

Field Tests of Environmentally Friendly Malathion Replacements to Suppress Wild Mediterranean Fruit Fly (Diptera: Tephritidae) Populations

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ABSTRACT This article reports a large-scale field test of two environmentally friendly malathion replacements on wild populations of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann): spinosad, a bacteria-derived toxin, and phloxine B, a red dye with phototoxic properties. The comparison test was conducted on 11 coffee fields infested with wild populations of Mediterranean fruit fly on the Hawaiian island of Kauai with 8-wk protein bait sprays with and without toxicants. To assess effectiveness, adults were trapped and larval infestation levels were evaluated with fruit collections. Malathion was found to be the most effective treatment. However, the two replacements gave significant levels of control, and because they are environmentally safer, should be considered for eradicating incipient populations of this invasive species of fruit fly. Cage tests were also conducted to ensure that the wild flies consumed the bait and to assess how long the bait-toxicant combination remained effective in the field. Although spinosad and phloxine B were found to be effective up to 1 wk, malathion remained effective at least 2 wk.

KEY WORDS *Ceratitis capitata*, malathion, spinosad, phloxine B

MEDITERRANEAN FRUIT FLY, *Ceratitis capitata* (Wiedemann), is one of the most destructive pests of fruits in the world. The larvae attack >300 species of fruits and vegetables (Liquido et al. 1997). It is thought to have originated in Africa and from there spread throughout much of the world between 30° N and 30° S latitudes, except tropical Asia and controversially, North America (Carey 1991, White and Elson-Harris 1992). Sustained efforts to control this pest are ongoing throughout the world, including Australia, South Africa, Israel, Central America, and the Mediterranean area. Because of its destructive potential to fruit producers in the continental United States, large-scale monitoring and action programs have been implemented in states such as California and Florida to combat the arrival of this invasive species (Dowell 1988, Siebert and Cooper 1995, Dowell et al. 1999).

Malathion bait sprays are used to help eradicate Mediterranean fruit fly invasions, but their use has been controversial because of human health concerns (Flessel et al. 1993, California Department of Food and Agriculture 1994, Marty et al. 1994) and harmful effects on beneficial insects, including bees and the natural enemies of pest insects (Troetschler 1983, Ehler and Endicott 1984, Hoy and Dahlsten 1984, Cohen et al. 1987, Daane et al. 1990, Hoelmer and

Dahlsten 1993, Messing et al. 1995). Finding malathion replacements has been identified as a primary concern for agencies such as California's fruit fly action programs (Dowell 1995, Buchinger 1996). Two possible malathion replacements, spinosad and the photoactive dye phloxine B, are currently under consideration.

Spinosad is an insecticidal toxin of two macrocyclic lactones called spinosyns A and D, derived from metabolites of the actinomycete bacterium *Saccharopolyspora spinosa* (Sparks et al. 1998). It is the active ingredient of DowAgro (Indianapolis, IN) insecticides Conserve, SpinTor, Success and Tracer. These products are effective against many dipteran and lepidopteran pests (Adán et al. 1996, King and Hennessey 1996, Sparks et al. 1998). Experimental formulations of spinosad are effective against fruit flies in the family Tephritidae, including *C. capitata*, when incorporated into protein bait at doses as low as 1 ppm active ingredient (unpublished data). Spinosad also has very low vertebrate toxicity (e.g., rat acute oral toxicity [Fischer 344] LD₅₀ > 3,500 mg/kg [DowElanco 1994]). Spinosad is most effective when consumed but also can affect insects that have ectodermic contact with the toxin (DowElanco 1994).

Phloxine B (2',4',5',7'-tetrabromo-4,5,6,7-tetrachloro-fluorescein, disodium salt) is a photoactive dye that has insecticidal properties and is effective against a variety of insects including the house fly, *Musca domestica* L., *C. capitata*, and other species of fruit fly in the family Tephritidae (Fondren and Heitz 1978, Heitz 1995, Liquido et al. 1995, Schroder et al. 1998). When an insect ingests the dye and is exposed to light, the dye oxidizes within the insect's tissues and causes

