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Evaluation of Ethoprop and Tetrathiocarbonate for Reniform Nematode Control in Pineapple[1]

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Abstract: Ethoprop and disodium tetrathiocarbonate (TTC) were evaluated as replacements of fenamiphos and 1,3-dichloropropene (1,3-D) for control of *Rotylenchulus reniformis* on pineapple in Hawaii. Treatments were established in a field on the Del Monte Fresh Fruit (Hawaii) plantation in spring 1991. Preplant soil treatments consisted of fumigation with 1,3-D at 226 kg a.i./ha and TTC at 135 kg or 270 kg a.i./ha. Postplant nematicides for the 1,3-D treated plots were fenamiphos (3.4 kg a.i./ha trimonthly) and ethoprop (3.4 or 6.7 kg a.i./ha monthly). Tetrathiocarbonate was applied postplant to the TTC-treated plots every 2 months at 67 kg a.i./ha. Nematode population densities were monitored in all plots at 3-month intervals. Tetrathiocarbonate was not effective in reducing the preplant soil population densities of *R. reniformis* or limiting subsequent nematode damage to the plants. Ethoprop and fenamiphos reduced nematode damage, resulting in greater yield in the first and second crop harvests ($P < 0.05$). Ethoprop was an effective alternative to fenamiphos for control of *R. reniformis* in pineapple.
Key words: *Ananas comosus,* chemical control, ethoprop, fenamiphos, nematicide, nematode, pineapple, reniform nematode, *Rotylenchulus reniformis,* tetrathiocarbonate.

Certain species of reniform (*Rotylenchulus*), root-knot (*Meloidogyne*), and lesion (*Pratylenchus*) nematodes are serious pests of pineapple, *Ananas comosus,* reducing fruit size and yield and the number of ratoon crops to be harvested economically before replanting is required (5,11). *Rotylenchulus reniformis* infests most fields in Hawaii and is the most serious nematode problem on pineapple in the state. Researchers have estimated that the pineapple crop would not be harvestable for fresh fruit without some form of nematode control (4,13).

Pineapple growers in Hawaii employ two tactics for nematode control: fallow and pesticides. A 3- to 6-month fallow period between pineapple plantings is an integral component of the cropping system. Nearly all of the 10,000 ha cultivated in Hawaii are fumigated 2 weeks before planting with methyl bromide (MB) or 1,3-dichloropropene (1,3-D). To ensure successful ratoon crops (two ratoon harvests are standard for Hawaiian production), postplant nematicides, such as fenamiphos and oxamyl, are applied at 3-month intervals after planting. These measures are required to maintain the desired fruit size range and, consequently, the existence of the industry in Hawaii.

Reliance upon a few nematicides presents a high risk to pineapple producers in the event that one or more is no longer available for use in pineapple. Other nematicides are registered, but are perceived as less effective or are more costly than the standard chemicals. Due to environmental concerns and improvements in application technology, some compounds should be reevaluated to determine their usefulness and adaptability to current pineapple production practices. The objective of this research was to evaluate ethoprop as an alternative to fenamiphos and disodium tetrathiocarbonate (TTC) as an alternative to 1,3-D and MB for *R. reniformis* control in pineapple.

Materials and Methods

An experiment was established in a field on the Del Monte Fresh Produce (Hawaii) plantation. The field was prepared with commercial equipment to form 2-row

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planting beds 1.1 m wide containing a 2.5-cm-d drip tube in the center of each bed. Beds were covered with a 25-μm-thick black plastic film with planting marks at 25-cm intervals along both edges. Plots were four beds wide and 15.25 m long. The crop system was modified with a series of gate valves so that each plot could be treated independently or interconnected to all other plots for irrigation and fertilization.

