

Postplant Fumigation with DBCP for Citrus Nematode Control in Florida¹

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Abstract: Eleven citrus groves of diverse varieties and ages infected with *Tylenchulus semipenetrans* growing in differing soils in Florida were treated with three rates of 1,2-dibromo-3-chloropropane (DBCP) applied by various means. Yield, fruit size, and *T. semipenetrans* populations in the roots were compared between DBCP-treated and untreated trees over a period of 1-3 yr. Maximum fruit size and yield were obtained by applying DBCP at 38-58 kg/hectare (ha) (34-52 lb/acre); whereas best nematode control was with a rate of 77 kg/ha (69 lb/acre). Application of chemical emulsion with a special, drilled, low-profile sprinkler irrigation ground pipe was the most suitable method. Effect of DBCP treatment generally lasted for 3 yr. A mean annual 1.1% increase in fruit diameter, 15.2% increase in fruit yield and a 55.7% decrease in citrus nematode populations was found for DBCP-treated trees in contrast to untreated trees. **Key Words:** postplant control, dibromochloropropane, citrus nematode.

Tylenchulus semipenetrans Cobb, 1913 was first recorded in Florida and California in 1913 (5). In 1947, the species was reported to be widely distributed in Florida (21). Hannon (8) reported that 20% of Florida citrus groves were infested with *T. semipenetrans*; Tarjan (22) later revised this estimate to 53%.

Control of the citrus nematode on living citrus was first practiced in the U.S. in California (1, 2, 3) and Arizona (15, 20). In Florida, control of the citrus nematode was initiated by Hannon (9). Later, experiments by O'Bannon and Tarjan (16) showed the importance of citrus nematode control in established citrus groves in Florida. More recently, Heald (10) reported increased yields of 'Valencia' oranges in Texas after control of the citrus nematode.

Investigations on citrus nematode control and tree response have also been reported

from other areas of the world (7, 11, 13, 17, 18, 25, 28, 29).

Tylenchulus semipenetrans causes the disease of citrus known as "slow decline". Root, and above-ground, symptoms of infected trees have been described (6, 8, 20, 24). Severity of the disease can vary from no above-ground symptoms to severe decline of infected trees. Symptom expression is influenced by several physical and chemical factors, as shown by various investigations (14, 20, 27).

At present, the most effective chemical for control of *T. semipenetrans* on living citrus trees is 1,2-dibromo-3-chloropropane (DBCP), a volatile chemical with short residual activity in the soil. Populations are reduced by initial contact with DBCP (3) but at least 50 days (4) are required for maximum (99%) kill of nematodes.

Citrus nematode control generally results in improved tree growth and fruit production, lasting 2-4 yr. Various methods for application of DBCP have been investigated in an attempt to develop maximum control. The two most effective practical methods reported are chisel injection and flood irrigation (2, 3, 20).

Investigations to develop practical field control of the citrus nematode in Florida were initiated in 1966. Since then, DBCP has been applied as postplant treatments to 27.3 ha (67.4 acres) in 11 groves throughout the Florida citrus belt. This paper reports the results from these field tests of 1-3 yr duration.

MATERIALS AND METHODS

Experiments were conducted in citrus-growing areas in the southern Florida flatwoods region, the central Florida ridge

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² Professor (Nematologist), University of Florida, AREC, Lake Alfred 33850; and Nematologist, Agricultural Research Service, U.S. Department of Agriculture, Orlando, Florida 32803, respectively. The Shell Chemical Company furnished most of the DBCP used and some technical assistance; the Dow Chemical Company furnished DBCP for one test. Race and Race, Inc. of Winter Haven, Florida provided the special drilled sprinkler irrigation ground pipe. The following either located or provided for us suitable test groves: D. McCranie and F. W. Chase of Windermere, J. M. Coursey and W. L. Baker of Tampa, H. James and J. R. Graves of Wabasso, H. K. Magarian and W. L. Sims of Orlando, Charles Shinn, Jr. of Lake Alfred, Walter and Whiting Preston of Palmetto and E. E. Russell and K. O. Wells of Arcadia. Dr. J. A. Cornell kindly offered advice on statistical analyses.

