treatments hovered around 90% for days 3-6 with lowest mortalities of 86 and 84%, respectively, also occurring on day 5 for those 2 treatments. The mortality curves for the 3 treatments at 24 h tended to separate widely, but they moved closer together for weevils spending 48 h in the petri dishes. Mortality for the 10 groups of control weevils averaged 1.5 ± 2.4% and 2.0 ± 2.6% at 24 and 48 h, respectively; control mortality never exceeded 5% (= 1 dead of 20 tested).

More frequent recordings of mortality were taken for the third through sixth applications of malathion. Mortality trends at various time periods following leaf collection over days 0-6 after malathion application are depicted in Figs. 2-5. In general, the curves showed a noticeably wide initial gap in mortality between the 3 treatments with greater mortality occurring at the greater malathion rates. This gap tended to narrow as weevils were exposed to treated leaves for longer periods of time, but the 1.17 L per ha rate usually remained higher than the 0.88 L per ha rate which remained higher than the 0.73 L per ha rate. In September, the differences between the treatments did not appear to be as great as they were in August, perhaps as a result of accumulation of greater malathion residues on the September leaves. Greater ambulatory activity by the late-season weevils on the treated leaves is another possible explanation, but we have no data to support this assumption.

As might be expected, boll weevils accumulate more malathion on their bodies while traveling over surfaces with higher malathion residues than over surfaces with lower residues; however, the distance they must travel to accumulate half of the maximum amount they will accumulate at a given level of residue is shorter for the lower residues than for the higher ones. Thus, they accumulate a greater percentage of available malathion faster when traveling over surfaces with lower residues (Mulrooney 2001). Still, the time required to observe a given percent mortality in our study was longer as rate decreased indicating that lethal amounts of malathion were accumulated slower at the lower rates. This circumstance can have consequences for boll weevil eradication. Malathion residues tend to persist or accumulate on leaf surfaces with succeeding applications if rainfall does not occur (Mulrooney and Smith 2001), a phenomenon that our residue data supports. However, frequent rainfall will reduce or eliminate malathion from the field, and where lower rates have been applied, fewer weevils may be in contact with the insecticide long enough to accumulate a lethal dose. During periods of frequent rainfall, timely reapplication should be undertaken.

Our results and those of Mulrooney and Smith (2001) emphasize that focus should be on the amount of malathion on the leaf surface and not necessarily on the number or interval of applications. Ideally, the rate of malathion applied in repeated applications should be adjusted for the amount of malathion on the leaf surface at the time of application. Less malathion should be applied when residues on leaves from previous applications are more than that required for boll weevil control. Previous bioassays have shown that residues of 2.7 and 1.7

μg per cm^2 resulted in 90% mortality of boll weevils exposed to treated leaves for 24 and 48 h, respectively (Villavaso et al. 2001). Full rate applications made when residues on leaves are above 2.7 μg per cm^2 may not be economically justified. This is especially true during rain free periods in late season when the loss of malathion from leaf expansion and plant metabolism is low. Since the greatest amount of malathion is applied during this time of the growing season when program start-ups are initiated, the cost of eradication possibly could be substantially reduced by adjusting the rate of application for the amount of residue already present on the leaf surface.

Mortality Following Short Term Exposure to Treated Leaves. Mortality for laboratory-reared weevils allowed to remain on treated leaves in petri dishes for 0.5, 1, 2, and 4 h, and then removed from the leaves was similar for all 3 malathion rates used (Fig. 6). In the 24 h period following 0.5 h exposure interval, 75, 80, and 95% mortality was observed in the 0.73, 0.88, and 1.17 L per ha groups, respectively; at 48 h mortalities were 80, 100, and 100%. After 1 h of exposure to treated leaves, mortalities were 95, 100, and 90% at 24 h for the 3 treatments, respectively. After 2 h on treated leaves 90% of the 0.73 L per ha group had died compared with 100% in the other 2 treatments; by 48 h all weevils in all treatments were dead. After 4 h of exposure to treated leaves all weevils in all treatments were dead within 24 h. The lag time for mortality to occur in the lower doses was not readily evident in this test.

Mortality of Weevils of Different Ages. Trends in mortality associated with weevils from newly emerged to 3-d-old were not apparent (Fig. 7). These weevils had emerged from field-collected infested squares, and all age groups were placed on leaves collected on the day of malathion application of 0.73 L per ha. The 3-d-old group exhibited the lowest mortality at all time intervals except 2 h, but mortality was not consistent over time for the other 3 age groups. We do not know whether age-related trends would have appeared had we used older weevils.

