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Control of Citrus Nematode, *Tylenchulus semipenetrans*, with Cadusafos[1]

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Abstract: Granular (Rugby 10G) and liquid (Rugby 100 ME) formulations of cadusafos were evaluated for the control of *Tylenchulus semipenetrans* on mature lemon trees in a commercial citrus orchard at Yuma, Arizona. Three applications of cadusafos, with 2 months between applications, at the rate of 2 g a.i./m^2 reduced nematode populations to undetectable levels and increased the yield and rate of fruit maturity of 'Rosenberger' lemons. Yields were increased 12,587 kg/ha with Rugby 100ME and 8,392 kg/ha with Rugby 10G. Nematode populations were suppressed for at least 12 months after the last application.

Key words: cadusafos, chemical control, citrus nematode, lemon, management, Rugby, *Tylenchulus semipenetrans*.

The citrus nematode *Tylenchulus semipenetrans* is one of the most debilitating pests of citrus worldwide (2). It occurs throughout Arizona, where up to 65% of the bearing trees are infested (1). Until 1977, 1,2-dibromo-3-chloropropane (DBCP) was used to maintain nematode populations at acceptable levels. DBCP was low in phytotoxicity, highly nematicidal, and easily applied in irrigation water. Fruit size and total yield were increased for up to 3 years following a single treatment (4).

In 1977 the registration of DBCP was suspended due to environmental and human health concerns, leaving Arizona's citrus growers with few alternatives for nematode control. Currently, the only nematicides registered for use on citrus in Arizona are aldicarb and fenamiphos. Fenamiphos has not proven effective on desert-grown citrus that is flood irrigated (5), and aldicarb, while effective, has not gained favor in Arizona due to its high mammalian toxicity, mobility in soil water, and requirements for mechanical incorporation into the soil. Discovery of aldicarb in groundwater in California and Florida has restricted its use in those states.

Cadusafos (S,S-di-sec-butyl O-ethyl phosphorodithioate), an organophosphate pesticide (FMC Corp., Philadelphia, PA) has been registered in the Republic of South Africa for citrus nematode control since 1992. The efficacy of cadusafos has been thoroughly documented by Le Roux (3), who found that the life cycle of *T. semipenetrans* could be broken by three applications of 2.0 g a.i./m^2 at 2-month intervals during the growing season. In addition to its nematicidal properties, cadusafos has several characteristics that make it a promising nematicide for citrus nematode control. According to the manufacturer, cadusafos is not absorbed by the plant, and residues of the material are not found in fruit of treated trees. Limited water solubility and low to moderate soil mobility reduce the threat of groundwater contamination. Its half-life in silty clay loam and sandy soils is estimated to be about 45 days. It is formulated as both an emulsifiable concentrate (10% w/v), or granule (10% w/w), under the trade names Rugby 100ME and Rugby 10G, respectively.

Our purpose was to evaluate cadusafos for the control of citrus nematode on desert-grown citrus. Emulsifiable liquid and granular formulations were tested for efficacy and improvement of citrus yield and quality.

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Materials and Methods

Two experiments were established in a commercial citrus grove in Yuma, Arizona. Both sites, naturally infested with *T. semipenetrans,* contained 27- to 30-year-old 'Rosenberger' lemon trees, *Citrus limon* (L.) Raf., on rough lemon root stock at a density of 118 trees/hectare. One site, irrigated by a low-pressure microjet system, was used to evaluate the emulsifiable formulation of cadusafos (Rugby 100ME). Each tree trunk was surrounded with a 1.2-cm-diam. manifold tube fitted with three microjets that produced an overlapping spray pattern. The wetted area extended to the tree's drip line and encompassed approximately 18 m^2. The other site, which was flood irrigated, was used for the granular formulation (Rugby 10G). The sites were located approximately 5 km apart on the Yuma mesa. The soil of this area is a deep Superstition sand consisting of sandy, mixed, hyperthermic Typic Calciorthids; 85% sand, 7% silt, 8% clay, and 0.3% organic matter.