TABLE 1. Physical characteristics of the experimental areas and analysis of treatments applied.

Experiment no. (hectares/acres involved)	Citrus scion/ rootstock (age in yr)	Soil series	Rows/trees per row. Tree spacing in meters (feet)	No. reps.	Rates of application active ingredient [kg/ha (lb/acre)]	Method of application	Expt. duration (yr)
1 (1.8/4.5)	PS/SW ^a (12)	Blanton	2/7 9 × 9 (30 × 30)	3	48.2 (43.0)	Chisel 85 ^b Soil spray ^c	3
2 (2.5/6.2)	PO/RL (10)	Leon	3/8 7.5 × 7.5 (25 × 25)	3	57.9 (51.6)	Chisel 85 Chisel 65 ^d Irrig-Stan ^e	3
3 (5.4/13.4)	MS/SO (38)	Pompano	2/30 6 × 9 (20 × 30)	4	1) 77.1 (68.8) 2) 57.9 (51.6) 3) 38.6 (34.4)	Irrig-Stan	3
4 (2.2/5.5)	MS/SO (40)	Pompano	2/20 6 × 9 (20 × 30)	2	1) 57.9 (51.6) 2) 38.6 (34.4)	Irrig-Stan Irrig-Spec Irrig-Stan Irrig-Spec	3
5 (4.7/11.7)	TA/RL (35)	Orlando	2/14 7.5 × 7.5 (25 × 25)	4	1) 57.9 (51.6) 2) 38.6 (34.4)	Irrig-Stan Irrig-Spec Irrig-Spec ^f	2
6 (1.1/2.8)	PO/RL (48)	Astatula	2/8 7.5 × 7.5 (25 × 25)	4	1) 50.4 (45.0) 2) 57.9 (51.6)	Chisel 65 Irrig-Spec	2
7 (2.9/7.1)	DG/RL (52)	Immokalee	4/8 6 × 9 (20 × 30)	4	1) 77.1 (68.8) 2) 57.9 (51.6) 3) 38.6 (34.4)	Irrig-Spec	2
8 (2.3/5.7)	VO/RL (10)	Immokalee	2/12 7.5 × 7.5 (25 × 25)	4	1) 77.1 (68.8) 2) 57.9 (51.6) 3) 38.6 (34.4)	Pressure-Inj ^g	2
9 (2.5/6.2)	PO/RL (12)	Leon	4/7 7.5 × 7.5 (25 × 25)	4	77.1 (68.8)	Irrig-Spec Pressure-Inj	2
10 (0.7/1.8)	PS/SO (22)	Manatee	1/10 6 × 9 (20 × 30)	4	1) 57.9 (51.6) 2) 19.4 (17.3)	Irrig-Stan	1
11 (1.0/2.5)	PS/SO (23)	Manatee	2/10 6 × 9 (20 × 30)	3	1) 70.7 (63.1) 2) 64.3 (57.4) 3) 53.2 (47.5)	Soil spray	1

^aDG = Duncan grapefruit (*Citrus paradisi* Macf.), MS = Marsh seedless grapefruit (*C. paradisi* Macf.), PO = Pineapple orange (*C. sinensis* [L.] Osbeck), PS = Pope Summer orange (*C. sinensis* [L.] Osbeck), RL = Rough lemon (*C. limon* [L.] Brum. f.), SO = Sour orange (*C. aurantium* L.), SW = Sweet orange (*C. sinensis* [L.] Osbeck), TA = Tangerine (*C. reticulata* Blanco), VO = Valencia orange (*C. sinensis* [L.] Osbeck).

^bTrees treated on all sides; approximately 85% of surface area treated around each tree site.

^cChemical sprayed directly on soil followed by irrigation.

^dTrees treated on opposite sides; approximately 65% of surface area treated around each tree site.

^eStandard "ABCX" sprinkler irrigation pipe.

^fSpecial-drilled sprinkler irrigation pipe.