Mortality of Weevils Collected from Field Blooms. Weevils collected from white blooms in the field tend to be recently emerged insects, but a variety of ages can be found in the blooms. After 2 h on leaves treated with 1.17 L per ha, mortality was more than twice that of weevils

TABLE 1. Percentage Mortality Over Time of Boll Weevils Collected from Field Blooms and Placed on Malathion-Treated Cotton Leaves (0.73, 0.88, and 1.17 L per ha) in Petri Dishes.[a,b]

	L per ha		
Hours on Leaves	0.73	0.88	1.17
2	25	20	55
4	55	70	85
8	100	95	95
20	100	100	100

[a]Weevils collected near Mantee, MS; age unknown.
[b]Leaves collected on the day of malathion application.

on leaves treated with the 2 lower rates (55, 20, and 25%, respectively; Table 1). At 4 h mortality tended to be rate-associated, but by 8 h, mortality in the 3 rates had equalized and was at or near 100% for all treatments.

Mortality of Native Weevils from a Variety of Sources. High mortality was observed in most of the 24 groups of weevils collected by various means and placed on leaves collected from 0-5 d after malathion applications of 0.73 L per ha (Table 2). Even the oldest weevils

TABLE 2. Percentage Mortality at 24 and 48 Hours of Field-Collected Boll Weevils Placed on Malathion-Treated Cotton Leaves (10 oz per acre) in Petri Dishes.

Source of Insects	Age (Background)	Days Since Spray	24 h	48 h
Stoneville. MS	<1 day (lab-emerged)[a]	1	100	100
Stoneville, MS	<1 day (lab-emerged)[a]	2	100	100
Stoneville, MS	1 day (lab-emerged)[a]	3	100	100
Stoneville, MS	2 days (lab-emerged)[a]	1	100	100
Stoneville, MS	2 days (lab-emerged)[a]	2	95	100
Stoneville. MS	2 days (lab-emerged)[a]	3	100	100
Stoneville, MS	Unk. (field-collected)[b]	0	95	100
Stoneville, MS	Unk. (field-collected)[b]	0	90	100
Stoneville, MS	Unk. (field-collected)[b]	1	100	100
Stoneville, MS	Unk. (field-collected)[b]	1	90	100
Stoneville, MS	Unk. (field-collected)[b]	1	85	95
Stoneville, MS	Unk. (field-collected)[b]	2	35	75
Stoneville, MS	Unk. (field-collected)[b]	3	90	100
Indianola, MS	Unk. (bloom-collected)[c]	2	65	95
Indianola, MS	<1 day (lab-emerged)[a]	3	80	100
Indianola, MS	<1 day (lab-emerged)[a]	4	95	100
Coahoma Cty., MS	Unk. (pheromone traps)	2	90	95
Coahoma Cty., MS	Unk. (pheromone traps)	3	60	85
Coahoma Cty., MS	Unk. (pheromone traps)	4	55	80
Coahoma Cty., MS	Unk. (pheromone traps)	5	35	45
Marianna, AR	21 days (lab-emerged)[a]	2	100	100
Marianna, AR	21 days (lab-emerged)[a]	2	100	100
Marianna, AR	21 days (lab-emerged)[a]	3	95	100
Marianna, AR	21 days (lab-emerged)[a]	3	100	100

[a] Lab emerged = infested field squares collected and held in laboratory until weevils emerged. < 1 day = emerged since previous day collection.
[b] Field collected = weevils collected from cotton field as adults; not collected from blooms.
[c] Bloom-collected = weevils collected from blooms in field.
[a-c]and pheromone traps = 20 weevils per sample; weevils 1 day old or older fed squares from emergence until tested.

(21 d) collected near Marianna, AR exhibited 95+% mortality 24 h after being on leaves treated 2-3 d earlier, but age can not necessarily be eliminated as a factor affecting mortality. Some weevils of unknown age collected near Stoneville and Indianola, MS and in Coahoma County, MS exhibited lower than expected mortality when put in petri dishes on leaves treated that same day or days 1 or 2 after treatment. Unexpectedly low 24 h mortality of 35% was seen in one Stoneville group exposed to leaves collected 2 d after treatment, and mortality was 75% at 48 h. A group collected near Indianola showed 65% mortality after 24 h of exposure to leaves treated 2 days earlier, but mortality reached 95% by 48 h. None of the trap-captured groups of weevils from Coahoma County exhibited 100% mortality after 48 h on leaves collected from fields treated 2-5 days earlier. We can not explain why some groups exhibited high mortality and some low mortality under apparently similar circumstances. Uneven deposition of malathion in certain areas of the field may have resulted in the collection of some leaves with lower doses of malathion on them; however, variability in the weevils themselves can not be discounted as a potential influence on low mortality. In any case, fields with persistent weevil populations in spite of eradication efforts should be closely monitored to verify boll weevil susceptibility to malathion and malathion residues on cotton leaves.

