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# Suppression of Colorado Potato Beetle, *Leptinotarsa decemlineata* (Say), (Coleoptera: Chrysomelidae) Populations with Antifeedant Fungicides<sup>1</sup>

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**ABSTRACT** Laboratory, small-field plot, and commercial-scale experiments were completed, using Connecticut, Rhode Island, and New York Colorado potato beetle, (CPB) *Leptinotarsa decemlineata* (Say), populations to determine if "antifeedant fungicides" might reduce the suitability of potato for CPB while simultaneously protecting potato from early and late blight. In the laboratory, fungicides formulated from triphenyltin hydroxide (TPTH) or  $\text{Cu}(\text{OH})_2$  reduced CPB feeding 95 and 61%. In small-field plots, CPB larval densities were significantly reduced where TPTH and  $\text{Cu}(\text{OH})_2$  were used regularly. In commercial-scale experiments, *L. decemlineata* populations were significantly reduced and required fewer insecticide applications for acceptable control where TPTH was used regularly.

The Colorado potato beetle (CPB), *Leptinotarsa decemlineata* (Say), is a destructive pest of potato in most of North America and Europe. Populations are capable of completely defoliating plants and causing substantial yield reduction (Hare 1980a). To manage pest populations, growers may apply up to nine insecticide applications per season at a materials cost of up to \$60/ha per application (Wright et al. 1983). Managing southern New England CPB populations with pesticides is hindered by the relatively low toxicity of most registered insecticides (Hare 1980b).

Potato is also susceptible to early blight, *Alternaria solani*, and late blight, *Phytophthora infestans*. Growers customarily make up to 13 applications of protectant fungicides at intervals of 5 to 14 days, depending on disease incidence and weather conditions (Wright et al. 1983).

CPB feeding behavior can be altered by a number of organic and inorganic compounds synonymously known as "feeding deterrents" or "antifeedants" (Schoonhoven 1982). Known antifeedants include glycoalkaloids (Hsiao 1974), various phytochemicals from nonhost species (Jermy et al. 1981), and several inorganic and organometallic compounds (Jermy 1961, Chapman 1974). Some of the latter are also the active ingredients in registered fungicides effective for potato disease protection.

We performed several laboratory and field experiments with Connecticut, Long Island, N. Y., and Rhode Island CPB populations to determine if "antifeedant" fungicides significantly inhibited CPB feeding, reproduction, growth, or survival. With the cooperation of three Connecticut commercial potato growers, we also determined if one antifeedant fungicide formulated from triphenyltin hydroxide (TPTH) was compatible with other potato cultural practices and sufficiently effective as a feeding deterrent to reduce the frequency of insecticide applications necessary for acceptable CPB control.

## Materials and Methods

### Laboratory Experiments

Formulations of TPTH (Duter, 47.5% WP),  $\text{Cu}(\text{OH})_2$  (Kocide 101, 83% WP), maneb (Dithane M-22, 80% WP) mancozeb (Dithane M-45, 80% WP), and chlorothalonil (Bravo 500 F) were mixed with distilled water at concentrations equivalent to those used for disease protection in the field (0.20% AI for maneb and mancozeb, 0.125% AI for chlorothalonil, 0.10 and 0.20% AI for  $\text{Cu}(\text{OH})_2$ , and 0.02% AI for TPTH). The control solution for all experiments was distilled water.

CPB adults used in these experiments were the first-generation progeny reared on 'Katahdin' potato foliage in the laboratory (24°C 40 to 60% relative humidity [RH], photoperiod LD 16:8) from adults collected from the Lockwood Farm, Mt. Carmel, Conn. Within 24 h after emergence, experimental adults were sexed and confined as pairs in 500-ml unwaxed paper containers with transparent lids.

Mature leaves were excised from 'Katahdin' potato plants in the greenhouse. Overlapping leaflets were removed, and the area of the remaining leaflets was determined photoelectrically. Each leaf was dipped in one of the test solutions and allowed to dry. The leaf was then inserted into a water reservoir and placed in the container with the adult pair. Leaves were measured and replaced every 24 h, consumption being calculated by subtraction. Any eggs were counted and removed. Consumption was monitored for the first 14 days for 10 pairs per treatment. Egg production was monitored for the first 28 days for 20 pairs per treatment, except for TPTH, where only 10 pairs were monitored.