^gHigh-pressure injector.

and the Gulf Coast flatwoods region. All groves selected were infested with *T. semipenetrans*. The soils ranged from well-drained acid sands to shallow, poorly drained acid or alkaline sands. Organic matter content varied from 0.25-5.0%. Details concerning groves and treatments are shown in Table 1.

Soils were disked prior to treatment. DBCP (1,2-dibromo-3-chloropropane) was applied at rates of 38.1-77.3 kg/ha (34-69 lb/acre) by: (i) chisel, using a tractor-drawn conventional chisel-type applicator; (ii) irrigation, using two types of perforated sprinkler irrigation ground pipe; (iii) soil spray, using a boom sprayer suspended from a spray tank; or (iv) by means of a high pressure

injector. Control plots for each test were given chisel and/or irrigation treatment without chemical.

The chisel applicator was equipped with five chisels, spaced 41 cm (16 inches) apart, that penetrated 25 cm (10 inches) into the soil. The chemical was metered using a wheel-driven pump. After treatment, the areas were sealed with a cultipacker.

Irrigation applications were made with either standard sprinkler irrigation ground pipe, 10.2 and 12.7 cm (4 and 5 inches) diam or a special-drilled, low-profile pipe, specifically designed to place the chemical emulsion directly on the soil, especially under tree canopies (Fig. 1). The special pipe was 12.7 cm



FIG. 1. DBCP emulsion application using special-drilled, low-profile, perforated irrigation ground pipe in a citrus orchard.

(5 inches) diam aluminum pipe with 1.98-mm (5/64-inch) diam holes spaced 152 cm (6 inches) apart and positioned 5°, 10°, 15° and 20° above the horizontal axis. Additional holes were bored 85° above the horizontal axis, alternately spaced 30.5 cm (12 inches) apart to treat row middles (16). All sprinkler pipe applications were made at a line pressure of 1.41 kg/sq cm (20 psi). The treatment sites were pre-wet with 2.5-5 cm (1-2 inches) of water before application of chemicals. DBCP was injected into the irrigation stream during the first 15 min of treatment by air pressure injection systems, by a small power sprayer or by use of a venturi, followed by additional application of water to deliver 5 cm (2 inches) of water. This required 2 h or longer when using standard pipe, but only 20-30 min when using the special drilled pipe, because of the greater number of holes.

Soil spray applications were made using a boom sprayer suspended 13 cm (5 inches) above the ground. The emulsion was sprayed on the soil surface and followed by 5 cm (2 inches) of water applied by overhead irrigation.

The high pressure injector applied the

chemical in solid streams behind chisels which cut furrows 10 cm (4 inches) deep in the soil. Jets of chemical emulsion were delivered at the base of the furrows at a pressure of 28.2 kg/sq cm (400 psi) to soil depths of 15-20 cm (6-8 inches) (23). The furrow openings were sealed with a cultipacker.

Response to treatments was determined by measuring root nematode populations, fruit diam, and annual yields.

About 2 mo preceding harvest, standard fruit calipers were used to measure 10 fruit at random, on each of two adjacent trees, in three areas within each plot. All data were computed to represent the mean fruit measurement per treatment for each test.

Root samples were taken from the upper 30 cm (12 inches) of soil from two-to-four places around the drip line of each tree. Samples were combined and placed in plastic bags. A modification of the Young incubation technique (30) was used for extracting *T. semipenetrans* juveniles from root samples. Five g of roots per sample were placed in individual 473-ml (1-pint) jars or polyethylene plastic bags of 0.025-mm (1-mil) thickness. Three to 10 ml of water or 3% hydrogen

peroxide were added, and then the samples were incubated at 21-23 C for 3-4 days. The roots were flushed with water, and the

extracted nematodes counted. Data were reported as the number of citrus nematodes per gram of moist root for each sample.