Six treatments were arranged in four randomized complete blocks (Table 1). Tetrathiocarbonate and 1,3-D were injected with fumiguns (N. A. MacLean Co., San Francisco, CA) to a depth of 30 cm at each planting mark. Pineapple crowns were planted 8 weeks later. Postplant chemicals were applied to each plot in 19 liters of water through the drip tube. The equivalent of 51.4 m^3/ha water was applied to a plot during each postplant pesticide treatment. Ethoprop- and fenamiphos-treated plots received 80% of the irrigation water prior to chemical injection, and TTC-treated plots were given 100% of the water after injection. Ethoprop applications began 1 month after planting and continued monthly until 3 months prior to harvest. Fenamiphos was applied at 3-month intervals after planting. Postplant applications of TTC commenced 2 months after planting and were repeated at 2-month intervals thereafter. All postplant treatments ceased 3 months before plant crop harvest (first crop from the planting), began again 1 month after plant crop harvest, and ended 3 months before the first ratoon harvest (second crop from the planting).

Population densities of *R. reniformis* and plant-growth parameters were recorded throughout the experiment. Nematode populations were monitored approximately every 3 months in six soil samples collected with a 7.5-cm-wide trenching shovel to 30 cm deep from along the outside plant rows from the center of each plot, composited, and mixed. Vermiform *R. reniformis* were extracted from a 250 cm^3 subsample of the soil by elutriation (3) and centrifugation (7). Crop growth was evaluated 12 months after planting as a function of D-leaf (youngest mature leaf) weight (11). Pineapple fruit weight and appearance of the plant crop and first ratoon harvests (about 18 and 30 months after planting, respectively) were recorded from 100 plants in the center two beds. These data were used to calculate percentage packable fruit, average fruit weight, total yield, and marketable yield (11). The number of first ratoon suckers in each plot was counted and used to adjust yield data for the plot.

Nematode population densities transformed to $\log_{10}(n + 1)$ values and plant-growth data were subjected to analysis of variance. Means were separated according to the Waller-Duncan k-ratio *t*-test (k = 100) where *F* tests were significant. Correlations between nematode population levels and plant crop and first ratoon yields were calculated.

Results

Soil population densities of *R. reniformis* before preplant treatment ranged from

TABLE 1. Pre- and postplant treatment combinations used to control nematodes in pineapple.

Preplant		Postplant		
Chemical	Rate (a.i.)	Chemical	Rate (a.i.)	Frequency
None		None		
1,3-D	226 kg/ha	Fenamiphos	3.4 kg/ha	Every 3 months
1,3-D	226 kg/ha	Ethoprop	6.7 kg/ha	Monthly
1,3-D	226 kg/ha	Ethoprop	3.4 kg/ha	Monthly
TTC[a]	270 kg/ha	TTC	67 kg/ha	Every 2 months
TTC	135 kg/ha	TTC	67 kg/ha	Every 2 months

[a] TTC = Tetrathiocarbonate.

310–1,600/250 cm^3 soil but did not differ among treatments or replications. Preplant application of 1,3-D reduced the preplant numbers of *R. reniformis* by 91.2% (Fig. 1). Population densities of *R. reniformis* in the TTC-treated plots decreased 28.3%, which was not different from the natural reduction (20.6%) in the untreated plots. As the experiment proceeded, postplant nematicide treatments had little effect on soil population densities of *R. reniformis*. *Rotylenchulus reniformis* reached average population densities of 2,000/250 cm^3 soil within 10 months after planting and peaked at 6,440/250 cm^3 soil in one plot 30 months after planting.

Nematode numbers were significantly correlated with pineapple yield at several sampling dates. Soil population densities of *R. reniformis* at 5 months after planting were negatively correlated with average fruit weight ($P < 0.05$), total yield, and marketable yield at plant crop ($r = -0.74$, -0.61, and -0.74, respectively) and at first ratoon harvest ($r = -0.38$, -0.71, and -0.68, respectively). Within 8 months after planting, numbers of *R. reniformis* remained negatively correlated with percentage packable fruit and marketable yield in the plant crop ($P < 0.05$, $r = -0.44$ and -0.46, respectively) and first ratoon harvests ($r = -0.55$ and -0.43, respectively). Soil population densities of *R. reniformis* were correlated with total ratoon yield at 12, 25, and 30 months ($r = -0.64$, -0.59, and -0.46, respectively, $P < 0.01$).

