Control of *Rotylenchulus reniformis* on Pineapple with Emulsifiable 1,3-Dichloropropene

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ABSTRACT

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An emulsifiable formulation of 1,3-dichloropropene (1,3-D SL) was tested for efficacy against *Rotylenchulus reniformis*, the reniform nematode, in pots and in the field. Nematode population densities were reduced by 50% at 25 μg a.i. per g of soil in pot trials. In the field, efficacy (posttreatment numbers divided by pretreatment numbers) was similar between 1,3-D SL and 1,3-D VL (volatile liquid) at 407 kg a.i./ha. At 204 kg a.i./ha, 1,3-D SL was less effective than 1,3-D SL or VL at 407 kg a.i./ha in controlling the nematode but gave better control than no treatment ($P < 0.05$). Postplant application of 113 kg a.i. 1,3-D SL per ha did not provide sufficient nematode control to prevent yield reduction compared with a postplant fenamiphos (1.7 kg a.i./ha) treatment. Preplant fumigation with 1,3-D reduced the numbers of reniform nematode, but the population resurged within 10 months. Thereafter, regardless of nematicide, soil population densities of *R. reniformis* did not differ among treatments.

Additional keywords: *Ananas comosus,* Telone II

Fumigant nematicides such as EDB (ethylene dibromide), DBCP (dibromochloropropane), MB (methyl bromide), and 1,3-D (1,3-dichloropropene) have provided efficacious and economical control of *Meloidogyne javanica* (Treub) Chitwood and *Rotylenchulus reniformis* Linford and Olivera in pineapple, *Ananas comosus* (L.) Merr., since the 1940s. Without nematode control, pineapple fruit is small and variable in size and ripens unevenly; the resulting crop is unharvestable (8). The environmental impacts (i.e., groundwater contamination and unacceptable air emissions) of fumigant nematicides have resulted in withdrawal of some and review of others by the United States Environmental Protection Agency. Hawaiian pineapple plantations currently rely upon MB and 1,3-D for preplant nematode control (3). The continued availability of these nematicides is questionable. MB is to be discontinued by 2001 because it has been implicated as a factor contributing to ozone depletion (16). Unacceptably high concentrations of 1,3-D (Telone II, a volatile liquid) in the air was the reason a California regulatory agency temporarily suspended its use (4). Its reintroduction has been incumbent upon good stewardship practices (J. Mueller, personal communication). Alternative nematode control tactics in pineapple, such as biological control and host plant resistance, are ineffective or insufficiently developed to replace nematicides. Consequently, the lack of options places considerable pressure on pineapple producers to modify chemical control methods to minimize environmental impacts of 1,3-D (11,12).

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Several stewardship practices have been adopted in Hawaii and others are being explored (12,15). Deeper injection (45 versus 40 cm) of the fumigant with a single chisel in the center of the bed has reduced peak air emissions of 1,3-D by 25% while maintaining efficacy (12,15). Fumigant toxicity, solubility, and volatility can be reduced or enhanced by product formulation. An emulsifiable formulation of 1,3-D may reduce loss from volatility due to the lack of a chisel trace and formation of a water seal during application. The objective of our research, conducted in pot and field experiments, was to determine the efficacy of a 66.2% a.i. emulsifiable formulation of 1,3-D (1,3-D SL) for control of *R. reniformis* in pineapple.

MATERIALS AND METHODS

Dosage response. Soil (Wahiawa silty clay, pH 4.2, 17% o.m.) infested with *R. reniformis* was collected, sieved, gently mixed, and placed into 15-cm-diameter clay pots (1.5 liter per pot). A 100-cm^3 soil subsample from each pot was processed by elutriation (2) and centrifugation (5) to extract nematodes. Vermiform nematodes were enumerated. Ten replications of each 1,3-D SL treatment described below were blocked on a greenhouse bench according to nematode population densities.

Chemical treatments were randomly assigned within blocks. Each pot was treated with a 100-ml aliquot containing 0, 5, 25, 50, 100, 150, or 200 g of 1,3-D SL a.i. per g of air-dried soil. After treatment, the pots were irrigated to distribute the chemical throughout the pot. No leaching was allowed to occur from any pot. One week after treatment, crowns of *A. comosus,* clone Smooth Cayenne, were dipped into a fungicide (aluminum tris [O-ethyl phosphanate] at 3.0 g/liter) to control *Phytophthora* (7) and planted into each pot. The test was terminated after 60 days, when a 250-cm^3 soil sample was collected from each pot. Nematodes were extracted by elutriation (2) and centrifugation (5) and counted.