Another oviposition experiment was completed using potato leaves taken from untreated plants in the field or from plants sprayed weekly with  $\text{Cu}(\text{OH})_2$  (1.86 kg of AI/ha), mancozeb (1.80 kg of AI/ha), or TPTH + mancozeb (0.17 + 0.90 kg of AI/ha). Newly emerged summer adults were sexed and confined as pairs as described above. Insects were maintained in an outdoor insectary so that they were exposed to ambient temperatures and photoperiods, but were shaded from direct sunlight. Leaves were replaced every 24 to 36 h, and eggs were

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counted and removed at that time. Egg production was monitored for the first 21 days for 18 pairs per treatment.

Other experiments were performed with the Long Island population to examine the effects of TPTH of CPB adults. In the first study, laboratory-reared, overwintered adults were used. These postdiapause adults were maintained in the growth room (27°C, LD 16:8) and fed 'Superior' potato leaves from the greenhouse for 10 days, until 80% of females had begun oviposition. Five pairs of adults each were then offered leaves treated with 0, 0.02%, or 0.04% TPTH. Leaves were changed and adult survival and egg production were recorded on a Monday-Wednesday-Friday (M-W-F) schedule for 31 days. A second Long Island study repeated the first, using 1- to 4-day-old, laboratory-reared, nondiapause adults.

To determine the effect of various fungicides on larval survival in the laboratory, 10 groups of 15 neonate larvae from the Connecticut population were placed on fungicide-treated leaves in chambers, as described above. A layer of moist, sterile vermiculite was added before pupation to provide a substrate into which prepupae could burrow. Larvae were counted and transferred to freshly treated leaves daily.

The effect of TPTH on larval survival was also examined using Long Island larvae. Leaves were treated with 0, 0.005, 0.01, 0.02, or 0.04% TPTH solutions as described above. Five groups (10 for the controls) of 10 neonate larvae each were placed on a treated leaf, and maintained as described above. Leaves were changed and larval survival was determined on an M-W-F schedule.

The effect of TPTH on larval food consumption was also examined using the Long Island population. Five neonate larvae were placed in petri dishes lined with moist filter paper. Two leaf discs (17 mm in diameter) were cut from 'Superior' potato leaves and treated with 0, 0.02, 0.04, 0.06, 0.08, or 0.10% TPTH solutions. Larvae were maintained in the growth room for 48 h, at which time survival was recorded and the total weight of survivors was determined. Leaf area remaining was determined photoelectrically, and leaf area consumption was compared with that for leaf discs treated with distilled water but not subjected to larval feeding.

Data from the Connecticut experiments were analyzed by single-classification analyses of variance (ANOVAs) and means were separated by Duncan's multiple range test ( $P \leq 0.05$ ). Data from the Long Island experiments were analyzed by linear regression analysis.

#### *Small-Plot Field Experiments*

The 120-day potato variety, 'Katahdin,' was hand planted on 22 April 1982 at Lockwood in four-row blocks 2.78 m long (spacing: 0.96 m between rows, 0.32 m within rows). Blocks were surrounded by a 2.78-m buffer of tilled soil. Plots were fertilized with 1,450 kg of 10% N, P, and K per ha. Weeds were controlled with a pre-emergence herbicide.

There were nine treatments with two or four blocks per treatment (two blocks for treatments no. 2 and 3,

four blocks for the others) in a completely randomized design. One block each from treatments 1, 5, and 9 was lost due to flooding. Plants in treatment 1 were not treated with any pesticide. Plants in treatment 2 were sprayed weekly with mancozeb (1.80 kg of AI/ha) until blocks were completely defoliated. Plants in treatment 3 were sprayed weekly with  $\text{Cu}(\text{OH})_2$  (1.86 kg of AI/ha). Plants in treatment 4 were sprayed weekly with TPTH + mancozeb (0.17 + 0.90 kg of AI/ha). Plants in treatments 5 to 7 were treated with aldicarb at planting (3.36 kg of AI/ha) for early-season CPB control and then sprayed weekly with the fungicides used in treatments 1, 2, and 4 above.