The effects of infection by *R. reniformis* were evident on the pineapple plants at 12 months after planting (Fig. 2). D-leaf weight was greater for plants in plots receiving postplant applications of ethoprop and fenamiphos than plants in plots treated with TTC or those untreated. The 3.4 kg a.i./ha rate of ethoprop resulted in the largest D-leaves of any treatment, whereas the smallest D-leaves were on plants treated with TTC.

Preplant 1,3-D treatment followed by

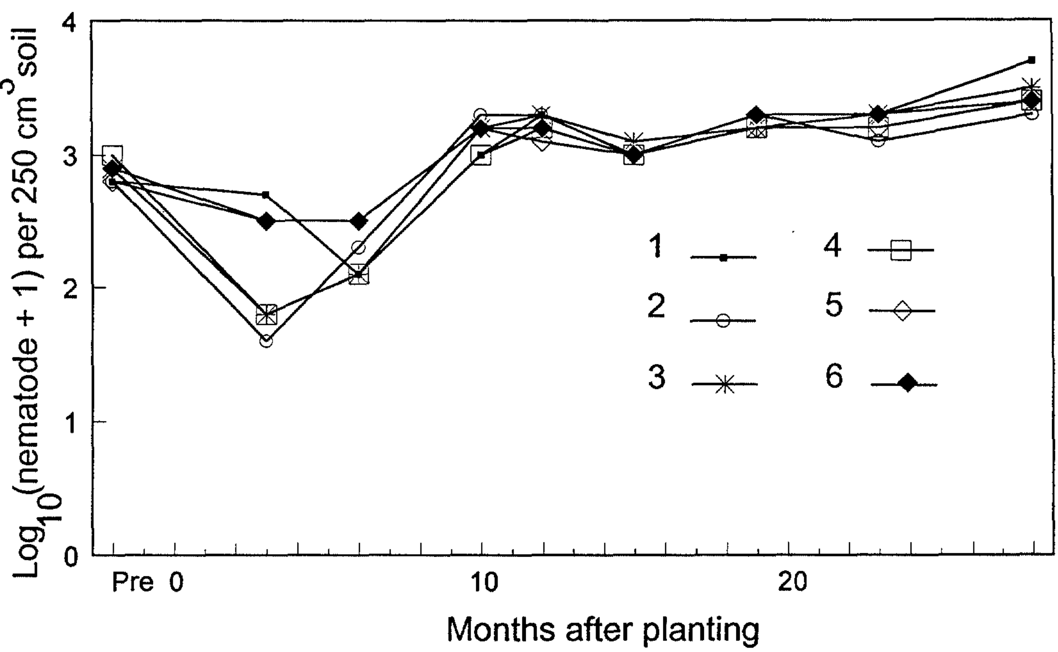

FIG. 1. *Rotylenchulus reniformis* population densities ($\log_{10}(n + 1)$ transformed) as influenced by different nematicide programs in a field located near Kunia, Oahu, Hawaii. Treatments were as follows: 1) untreated control; 2) 1,3-D 226 kg a.i./ha preplant, fenamiphos (F) 3.4 kg a.i./ha every 3 months; 3) 1,3-D 226 kg a.i./ha preplant, monthly applications of ethoprop (E) 3.4 kg a.i./ha; 4) 1,3-D 226 kg a.i./ha preplant, monthly applications of ethoprop (E) 6.7 kg a.i./ha; 5) tetrathiocarbonate (TTC) 270 kg a.i./ha preplant and TTC 67 kg a.i./ha every 2 months postplant; and 6) TTC 135 kg a.i./ha preplant and followed by TTC 67 kg a.i./ha every 2 months postplant.