Both sites received three applications of cadusafos at 2-month intervals on 18 May, 14 July, and 13 September 1994. The Rugby 100ME site consisted of 15 treated trees and 15 untreated control trees, in 10 rows of three trees each. Treated rows alternated with untreated rows. Rugby 100ME was applied by pressure-injection though the microjet system at the rate of 2.0 g a.i./m^2. Each tree received approximately 36 g a.i. of Rugby 100ME in 75 liters of water followed by 300 liters of water from the microjets. Thereafter, the orchard was irrigated daily with 300 liters of water per tree from June through October and, as needed, from November to May.

The Rugby 10G site consisted of a single block of 24 trees, 12 treated and 12 controls, in a completely randomized design. Rugby 10G was distributed evenly, from the drip line to the trunk of the tree, with a hand-held fertilizer spreader at the rate of 2.0 g a.i. per m^2. Each tree received about 36 g a.i., depending upon the area treated. The granules were then hand-raked into the top 2.5 cm of soil and the orchard was flooded with approximately 200 cm of water. Irrigation by flooding continued every 14 days from June through October and at irregular intervals, as needed, from November to May.

Pretreatment and post-treatment nematode population densities were estimated by counting the number of juveniles and males extracted from feeder roots. Roots were taken from the top 30 cm of soil from the north, east, south, and west sides of each tree, 30 to 60 cm inside the drip line just before each application of cadusafos (18 May, 14 July, and 13 September 1994) and at 2 months (17 November 1994) and 12 months (21 September 1995) after the third application. Roots were shaken gently to remove soil and the four subsamples from individual trees were combined and cut into 2-cm pieces. A 5-g portion was incubated on a Baermann funnel under an intermittent mist of distilled water for 72 hours. Juveniles and males that migrated from the roots, or hatched from egg masses on the roots, were collected and counted.

Rate of fruit maturity was estimated by measuring fruit diameter at weekly intervals for the 9 weeks before harvest on 11 October 1994. Fifty lemons, selected at random from each tree, were measured and their mean diameter calculated. Five of these, each with a diameter within the standard error of the mean of the parent set, were tagged and measured thereafter at weekly intervals. Yields were not measured in 1994.

At harvest, 12 months after the third treatment with cadusafos, all of the lemons from each tree were removed in a single picking and weighed. Fifty lemons from each tree were randomly selected and graded according to industry standards (1st grade, 2nd grade, and culls) by Associated Citrus Packers, Yuma, Arizona.

All numerical data were subjected to analysis by SigmaStat Scientific Software (Jandel Corp., San Rafael, CA). Means of rhizoplane nematode populations, fruit size, and yield were compared by unpaired *t*-tests. Nonparametric data were analyzed by the Mann-Whitney Rank Sum Test.

Results

Populations of *T. semipenetrans* were reduced with both Rugby 100ME and Rugby 10G ($P < 0.001$) (Fig. 1). Two months after the third application of these materials, nematodes were detected on roots of only 2 of the 15 trees treated with Rugby 100ME and only 3 of 12 trees treated with Rugby 10G. Twelve months after the third application, nematodes were detected on roots of six trees treated with Rugby 100 ME and on five trees treated with Rugby 10G. On the treated trees with detectable nematode populations, the numbers of nematodes ranged from 10% to 22% of the controls. Natural seasonal fluctuations in nematode populations, unrelated to the treatments, were evident at both sites.

Rugby 100ME increased fruit size during the 9 weeks before harvest ($P = 0.007$) (Fig. 2). Fruit size was not affected by treatment with Rugby 10G (data not shown). Based on 118 trees/ha, yield was increased by 12,587 kg/ha following three applications of Rugby 100ME ($P = 0.005$) and by 8,392 kg/ha with Rugby 10G ($P = 0.019$) —a 45% and 29% increase, respectively (Fig. 3). Fruit quality, based on the percentage of 1st and 2nd grades, was not affected by either treatment (data not shown).

