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ENHANCEMENT OF TRANSFER OF TECHNICAL MALATHION FROM COTTON LEAVES TO BOLL WEEVILS USING COTTONSEED OIL

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ABSTRACT

Transfer tests of technical malathion alone and in mixtures of different ratios of cottonseed oil (CSO) were conducted in the laboratory. A Potter spray tower was used to treat cotton leaves excised from plants grown in a greenhouse. Mixtures of malathion:CSO were applied first at constant volume and then at constant rate. CSO was found to enhance transfer of malathion from cotton leaves into boll weevils. Mortality and the amount of malathion transferred to weevils were related to the rate of malathion, the amount of CSO in the mixture, and the volume applied. A three-parameter modified Weibull Function was found to best fit the data. Two types of data were fit. First, maximum cumulative mortality was found to increase with increasing volumes of malathion and a steady state of insecticide transfer to the boll weevil was reached within 5 - 15 cm of travel across a treated cotton leaf. The distance at which half of the maximum cumulative mortality occurred increased as the volume of application increased. Also the rate of cumulative mortality over distance traveled increased when malathion was mixed with CSO. All mixtures except the 1:1 ratio of malathion:CSO had greater maximum cumulative mortalities than an undiluted application of malathion. The highest ratio, 1:9, produced the greatest maximum cumulative mortality (99%) and transferred the greatest amount of malathion from cotton leaves to boll weevils. The second type of data modeled by the cumulative Weibull function was the malathion residue that was transferred to boll weevils as they traveled various distances across leaves treated with various mixtures. Cumulative malathion residue on boll weevils for each treatment followed similar trends as cumulative mortality.

INTRODUCTION

The use of oils as adjuvants for insecticides increased with the popularity of ultra-low-volume application of insecticides to cotton in the early 1980's. Oil diluents have been proposed to have several advantages over water as a carrier. These include a more uniform droplet size, better to be more toxic to boll weevils than a permethrin/cottonseed oil mixture.

During insecticide application; atomization, sedimentation, impaction, and retention on the plant surface affect the amount of insecticide deposited on the plant. Once on the plant surface, the success of the application is dependent upon the amount of insecticide transferred from the plant to the target insect. There is a crucial interaction between the surfaces of the plant and the insect that occurs before the insecticide reaches the target site within the insect. The degree of insecticide transfer depends upon the adhesion forces between the insecticide deposit, the plant surface, and insect surface, and possibly upon the internal cohesion of the insecticide deposit itself (Ford and Salt 1987).

The objectives of this research were to elucidate the process of malathion transfer from cotton leaves to boll weevils and to evaluate cottonseed oil as a facilitator of malathion transfer.

MATERIALS AND METHODS

Different mixtures of malathion and cottonseed oil (CSO) were applied to excised cotton leaves randomly collected from cotton plants grown in a greenhouse. Applications were made using a Potter Spray Tower (Burkard Manufacturing Co., LTD, Rickmansworth, England) set at 68 kPa (Potter 1952). A Potter nozzle with a 0.08 mm diameter orifice was used for atomization. This nozzle applies very fine droplets (10 - 50 µm) with very uniform distribution over a 105 cm^2 area. Once-refined CSO was obtained from Yazoo Valley Oil Mill, Greenwood, MS. Fyfanon® ULV (96.8%), Cheminova Agro, Lemvig, DK was the formulation of malathion used in three tests. The three tests differed as follows:

Test 1. Technical malathion was applied in 50, 100 and 150 µl volumes to excised cotton leaves collected from plants grown in a greenhouse.

Test 2. A constant rate of 39 mg of technical malathion was mixed with CSO at the following ratios (malathion:CSO): 1:1, 1:1.5, 1:4, 1:9 and applied to excised cotton leaves at 66, 82, 165, and 330 µl, respectively. Technical malathion was also applied as an undiluted spray at 33 µl (39 mg).