Field evaluation. A randomized complete block experiment with six treatments, replicated four times, was established in a pineapple field on the Del Monte plantation in April 1991. Commercial equipment was used to prepare the field and lay drip irrigation tubing and a black polyethylene film (25 μm thick, 81 cm wide) (8). Plots were six beds wide (1.1 m spacing) and 15.25 m long.

Six treatments were established in the field (Table 1). 1,3-D VL was manually injected with a fumigun (N. A. MacLean

Table 1. Nematicides applied to pineapple for control of *Rotylenchulus reniformis*

Nematicide	Rate
Preplant treatment	
Untreated	–
1,3-D VL[y]	407 kg a.i./ha
1,3-D SL[z]	407 kg a.i./ha
1,3-D SL	204 kg a.i./ha
1,3-D SL	407 kg a.i./ha
1,3-D SL	204 kg a.i./ha
Postplant treatment	
Untreated	–
Fenamiphos	1.7 kg a.i./ha
Fenamiphos	1.7 kg a.i./ha
Fenamiphos	1.7 kg a.i./ha
1,3-D SL	113 kg a.i./ha
1,3-D SL	113 kg a.i./ha

[y] A volatile liquid formulation of 1,3-dichloropropene.
[z] A soluble liquid formulation of 1,3-dichloropropene.

Co., San Francisco, CA) through the plastic mulch at every planting mark (23 cm spacing) to a depth of 30.5 cm. Pre- and postplant applications of 1,3-D SL were diluted in 19 liters of water and delivered through the drip irrigation line. After the 1,3-D SL applications, the equivalent of 51 m^3 water/ha was applied to distribute the chemical in the soil. Before postplant fenamiphos applications, plots were irrigated with the equivalent of 51 m^3 water/ha. Fenamiphos was then applied in 19 liters of water and the drip lines rinsed with 20 liters of water per plot. All plots received standard plantation practices to maintain the crop (7,8). Postplant nematicide applications began 3 months after planting and continued regularly at 3-month intervals, ceasing 3 months prior to each harvest.

Plots were assayed for nematodes before the preplant and the first postplant treatments, and 30 days after subsequent postplant nematicide applications. Soil was collected from the plant lines between the two center beds of each plot. Nematodes were extracted from 250-cm^3 soil subsamples by elutriation (2) and centrifugation (5), and then counted.

Plant weight (kg) was recorded at 6 and 12 months after planting. Plant crop and first ratoon fruit yields were weighed and grouped according to fresh fruit packing sizes (under 1.0 kg = discard; 1.0 to 1.1 kg = 16 fruit/box; 1.2 to 1.3 kg = 14 fruit/box; 1.4 to 1.6 kg = 12 fruit/box; 1.7 to 2.0 kg = 10 fruit/box; 2.1 to 2.5 kg = 8 fruit/box; 2.6 to 2.9 kg = 7 fruit/box; and over 2.9 kg = discard). Yield was based on 25 consecutive plants from each of the four center beds of each plot. Average fruit weight (kg), Mg/ha, percentage of packable fruit (fruit between 1.2 to 2.9 kg), and marketable Mg/ha (percentage packable × Mg/ha) were determined for each plot.

Data were analyzed for variance and means separated with the Waller-Duncan k-ratio t test. Linear regression of 1,3-D SL concentration on percent reniform nematode control was conducted.