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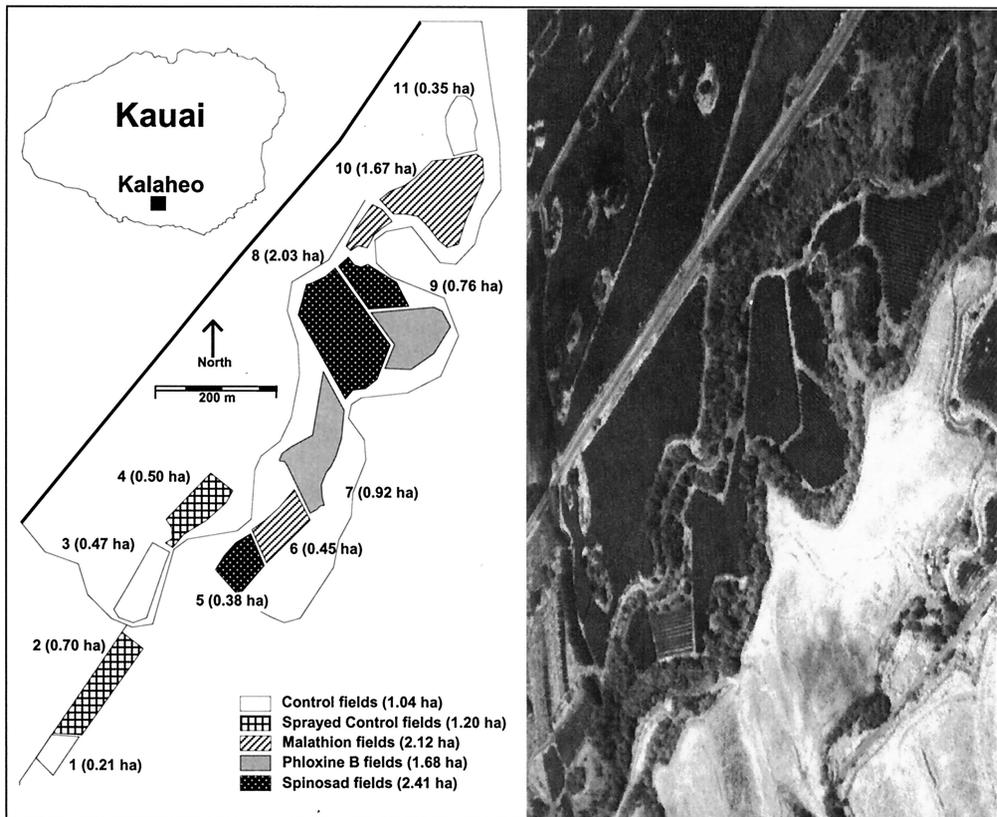


Fig. 1. Treatment and control fields in the Kalaheo Gulch area on the island of Kauai in Hawaii. Fields 5–11 are within the gulch, a stream bottom area varying between 10 and 50 m below fields 1–4, which are situated on the western bench at ≈ 220 m elevation. Roads ≈ 10 m wide separate each of the fields. Control fields one and two are surrounded on the north and west by pruned coffee trees and by scrub vegetation on the south and east, all of which is without fruit to act as host for the medfly larvae. Control fields three and four are surrounded on the north and west by continuous planting of mature coffee trees and on the south and east by scrub vegetation without Mediterranean fruit fly host. The walls of the gulch valley contain scrub vegetation and scattered individuals of volunteer passion fruit, mango, and guava.

death. The specific mode of action of these dyes, however, has not yet been determined. It has no contact toxicity. An advantage of this dye is that it has very low vertebrate toxicity. Phloxine B is registered as D and C Red Dye No. 28 in the United States for use in pharmaceuticals and cosmetics, with the U.S. Food and Drug Administration estimating a maximum acceptable daily intake for humans to be 1.25 mg/kg body weight per day (Anonymous 1982). Because the dye must be ingested to be effective, it is considered safe for beneficial insects as they generally do not eat the bait (Dowell 1997). A formulation of phloxine B and protein bait for fruit flies is marketed as SureDye by Photodye International (Baltimore, MD).

Despite the potential of these alternatives, field tests that provide a direct comparison of the effectiveness of these toxicants to malathion in fruit fly bait sprays has been lacking on wild populations of *C. capitata*. Herein we report on a large-scale field test to compare the effectiveness of these three insecticides in controlling wild Mediterranean fruit fly populations.

Materials and Methods

The test was conducted on 11 coffee fields managed by Kauai Coffee located in the Kalaheo gulch on the island of Kauai in Hawaii (Fig. 1). These fields were selected because their isolation from other coffee fields minimized potential immigration of the flies after pesticide treatment, and because the population dynamics of these flies has been studied for several years (Vargas et al. 1995). From these fields, two were selected (except for unsprayed control for which three fields were selected) for each of the following five treatments: (1) unsprayed control, (2) control sprayed with protein bait lacking a toxicant, (3) sprayed with protein bait containing spinosad, (4) sprayed with protein bait containing phloxine B, and (5) sprayed with protein bait containing malathion. The fields were selected rather than randomized because control fields could not be dispersed among treatment fields in the gulch without the risk of treatment effects swamping the effects of neighboring plots and the potential problems in creating a popu-

lation sink if malathion plots were placed together. This spatial arrangement of plots allowed each of the treatments to be bordered by the other two treatments. Coffee plants were in rows spaced ≈ 3.7 m apart, with fields all separated by natural ≈ 10 -m breaks. *C. capitata* is not a strong flier and does not disperse far from its place of origin if mating opportunities are present, and host fruit is available for oviposition (Plant and Cunningham 1991). Therefore, the fields were assumed far enough apart to provide independent assessments of treatment effects. Coffee was commercially harvested in both of the sprayed control fields and two of the three unsprayed control fields in the course of this study. Two weather stations were set up within the study area to record rainfall, temperature, relative humidity, wind speed, and wind direction throughout the course of the experiment.