Test 3. The malathion/CSO mixtures used in Test 2 were applied at a constant volume of 100 µl to excised cotton leaves.

Bioassay and Residue Recovery. Boll weevils, marked with white acrylic paint, were placed on treated leaves one weevil at a time. The distance traveled by the weevil over the leaf surface during a maximum time period of 30 s was measured using a VideoMex-V motion analysis system (Columbia Instruments, Columbus, Ohio). There were five leaves per treatment with ten weevils per leaf. After exposure to the leaf, even numbered weevils were individually placed in 35 ml diet cups containing a diet plug and held for 48 h at which time mortality was recorded and odd numbered weevils were washed in a test tube containing 1.0 ml of iso-octane. After all weevils were exposed to treated leaves, a 2.54 cm diameter leaf disk was cut from the center of each leaf and washed with 5.0 ml of iso-octane to remove insecticide residues. Malathion residues from leaf disks and odd numbered weevils were analyzed using a gas chromatograph equipped with a flame photometric detector (Mulrooney et al. 1997). Percent recoveries of malathion mixed in different volumes of CSO with known amounts placed on cotton leaves were 97 - 103%.

Control weevils were placed on untreated cotton leaves and allowed to crawl across the leaf surface just as those on treated leaves. After exposure to the leaf surface for 30 sec., weevils were placed on diet in 35 ml diet cups for 48 h after which mortality was recorded.

The leaf area covered by a weevil as it travels over the leaf surface was estimated by placing weevils on glass slides covered with carbon soot. The weevil removed the soot from the slide as it crawled over the surface. This area was measured using image analysis (Sigma Scan Pro, Jandel Scientific). The average area (±STD) contacted by an untreated boll weevil as it travels 1.0 cm was estimated to be 0.026 (±0.012) mm^2.

Data Analysis. Cumulative mortality and cumulative insecticide residue were regressed on distance traveled using a Weibull cumulative distribution function to model cumulative mortality (y_1) or cumulative insecticide residue (y_2):

$$F(y_i) = max[1-1/exp(distance/mu)^{rate}] \quad (1)$$

The estimates of parameters from the Weibull function (eqn 1) describe the following:

- max - maximum cumulative mortality (%) or maximum cumulative insecticide residue (µg).
- mu - distance (cm) traveled by the weevil at which half of the maximum mortality or half the maximum insecticide transfer occurs.
- rate - slope of the curve.

F tests were used to compare estimates of these parameters for each treatment.

RESULTS AND DISCUSSION

Test 1. Maximum cumulative (max) mortality increased ($F = 20.91$; df = 2, 76; $P < 0.05$) with increasing volume of malathion as expected (Table 1, Fig. 1). The highest max cumulative mortality was produced by the highest rate applied, 177.1 mg(AI). All malathion rates reached a plateau. The leveling off of insecticide transfer indicates that a steady state is reached at which no additional insecticide is transferred in spite of increased travel across the leaf. A steady state was reached within 5 - 15 cm of travel across the leaf.

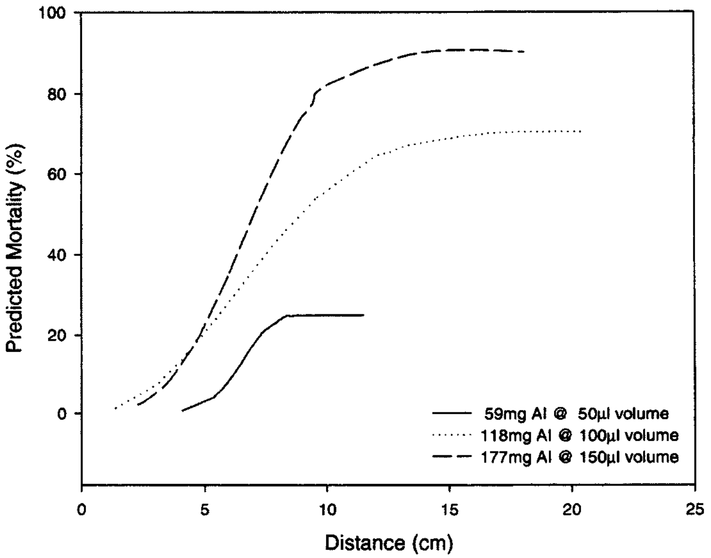

FIG 1. Predicted mortalities (cumulative) of boll weevils after crawling over the surface of leaves treated with different volumes of malathion ULV in Test 1.

