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Correlations of *Rotylenchulus reniformis* Population Densities with 1,3-Dichloropropene Dosage Rate and Pineapple Yields[1]

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Abstract: The relationships between *Rotylenchulus reniformis* population densities and pineapple growth and yield were studied in a small-plot field experiment. Increasing rates of handgun-injected 1,3-dichloropropene (1,3-D) preplant fumigant from 0 to 337 liters/ha resulted in greater nematode control, faster plant growth, and larger pineapple fruits. *Rotylenchulus reniformis* population densities at 2, 4, 6, and 8 months postplant were correlated with plant size and yield. The shorter the time period following planting in which *R. reniformis* densities remained low, the greater was the average loss in yield. A measurement of nematode-days as the area under the *R. reniformis* population growth curve indicated that this parameter was also correlated with plant growth and yield. Both population density and length of the control period affected the amount of crop damage.

Key words: 1,3-dichloropropene (1,3-D), *Ananas comosus*, crop loss, pineapple, population fluctuation, *Rotylenchulus reniformis*, soil fumigation.

The reniform nematode (*Rotylenchulus reniformis* Linford & Oliveira) is a damaging parasite of pineapple (*Ananas comosus* (L.) Merrill) in Hawaii and can dramatically reduce commercial yields. Pineapple in Hawaii has a 3–5-year crop cycle with 2–4 harvests. During the first year the plant produces a root system that nourishes the mother plant and provides most of the stored nutrients for the following ratoon crops. If this initial root system is lost, it cannot be regenerated. Thus, nematode damage early in the crop cycle tends to result in successively poorer yields in the ratoon harvests (1,9). It seems likely that delaying *R. reniformis* population increase would be beneficial.

Damage by *R. reniformis* to other crops has been documented as well. Plant root and shoot weights of castor, cotton, cowpea, greengram, okra, and tomato were inversely correlated with initial *R. reniformis* counts (13). The use of initial nematode densities in soil to estimate yield loss was applicable to these annual crops in temperate climates (4,5,12), but it may not apply as well to pineapple. In pineapple, *R. reniformis* can multiply from undetectable numbers at planting to damaging levels within 3 months; however, the first harvest does not take place until nearly 2 years later. Thus, the pineapple–*R. reniformis* interaction may be better described by models designed for perennial crops (3,4) rather than by initial nematode density estimates. The proposed nematode–days model should reflect more accurately the pineapple–*R. reniformis* interaction (8).

In perennial crops, initial nematode densities can eventually stabilize to an equilibrium (2,7). *Rotylenchulus reniformis* densities in pineapple may reach equilibrium in only 6 months (Schenck, unpubl.), long before the first harvest at 18–24 months postplant. Thus, the control period after planting, during which *R. reniformis* populations remain low, may have more effect on crop yield than the final level of the equilibrium population density. The purpose of this research was to gain a better understanding of the relationships between *R. reniformis* population densities and pineapple yield in order to implement more efficient control procedures.

MATERIALS AND METHODS

Small plots (2.4 m × 9.1 m) were installed in a field area in Hawaii heavily infested with *R. reniformis*. The plots were fumigated by handgun with 1,3-dichloropropene (1,3-D) at four dosage levels: 337

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liters/ha, 224 liters/ha, 112 liters/ha, and 0 (untreated controls). Fumigant was injected through the polyethylene mulch at points between each plant position. The handgun was calibrated to deliver the quantity of 1,3-D that was equivalent to the stated rate per hectare.

The use of nematicide rates to produce different soil population densities of *R. reniformis* introduced the variable of the fumigant itself. Twelve plots at each rate were arranged in a randomized complete block design. During the 2-year experiment, the beds remained covered with polyethylene mulch and were irrigated by a single drip irrigation tube running down the center of each bed. The soil was a lateritic silty clay loam with a pH of 4.5–5.0. In order to measure the effect of soil moisture on fumigant efficacy, each plot was preirrigated to one of three different moisture levels: 24, 29, or 33%.