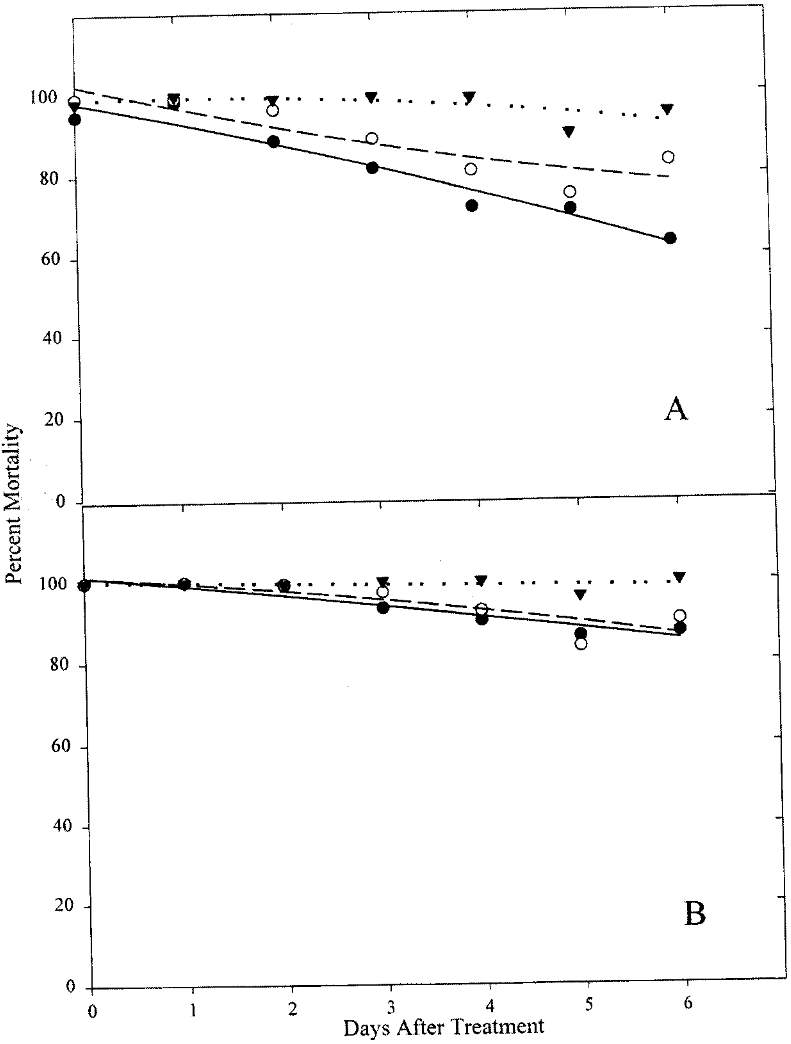

FIG. 1. Average percentage mortality of boll weevils in petri dishes for 24 (A) and 48 (B) hours with leaves from fields receiving 3 rates of malathion. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