TABLE 1. Estimated Parameters of Weibull Function[a] of Cumulative Boll Weevil Mortality (%) and Malathion Residue (μg) Recovered From Boll Weevils Regressed over Distance Traveled across Cotton Leaves Treated with Different Volumes of Malathion ULV.

Volume (μl)	Malathion (mg AI)	Deposition on Leaf (μg/cm²)	Max[b]		Mu[c] (cm)		Rate[d]	
			Mortality	Residue	Mortality	Residue	Mortality	Residue
50	59	6.84 c[e]	25.2 c	5.01 c	6.81 a	6.90 c	7.04 a	5.52 a
100	118	10.83 bc	71.2 b	7.51 b	8.12 a	7.30 b	2.22 c	3.19 b
150	177	22.52 a	90.5 a	16.97 a	7.54 a	7.76 a	3.09 b	3.15 c

[a] $F(y_i) = max[1-1/exp(distance/mu)^{rate}]$.

[b] Maximum cumulative mortality (%) or maximum cumulative insecticide residue (μg).

[c] Distance (cm) traveled by the weevil at which half of the maximum mortality or half the maximum insecticide transfer occurs.

[d] Slope of the curve.

[e] Means in a column not followed by the same letter are significantly ($P<0.05$) different as determined by PDIFF (Littell et al. 1996).

The value of mu for the 177.1 mg(AI) treatment was 7.54 cm. This means that a level of 45% mortality, or one half the maximum mortality of 90%, would occur if weevils traveled 7.54 cm over a cotton leaf treated with 177.1 mg(AI) or a 150 μl volume. Comparisons of mu's showed no significant differences. The numerically shortest mu occurred when weevils walked over cotton leaves treated with 59 mg(AI); however, this mu only resulted in 12% mortality.

Rate is the slope of the curve. The highest ($F=10.36$; $df=3,76$; $P<0.05$) rate among the treatments was that of the 59 mg treatment.

Maximum cumulative residue transferred to the weevil increased ($F=549.24$; $df=3,144$; $P<0.05$) with increasing volume applied (Table 1, Fig. 2). Mu increased ($F=12.46$; $df=3, 144$; $P<0.05$) with increasing volume, while rate decreased ($F=94.84$; $df=3, 144$; $P<0.05$).

Test 2. There were differences between treatments in the amount of malathion deposited on the leaf even though the same rate of malathion was applied with each treatment. Percentage recovery of malathion from cotton leaves with iso-octane washes was 97 - 103%. Therefore, differences in the amount recovered from the leaf were due to application constraints rather than efficiency of the residue recovery method. The greatest amount of malathion (12.13 μg) was recovered from leaves treated with technical malathion (Table 2). The lowest amount of malathion (6.75 μg) was recovered from leaves treated with the 1:4 mixture ratio of malathion:CSO. It is not known why this decrease in deposition for the 1:4 ratio occurred. There were no significant differences in leaf residues between the other three malathion:CSO mixtures.