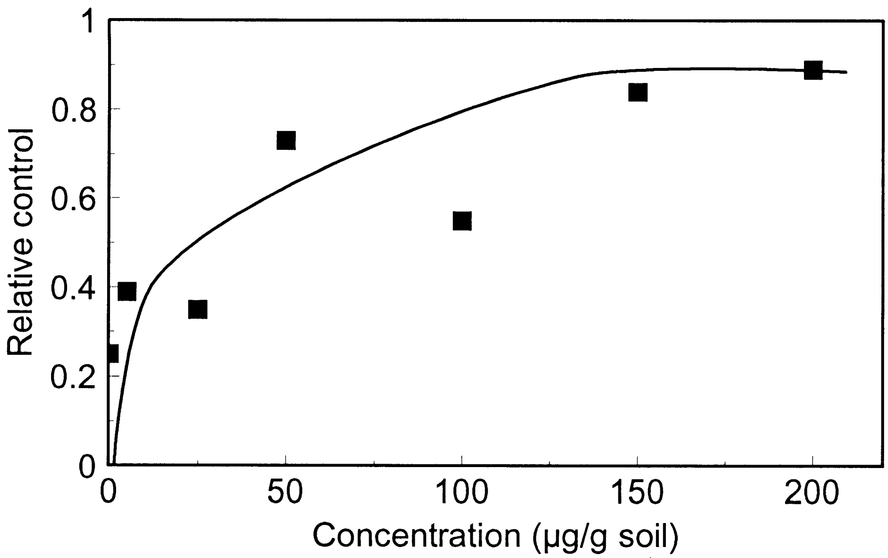

Fig. 1. Control of *Rotylenchulus reniformis* in response to dosage of an emulsifiable formulation of 1,3-dichloropropene (1,3-D SL) in a pot experiment. Control is relative to reproduction of nematodes in untreated pots.

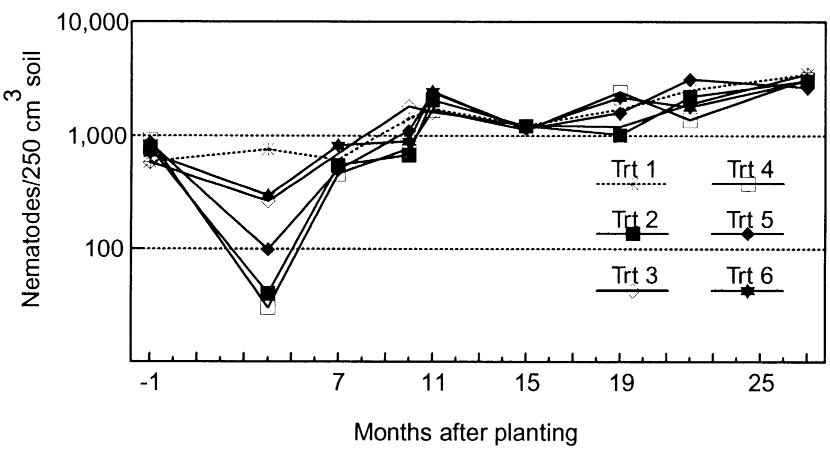

Fig. 2. Soil population densities of *Rotylenchulus reniformis* as influenced by nematicide where treatments (Trt) are as follows: Trt 1 = no nematicide; Trt 2 = 1,3-dichloropropene (1,3-D) volatile liquid (VL) at 407 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 3 = an emulsifiable formulation (SL) of 1,3-D at 407 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 4 = 1,3-D SL at 204 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 5 = 1,3-D SL at 407 kg a.i./ha preplant followed by 1,3-D SL at 113 kg a.i./ha postplant; and Trt 6 = 1,3-D SL at 204 kg a.i./ha preplant followed by 1,3-D SL at 113 kg a.i./ha postplant.

RESULTS

Dosage response. The data were fitted to a Gompertz model such that Control = $e^{0.16e(-0.01c)}$ ($P < 0.01$, $r^2 = 0.43$) where c is the concentration of 1,3-D SL (Fig. 1). The LD_{50} of 1,3-D SL for *R. reniformis*, as derived from the regression equation, was 25 g a.i. Population densities decreased 65% with 50 g a.i. 1,3-D SL per g of dry soil compared with the untreated control. Nematode population increase was lower as 1,3-D concentration increased, with an 89% reduction at 200 g a.i. per g of soil.

Field evaluation. Preplant population densities of vermiform *R. reniformis* averaged 734 per 250 cm^3 soil among plots and did not differ among treatments. *Pratylenchus*, *Helicotylenchus*, and *Paratylenchus* were also occasionally recovered from the soil samples but never at levels above 200 nematodes per 250 cm^3 soil. Preplant treatment with 1,3-D VL or 1,3-D SL at 407 kg a.i./ha reduced soil population densities of *R. reniformis*. The nematode control was equivalent (92 and 95%, respectively) between these treatments ($P < 0.05$) (Fig. 2). However, preplant treatment with 1,3-D SL at 204 kg a.i./ha reduced soil population densities of *R. reniformis* by only 63%. No nematode population reduction was observed in the untreated plots.