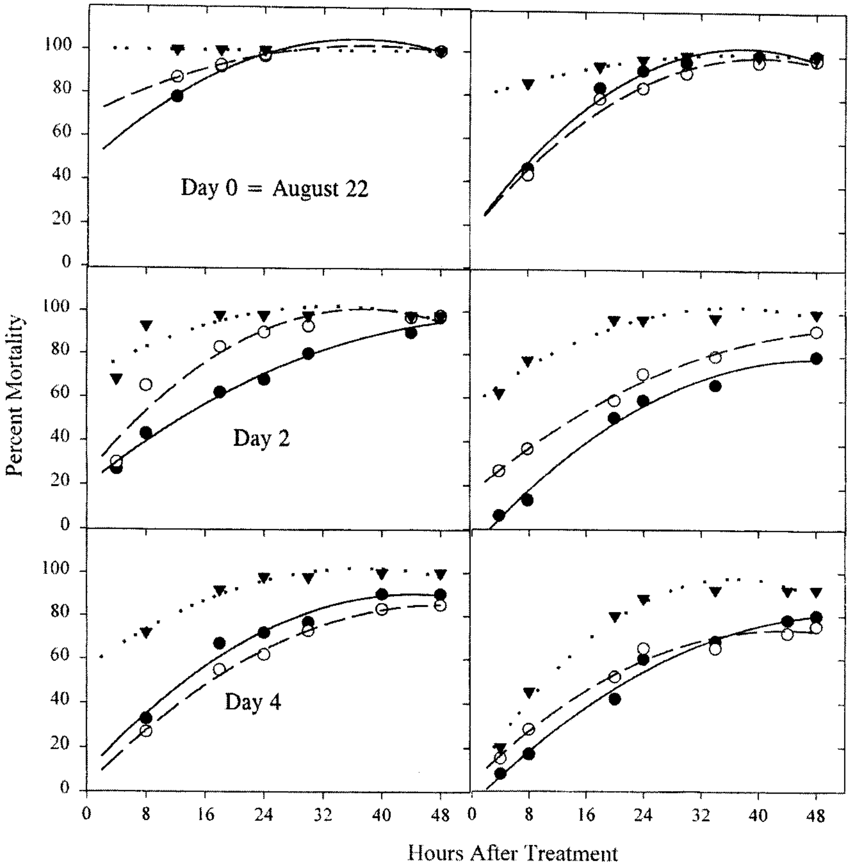

FIG. 2. Average percentage mortality of boll weevils in petri dishes for selected time intervals with leaves from fields receiving 3 rates of malathion on August 22. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

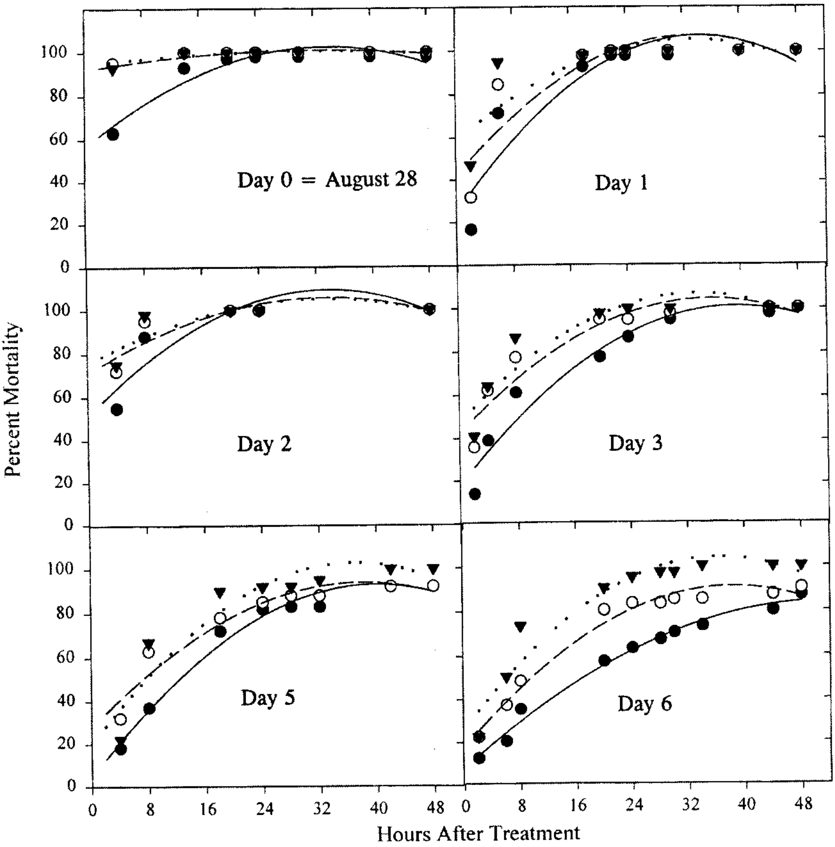

FIG. 3. Average percentage mortality of boll weevils in petri dishes for selected time intervals with leaves from fields receiving 3 rates of malathion on August 28. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