Bait Spray Solutions. Four different bait solutions were prepared: control, spinosad bait solution, phloxine B bait solution, and malathion bait solution. The control was composed of 70% (vol:vol) Mazoferm E802 (Corn Products, Argo, IL), 20% (vol:vol) invertose (Liquid Sugar Incorporated, Emeryville, CA), 6.0% (vol:vol) water, 2.0% (vol:vol) polyethylene glycol 200 (ICN Biomedicals, Aurora, OH), 1.0% (vol:vol) polysorbate 60 (Soco-Lynch, Los Angeles, CA), 1.0% (vol:vol) soybean oil (Hunt-Wesson, Fullerton, CA), and 0.6% (wt:vol) ammonium acetate (Sigma, St. Louis, MO). The spinosad bait solution was composed of 0.01% (wt:wt) spinosad active ingredient (a mixture of Spinosyn A and Spinosyn D) mixed into the control bait. The spinosad (NAF-315; Lot #MB1116OP21) was provided by Dow AgroSciences (Indianapolis, IN). This sample consisted of 22.8% active ingredient. The phloxine B bait solution included 0.5% (wt:wt) phloxine B (89.0% purity; Hilton-Davis, Cincinnati, OH) mixed into the control bait. The malathion bait solution consisted of 20% technical malathion (Fyfanon ULV, Cheminova, Wayne, NJ) and 80% NuLure (Miller Chemical and Fertilizer, Hanover, PA). Concentrations of toxicants in the bait sprays were based on preliminary laboratory experiments (spinosad, unpublished data), prior field trials (phloxine B [unpublished data] and spinosad [King and Hennessey 1996]), and standard formulation for aerial spray programs (malathion). The spray was applied through two Tee Jet 5500-X2 (for the Malathion bait spray) or two Tee Jet 5500-X3 (for the other three treatments) cone jet spray nozzles, one on each side, set to deliver a slightly loose stream spray, attached to a boom at the back of an all terrain vehicle. Each coffee row was sprayed on both sides. Fields for each treatment were sprayed concurrently with the order of spraying reversed each week. Weekly spraying began on 3 November 1998, after trapping indicated that fly populations in most of the fields had begun their annual increase, and continued until 22 December 1998, for a total of eight sprays. Rate of application of bait sprays averaged 15 liters/ha (malathion bait spray) and 22 liters/ha (other treatments). A lower spray rate was used for malathion to bring the application rate closer

to the standard used in aerial sprays. Total area sprayed was 1.20 ha (sprayed control), 2.41 ha (spinosad treatment), 1.68 ha (phloxine B treatment), and 2.12 ha (malathion treatment). Based on the concentration of active ingredients in the bait solutions, the spray rates, and estimates of spray areas, the applications provided 2.08, 146, and 3,720 g (AI)/ha for spinosad, phloxine B, and malathion, respectively (ratio of 1:70:1,790).

Population Assessment. Population assessment was based on servicing traps weekly and weekly ripe coffee cherry collections. Traps were covered 90 mm diameter by 150 mm cylindrical plastic tubes with three 23-mm holes regularly spaced around the sides. The trap had an open bottom into which a 78 by 127-mm double-sided sticky card was inserted to capture the flies. Traps were baited with a synthetic food bait (ammonium acetate, putrescine, and trimethylamine; Consep, Bend, OR) attractive to Mediterranean fruit flies (Epsky et al. 1999). Traps were placed in all fields on 25 August 1998, and serviced weekly until 4 wk after the last spray, at which time Kauai Coffee harvested and destroyed coffee cherries from all treated fields. Additional traps were added on 26–27 October, the week before the first spray, to increase trap number in each field. A density of nine traps per hectare with a minimum of three traps per field was targeted for the trapping scheme, with all traps placed well within the borders of their respective fields. The sticky panels in the traps were replaced weekly and the three chemical attractant packages (putrescine, ammonium acetate, and trimethylamine) were replaced every month. These traps have an effective radius of attraction of ≈ 20 m (unpublished data).

Ripe Fruit Collections. Three-quarters to full ripe coffee cherries were randomly sampled weekly from each field from 10 September 1998 to 19 January 1999 to assess level of infestation by tephritid fruit flies. Each week, in each field, 25 cherries were taken from each of 10 points, determined by a randomly selected interval of one to five trees, in four randomly selected rows. The morning after collection, cherries were dipped in a 10% bleach solution to reduce mold growth, allowed to drain, and then placed in 41.0 by 28.0 by 6.3-cm wooden screened bottom, open-top trays that were then tape sealed into 50.0 by 32.0 by 15.0-cm fiberglass bins with screened openings in the sides to provide aeration and sand on the bottom to provide a medium for pupation. The sand in the bins was sifted 1, 2, and 3 wk later to recover any pupae or popping third instars, which were then transferred to cups with sand in which adults were allowed to emerge. Adult flies and parasitoids that emerged from the cherries were identified and sexed. Unemerged pupae were dissected for species identification and assessment of parasitization. Total Mediterranean fruit fly per kilogram of coffee was calculated based on the sum of emerged adults, unemerged and partially emerged pupae, and all recovered parasitoids. Parasitoids were included in the total because, for the predominant Mediterranean fruit fly parasitoids, one

parasitoid emerged per parasitized pupa, accompanied by the death of the Mediterranean fruit fly. The sum of the recovered Mediterranean fruit flies plus parasitoids thus provides a good overall measure of the coffee infestation level.