The final two treatments (8 and 9) were designed to determine how TPTH might be incorporated into a more economical and effective commercial potato pest management program. Aldicarb (3.36 kg of AI/ha) was applied to both treatments at planting. Plants in treatment 8 were sprayed with mancozeb (1.80 kg of AI/ha), fenvalerate (0.11 kg of AI/ha), and piperonyl butoxide (0.44 kg of AI/ha) weekly for disease and insect control. In treatment 9, TPTH + mancozeb (0.17 + 0.90 kg of AI/ha) was used weekly for disease control and insecticides (fenvalerate + piperonyl butoxide, 0.11 + 0.44 kg of AI/ha) were added to the fungicide whenever the mean density of CPB larvae + adults was  $\geq$  five per stem. This arbitrary action threshold was based on previous studies (Hare, unpublished data) showing that CPB densities up to five per stem at any time during the growing season did not affect tuber production. More recent experiments (Wright et al. 1983) show this value to be a conservative action threshold.

Beginning on 8 June, egg masses, larvae, and adults were counted weekly from 25 stems per block from all blocks, and pesticides were applied after counts were completed. Up to 25 egg masses per treatment were collected, and the mean number of eggs per mass for each treatment was determined. The number of eggs per stem was then estimated as the mean eggs per mass times masses per stem. On 24 September, all blocks were harvested, and the total weight of tubers per row was recorded.

Significant variation in larval abundances was determined by two-factor (time  $\times$  treatment) ANOVAs with unequal subclass sizes (Harvey 1960). The block factor was nested within the (time  $\times$  treatment) cells and was the error term for tests for significant variation among treatments. The  $\log(x + 1)$  transformation was employed so that the data would more closely conform to the assumptions for the analysis of variance (Harcourt 1963, Logan 1981). Analyses were performed on mean weekly larval densities over time periods corresponding to the full season (11 or 12 weeks), and over the first 6 or 7 weeks (until 20 July) and last 5 weeks (27 July to 24 August), corresponding to the abundance periods of first- and second-generation larvae.

Yields were analyzed by two-factor (treatment  $\times$  row position) ANOVAs. Row position (exterior vs. interior) was considered a main effect, because exterior rows might differ consistently in yield from interior rows in

all treatments, for example, due to reduced competition for light.

At the University of Rhode Island Agronomy farm, Kingston, four rows of the 90-day variety, 'Superior,' were planted in blocks (4 by 4 m) with a tilled buffer of soil 6.5 m wide surrounding each block. Seed pieces were planted by machine but were checked for skips and proper spacing before covering. Plots were fertilized with 2,200 kg of 10% N, P, and K per ha before planting, and weeds were controlled with a preemergence herbicide.

Each of the four treatments consisted of three blocks. No pesticides were applied to plants in treatment 1. Mancozeb (1.80 kg of AI/ha) was sprayed on plants in treatment 2 weekly for 6 weeks. TPTH + mancozeb (0.17 + 0.68 kg of AI/ha) was sprayed on plants in treatments 3 and 4 on 14- and 7-day schedules, respectively, for the same 6-week period. An attempt to schedule fungicide applications according to Blitecast (Krause et al. 1975) led to a steady 7-day schedule, and results were pooled accordingly.

Egg masses and larvae were counted one to three times weekly from 30 stems per block. On 15 July, an instar-specific larval count was taken, with larvae classified by headcap width.

#### Commercial-Scale Field Experiments

Three Connecticut growers planted 5 to 6 ha with 'Katahdin' potatoes. Aldicarb (3.4 kg of AI/ha) was applied at planting for early-season CPB control. The field was divided into two treatments. Growers used TPTH + mancozeb (0.17 + 0.90 kg of AI/ha) as the regular fungicide in the "experimental" treatment and mancozeb only (1.80 kg of AI/ha) in the "conventional" treatment. Growers added insecticides of their choice to the fungicides as they thought necessary. The experimental objective was to achieve acceptably low CPB densities and equivalent yields in both treatments and determine if the regular use of TPTH would permit a reduction in the number of required insecticide applications. This objective was chosen to minimize the risk of yield losses to participating growers.

Once a week starting on 15 June, we censused the CPB population from 25 randomly chosen stems from

four randomly chosen sampling sites per treatment. Mean abundances of eggs, larvae, and adults were reported to the growers, and the type and quantity of pesticides applied during the previous week were recorded. Yields were sampled by hand before commercial harvest from two 4.6 m sections of row from each of four sampling sites per treatment.