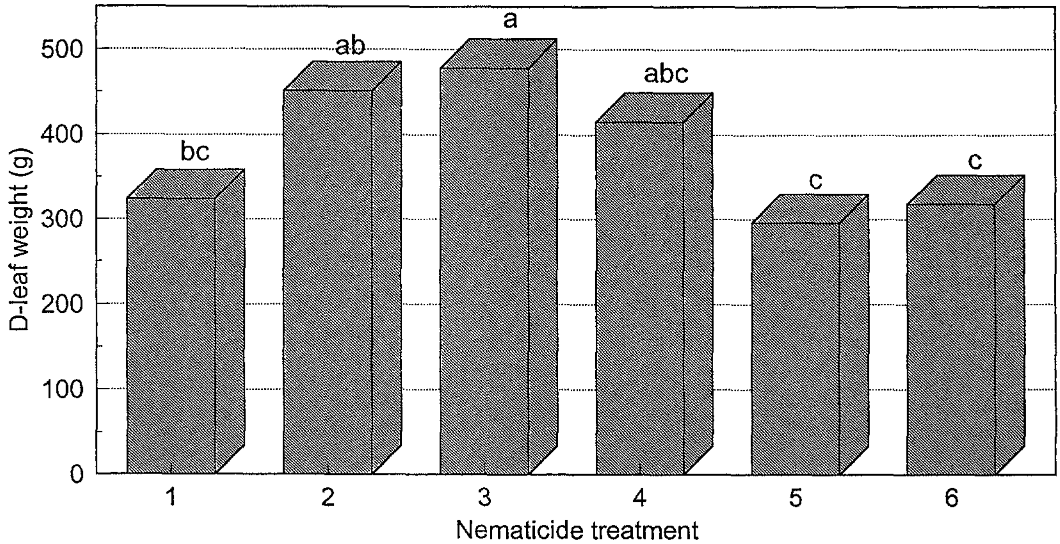

FIG. 2. Weight of 10 D-leaves 12 months after planting as affected by *Rotylenchulus reniformis* and nematicide treatment. Bars with the same letter are not different according to the Waller-Duncan k-ratio *t* test (k = 100). Treatments were as follows: 1) untreated control; 2) 1,3-D 226 kg a.i./ha preplant, fenamiphos (F) 3.4 kg a.i./ha every 3 months; 3) 1,3-D 226 kg a.i./ha preplant, monthly applications of ethoprop (E) 3.4 kg a.i./ha; 4) 1,3-D 226 kg a.i./ha preplant, monthly applications of ethoprop (E) 6.7 kg a.i./ha; 5) tetrathiocarbonate (TTC) 270 kg a.i./ha preplant and TTC 67 kg a.i./ha every 2 months postplant; and 6) TTC 135 kg a.i./ha preplant and followed by TTC 67 kg a.i./ha every 2 months postplant.

postplant application of either fenamiphos or ethoprop resulted in the greatest pineapple yield (Table 2). The trend for greater fruit weight, total yield, and marketable yield was from plants in plots that received monthly ethoprop treatments. The 3.4 kg a.i./ha ethoprop treatment was as effective as the 6.7 kg a.i./ha treatment in terms of pineapple yield in the plant crop and first ratoon harvests. Tetrathiocarbonate treatment resulted in a slight, but insignificant, increase in fruit weight, total yield, packable fruit, and marketable yield over the untreated control.

TABLE 2. Harvest data from nematicide-treated pineapple plots located near Kunia, Oahu, Hawaii. The plant crop was harvested in 1993 and the first ratoon crop in 1994.

	Treatment[a]					
	Untreated	1,3-D/F	1,3-D/E(3.4)	1,3-D/E(6.7)	TTC(270)/TTC	TTC(135)/TTC
			Plant crop harvest			
Fruit weight (kg)	1.3 [b]	1.7 a	1.8 a	1.8 a	1.4 b	1.4 b
Total yield (Mg/ha)	96.0 b	126.0 a	131.0 a	134.0 a	106.0 b	105.0 b
Percent packable	46.4 c	76.1 a	81.6 a	80.4 a	60.8 b	58.0 bc
Marketable yield (Mg/ha)	45.0 b	96.0 a	107.0 a	108.0 a	64.0 b	62.0 b
			First ratoon harvest			
Fruit weight (kg)	1.3 b	1.6 a	1.6 a	1.7 a	1.3 b	1.3 b
Total yield (Mg/ha)	103.0 a	137.0 a	129.0 a	134.0 a	121.0 a	112.0 a
Percent packable	32.2 b	54.1 a	63.8 a	61.2 a	28.2 b	32.0 b
Marketable yield (Mg/ha)	33.0 b	74.0 a	82.0 a	82.0 a	34.0 b	36.0 b