Soil population densities of *R. reniformis* did not differ among the treatments within 7 months after planting (Fig. 2). Population densities of *R. reniformis* reached preplant densities within 10 months after planting in all treatments, and then increased, with slight fluctuations, to an average of 3,138 vermiform nematodes per 250 cm^3 soil 27 months after planting.

Although postplant nematicide applications did not affect soil population densities of *R. reniformis*, plant growth and yield were enhanced in the nematicide-treated plots (Fig. 3; Table 2). The plants in untreated plots were smaller at 6 months than plants in plots treated with 1,3-D SL at 407 kg a.i./ha and postplant fenamiphos. At 12 months, the largest plants were those that received preplant treatments of 1,3-D VL or 1,3-D SL at 407 kg a.i./ha followed by postplant fenamiphos applications. The smallest plants were those in the untreated plots. The 204 kg a.i./ha 1,3-D SL preplant treatment and all postplant applications of 1,3-D SL failed to enhance plant growth above that observed in the untreated plots ($k = 100$).

Pineapple yield in the first (plant crop) and especially the second harvest (first ratoon) was lower in the treatments in which vegetative growth was reduced (Table 2). The untreated control and plots receiving postplant treatments of 1,3-D SL had the lowest average fruit weight, total yield, and marketable yield in the plant and ratoon crops. Those plots receiving postplant fenamiphos treatments, regardless of preplant treatment, had the greatest percentage of packable fruit.

Fruit size distribution was a major component of yield affected by the nematicide treatment. A fruit weight between 1.2 and 2.9 kg is required for the fresh fruit market. Data from the untreated and 1,3-D SL postplant treatments and the fenamiphos postplant treatments were combined because no differences in total yield, marketable yield, and percentage of packable fruit were detected (Table 2). A lower average fruit weight and greater percentage of smaller fruit reduced marketable yield in the untreated and 1,3-D SL postplant treatments compared with the postplant fenamiphos treatments (Table 2; Fig. 4). The shift to a greater percentage of smaller fruit was evident in the first ratoon crop in the untreated and 1,3-D SL postplant plots (Fig. 4). A higher percentage of first ratoon fruit remained in the 1.7 to 2.0 kg range in the fenamiphos-treated plots (Fig. 4).

DISCUSSION

The SL and VL formulations of 1,3-D have similar efficacy. The LD_{50} calculated for 1,3-D SL and *R. reniformis* in the pot experiment was similar to that reported for *M. javanica* and 1,3-D VL (6). In another aspect of our field experiment previously reported, soil gas concentrations of 1,3-D were similar between the SL and VL formulations at 407 kg a.i./ha (10). The 407 kg a.i./ha preplant application level gave a 184 ppm concentration in the soil with both formulations (10), and the resulting nematode control by SL and VL treatments was nearly identical. The lower application level resulted in less nematode control, reflective of the dosage response curve observed in the pot experiment.