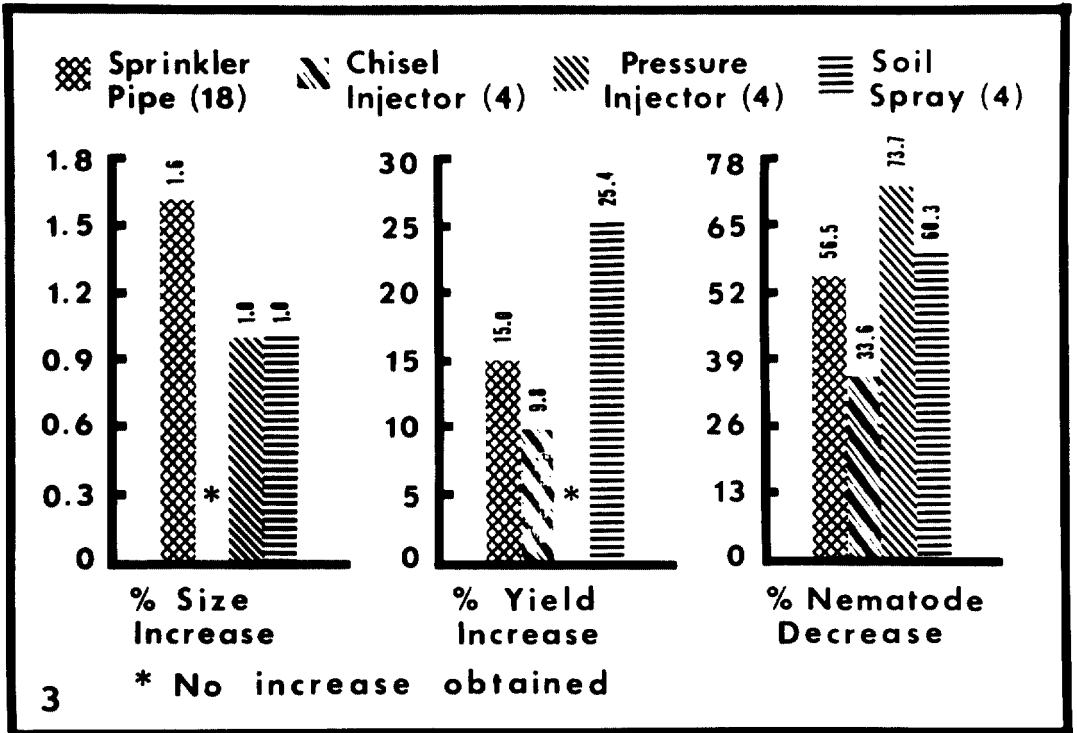
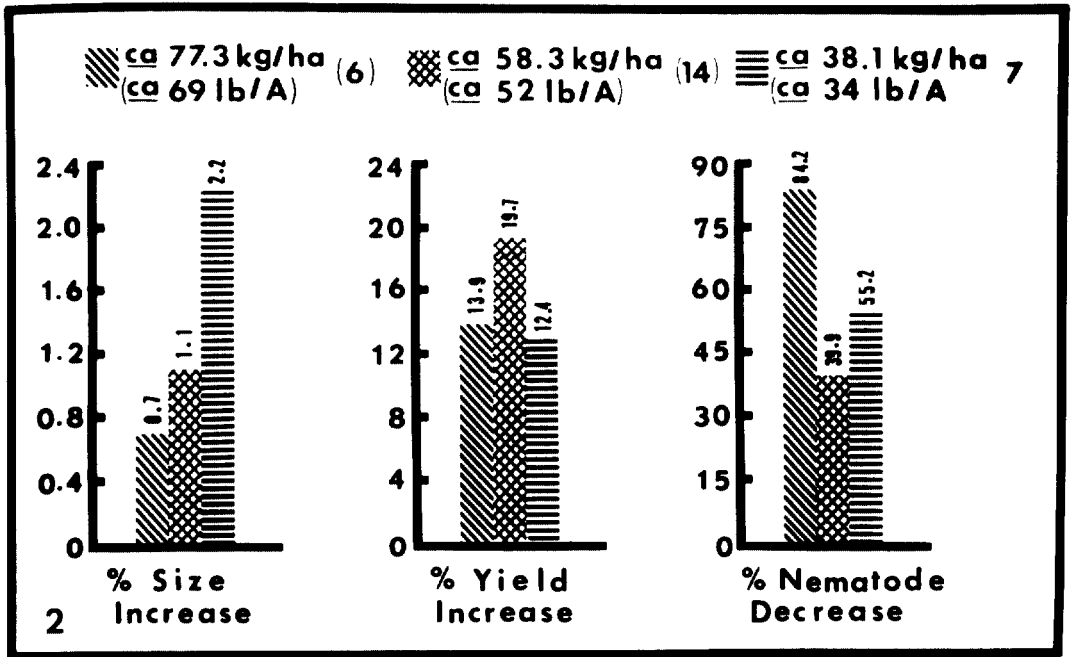