Cage Tests. To further assess the effectiveness of each of the treatments and to ensure the wild flies were eating the bait used for the tests, cage tests were conducted with leaves that had been sprayed by hand and flies that had been caught live in yellow-bottom plastic dome traps baited with the three-component lure from nearby coffee fields.

Each of the bait solutions was prepared on 27 January 1999. On the same day, they were sprayed on the underside of coffee branches, $\approx 25\text{--}30$ ml per branch. Coffee branches that were sprayed were ≈ 1.0 m in height, the approximate height of the main spray band applied by all terrain vehicles in the field trial. For each test, three sprayed leaves of each of the treat-

ments and three unsprayed leaves were randomly selected, cut, and transported to 30.5 by 30.5 by 61.0-cm aluminum cages where they were suspended by two wires, right side up, in the middle of the cages. Cages were organized in random complete blocks of the control leaves and the treatment leaves other than malathion. Cages with malathion bait sprayed leaves were kept separate from the other cages to prevent malathion fumes from adversely affecting the flies in the other cages. Cages were kept under roofs through which light could pass and which protected the cages from rain.

Flies. To capture live wild flies, yellow-bottom plastic dome traps were set out in a nearby coffee field where cherries had not been harvested. Each trap held the three chemical attractant packages, as used for the population assessment trapping, plus agar (a water source). Traps were set out the day before the start of the cage test and retrieved the morning of the test.

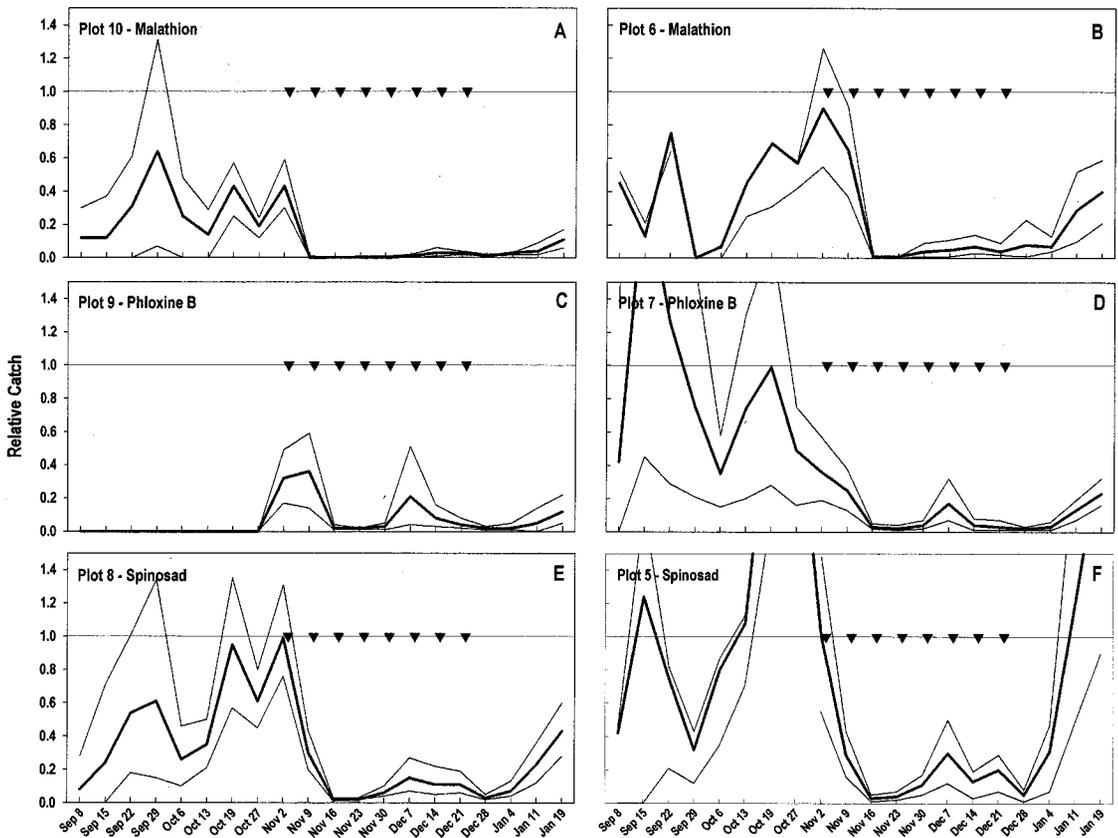


Fig. 2. Trap catch in given treatment field relative to trap catch of unsprayed controls (trap catch in treatment fields divided by trap catch in control fields). Bootstrap estimate of pointwise mean ratio of trap catch in the given treatment fields divided by random subsets of trap catch chosen from the control fields 1, 3, 11, (Efron and Tibshirani 1993) are given in bold, and bootstrap confidence intervals (0.05, 0.95) of mean ratio are given in lighter lines, both plotted against date. Spray dates are marked by inverted triangles on y-axis = 1.0 reference line. If the confidence band does not overlap the y-axis = 1.0, then there is a statistical difference between unsprayed control field fly catches and the treatment field fly catches on that date. Bootstrap confidence intervals are not symmetric. Plots A and B are the two replications of the malathion treatments within the Kalaheo gulch: fields 6 and 10 (Fig. 1). Plots C and D are the replications of the phloxine B treatments within the Kalaheo gulch: fields seven and nine (Fig. 1). Plots E and F are the replications of the spinosad treatments within the Kalaheo gulch: fields 5 and 8 (Fig. 1). Data were not taken in field nine before the beginning of the weekly sprays.