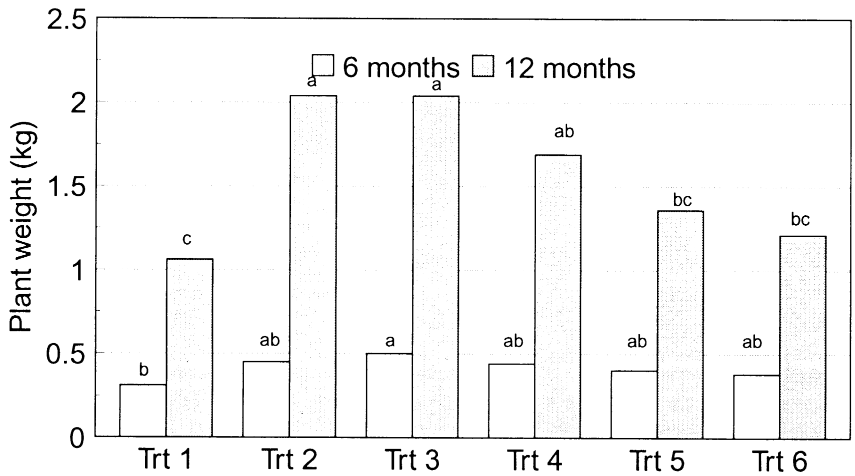

Fig. 3. Weight of pineapple plants at 6 and 12 months after planting as affected by 6 nematicide treatments (Trt), as follows: Trt 1 = no nematicides; Trt 2 = 1,3-dichloropropene (1,3-D) volatile liquid (VL) at 407 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 3 = an emulsifiable formulation (SL) of 1,3-D at 407 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 4 = 1,3-D SL at 204 kg a.i./ha preplant followed by fenamiphos at 1.7 kg a.i./ha postplant; Trt 5 = 1,3-D SL at 407 kg a.i./ha preplant followed by 1,3-D SL at 113 kg a.i./ha postplant; and Trt 6 = 1,3-D SL at 204 kg a.i./ha preplant followed by 1,3-D SL at 113 kg a.i./ha postplant. Bars with the same letter within each date are not different according to the Waller-Duncan *k*-ratio *t* test ($k = 100$).

The postplant nematicide applications appeared to have little effect on soil population densities of *R. reniformis*. We have observed similar results in other experiments (13,14). Postplant soil population densities of *R. reniformis* may not accurately reflect the nematode pressure on the pineapple because a clear increase in plant growth and fruit yield resulted from postplant fenamiphos applications. Fenamiphos-treated plots contain greater root biomass than untreated plots (13); consequently, there were fewer nematodes per g of root tissue in the fenamiphos-treated plots (B. S. Sipes, unpublished). It is unlikely that the nematicide is promoting plant growth; rather, nematode feeding and reproduction are being inhibited.

1,3-D SL should be effective as a postplant treatment. Toxicity can be defined as the product of concentration and time (6); thus, two application regimes may be appropriate for 1,3-D SL. One option is to apply the chemical at frequent intervals, perhaps monthly, at low dosages (1). This would continually expose the nematodes to 1,3-D and give control as long as the threshold concentration × time factor required for nematode control was realized. Another option, similar to previous DBCP application methods (3), is to apply 1,3-D SL at or near preplant rates immediately following fruit harvest. Pineapple can tolerate up to 455 kg a.i./ha 1,3-D SL without noticeable phytotoxicity (D. P. Schmitt, unpublished data). The flush of root growth following fruit harvest (13) could then be protected.

Without adequate nematode control, pineapple production is unprofitable in Hawaii (9). The key element in nematode control is to achieve plant growth during the first 12 months after planting sufficient to produce fruit of size required for the fresh fruit market in the plant crop and first ratoon crops. Currently, this is accomplished by preplant fumigation and application of postplant nematicides. In the foreseeable future, the industry will need to adopt methods that minimize environmental hazards. The SL formulation of 1,3-D reduces losses due to volatility (10) and is as effective as the VL formulation.

Table 2. Pineapple fruit yield from plots infested with *Rotylenchulus reniformis* and receiving a volatile liquid formulation of 1,3-dichloropropene (1,3-D VL) (407 kg a.i./ha) or a soluble liquid formulation of 1,3-dichloropropene (1,3-D SL) (407 or 204 kg a.i./ha) preplant followed by 1,3-D SL (113 kg a.i./ha) or fenamiphos (F) (1.7 kg a.i./ha) postplant

Yield parameter	Untreated	VL/F	SL (407 kg)/F	SL (204 kg)/F	SL (407 kg)/SL	SL (204 kg)/SL
Plant crop						
Fruit weight (kg)	1.5 b[z]	2.0 a	2.0 a	1.9 a	1.6 b	1.5 b
Mg/ha	112.0 b	146.0 a	145.0 a	139.0 a	116.0 b	114.0 b
Percent packable	67.0 b	84.0 a	85.0 a	84.0 a	74.0 ab	67.0 b
Marketable Mg/ha	76.8 b	122.9 a	123.4 a	116.3 a	86.3 b	76.3 b
First ratoon harvest						
Fruit weight (kg)	1.1 c	1.6 a	1.5 a	1.6 a	1.3 b	1.3 b
Mg/ha	94.0 b	120.0 a	114.0 a	117.0 a	101.0 ab	93.0 b
Percent packable	32.0 c	64.0 a	67.0 a	65.0 a	46.0 b	43.0 bc
Marketable Mg/ha	30.6 b	77.2 a	77.3 a	76.6 a	47.9 b	41.2 b

[z] Means followed by the same letter are not significantly different according to the Waller-Duncan *k*-ratio *t* test ($k = 100$).