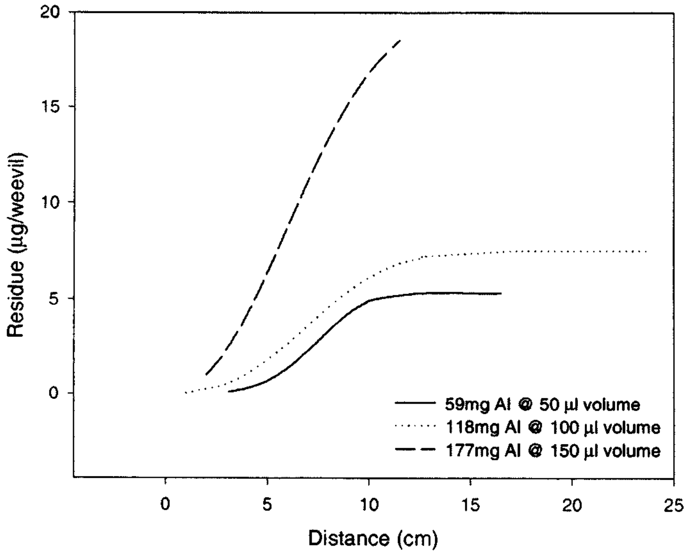

FIG 2. Predicted malathion residue (cumulative) transferred to boll weevils from leaves treated with different volumes of malathion ULV in Test 1.

An examination of the parameters of the Weibull function showed that, except for the 1:1 ratio of malathion to CSO, all mixtures of malathion with CSO had greater ($F=46.44$; $df=4, 82$; $P<0.05$) max mortality than sprays of technical malathion ULV (Table 2, Fig. 3). The 1:9 ratio, which was the highest volume applied, produced the greatest maximum cumulative mortality (99%) and transferred the greatest ($F = 4.74$; $df=1, 37$; $P<0.05$) amount of malathion (2.94 μg) from cotton leaves to boll weevils (Fig. 4).

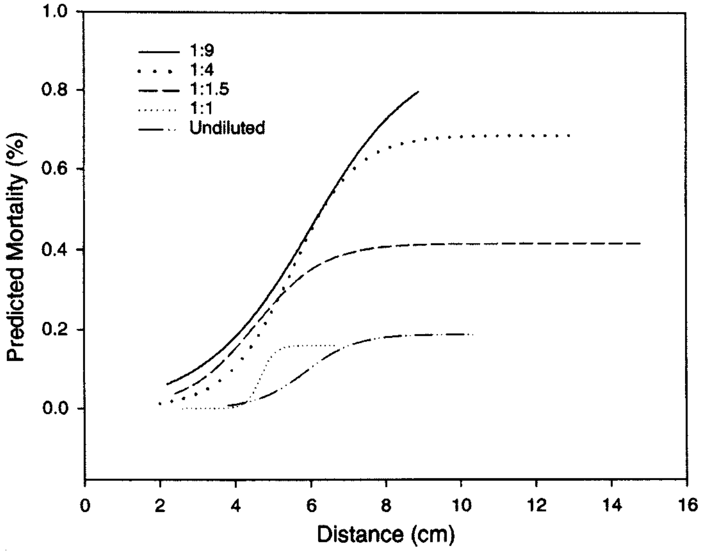

FIG 3. Predicted mortalities (cumulative) of boll weevils after crawling over the surface of leaves treated with different ratios of malathion ULV:cottonseed oil applied at constant rate of malathion in Test 2.

The degree to which a pesticide is bound to the plant is dependent upon different physical processes acting simultaneously, such as adhesion, electrostatic forces, and solubility. Malathion being lipophilic is attracted to both the wax found on the plant and on the boll weevil. For increased transfer to occur this competition for malathion between the leaf and the weevil must be minimized. Increasing the volume of application with CSO should make malathion more available for transfer to weevils contacting residues on the leaf surface.

Boll weevils accumulated a slightly greater amount of malathion after walking across leaves treated with the 1:1.5 ratio (2.03 μg) than with the 1:4 (1.73 μg). This difference in transfer is probably due to the decreased deposition that occurred when the 1:4 ratio was applied to leaves. Except for the result with the 1:4 mixture, mortality and the amount of malathion transferred to weevils were relative to the amount of CSO in the mixture and to the volume applied.