Discussion

Cadusafos is one of the most promising nematicides for control of citrus nematode since DBCP was withdrawn from the market in 1977. Not only were nematode populations controlled but, on many trees, were reduced to a level below the limit of detection. Nematode suppression was achieved for at least 12 months, suggesting

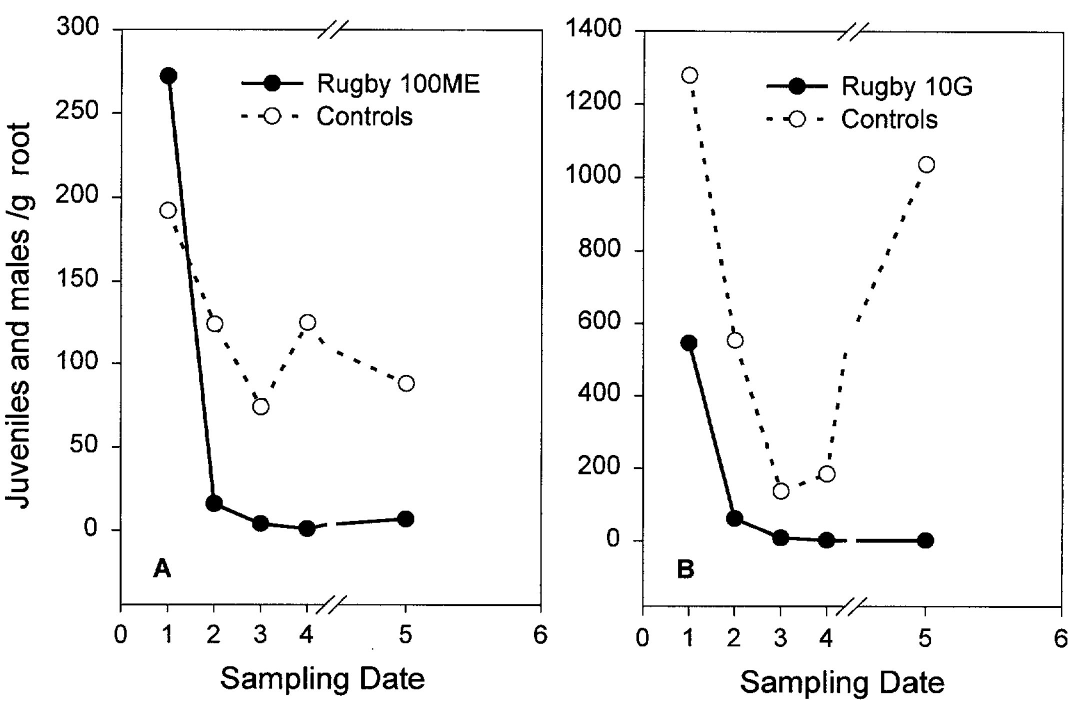

FIG. 1. Juveniles and males of *Tylenchulus semipenetrans* extracted from roots of lemon trees before and after treatments with A) liquid (Rugby 100ME) and B) granular (Rugby 10G) formulations of cadusafos at the rate of 2.0 g a.i./m^2 of soil. Data points are the means of 15 trees (Rugby 100ME) and 12 trees (Rugby 10G). Cadusafos was applied between the drip line and tree trunk immediately after sampling, on sampling dates 1, 2, and 3. Sampling and treatment dates: 1 = 18 May 1994; 2 = 14 July 1994; 3 = 13 September 1994; 4 = 17 November 1994; 5 = 21 September 1995.