Insect abundances were analyzed as described for the small-plot experiments, the "site" factor in these analyses being equivalent to the block factor in the previous experiments. All rows sampled for yields were "interior"; thus, row position was not a systematic source of variation in these experiments. Thus, the proper ANOVA model was a three-level, nested ANOVA (treatments, sites within treatments, rows within sites) (Sokal and Rohlf 1981).

## Results

### Laboratory Experiments

TPTH and  $\text{Cu}(\text{OH})_2$  reduced feeding by Connecticut CPB adults 95% and 50% and egg production 100% and 90% at their minimum concentrations for potato disease control (Table 1). The other three fungicides had no effect on Connecticut CPB adults at their maximum labeled rates. TPTH affected egg production by nondiapausing Long Island adults similarly (Table 2). All adults fed leaves treated with 0.04% TPTH died within 8 days, and 90% of all adults fed leaves treated with 0.02% TPTH died within 14 days. No survivors reproduced. Postdiapausing adults, however, survived as well on TPTH-treated leaves as on control leaves up to 21 days, although egg production was reduced 95.3 and 96%, by 0.02 and 0.04% TPTH, respectively.

All fungicides significantly reduced Connecticut larval survival (Table 1); TPTH and  $\text{Cu}(\text{OH})_2$  (at 0.20%) caused 100 and 98.7% mortality, respectively. Long Island larvae were also susceptible to TPTH. After 2 days, survival varied inversely with TPTH concentration (Table 3), and after 7 days, all larvae died, even on leaves treated with 0.005% TPTH, one-fourth the minimum concentration used for potato disease control. Larval feeding and weight gain also varied inversely with TPTH concentration (Table 3).

Table 1. Adult foliage consumption ( $\text{cm}^2$ ) egg production, and larval survival (%) of *L. decemlineata* when fed potato leaves dipped in various fungicide solutions in the laboratory

Fungicide	Concn (%)	Adult consumption (14 days)	Adult egg production (28 days)	Larval survival to adulthood
TPTH	0.02	9.27 ± 2.08a <sup>w</sup>	0.0a	0.0a
$\text{Cu}(\text{OH})_2$	0.20	68.49 ± 9.72b	4.4 ± 4.3a	1.3 ± 0.9a
	0.10	87.49 ± 7.01b	44.8 ± 19.0a	24.7 ± 5.9c
Mancozeb	0.20	160.52 ± 12.08c	402.9 ± 80.7b	11.3 ± 2.6ab
Chlorothalonil	0.125	160.83 ± 15.82c	397.4 ± 57.3b	18.7 ± 4.4bc
Maneb	0.20	160.88 ± 13.81c	384.8 ± 65.7b	52.7 ± 4.3d
Control (distilled water)	—	175.37 ± 9.52c	465.8 ± 49.5b	67.3 ± 5.2e

<sup>w</sup>Means (±SE) within columns followed by the same letter do not differ at  $P \leq 0.05$  (Duncan's multiple range test).

Table 2. Egg production by Long Island *L. decemlineata* adults fed TPTH-treated potato leaves in the laboratory<sup>a</sup>

Adult type	Concn (%)	Eggs/female per day in the following days:			
		1-3	4-5	6-8	9-31
Nondiapause	0.04	0.0 (4)	0.0 (2)	0.0 (0)	—
	0.02	0.0 (5)	0.0 (4)	0.0 (2)	0.0 (1)
	0.0	0.0 (5)	10.1 (5)	15.2 (4)	3.2 (3)
Postdiapause	0.04	7.2 (5)	3.4 (5)	0.3 (5)	0.0 (0) <sup>b</sup>
	0.02	5.7 (5)	3.1 (5)	0.0 (5)	0.0 (0) <sup>c</sup>
	0.0	7.5 (5)	15.3 (5)	6.9 (5)	25.7 (4)

<sup>a</sup>Values in parentheses represent the number of surviving females from an initial number of five per treatment.

<sup>b</sup>All deaths occurred between day 12 and day 29.

<sup>c</sup>All deaths occurred between day 19 and day 26.

In summary, under laboratory conditions, TPTH substantially inhibited CPB feeding, growth, survival, and reproduction at or below concentrations used for potato disease control. Cu(OH)<sub>2</sub> was nearly as deleterious as TPTH at its intermediate fungicidal concentration. There was no evidence of habituation over the 28- to 32-day experimental periods. Postdiapause adults that had fed before the experiment on untreated potato foliage were less affected by TPTH than nondiapause adults fed TPTH-treated leaves from emergence.