TABLE 2. Estimated Parameters of Weibull Function[a] of Cumulative Boll Weevil Mortality (%) and Malathion Residue (µg) Recovered from Boll Weevils Regressed over Distance Traveled across Cotton Leaves Treated with a Constant Rate (39 mg) of Malathion ULV Mixed with Different Volumes of Cottonseed Oil.

Ratio (malathion:CSO)	Volume Applied (µl)	Deposition on Leaf (µg/cm^2)	Max[b]		Mu[c] (cm)		Rate[d]	
			Mortality	Residue	Mortality	Residue	Mortality	Residue
1:9	330	8.48 b[e]	99 a	2.94 a	7.23 a	5.88 c	2.64 d	3.95 a
1:4	165	6.75 c	67 b	1.73 c	5.92 b	5.55 d	4.44 b	3.76 ab
1:1.5	82	7.12 bc	41c	2.03 b	4.97 c	6.10 ab	3.45 c	3.28 bc
1:1	66	8.45 b	16 d	1.34 d	4.78 c	6.27 a	17.92 a	4.10 a
undiluted	33	12.13 a	19 d	1.07 e	6.24 ab	6.00 bc	6.34 b	2.50 c

[a] $F(y_i) = max[1-1/exp(distance/mu)^{rate}]$.

[b] Maximum cumulative mortality (%) or maximum cumulative insecticide residue (µg).

[c] Distance (cm) traveled by the weevil at which half of the maximum mortality or half the maximum insecticide transfer occurs.

[d] Slope of the curve.

[e] Means in a column not followed by the same letter are significantly ($P<0.05$) different as determined by PDIFF (Littell et al. 1996).

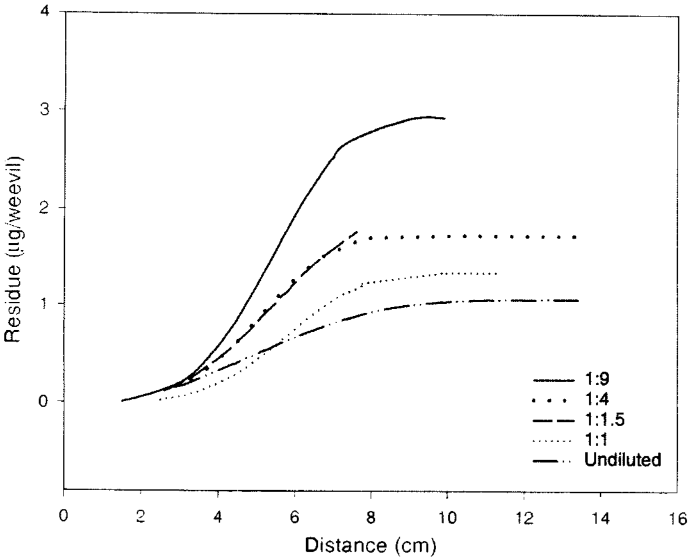

FIG 4. Predicted malathion residue (cumulative) transferred to boll weevils from leaves treated with different ratios of malathion ULV:cottonseed oil applied at constant rate of malathion.

Mu is the distance in centimeters traveled by the weevil over the leaf surface required to reach 50% of maximum mortality or to accumulate 50% of maximum insecticide residue. The lower ratios of malathion:CSO, 1:1 and 1:1.5, had shorter mu's for mortality, 4.78 and 4.97 cm respectively, than the undiluted (6.24 cm) and the highest ratio, 1:9 (7.23 cm).