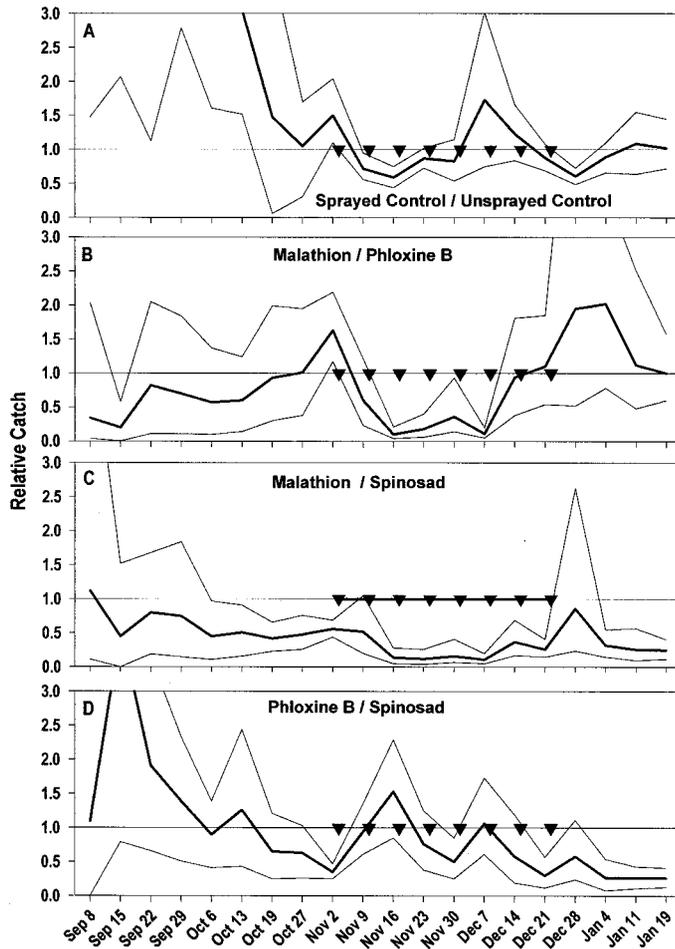


Fig. 3. (A) Trap catch in sprayed control fields relative to trap catch of unsprayed controls (trap catch in sprayed control fields divided by trap catch in unsprayed control fields). Bootstrap estimate of pointwise mean ratio of trap catch in the given treatment fields divided by random subsets of trap catch chosen from the control fields 1, 3, 11 (Efron and Tibshirani 1993) are given in bold, and bootstrap confidence intervals (0.05, 0.95) of mean ratio given in light lines, both plotted against date. (B–D) Comparison among treatments. (B) A bootstrap estimate of pointwise mean ratio of trap catch in malathion divided by trap catch in the phloxine B fields. Bootstrap estimate and confidence intervals (0.05, 0.95) of mean ratio plotted against date. Similarly, (C) comparison of spinosad and malathion. (D) The ratio of trap catches in phloxine B (fields 5 and 8) divided by those in spinosad (fields 7 and 9). Spray dates are marked by inverted triangles on y-axis = 1.0 reference line. If the confidence band does not overlap the y-axis = 1.0, then there is a statistical difference between fly catches in the two treatments being compared. Bootstrap confidence intervals are not symmetric. (A) Demonstrates there is no significant difference between the two types of control field plots. (B) and (C) demonstrate that malathion significantly reduced the population compared with phloxine B and spinosad, respectively. (D) Except at two time periods, there is no statistical difference in control between spinosad and phloxine B.

Bioassay. After leaves had been added to the cages, flies retrieved from the field were added to each cage at 1200 hours (HST) and mortality counts were begun. Counts were made every half-hour for the first 2 h, and every hour thereafter until 6 h after the introduction of the leaves. Flies were tested with leaves harvested within 24 h of spraying and 1 and 2 wk after spraying. Because of the reduced amount of protein remaining after weathering, protein and sugar were added to the cages 4 h after initial exposure of flies to the coffee branches that had weathered for 2 wk.

Statistical Analysis. We used subsample replication of the multiple traps within each field to construct

pointwise bias-corrected and accelerated bootstrap confidence intervals that were then used to compare the treatment and control fields (Efron and Tibshirani 1993). Formally, for each iteration of the bootstrap, at each time t and for each treatment field separately, a random sample (with replacement) of size N_i was taken from the trap-catch data collected in the i^{th} treatment field, where N_i is the total number of traps in the i^{th} treatment field. Similarly, a random sample was taken of size N_i from the trap-catch data of a previously chosen sample taken from the control fields. (Before the bootstrap, rather than match the i^{th} treatment field with a specific control field, a random

Table 1. Median (25th, 75th quartiles) daily trap catch by treatment in plots 1-11 and by three periods defined by heavy rains occurring midway through spray test: 9-30 November (prior to rain effect), 1-21 December (during rain effect), and 22 December-11 January (after rain effect)