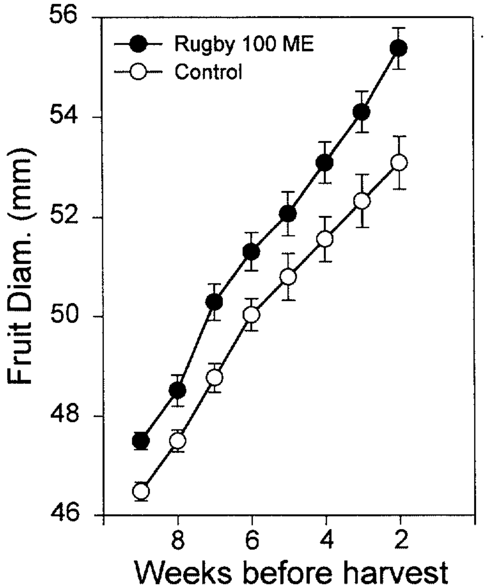

FIG. 2. Diameter of Rosenberger lemons in the 9 weeks before harvest on 11 October 1994. Trees were treated with Rugby 100ME at the rate of 2.0 g a.i./m^2 of soil, between the drip line and tree trunk. Data points are the means of five lemons. Fifty lemons, selected at random from each tree, were measured and their mean diameter calculated. Five of these, each with a diameter within the standard error of the mean of the parent set, were tagged and measured thereafter at weekly intervals. Vertical bars are standard errors of the means.

that additional applications would be needed only in alternate years or longer intervals. Le Roux (3) estimated that, in South Africa, it would take at least 4 years for populations to reach levels requiring additional treatment.

Because the test sites used in this trial were geographically separated and employed different irrigation systems, it was not possible to compare the efficacy of Rugby 100ME and Rugby 10G. Both formulations reduced nematode populations, but yield responses and fruit maturity rates were greater in the site treated with Rugby 100ME. This may have been due, in part, to the higher initial populations of nematodes in the Rugby 10G plot. According to Le Roux (3), nutritional imbalances, which occur in citrus trees infected for many years with nematodes, may not be rectified immediately when the nematodes are eliminated. Initial populations of citrus nematodes in the Rugby 10G site were four times those in the Rugby 100ME site; therefore, it is reasonable to infer that damage to these trees was correspondingly greater and that the trees would take longer to recover.

Relative amounts of 1st- and 2nd-grade lemons harvested from the test sites did not change as a result of cadusafos treatment. However, because total yield was substantially increased, the absolute yield of higher grades increased proportionally. Thus, greater economic returns could be expected from treatment with cadusafos than would be realized from yield increases alone.

Currently, cadusafos is not registered for use on any crop in the United States. Should registration be achieved, our trials show that cadusafos could be an alternative to DBCP or currently registered nematicides. Cadusafos also may prove to be a management tool for "earliness" when date of fruit maturity is an important factor in marketing strategy.

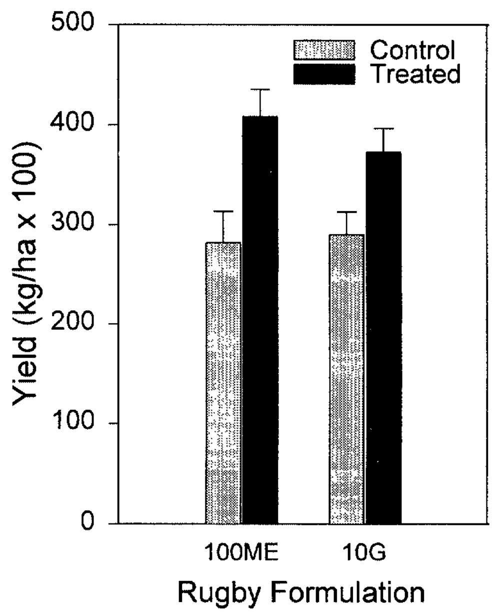

FIG. 3. Yield of Rosenberger lemons, 12 months after treatment with three applications of Rugby 100ME or Rugby 10G at the rate of 2.0 g a.i./m^2 of soil, between the drip line and tree trunk. Yield was extrapolated from mean yields of 15 trees (Rugby 100ME) or 12 trees (Rugby 10G). Vertical bars are standard errors of the means.

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