Following fumigation, vegetative seed material (crowns from pineapple fruit) was planted in two beds per plot. Each bed contained two rows of plants, a total of 144 plants per plot. Before planting, the crowns were dipped in a fosetyl-Al (2.4 g/liter)-benomyl (0.75 g/liter) suspension to prevent fungal infection. Foliar sprays of urea and ferrous sulfate were applied biweekly. *Rotylenchulus reniformis* numbers were estimated bimonthly in each plot from 50-cm^3 composite soil samples extracted on Baermann funnels. Composite soil samples were made by thoroughly mixing six soil samples taken at random spots within each plot. Each sample was taken next to a plant in the root zone to a depth of 15 cm. Average plant weights were estimated at 6 and 12 months postplant. The yield from the first harvest, at 21 months after planting, was recorded as average fruit weight per plot. The total fruit weight per plot was used to estimate metric tons of fruit per hectare.

Results and Discussion

The *R. reniformis* densities at test installation before fumigation averaged 52/50 cm^3 soil sample measured at 10-cm increment depths to a depth of 40 cm. Average densities were 18/50 cm^3 at the 0–10-cm depth and 78/cm^3 at 10–30 cm. Below 40 cm there were very few nematodes, which probably reflects the rooting pattern of the previous pineapple crop.

Initial population densities of *R. reniformis* were reduced to nearly undetectable levels by all rates of the fumigant. The nematodes eventually multiplied to high densities in all plots, but the increase, which tended to be sudden rather than gradual, was delayed by 1,3-D. As the fumigant rate increased, the delay increased. Thus, a range of population sizes over a period of time could be correlated with plant growth and yield. A series of nematicide rates may be used to produce nematode population differences for study, but the effect of the fumigant variable itself must be considered (2). In this particular test, *R. reniformis* numbers were very high and the relative importance of other nematode species or fungal diseases was negligible. Furthermore, in previous experiments with 1,3-D applied before planting, no direct effect of the chemical on pineapple growth or yield in the absence of nematode pests was ever detected.

In this test, although all 1,3-D rates reduced *R. reniformis* populations to very low densities, the populations increased more rapidly in plots with lower rates (Table 1). This indicated that many survivors remained with the low fumigant rates even though these could not be detected by the sampling method used. With each increase in 1,3-D rate, *R. reniformis* population density increase was further delayed and plant growth and yields were increased.

The correlation of fumigant rate with nematode densities, plant weight, or fruit yield was highly significant ($P < 0.01$) in all cases. The correlation coefficient between the 1,3-D rate and plant weight was $r = 0.78$ at 6 months and $r = 0.87$ at 12 months. Fumigant rate was also correlated with average fruit weight ($r = 0.88$). Soil moisture as percentage of soil dry weight was measured at time of fumigation and found not to affect the results ($r = -0.08$).

TABLE 1. Average numbers of *Rotylenchulus reniformis* at 2, 4, 6, and 8 months after planting, average plant weight at 6 and 12 months after planting, and average pineapple fruit weight for each rate of 1,3-dichloropropene (1,3-D).

1,3-D (kg/ha)	*R. reniformis*/50 cm³ soil				Plant weight (kg)		Fruit weight (kg)
	2 mo	4 mo	6 mo	8 mo	6 mo	12 mo	
0	27	50	373	366	0.22 a	0.81 a	0.70 a
112	1	3	125	289	0.36 b	1.09 b	0.81 ab
224	0	2	47	179	0.41 bc	1.29 c	0.91 b
337	1	9	21	131	0.47 c	1.54 d	1.09 c

Data are means of 12 replicates, arranged by number of months after planting. Means in columns followed by the same letter are not different ($P = 0.01$) according to Duncan's multiple-range test.

Soil moistures ranged from 33% (field capacity) to 24% (dry) and covered the soil moisture range over which these soils can be worked. Therefore, soil fumigation with 1,3-D can be carried out effectively within the normal range of soil moistures in this lateritic silty clay loam soil.

Significant negative correlations were found between pineapple plant weight at 6 or 12 months postplant with average numbers of *R. reniformis* at each of the months measured (Table 2). Similar relationships were found also for average fruit weight and estimated metric tons per hectare. These correlations were highly significant ($P \leq 0.01$) except with nematode numbers collected 4 months after planting ($P \leq 0.05$; Table 2).