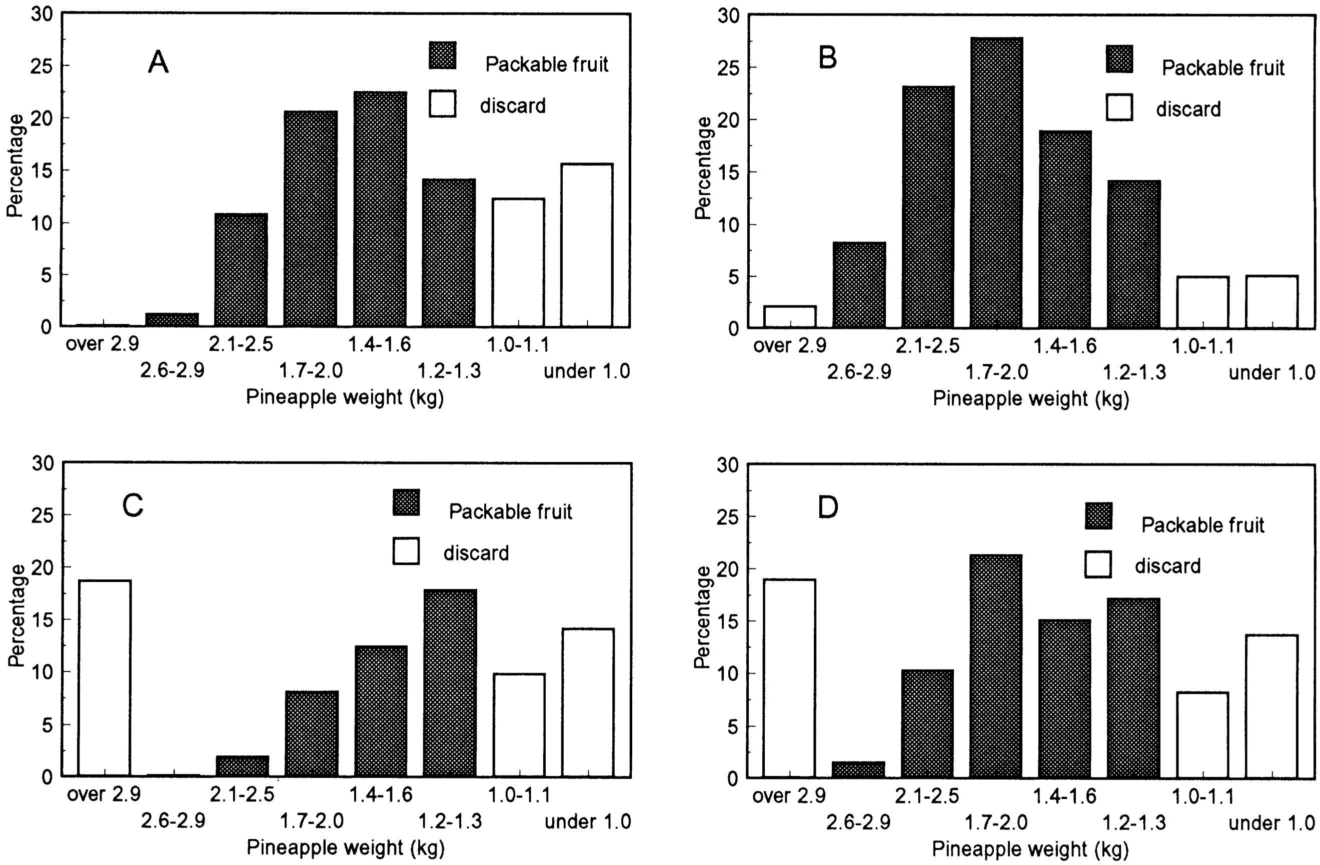

Fig. 4. Plant crop harvest (shown as percentage of fruit in each weight class) for pineapple plants under different nematicide control programs. Data from the untreated and postplant-treated with an emulsifiable formulation of 1,3-dichloropropene (1,3-D SL) have been combined, as well as data from all plots receiving postplant applications of fenamiphos. Plant crop harvest **(A)** untreated and 1,3-D SL postplant and **(B)** fenamiphos postplant. First ratoon harvest **(C)** untreated and 1,3-D SL postplant and **(D)** fenamiphos postplant.

Further development of 1,3-D SL should help pineapple growers continue to operate in Hawaii while meeting strict emission requirements and controlling nematode damage.

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