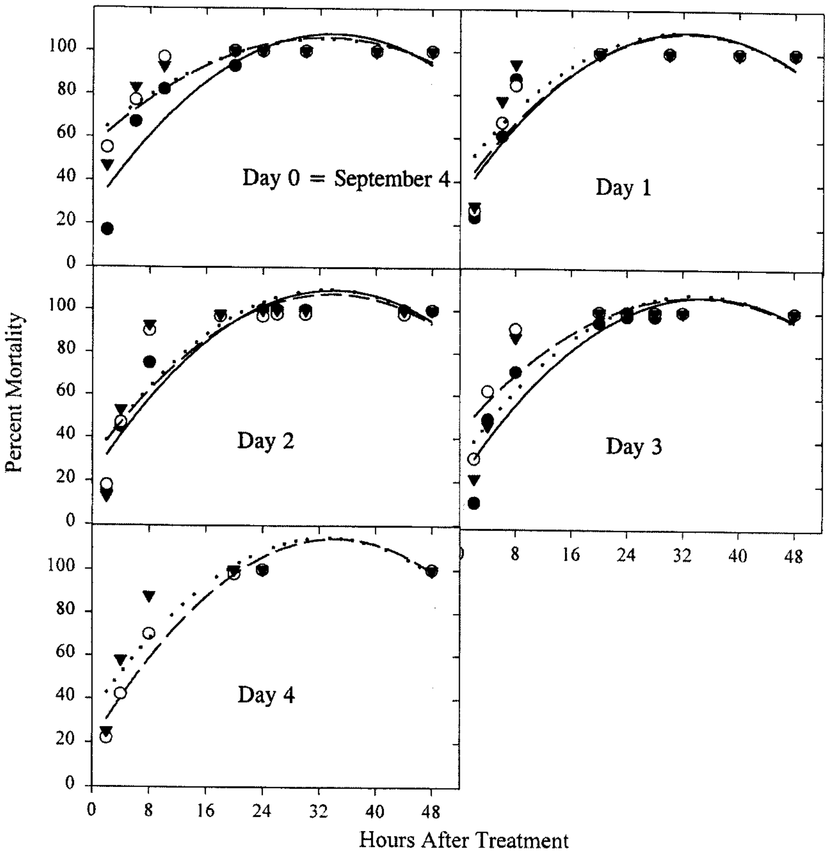

FIG. 4. Average percentage mortality of boll weevils in petri dishes for selected time intervals with leaves from fields receiving 3 rates of malathion on Sept. 4. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

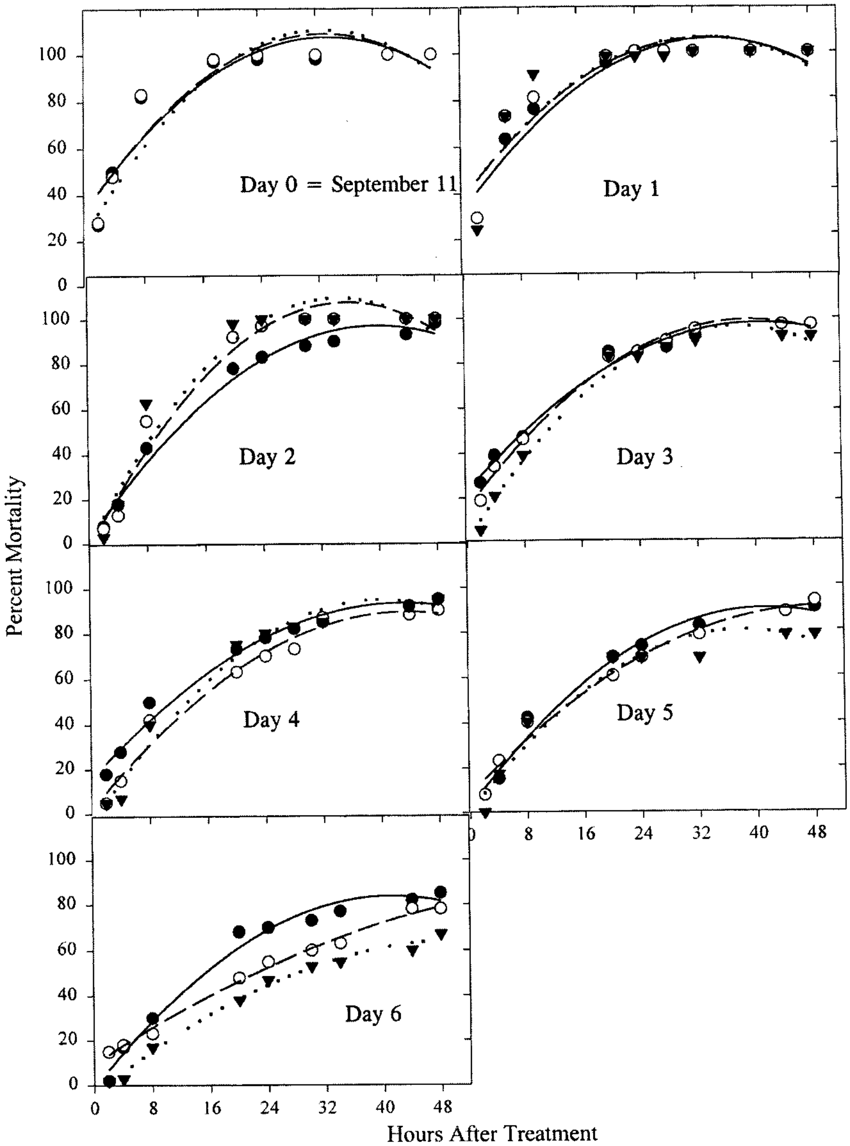

FIG. 5. Average percentage mortality of boll weevils in petri dishes for selected time intervals with leaves from fields receiving 3 rates of malathion on Sept. 11. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