Rotylenchulus reniformis population densities at each month postplant were all correlated with final yield, but because the nematode counts over the several months were closely correlated with each other, it is not certain to what extent counts at every month actually affected final yield. It is likely that high *R. reniformis* population densities developing soon after planting were more damaging than populations that did not increase until later (1). This hypothesis was tested by assigning a population control period to each plot and relating control period to yield (Table 3). As an example, the densities in plot B4 remained low at 2 months and at 4 months, but increased to high levels by 6 months and remained high after that. Plot B4, therefore, had a nematode control period of at least 4 months. A "high" population was arbitrarily set at 20 or more nematodes per 50-cm³ sample. *Rotylenchulus reniformis* populations in pineapple lend themselves to this type of analysis because they usually have a very steep exponential growth phase.

Average *R. reniformis* numbers in the plots with the same length of control period, along with the average fruit weight and metric tons per hectare for those plots, were obtained (Table 3). Although the difference between the fruit weight means was not significant ($P \leq 0.05$), the increase in yield with increasing period of *R. reniformis* control was consistent. Correlation of control period with average fruit weight was highly significant ($r = 0.73$; $P < 0.01$). Few plots remained low over 8 months, so continued comparisons of low vs. high populations could not be carried out. However, 1.13 kg per fruit is typical of healthy commercial plantings. It is not likely that a nematode control period longer than 10 months would have resulted in any further significant gain in yield (1). Fumigant rate

TABLE 2. Correlation coefficients of *Rotylenchulus reniformis* numbers at 2–8 months after planting with plant weight at 6 and 12 months and fruit yield.

Time of *R. reniformis* sampling	Plant weight		Av. fruit weight	Metric tons/ha
	6 mo	12 mo		
2	−0.60	−0.61	−0.56	−0.57
4	−0.38	−0.38	−0.34	−0.31
6	−0.67	−0.73	−0.69	−0.64
8	−0.36	−0.53	−0.54	−0.52

For 45 degrees of freedom, $r(P = 0.05) = 0.288$, $r(P = 0.01) = 0.372$.