In the Connecticut oviposition experiment using field-treated leaves, total egg production ranged from 0 to 280 per female over the 21-day experiment period. Within-treatment variances were significantly heterogeneous, and no transformation made the variances homogeneous. Therefore, the data were analyzed by a Kruskal-Wallis test (Sokal and Rohlf 1981). Adults fed untreated foliage from the field produced a mean of 58.2 eggs (median = 11), and those fed mancozeb-treated leaves produced

a mean of 49.8 (median = 31.5). In contrast, adults fed TPTH + mancozeb-treated leaves produced a mean of 43.1 eggs, but the median was only 5.0. No adults reproduced when fed Cu(OH)<sub>2</sub>-treated leaves. An analysis on the three groups that produced eggs showed a highly significant difference in "location" of the samples (Kruskal-Wallis H = 24.83, df = 2, P ≤ 0.001); thus, TPTH adversely affected CPB egg production, but not nearly as much as in the laboratory.

#### Small-Plot Field Experiments

Field data were taken weekly from Lockwood, Conn., growers' fields, and from Kingston, R.I. However, due to climatic differences among the three regions, comparisons of insect abundances on a specified calendar date were less meaningful than comparisons made on a physiological time scale. Accordingly, CPB developmental degree-days (DD) (Allen 1976) were calculated for each region from the date of plant emergence. For the growers' fields, we used the temperatures recorded at the Connecticut Agricultural Experiment Station's research farm at Windsor, located within 24 km of the three fields.

In the first series of treatments at Lockwood (no. 1 through 4), the mean larval densities during the first 4 weeks differed significantly among treatments (F<sub>3,36</sub> = 9.47, P ≤ 0.001). Larval densities peaked at 32.8 and 41.0 per stem at 370 DD on the control (no. 1) and mancozeb-only (no. 2) treatments, and all blocks in these treatments were 100% defoliated shortly thereafter (Fig. 1). In contrast, larval densities on the Cu(OH)<sub>2</sub> (no. 3) and the TPTH + mancozeb (no. 4) treatments peaked at only 11.2 and 15.7 per stem at the same time.

We obtained similar results in the second series of treatments (no. 5 through 7), where aldicarb was applied to limit the first generation. In the aldicarb-only treatment (no. 5), larvae reached a maximum density of 17.6 per stem, and all blocks in this treatment were also completely defoliated before the end of the season (Fig. 2). Weekly mean larval densities over the full season were significantly lower in the TPTH + mancozeb treatment (no. 7) than in the mancozeb-only treatment (no. 6) F<sub>1,69</sub> = 8.90, P ≤ 0.01). Weekly mean larval densities also differed significantly at P ≤ 0.05 (F<sub>1,40</sub> = 5.08) during

Table 3. Survival, consumption, and weight of Long Island *L. decemlineata* larvae fed TPTH-treated potato foliage in the laboratory

Concn (%)	Survival (%)		
	Day 2	Day 5	Day 7
0.04	44.0	0.0	0.0
0.02	44.0	0.0	0.0
0.01	72.0	4.0	0.0
0.005	82.0	6.0	0.0
0.0	88.0	67.0	58.0
	Consumption (cm <sup>2</sup> , 48 h)		Wt (mg, 48 h)
0.10	0.0 <sup>a</sup>		18.4 <sup>b</sup>
0.08	0.0		19.8
0.06	0.3		22.2
0.04	0.4		21.6
0.02	1.1		32.4
0.0	3.7		62.4

<sup>a</sup>Regression equation of consumption (Y) on TPTH concentration (X) is: Y = 2.51 - 3.21X, F<sub>(1,28)</sub> = 35.2, P ≤ 0.001.

<sup>b</sup>Regression equation of weight (Y) on TPTH concentration (X) is: Y = 47.8 - 3.67X, F<sub>(1,28)</sub> = 33.1, P ≤ 0.001.