Treatment	9 Nov.-30 Nov.	1 Dec.-21 Dec.	22 Dec.-11 Jan.
Malathion	0.0 (0.0, 0.143)	0.714 (0.143, 1.286)	0.429 (0.143, 0.926)
Spinosad	0.857 (0.286, 1.571)	3.143 (1.143, 5.714)	1.643 (0.429, 3.0)
Phloxine B	0.714 (0.143, 1.0)	1.429 (0.286, 3.429)	0.429 (0.0, 1.286)
Sprayed control	22.929 (17.214, 28.5)	40.286 (31.214, 54.786)	17.215 (9.643, 25.286)
Unsprayed control	28.857 (21.571, 38.286)	43.214 (26.929, 47.214)	22.643 (10.643, 35.286)

sample of N_i traps was drawn from any of the unsprayed control fields 1, 3, or 11 [Fig. 1]. This constructed a control field sample with the same number of traps as the treatment field.) From these two samples the statistic

$$\theta_i = \frac{\sum_{j=1}^{N_i} t_{ij}}{\sum_{k=1}^{N_i} c_k}$$

was computed, where t_{ij} is the total number of flies found in the j^{th} trap in the random sample drawn from the i^{th} treatment field, and c_k is the total number of flies found in the k^{th} trap in a random sample from the previously selected subset of unsprayed control fields. This was repeated for a total of 1,000 bootstrap samples and estimates of the mean θ_i and the 0.05 and 0.95 confidence intervals were constructed. Because the estimates of these parameters were based on a random sample of the control fields, this was repeated 100 times and the average of the parameters was used for reporting the results. If θ_i and its confidence bands are found below 1.0 that implies that the flies captured in treatment fields were statistically different from those caught in the unsprayed control fields. S++ (S-PLUS 1998) and a bootstrap module developed by Efron and Tibshirani (1993) were used for these analyses.

Results

Based on trap data from the treatment fields (fields 5-10; Fig. 1), all three of the pesticides tested provided significant levels of fruit fly suppression compared with unsprayed control fields (Fig. 2). There was no statistical difference in trap catches between the unsprayed control and bait-sprayed control fields (Fig. 3A). At the start of the test, the malathion fields had significantly fewer flies than the unsprayed control fields (Fig. 2 A and B). In addition, Fig. 2 A-C suggest that some of the populations had begun to rise more slowly than the control populations. This was caused in part because the coffee began to ripen earlier in the upper control fields 1-4 than it did down in the gulch (fields 5-11) and earlier in the southern part of the gulch than in the northern. As a result, the population in the controls began to grow more rapidly than the northern half of the treatment fields. However, in unsprayed control field 11, which is adjacent to malathion-treated field 10 and is the northernmost field in the gulch (Fig. 1), fly trap catches continued to grow and by 9 November they were not statistically different from the controls in fields 1 and 3, suggesting that

had field 10 not been treated with malathion, the trap catches would have equaled those seen in controls and the level of population reduction observed in Fig. 2 A-C is representative of the treatment effect.

Table 1 gives the median (25th and 75th quartiles) of the average daily catch of the fruit flies over the course of the study. Trap catch from 9 to 30 November in the treatment fields was very low: less than one fly per trap per day compared with an average of >22 and >28 flies per trap per day in the bait sprayed and unsprayed controls, respectively. Heavy rains in early December affected all of the treatments and led to Mediterranean fruit fly population increases in all of the treatment fields (Fig. 4; Table 1). These increases are not unexpected because rains potentially wash the bait spray from the leaves of the treated coffee plants. The population increase was most pronounced in the spinosad fields, but none of the population increases were significant compared with those in the control populations. After the rainy period (22 December-11 January) ended the populations in the controls increased, but not to the level seen in the first 3 wk of the spray. This may be caused, in part, by increased movement of the flies. Most of the fruit had ripened in the controls and much of the remaining available fruit was found in the gulch (which might have attracted the flies), thus potentially increasing trap catches.

When trap catches in spinosad and phloxine B fields were compared with those in malathion fields, malathion was more effective than spinosad during the entire course of the experiment and more effective than phloxine B in 4 of the 8 wk of spray (Fig. 3 B and C). The spinosad treatment fields had significantly more flies before the start of the study, however, making interpretation problematic. For most weeks there was no significant difference between population suppression in the spinosad and phloxine B fields (Fig. 3D).

Fly emergence data from fruit collections provides qualitative information indicating that all of the pesticides were effective in reducing the fly numbers to the level at which oviposition rates were reduced (Fig. 5). In these data, it was much less clear which of the toxicants was the most effective, although the population in the malathion fields was lower on all but two of the spray dates. For spinosad and phloxine B treatment fields no clear pattern emerges.