The relationship between maximum cumulative residue and mu for residue seems to be more direct than the relationship between maximum cumulative mortality and mu for mortality. For example, the highest maximum residue found on the weevil was 2.94 µg, observed for the highest ratio, 1:9. This ratio had the shortest mu, 5.88 cm. Indicating that a greater volume of CSO mixed with malathion increases transfer of malathion from the cotton leaf to the boll weevil over a shorter travel distance. Whereas, a comparison of maximum mortality and mu for mortality showed that the 1:9 ratio had a maximum mortality of 99% with a mu of 7.23 cm which was the longest mu among the treatments. The malathion:CSO ratios that had higher maximum cumulative mortalities generally had longer mu's for mortality. The exception was undiluted malathion which had a statistically identical mu (6.24 cm) to that of the 1:9 ratio (7.23 cm).

There was no relationship between rate (slope) and the volume of CSO in the mixture for either mortality or residue. The lowest ratio, 1:1, had a much higher rate for mortality than the other ratios, yet maximum cumulative mortality for this ratio was only 16%.

Test 3. When a constant volume was applied, maximum cumulative boll weevil mortality was related to the concentration of malathion in CSO (Table 3, Fig. 5). This would be expected since lower amounts of malathion were applied when a constant volume of 100 µl of each mixture was sprayed onto each leaf. The highest ($F=24.65$; $df=4, 94$; $P<0.05$) mortality (81%) occurred when boll weevils crawled across leaves treated with 100 µl of undiluted technical malathion (118 µg). The lowest mortalities were observed in weevils exposed to leaves treated with 1:9 and 1:4 ratios, which were the more dilute mixtures of malathion and CSO. Maximum cumulative residue found on the weevil was also related to the amount of technical malathion applied to the leaf (Table 3, Fig. 6). The greatest ($F=62.50$; $df=4, 93$; $P<0.05$) maximum cumulative residue, 4.58 µg, was found on weevils that had crawled over leaves treated with 118 mg of undiluted technical malathion. While the lowest residue, 1.28 µg, was recovered from weevils placed on leaves treated with 14 mg of malathion mixed in a 1:9 ratio with CSO.

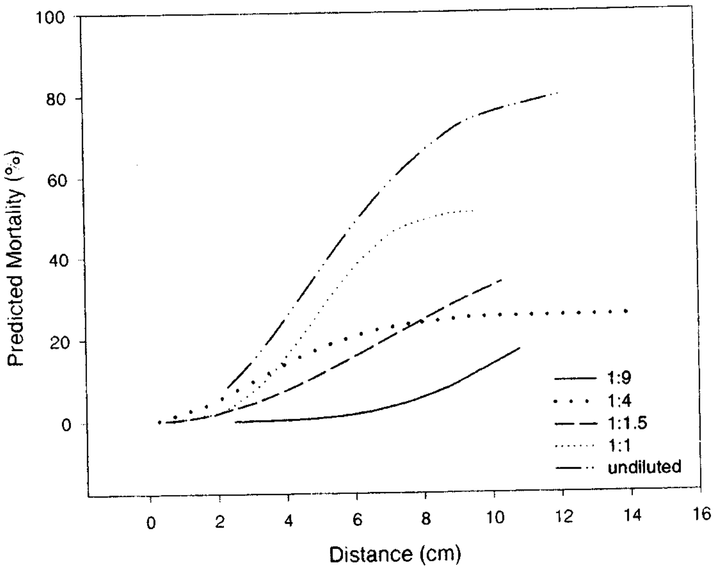

FIG 5. Predicted mortalities (cumulative) of boll weevils after crawling over the surface of leaves treated with different ratios of malathion:cottonseed oil applied at constant volume in Test 3.

Cottonseed oil seems to be aiding the movement of malathion into the weevil. For example, when 118 mg of undiluted malathion was applied to the leaf in the constant volume (100 µl) test, maximum cumulative residue found on the weevil was 4.58 µg. Mortality of weevils crawling over these leaves was 81%. When 39 mg of malathion was mixed in a 1:9 ratio with CSO in the constant rate test and applied at 330 µl to leaves, maximum cumulative residue found on the weevil was 2.94 µg, yet maximum cumulative mortality of weevils crawling over the leaves was 99%.