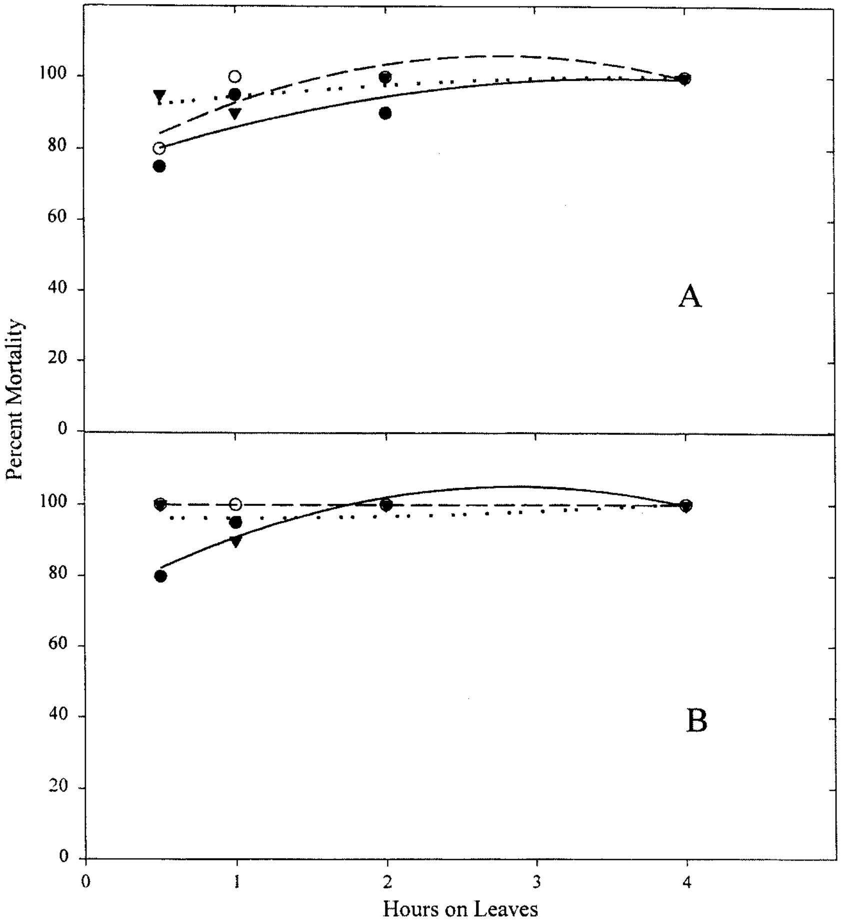

FIG. 6. Percentage mortality of boll weevils 24 (A) and 48 (B) hours after being in petri dishes for 0.5, 1.0, 2.0, or 4.0 hours with leaves from fields receiving 3 rates of malathion on September 11. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

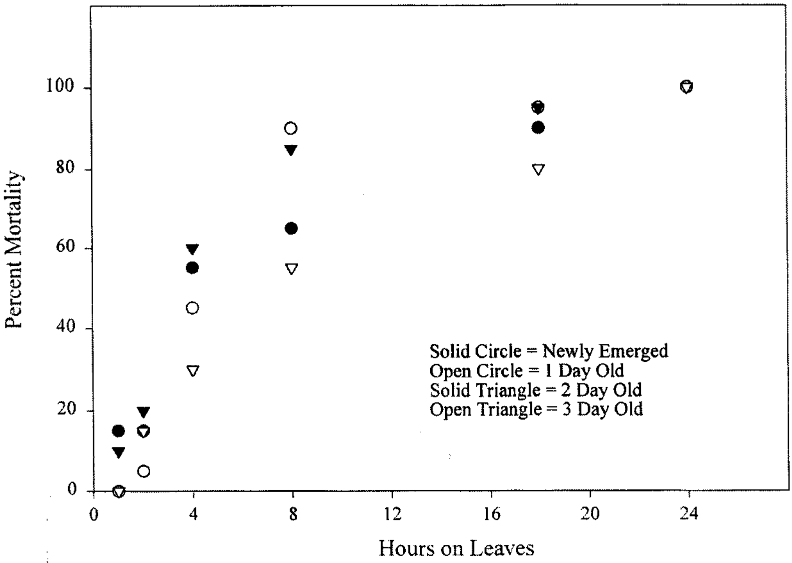

FIG. 7. Percentage mortality of newly-emerged 1, 2, or 3-day-old boll weevils placed in petri dishes for up to 24 hours with leaves from fields receiving 3 rates of malathion. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