FIG. 2-3. Size and yield increases of fruit and nematode control as affected by: 2. DBCP rate. 3. Application methods (numbers in parentheses represent number of trials).

Fruit yield from treated groves was obtained annually. The total yield in boxes of fruit per plot was adjusted to represent the mean yield per tree for each plot and, ultimately, the mean yield per tree for each treatment within the test.

RESULTS

The data from the 11 separate experiments were summarized and are presented in Fig. 2-5. Percent increase in fruit size and yield and decrease in nematode populations within roots of treated vs. untreated trees were the best parameters to show the effects of soil treatment. Among the various experimental factors evaluated, the effect of: (a) DBCP rate, (b) application method, (c) tree age and (d) treatment after 1-3 yr were considered to be the most important. Some of the fruit diam and nematode population data were statistically significant. Fruit yields from treated trees were generally greater than yields from untreated trees, as indicated by percentage increases shown in Fig. 2-5, and were statistically significant in four of the nine tests analyzed.

An inspection of data for DBCP rate (Fig. 2) revealed that application of 38.1 kg DBCP/ha resulted in the greatest fruit size increase (2.2%) and the 77.3 kg/ha rate the smallest (0.7%). The 58.3 kg/ha rate gave the greatest percent increase in yield (19.7%) with

the other two rates nearly equal in promoting fruit yield, in contrast to that from untreated controls. Nematode control over a 1-3 yr period was greatest (84.2%) for the 77.3 kg/ha rate.

Of the four application methods, irrigation with sprinkler pipe in 18 trials resulted in the greatest increase in fruit size (1.6%), a 15% increase in fruit yield, and a 56% decrease in root nematode population in contrast to controls (Fig. 3). The other three methods were each used for only four trials; the soil spray method produced the greatest increase in yield of fruit while the pressure injector was best for reducing nematode populations.

The greatest increase in size of fruit (1.6%) as a result of treatment occurred on 35- to 38-yr-old trees (Fig. 4); trees 22-25 yr old had the greatest yield increase (25.4%); and trees 10-12 yr old showed the highest percent nematode control (67.7%).

All 11 experiments were maintained for at least 1 yr after treatment, while nine of the tests ran for 2 yr and four of them for 3 yr (Fig. 5). Compared to controls, the percent increase in size of fruit from treated trees decreased from 1.6% to 0.6% over the 3-yr period following treatment. Although percent yield increase was consistently good for the first 2 yr (15%), it dropped to 7% for the third yr. Nematode control was best the first yr after treatment (66% decrease) but decreased to 38

TABLE 2. Mean yearly yields in boxes of fruit per tree for 10 tests with DBCP.

Application method	DBCP rate (kg/ha)	Experiment ^a										
		1	2	3	4	5	6	7	9	10	11	
Chisel 85 ^a	57.9	-----	2.19									
	48.2	----	1.69									
Chisel 65	57.9	-----	2.87									
	50.4	-----					5.85					
Pressure-injection	77.1	-----							3.05			
Soil spray	70.7	-----									2.25	
	64.3	-----									2.60	
	53.2	-----									2.28	
	48.2	----	2.16									
Special-drilled irrigation pipe	77.1	-----							9.42		3.5	
	57.9	-----				-4.84*	-3.42	-6.60*		11.07		
	38.6	-----				-5.07*	-2.94		10.88			
Standard irrigation pipe	77.1	-----			4.59**							
	57.9	-----	2.83	-4.34*	-4.80						1.27*	
	38.6	-----		-4.39*	-4.64	-3.11						
	19.4	-----									1.17	
Controls		----	-1.89	-2.09	-4.06	-4.36	-2.77	-5.44	-9.32	-3.10	-0.89	-1.85

^a cf Table 1. Yields from Experiment 8 were not obtained.
 *Significant at .05 level.
 **Significant at .01 level.

and 48% respectively the second and third years after treatment.