[a] 1,3-Dichloropropene (1,3-D) was applied 2 months before planting at 226 kg a.i./ha followed by fenamiphos (F) at 3.4 kg a.i./ha every 3 months or ethoprop (E) at 6.7 or 3.4 kg a.i./ha monthly. Tetrathiocarbonate (TTC) was applied preplant at 270 or 135 kg a.i./ha preplant and postplant every 2 months at 67 kg a.i./ha.

[b] Numbers followed by the same letter within rows are not different according to the Waller-Duncan k ratio *t*-test (k = 100).

Discussion

The intercrop fallow period did not reduce population densities of *R. reniformis* below damaging levels as evidenced by yield in the untreated plots. Preplant soil fumigation, therefore, was needed to protect the plant in order to produce an acceptable crop. Preplant nematode control can often protect the plant crop harvest but is inadequate for the ratoon crops (1). Therefore, without postplant nematode control, ratoon crop yields are often too low to warrant harvest (1,13).

The standard nematicide program used in Hawaii relies predominantly on MB, 1,3-D, fenamiphos, and oxamyl. Withdrawal of registration of any of these compounds would seriously affect continued pineapple production in the state. Methyl bromide has been implicated as an ozone-depleting substance and the Montreal Protocol requires its use to be discontinued by 2001 (2). This will leave only 1,3-D as a preplant soil treatment in pineapple. Consequently, the development of alternatives is critical. Tetrathiocarbonate controls fungi (9) but has not been effective against *Pratylenchus* (14). Tetrathiocarbonate was not effective in reducing damage due to *R. reniformis* at the rates used in this experiment or when applied through drip irrigation at 963 kg a.i./ha (D. Williams, pers. comm.). However, in a separate experiment, TTC at higher rates (3,705 kg a.i./ha) did suppress soil population densities of *R. reniformis* for 3 months when applied through the drip irrigation tubes (Sipes, unpubl.). Other chemicals, such as metam-sodium, should be investigated as replacements or alternatives to 1,3-D to provide pineapple growers with preplant nematode control options in the near future.

Ethoprop is a viable alternative to fenamiphos and oxamyl for postplant nematode control. Ethoprop and fenamiphos are equally effective in vitro in reducing penetration of host roots by *Meloidogyne* spp. (6) and appear to be similarly effective against *R. reniformis.* In other field evaluations in pineapple, ethoprop has not matched the efficacy of fenamiphos (10). The differences in performance between the two postplant nematicides may lie in their chemical properties. Ethoprop is more soluble than fenamiphos and can be rendered ineffective with as little as 2.5 cm of precipitation (12). Fenamiphos, on the other hand, was not affected by 5 cm simulated rainfall applied 1 or 3 days after fenamiphos application (8). Ethoprop, therefore, requires more frequent applications and a higher cumulative dosage to be as effective as fenamiphos. In our experiment, the 3.4 kg a.i./ha rate of ethoprop was as effective as the 6.7 kg a.i./ha, suggesting that fewer applications could also be effective for *R. reniformis* control in pineapple.

The Hawaiian pineapple industry depends primarily on chemicals to control nematodes. However, over the years, environmental concerns have limited the number of pesticides registered for nematode control in pineapple. Effective alternatives exist, especially among the nonfumigant nematicides, and warrant more extensive use. The selection of a nematode control tactic will soon depend on consideration of potential groundwater contamination, worker safety, air emissions, and proximity to urban areas. Nematicide selection should be based on the target field's location, nematode species and population densities, and the properties of the pesticide. Ethoprop might be used preferentially in fields receiving limited rainfall or irrigation, whereas fenamiphos could be used where the potential exists for groundwater contamination. Future nematicide treatments in pineapple should be based on specific field requirements rather than general plantation-wide practices.

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