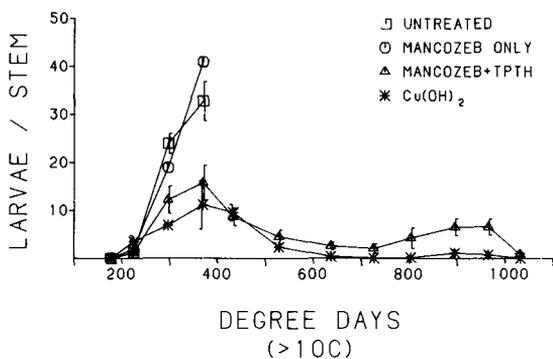


FIG. 1. *L. decemlineata* larval densities ( $\bar{Y} \pm SE$ ) over DD for treatments 1 to 4 at Lockwood, Conn. See text for pesticide treatments and sampling regimes. Pesticides were applied the same day after insect censuses.

the first generation at  $P = 0.06$  ( $F_{1,29} = 3.83$ ) during the second generation.

Mean adult and egg densities rarely differed significantly among treatments. Therefore, we suggest that the primary factor limiting larval density on TPTH-treated plants was reduced larval survival.

TPTH also limited the density of CPB larval populations in the Rhode Island field experiment (Fig. 3). Larval densities reached a maximum of 16.7 per stem and 16.2 per stem by 310 and 398 DD in the untreated and mancozeb-treated blocks, respectively (Fig. 3a and b). In contrast, applications of TPTH + mancozeb every 14 days reduced the maximum larval density to 12.2 per stem, and peak abundance occurred somewhat later (Fig. 3c). Increasing the application frequency to every 7 days considerably reduced the amplitude of the larval incidence curve as maximum densities were only 4.0 and 3.7 per stem at 372 and 491 DD (Fig. 3d).

The average age of larvae on the control and mancozeb-treated blocks on 15 July (DD = 415) (based on two blocks per treatment, defoliation claiming the others) was a weighted mean instar (WMI) of 3.49 and 3.20, (Table 4) indicating a relatively high proportion

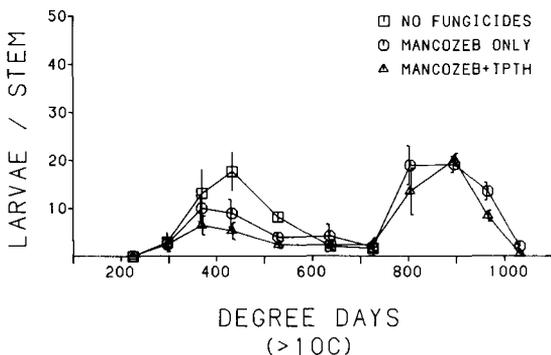


FIG. 2. *L. decemlineata* larval densities ( $\bar{Y} \pm SE$ ) over DD for treatments 5 to 7 at Lockwood, Conn. See text for pesticide treatments and sampling regimes. Pesticides were applied the same day after insect censuses.

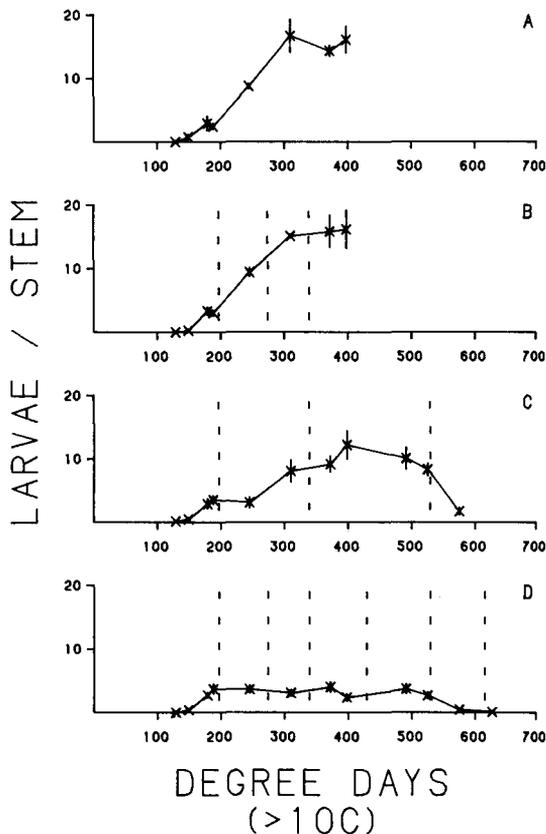


FIG. 3. *L. decemlineata* larval densities ( $\bar{Y} \pm SE$ ) over DD for treatments 1 to 4 (graphs a through d) at Kingston, R.I. See text for pesticide application and sampling regimes. Vertical dotted lines indicate dates of pesticide applications.

of 4th instars. The 14- and 7-day TPTH + mancozeb blocks showed WMIs of 2.13 and 1.83, indicating that the numerically smaller larval populations on these plots were largely comprised of 1st and 2nd instars.