Mean annual results from DBCP treatment, disregarding all variables, were a 1.1% increase in fruit diam, 15.2% increase in fruit yield, and a 55.6% decrease in root nematode populations.

DISCUSSION AND CONCLUSIONS

Sprinkler pipe application of DBCP was more effective than application by methods which use shanks or chisels that break roots. Many of Florida's citrus trees have roots above an impermeable clay or "stain" layer situated only 30-90 cm below the surface of

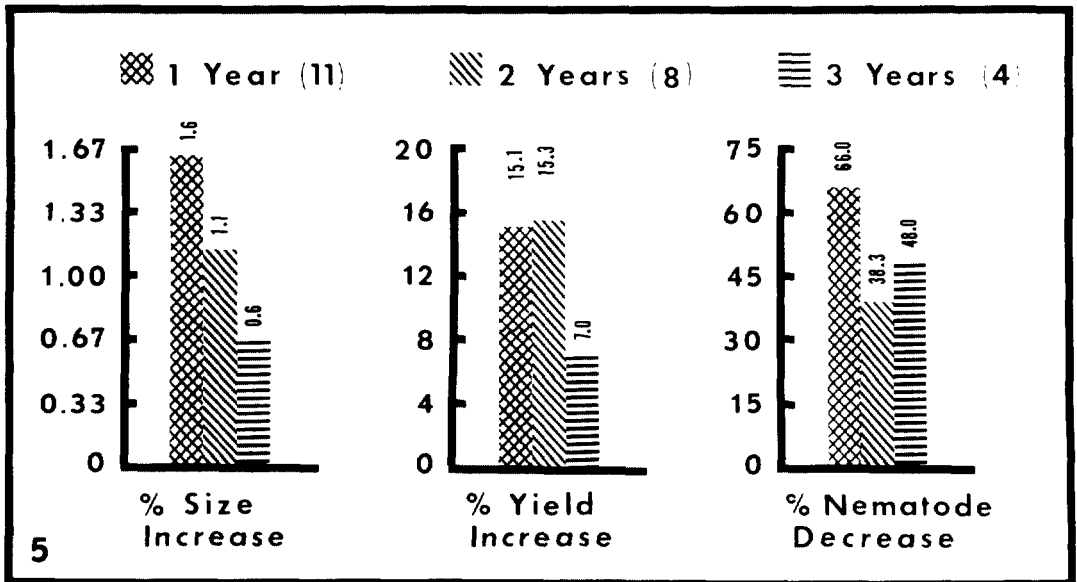
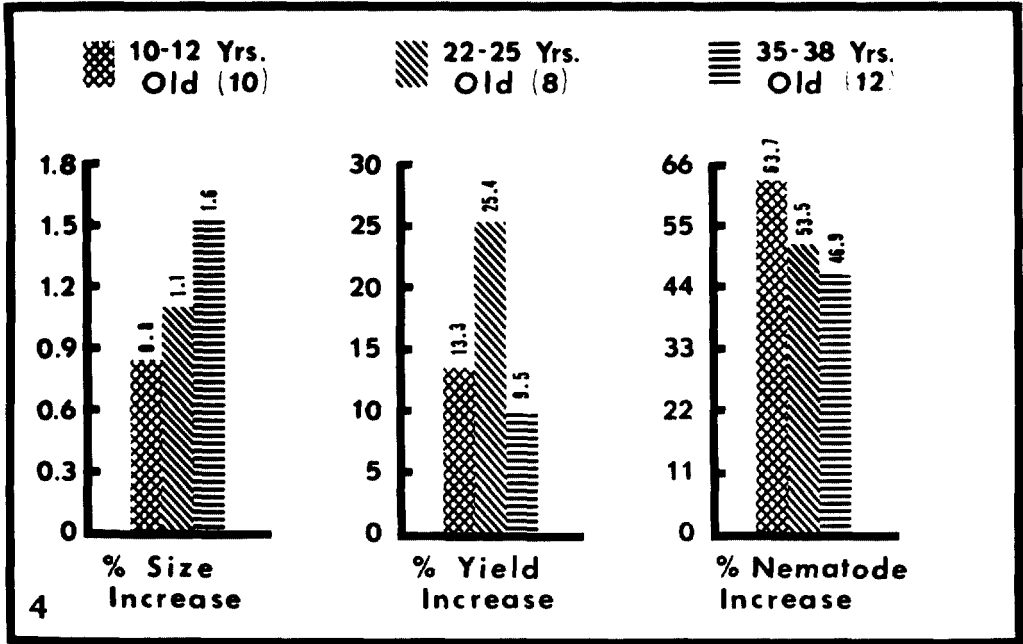