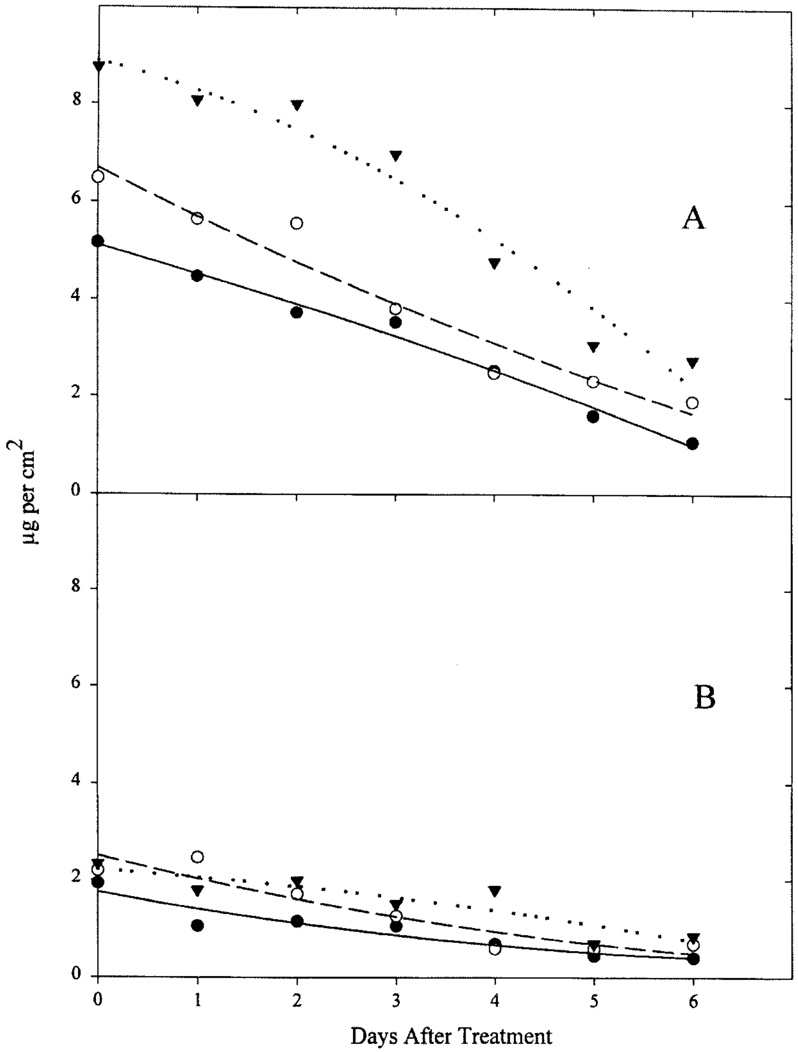

FIG. 8. Average malathion residues (µg per cm^2 of leaf area analyzed) on top (A) and bottom (B) surfaces of leaves collected during days 0-6 following 6 applications of malathion at 3 rates. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

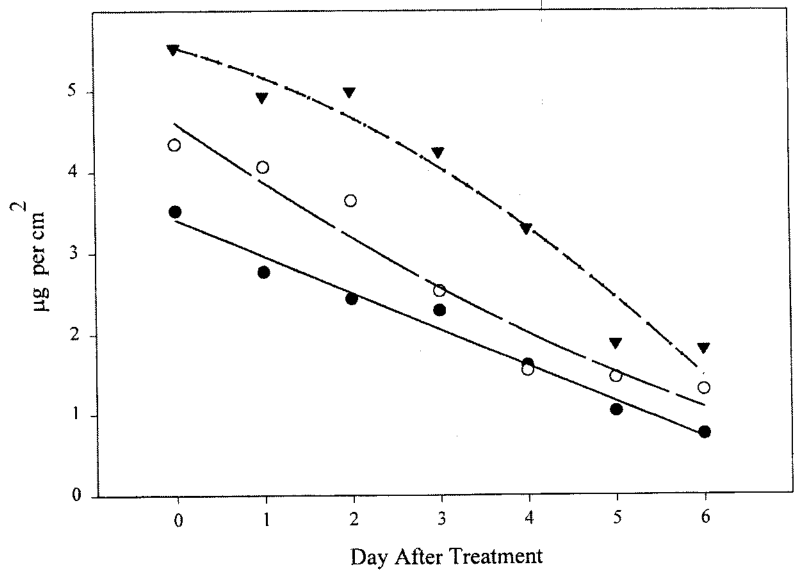

FIG. 9. Average malathion residues (µg per cm^2 of leaf area analyzed) on combined top and bottom surfaces of leaves collected during days 0-6 following 6 applications of malathion at 3 rates. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha.