The combined differences in larval density and age structure can be expressed as the produce of density times instar-specific "feeding potential." By using the feeding estimates of Tamaki and Butt (1978), and relating each instar to the 1st instar, feeding equivalents of 1, 2.5, 8, and 30 approximate the feeding potential of the four instars (i.e., 4th instars consume 30 times as much foliage as 1st instars). Multiplying these feeding equivalents by the mean instar-specific densities produced an index of feeding potential (Table 4). Regular use of TPTH + mancozeb reduced feeding potential of the larval population 74 to 89%.

In the final series of treatments at Lockwood (no. 8 and 9), the mean number of CPB larvae + adults exceeded our action threshold three times, on 370, 637, and 804 DD, where TPTH + mancozeb were applied weekly. Thus, insecticides were added to only 3 of the 10 fungicide applications. Although weekly mean larval densities were significantly higher in the TPTH + mancozeb treatment (no. 9) than in the mancozeb-only treat-

Table 4. *L. decemlineata* larval densities, weighed mean instar, and feeding potential on 15 July, 1982 at Kingston, R.I.<sup>a</sup>

Treatment	Instars/stem				Mean instar	Feeding index ( $\times 1,000$ )
	L1	L2	L3	L4		
Untreated	0.77 $\pm$ 0.33	1.17 $\pm$ 0.10	2.32 $\pm$ 0.45	9.22 $\pm$ 0.82	3.49 <sup>b</sup>	9.95 <sup>a</sup>
Mancozeb weekly	1.03 $\pm$ 0.43	3.17 $\pm$ 0.87	2.55 $\pm$ 0.08	9.85 $\pm$ 3.02	3.26a	9.90a
TPTH + mancozeb every 14 days	3.49 $\pm$ 1.04	5.08 $\pm$ 0.99	1.48 $\pm$ 0.21	1.74 $\pm$ 0.63	2.13b	2.61b
TPTH + mancozeb weekly	3.39 $\pm$ 0.98	0.90 $\pm$ 0.20	0.55 $\pm$ 0.14	0.74 $\pm$ 0.26	1.83b	1.12b

<sup>a</sup>Densities are based on 30 stems per block. Means  $\pm$  SE are based on means of block means.

<sup>b</sup>Means followed by the same letter do not differ at  $P \leq 0.05$  (Fisher's unprotected LSD).

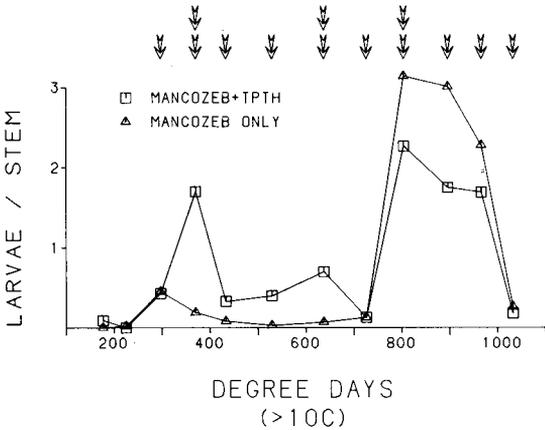


FIG. 4. *L. decemlineata* larval densities (backtransformed means) over DD for treatments 8 and 9 at Lockwood, Conn. See text for pesticide application and sampling regimes. Fungicides were applied the same day after insect censuses. Lower row of arrows indicates when insecticides were applied to treatment 8 (mancozeb only), and upper row of arrows indicates when insecticides were applied to treatment 9 (TPTH + mancozeb).

ment (no. 8) during the first generation ( $F_{1,34} = 25.13, P \leq 0.001$ ), mean larval densities did not differ significantly during the second generation ( $F_{1,35} = 1.42, P \leq 0.25$ ), despite the fact that the TPTH + mancozeb treatment (no. 9) received four fewer insecticide applications (Fig. 4). Mean yields ( $\pm$  SE) were  $26.04 \pm 2.25$  m<sup>3</sup>/ha in treatment no. 8 and  $23.99 \pm 1.42$  in treatment no. 9, and did not differ significantly due to treatments or row position.