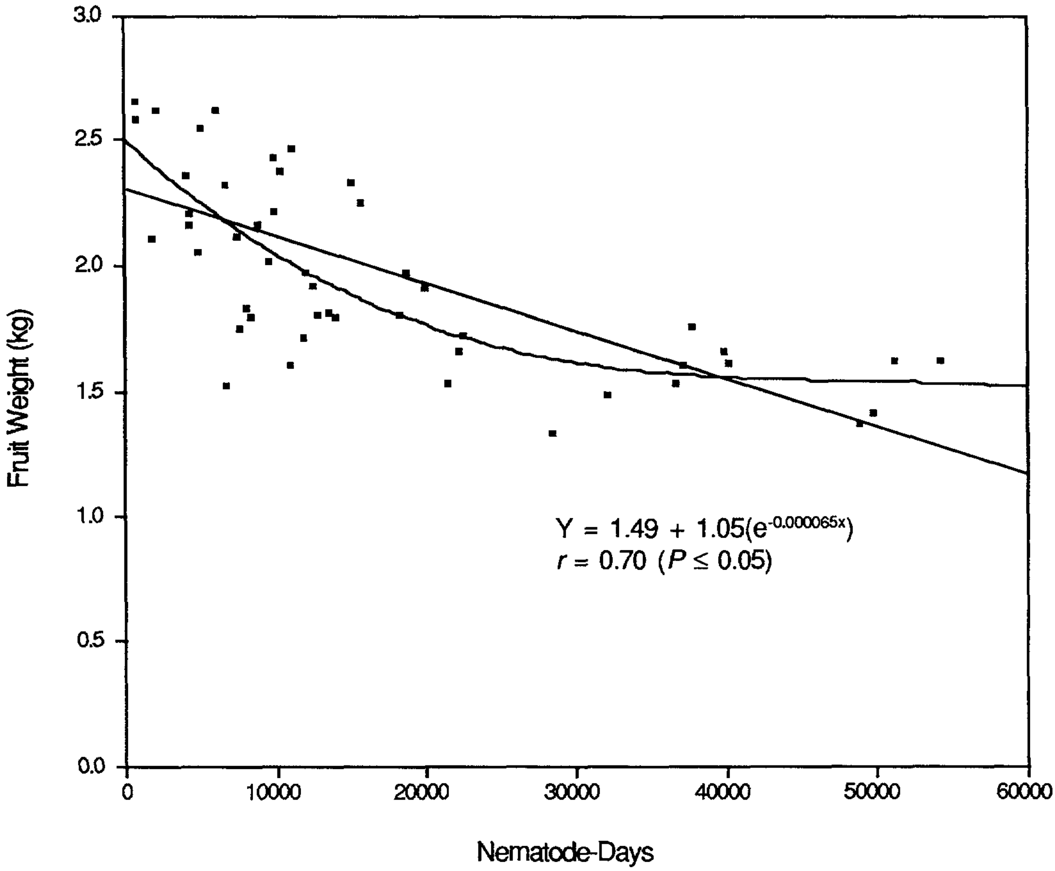

FIG. 1. Relationship between average pineapple fruit weight (Y axis) and nematode-days (X axis), where X = *Rotylenchulus reniformis* populations × days of infection.

was also correlated with the length of the control period ($r = 0.75$; $P < 0.01$).

Length of control period provided an estimate of nematode damage and yield, but the eventual magnitude of the populations should also affect yield (8). Using a modification of Noling and Ferris' nematode-degree day model (8), the area under each population curve was measured and recorded as nematode-days, ignoring temperature which varied little over the 8-month period.

A scattergram relating nematode-days and average fruit weight is shown (Fig. 1).

TABLE 3. Effects of length of *Rotylenchulus reniformis* control period on average fruit weight and tons of fruit per hectare.

Control period (months)†	Av. *R. reniformis* numbers/50 cm³ soil				Av. fruit wt. (kg)	Metric tons/ha
	2 mo	4 mo	6 mo	8 mo		
0 (5 reps)‡	43	68	341	457	0.69	43.25
2 (6 reps)	13	56	342	311	0.75	46.66
4 (26 reps)	1	2	110	229	0.88	56.02
6 (7 reps)	2	1	1	202	1.05	67.27
8 (4 reps)	0	6	8	18	1.13	72.98

Correlation of average fruit weight with length of control period, $r = 0.73$, $P \leq 0.01$.
† Control period = months after planting during which the numbers of *R. reniformis* remained less than 20/50 cm³ soil.
‡ The number of replication plots varied between treatments (see text).

The linear correlation of nematode-days (X) with average fruit weight (Y) was −0.70 ($P \leq 0.01$). The pattern of points indicated a negative exponential equation would better explain the data (6). Using the Marquardt nonlinear procedure of the Statistical Analysis System (10), the best-fit formula was

$$Y = 1.49 + 1.05(e^{-0.000065X}),$$

a negative exponential curve with an asymptote of 1.49.

In summary, it appeared that an incremental increase in nematode numbers at lower density levels caused greater yield reduction than at higher levels. The predicted asymptote of 1.49 kg fruit weight indicated that a certain minimum yield (2,12) remained, even at the highest possible nematode populations. Finally, the variation around the curve appears to be greater at lower nematode-days than at higher densities. This suggests that at lower levels of nematode damage, other environmental parameters exerted a greater influence on fruit weight than they did when the *R. reniformis* populations became severely limiting to plant growth.

Both the final density of the *R. reniformis* population and the length of time following planting that the exponential growth phase was delayed affected the yield. As expected, damage to the pineapple root system occurring soon after planting had a much greater effect on the crop than did damage occurring later. Therefore, the length of time that *R. reniformis* populations are kept under control is more important for management purposes than the actual population levels.

From a practical viewpoint, neither control period nor ceiling *R. reniformis* population densities can be measured sufficiently early in the pineapple crop cycle to be of use in deciding whether to apply postplant nematicides. After about 1 year following planting, *R. reniformis* populations begin to decline gradually (11). They usually decline even further during the intercycle fallow period, and *R. reniformis* levels during fallow are one indication of the potential for nematode damage to the next crop. However, the efficacy of the preplant fumigation is the key factor for control, and usually this cannot be determined at planting. In Hawaiian pineapple plantations, there are large differences in ceiling *R. reniformis* population levels between areas, and these differences remain consistent over many crop cycles (11). For the purpose of planning postplant nematicide applications, previous field nematode surveys are the best predictors.

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