TABLE 3. Parameters of Weibull Function[a] of Cumulative Boll Weevil Mortality (%) and Malathion Residue (μg) Recovered from Boll Weevils Regressed over Distance Traveled across Cotton Leaves Treated with a Constant Volume (100 μl) of Malathion ULV Mixed with Different Volumes of Cottonseed Oil.

Ratio (malathion:CSO)	Malathion Applied (mg)	Deposition on Leaf (μg/cm²)	Max[b]		Mu[c] (cm)		Rate[d]	
			Mortality	Residue	Mortality	Residue	Mortality	Residue
1:9	14	6.17	30 bc[e]	1.28 e	11.23 a	7.04 a	4.63 a	3.92 a
1:4	28	7.69	25 c	1.55 d	4.55 d	5.27 d	1.82 c	2.24 c
1:1.5	57	11.70	47 b	2.45 c	9.34 a	6.64 b	2.07 c	3.04 ab
1:1	71	18.74	51 b	3.09 b	5.52 c	4.88 d	3.16 b	2.57 bc
undiluted	118	41.20	81 a	4.58 a	6.34 b	6.15 c	2.18 c	2.34 c

[a]$F(y_i) = max[1-1/exp(distance/mu)^{rate}]$.

[b]Maximum cumulative mortality (%) or maximum cumulative insecticide residue (μg).

cDistance (cm) traveled by the weevil at which half of the maximum mortality or half the maximum insecticide transfer occurs.

[d]Slope of the curve.

[e]Means in a column not followed by the same letter are significantly ($P<0.05$) different as determined by PDIFF (Littell et al. 1996).

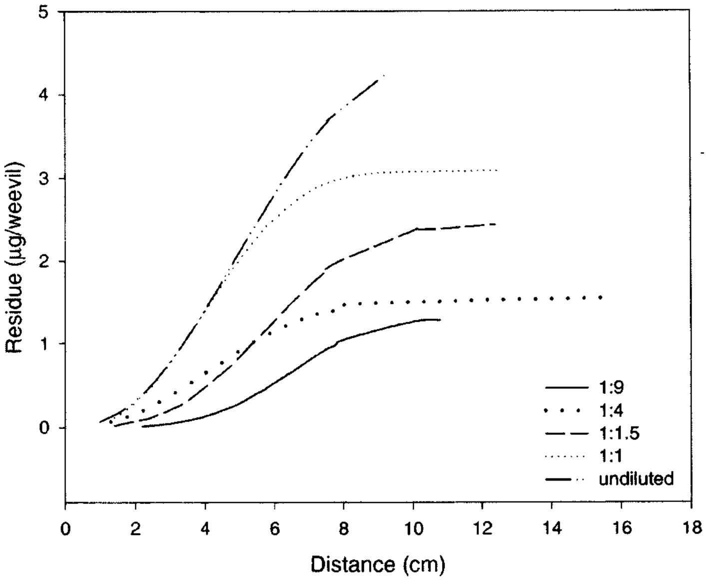

FIG 6. Predicted malathion residue (cumulative) transferred to boll weevils from leaves treated with different ratios of malathion ULV:cottonseed oil applied at constant volume in Test 3.

A measure of contact angles of malathion:CSO droplets on a paraffin substrate showed that malathion:CSO mixtures had contact angles that ranged from 24 - 28° compared to 43° for undiluted malathion (unpublished data). The lower the contact angle the greater the affinity of the liquid for the solid substrate and the greater the spread of the liquid over the surface. Increasing the spread of malathion:CSO mixtures should increase the amount of malathion entering the weevil.

This research was designed to investigate the relationship between rate and volume of application and how these variables affect the transfer of malathion from cotton leaves to boll weevils. The rates and volumes used were 10 - 80 and 13 - 130 times greater, respectively, than those used in the field. These high rates and volumes were necessary in order to obtain an observable response from boll weevils crawling short distances (0 -20 cm) across cotton leaves treated with malathion.

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