In summary, small-plot field experiments demonstrated that TPTH-based fungicides suppressed the buildup of CPB populations when applied to plants at rates and frequencies used for potato disease protection. Although reduction in larval growth rate cannot be entirely ruled out, the most important effect seemed to be reduced larval survival. TPTH did not give the near-total protection observed in the laboratory, however, and TPTH was not a sufficiently strong feeding deterrent in the field to maintain innocuous CPB population in the absence of insecticides. The final series of treatments at Lockwood, however, indicated that TPTH was compatible with current conventional potato-growing practices,

and that equal or lower insect densities could be maintained with substantially fewer insecticide applications where a fungicide mixture of TPTH + mancozeb was used regularly. This last possibility was examined in more detail with the cooperation of three Connecticut commercial potato growers.

### Commercial-Scale Experiments

Grower A made six insecticide applications to both treatments. Weekly mean larval densities during the second generation, however, were significantly lower in the experimental treatment ( $F_{1,30} = 8.39, P \leq 0.01$ ). Maximum mean ( $\pm$  SE) densities occurred at 876 DD and were  $1.89 \pm 0.40$  per stem in the control treatment and  $0.55 \pm 0.34$  per stem in the experimental treatment. Weekly mean egg densities during the same time period were also significantly lower in the experimental treatment ( $F_{1,30} = 6.21, P \leq 0.05$ ). Peak mean egg densities, occurring at 794 DD in both treatments, were  $21.0 \pm 3.5$  per stem in the control treatment but only  $10.3 \pm 2.2$  per stem in the experimental treatment. Yields were  $32.51 \pm 1.90$  mT/ha in the control treatment and  $32.50 \pm 1.69$  in the experimental treatment.

Grower B saved one of five insecticide applications in the experimental treatment. Mean weekly larval densities did not differ significantly between treatments in either the first or second generations ( $F_{1,36} = 2.30, P \leq 0.25$ , and  $F_{1,30} = 1.06, P \leq 0.50$ , respectively). Yields were  $26.49 \pm 4.10$  mT/ha in the control treatment and  $29.30 \pm 1.34$  in the experimental treatment.

Grower C saved three of six insecticide applications in the experimental treatment. In addition, weekly mean egg densities were significantly lower ( $F_{1,30} = 13.16, P \leq 0.01$ ), and larval densities nearly so ( $F_{1,30} = 3.123, P = 0.087$ ), in the experimental treatment during the second generation, despite the fact that no insecticide was applied to the experimental treatment during this time period. Peak egg densities, observed in our 794-DD census, were  $2.84 \pm 0.56$  per stem in the control treatment but only  $0.32 \pm 0.18$  per stem in the experimental treatment. Peak larval density in the control treatment occurred at 794 DD and was  $0.15 \pm 0.15$  per stem. Peak larval density occurred at 876 DD in the experimental treatment and was  $0.08 \pm 0.08$  per stem. Yields were  $41.62 \pm 1.88$  mT/ha in the control treatment and  $45.97 \pm 2.06$  in the experimental treatment.

properly and carefully, we found the fear of TPTH-induced phototoxicity to be unsubstantiated.

In closing, we stress that antifeedant fungicides are by no means the ultimate solution to the CPB problem in southern New England. TPTH used alone did not suppress CPB populations as effectively as the five to nine insecticide applications customarily made per season, and a single TPTH application was incapable of quickly suppressing a CPB population that had exceeded its action threshold (R. J. Wright, unpublished data). Nevertheless, when used regularly for potato disease control on a commercial scale, TPTH deterred CPB feeding sufficiently to reduce significantly the density of CPB populations and allow growers to maintain acceptably low CPB populations with a saving of from one to three insecticide applications. At current prices and application rates, this equals a saving of from \$16.50 to \$74.00 per ha in total pesticide costs, even after subtracting the additional cost of TPTH. Perhaps an additional, long-term benefit from the reduced frequency of insecticide applications would be in reducing the rate at which the CPB develops insecticide resistance, thus preserving the utility of the few effective insecticides remaining. Our results show that fungicides formulated from known CPB feeding deterrents are an economical and practical tool to reduce the suitability of potato foliage for the CPB (Hare, in press), and such fungicides may assume a greater role in more highly integrated programs to manage potato insect pests and pathogens.

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