Oriental fruit fly, *Bactrocera dorsalis* Hendel, was also found to infest these coffee fields. In coffee cherries on Kauai, the abundance of this species typically

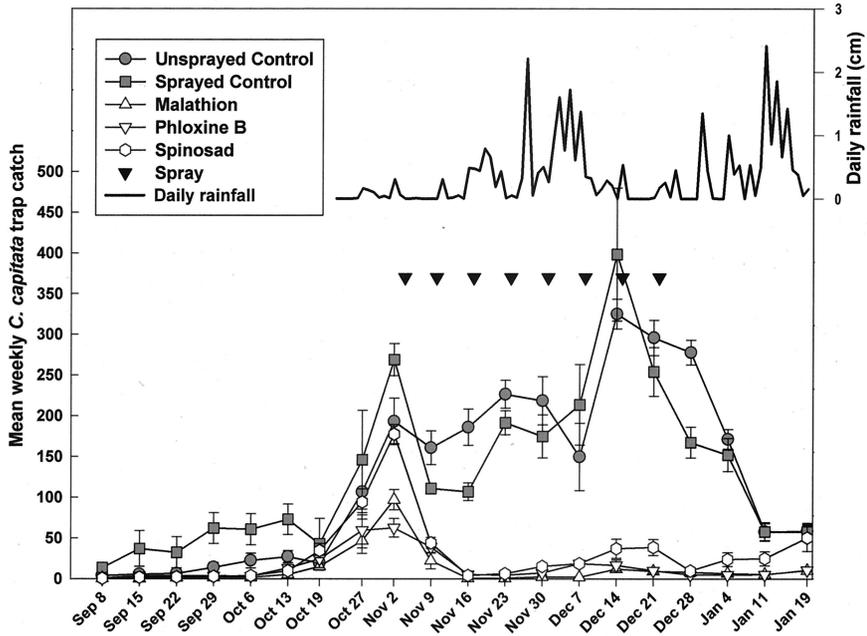


Fig. 4. Average number of flies caught per trap for each of the treatments over the course of the experiment plotted against date. Average daily rainfall for each day of the experiment in the lower fields (fields 5–11; Fig. 1) is plotted in the upper right corner.

declines as the coffee cherries ripen and there is a concurrent dramatic increase in Mediterranean fruit fly populations. In this study, oriental fruit fly abundance, as a percentage of all fruit flies recovered from coffee, dropped from a prespray average of 10.4 and

11.6% in the sprayed and unsprayed control fields, respectively, to only 1.2 and 2.2% from the start of spraying to the end of fruit collections. Because of the generally low levels of oriental fruit fly, combined with its natural seasonal decline in abundance, we cannot

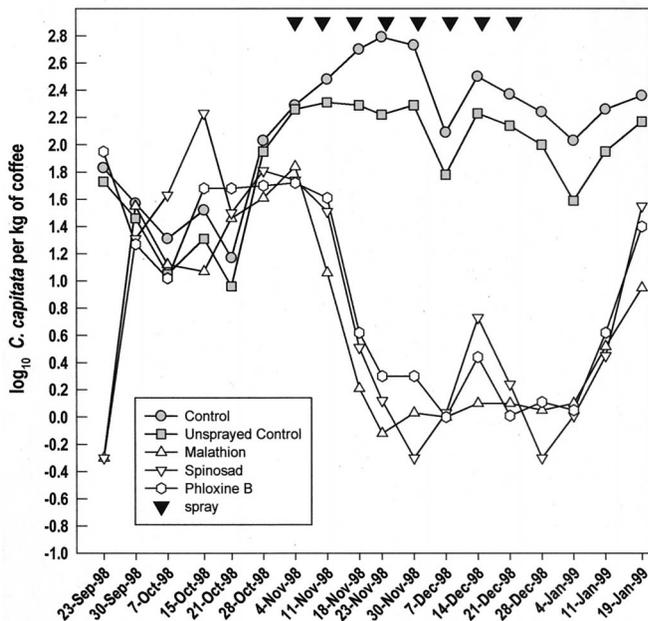


Fig. 5. Log₁₀ of the number (+0.5) of *C. capitata* per kilogram of coffee recovered from sampled coffee fruit averaged across treatment fields over the course of the experiment and plotted against date (fields 1–11; Fig. 1).