FIG. 4-5. Size and yield increases of fruit and nematode control in relation to: 4. Age of trees. 5. Effect of treatment after 1, 2, and 3 yr.

the soil. Accordingly, such trees may suffer seriously if their root systems are extensively damaged. However, chisel application on two sides (opposite sides) of trees was less damaging to the roots than treating all four sides. This method of application can be successfully used when sprinkler irrigation is not feasible. Spray application of DBCP was not sufficiently evaluated because of the inadequacy of available irrigation equipment. In subsequent tests, not reported here, application of DBCP from spray booms was feasible and effective, when followed by volume guns delivering strong overhead jets of water.

DBCP was successfully applied by ground pipe sprinkler irrigation to grapevines parasitized by *Xiphinema index* Thorne and Allen, 1950 and *Pratylenchus neglectus* (Rensch, 1924) by Raski (19) with resulting increases in yield from vines treated with 23.37 liters a.i./hectare (2-1/2 gallons a.i./acre). Cohn and Minz (7) used the same method but found that it resulted in inadequate nematode control. Van Gundy et al. (26) applied DBCP by overhead sprinkler irrigation and found that the area under the tree (protected by the canopy) was not penetrated by the DBCP emulsion. Although we used a standard-type ground sprinkler pipe, the same result was generally apparent. Adoption of special-drilled pipe solved the problem by applying the emulsion to the ground area below the tree canopy and also facilitated rapid transfer of the DBCP from the pipe to the soil, without excessive and unnecessary aeration.

The results generally show that 38-58 kg/ha of DBCP was adequate for good nematode control and subsequent fruit yield and size increases. In some tests, where 77.3 kg/ha was used, there seemed to be a resulting suppression of tree growth and yield response. Similar observations were made by Mendel et al. (12) who found that when DBCP was used in basin irrigation at a rate equivalent to 104 kg/ha, it had a transient depressing effect on growth and yield.

The responses that were measured, those of parasite control and yield improvement, were indicative of the relative immediate benefits of fumigation. One very important result of treatment which could not easily be evaluated was the subsequent effect on tree growth and vitality. In some tests, treated trees had more foliage with greener coloration about a year after treatment. In one grove

which experienced severe drought conditions 1 yr after treatment, trees which received DBCP applied by sprinkler irrigation showed little damage due to drought (10% leaf loss but no loss of fruit) whereas untreated trees were noticeably affected (50% leaf abscission and extensive fruit drop). Earlier in the spring, it had been noted that DBCP-treated trees had an earlier and more extensive production of new shoots than untreated trees.

Evaluation of yield data showed increases of 0.5-1.0 box of fruit per tree in most tests and, we believe, economically justified application of treatments. The foregoing account has shown that application of DBCP to Florida citrus trees infected with *Tylenchulus semipenetrans* has been effective in improving fruit yield and size, and decreasing nematode populations.

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