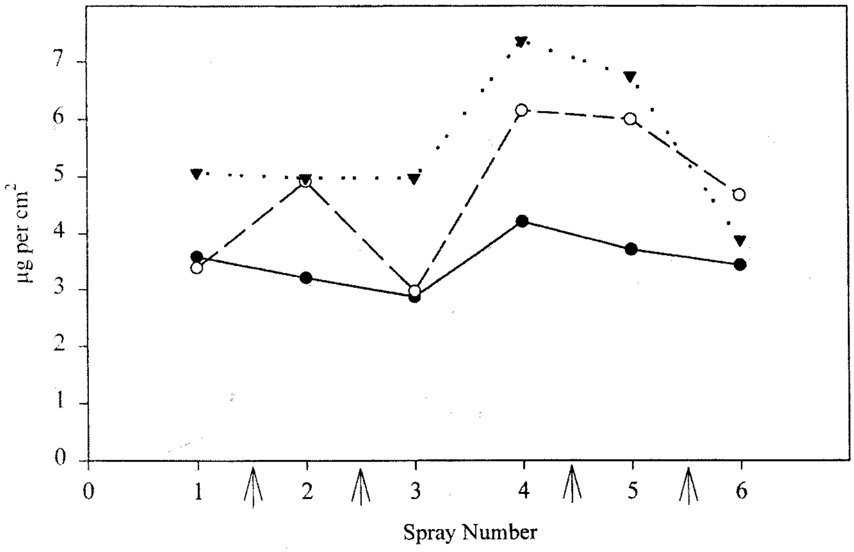

FIG. 10. Average malathion residues (µg per cm² of leaf area analyzed) on combined top and bottom surfaces of leaves collected during days 0-6 following 6 applications of malathion at 3 rates. Solid triangles and dotted lines = 1.17 L per ha; open circles and dashed lines = 0.88 L per ha; and solid circles and solid lines = 0.73 L per ha. Arrows indicate significant rainfall (considerable runoff of water from leaves) except for minor rainfall that occurred between 4th and 5th applications (no runoff).

Chemical Assay of Malathion Residues. Overall averages of 1.90, 2.42, and 3.64 μg per cm^2 were found on the top surfaces and 0.57, 0.81, and 0.94 μg per cm^2 on the bottom surfaces of leaves collected from the 0.73, 0.88, and 1.17 L per ha treatments, respectively. These data indicate that considerable amounts of malathion are deposited on the bottom surfaces of aerially-treated leaves. No rate-related trend in percent deposition on bottom surfaces versus top surfaces occurred. Bottom surface residues made up 23, 25, and 21%, respectively, for the lowest to highest rates.

The average amounts of malathion on the top and bottom leaf surfaces from 0-6 d after treatment are shown in Fig. 8. On the day of treatment, highs of 5.17, 6.48, and 8.87 μg per cm^2 were found on the top surfaces and 1.93, 2.19, and 2.34 μg per cm^2 were found on the top and bottom surfaces, respectively, of leaves collected from the 0.73, 0.88, and 1.17 L per ha treatments, respectively. Top surface lows of 1.08, 1.90, and 2.76 μg per cm^2 and bottom surface lows of 0.40, 0.59, and 0.69 μg per cm^2, respectively, were observed on days 5-6 after treatment.

The average amount of malathion on both surfaces over the test period is presented in Fig. 9. Both Figs. 8 and 9, show the expected: greater rates of malathion leaving the aircraft result in proportionally greater amounts on the leaf surfaces.

Significant rain fell between applications 1 and 2, 2 and 3, and 5 and 6, and malathion residues for application 1 and the 3 applications following the rains (2, 3, and 6) appear to be similar (Fig. 10). No rain occurred between applications 3 and 4 and the amount of malathion on the leaf surfaces on the day of the fourth application increased noticeably, supporting the cumulative effect of sequential applications in the absence of rainfall reported by Mulrooney and Smith (2001). A light drizzle which did not appear to run off of leaves fell between applications 4 and 5. Subsequent mortality in bioassays remained relatively high (Fig. 3), but residues following the fifth application did not increase over that of the fourth application indicating that the base amount of malathion on the leaves had been measurably reduced by this seemingly insignificant amount of rain. Residues collected after the sixth application indicated that the rainfall following the fifth application had washed most of the malathion from the leaves.

These tests were conducted as part of the diapause control phase of boll weevil eradication. Malathion applications were made in August and September when plants were maturing and growth of foliage was slower than that seen earlier in the year. Persistence or increase of malathion residues on older cotton plants in the absence of rainfall may play an important role in the effectiveness of lower rates. Malathion applications to younger plants in a more vigorous stage of foliage growth and leaf expansion will not necessarily duplicate results reported here. A previous study conducted earlier in the season showed that toxicity of treated leaves became erratic after 48 h (Villavaso et al. 1996). Overall, this research indicated that effectiveness of malathion increased as rate increased; however, rates of 0.88 or 0.73 L per ha (12 or 10 oz. per acre) are highly toxic to boll weevils, residual activity persists over several days, and residues accumulate in late season in the absence of rain. The reduced rates appear to be adequate for eradication and can save significant sums of money. Both rates are currently being used for boll weevil eradication in several states.

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