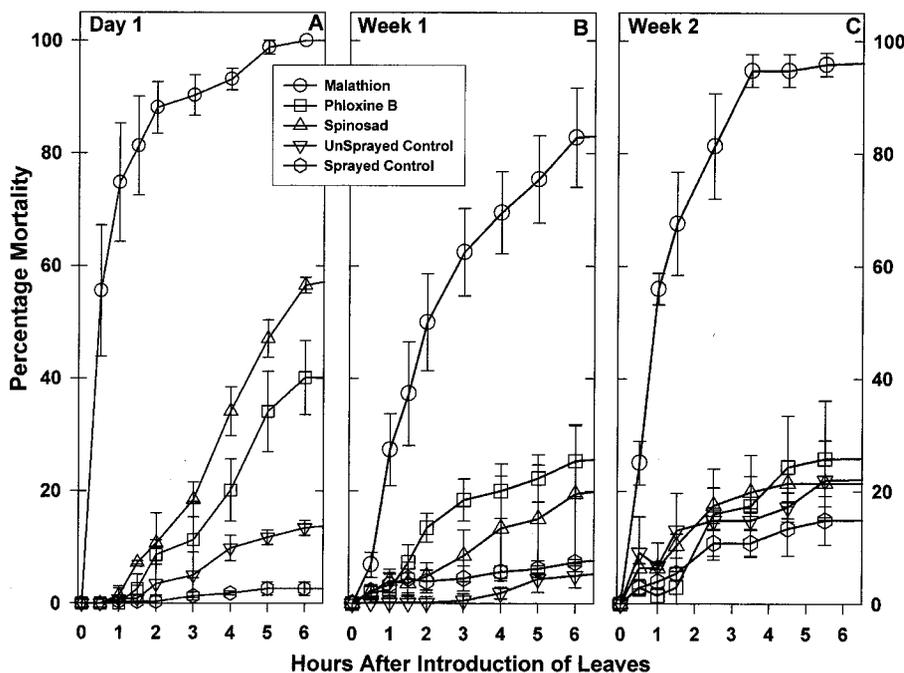


Fig. 6. Percentage mortality of flies exposed in cages to leaves treated with treatment pesticides. Leaves were treated in the field and left to weather for 24 h (A), 1 wk (B), and 2 wk (C) before removal from the trees and presented to flies.

report here on the effects of the spray treatments on this species.

Cage tests showed that the wild flies did consume the bait and were effected by the treatments (Fig. 6). After 6 h of exposure to leaves harvested within 24 h of spraying, mortality rates were 100, 56.5, and 40.1% for malathion, spinosad, and phloxine B treatments, respectively, whereas mortality rates for unsprayed and bait sprayed controls were only 13.4 and 2.6%, respectively. Weathering reduced the effectiveness of spinosad and phloxine B treatments more quickly than the malathion treatment. After 6 h of exposure to leaves harvested 1 and 2 wk after spraying, mortality rates in the malathion treatment remained high (82.8 and 95.8%, respectively), whereas mortality rates averaged 20% for spinosad and 25% for phloxine B for both weeks. Comparable unsprayed and bait sprayed control mortalities were low (7.3 and 5.0%, respectively) after 1 wk, but higher after 2 wk (14.8 and 22.0%, respectively), closer to the 2-wk values with spinosad and phloxine B.

We suggest that the difference in mortality rates and mortalities was the result of flies being constrained in the cages, the different pesticide modalities, and the different levels of feeding. Phloxine B must be consumed to be effective and spinosad is most effective when consumed although it does have some contact toxicity, whereas malathion has fumigant toxicity in addition to contact and consumption toxicity.

Putting the emergence data and the trap data together indicates that although malathion was the most effective treatment, impressive levels of control were

reached by both spinosad and phloxine B. It must be kept in mind that these pesticides were bait sprays applied in narrow bands under the coffee leaves once a week. Unlike malathion, which was applied at a very high rate and has fumigant, contact and feeding toxicity, for spinosad (which has some contact toxicity) and especially for phloxine B, the flies were required to locate and eat the presented bait before they were killed. Given the complexities of climate, weather, the ecological population dynamics of the wild flies, the unknown influences of individual movement, and the variation in spraying conditions, these levels of control are remarkable.

One concern with this study is that we had no information on the movement of flies among treatments and what effect movement may have had on our results. For example, if malathion were the only effective treatment and served as a sink (considering the fields as independent source-sink populations) it is conceivable that ineffective treatments may have looked effective because all the flies were moving through the malathion treatment. However, field 11 was the most isolated of the controls and was bordered on three sides by nonhost and by the largest malathion field in the study on the other. The population in this unsprayed control field (field 11) remained high throughout the study as did the other unsprayed control fields which bracket the two replications of treatment fields within the gulch.

These results give strong evidence that spinosad and phloxine B are potential malathion replacements. Both of these toxins were found to be effective, sub-

stantially less toxic to humans and other vertebrates than malathion, applied at substantially lower rates, and expected to have fewer adverse effects on non-target species. The use of phloxine B in aerial applications, however, may be limited to nonurban areas because of public reaction to a dye being sprayed on cars, houses, and other personal property.

These alternatives may be especially appealing if used in combination with sterile insect technique, where large numbers of reproductively sterilized insects are released to reduce the chance of wild insects finding viable mating partners. Sterile insect technique is known to be most effective when fruit fly populations are low (Gilmore 1989). We suggest that the strategy of first knocking the population down with one of these alternative pesticides, then using sterile insect technique to restrict the mating opportunities of the remaining wild flies has potential to suppress the population to even lower levels than found with malathion alone.

Despite our optimism about the use of these alternatives, malathion reduced the population to a lower level. Given the consequences of the Mediterranean fruit fly becoming established in the continental United States, care needs to be taken in moving forward with these new environmentally safer compounds. We recommend that any control of a Mediterranean fruit fly incursion should be attempted first with these environmentally safer alternatives, but it would be premature for the Environmental Protection Agency to completely restrict malathion from action agency use should these alternatives prove inadequate during the eradication of a Mediterranean fruit fly invasion. The potential worth of these alternatives will remain unknown until they are tried in a genuine eradication effort. It is unlikely that an experimental system that exactly mimics a Mediterranean fruit fly invasion will ever be possible. Doing an experiment such as this in an urban setting, where Mediterranean fruit fly invasions usually occur, would be impractical both ethically and logistically. Therefore, until these pesticides are tried in situ their potential for eradication use will remain a matter of speculation, despite any number of tests such as this that show their expected worth.

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