Partitioning Yield Loss on Yellow Squash into Nematode and Insect Components[1]

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Abstract: The effect of a complex of several insect and nematode pests on yield of yellow squash (*Cucurbita pepo* L.) was examined in two field tests in southern Florida. Applications of permethrin for insect control and oxamyl primarily for nematode control plus some insect control were made alone and in combination to achieve differential reduction of various insect and nematode components contributing to yield loss. The effect of these components on yield was further analyzed by multiple regression. Yield losses in weight of small fruit to nematode and insect pests together were estimated at 23.4% and 30.4% in each of the two tests, respectively. In the first test, this loss was attributed to the melonworm, *Diaphania hyalinata*, while in the second test, it was attributed to *D. hyalinata* and the nematodes *Quinisulcius acutus* and particularly *Rotylenchulus reniformis*. *D. hyalinata* accounted for further losses of 9.0% and 10.3%, respectively, from direct damage to the fruit. Despite the presence of low levels of *Diabrotica balteata*, *Liriomyza sativae*, and *Myzus persicae*, yields were little affected by these pests. Prediction of yield loss by multiple regression analysis was more accurate when both insect and nematode populations were present in the plots than when nematodes alone were present. *Key words:* green peach aphid, banded cucumber beetle, multiple pest control, reinform nematode, vegetable leafminer, permethrin, oxamyl. Journal of Nematology 14(1):110-118. 1982.

Accurate estimates of crop losses caused by nematodes are important in developing plant damage functions. However, problems can arise when making estimates of losses due to nematodes when chemicals (e.g., carbofuran, aldicarb, oxamyl) used to control nematodes are also insecticides (2,5). It is difficult to determine if yield increase due to treatment should be attributed to nematode or insect control. Methodology needs to be developed to correctly attribute yield loss to the proper pest group.

Yellow squash (*Cucurbita pepo* L.) is often simultaneously attacked by a variety of nematodes, insects, and diseases, and significant yield increases have resulted from control of such complexes (3,9). Selective control of insects or nematodes may be attained by the use of oxamyl (Methyl N'N'-dimethyl-N-[(methylcarbamoyl)oxy]-1-thiooxaminidate, an insecticide-nematicide) and permethrin (3-Phenoxybenzyl (±) cis-trans-3-(2,2-dichlorovinyl)2-2 dimethylcyclopropanecarboxylate, an insecticide) alone and in combination.

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MATERIALS AND METHODS

Two tests were conducted near Homestead, Florida, on a Rockdale fine sandy loam soil, of pH 7.5. A spring test was planted on 30 January 1979 in a site which had been previously planted to snap bean (*Phaseolus vulgaris* L. cv. Harvester). An autumn test was planted on 21 September 1979 following okra (*Hibiscus esculentus* L. cv. Clemson Spineless). 'Early Yellow Summer Crookneck' squash was used throughout this study. Before planting, chloramben at 3.36 kg ai/ha and fertilizer (7–14–14) at 448 kg/ha were applied to each site. Seeds were planted 8–10 cm apart in rows 1.83 m apart and 30 m long. Approximately 3 wk after emergence, plants were thinned to 25–30 cm apart and sidedressed with 224 kg/ha of fertilizer (7–14–14) incorporated with cultivation.

Four treatments were applied to individual rows in the spring test in randomized complete block design with six replications: 1) permethrin at 112 g ai/ha; 2) oxamyl at 0.56 kg ai/ha; 3) permethrin (112 g ai/ha) and oxamyl (0.56 kg ai/ha); and 4) control. Treatments for the autumn test were identical, except that oxamyl was applied at 1.12 kg ai/ha. All treatments were applied as foliar sprays in 935 liters water/ha at 21 kg/cm^3 pressure using one nozzle of a boom sprayer per row. The spring test consisted of eight weekly sprays beginning 15 February 1979, and the autumn test consisted of nine weekly sprays beginning 28 September 1979.

Fungicides were applied weekly, alternating mancozeb at 1.8 kg ai/ha and chlorothalonil at 1.7 kg ai/ha. Spring test plots were sprayed as needed with benomyl at 0.84 kg ai/ha for control of powdery mildew (*Sphaerotheca fuliginea* [Schlechtendal] Polacci). Autumn test plots received periodic applications of captafol (1.7 kg ai/ha) for control of downy mildew (*Pseudoperonospera cubensis* [Berkeley and Curtis] Rostowzew).

Soil samples for nematode analysis were collected from each of the 24 rows shortly after planting and at 2-wk intervals thereafter to give six sampling dates in each test. Subsamples were collected with a hand trowel to a depth of 10–12 cm from 15 locations in each row, and mixed to form a composite sample. Each sample was passed through a 4-mm sieve to remove rock, and a 100-cm^3 aliquant was then suspended in water and processed by decanting and sieving followed by suspension of the residues in modified Baermann funnels (1,4). Collected nematodes were heat relaxed, counted, fixed in 5% formalin, infiltrated with 1.5% glycerin, and mounted on metal slides for identification. Complete root systems from plants in the middle of each row were examined for root-knot nematodes (*Meloidogyne* spp.) and reniform nematodes (*Rotylenchulus reniformis* Linford & Oliveira) after the last harvest.

Insect counts were recorded four times between 23 February and 19 March in the spring test and five times between 5 October and 14 November in the autumn test. A sample site was randomly selected in each plot and six consecutive plants examined for the presence of insects. Vegetable leafminer (*Liriomyza sativae* Blanchard) and green peach aphid (*Myzus persicae* Sulzer) counts were made by examining one leaf from the middle section of each of the six plants. Banded cucumber beetle (*Diabrotica balteata* LeConte), pickleworm (*Diaphania nitidalis* Stoll), and melonworm (*D. hyalinata* L.) counts were made by whole-plant examination of the six plants.

Fruit were harvested from a 15-m section of each plot six times between 23 March and 10 April during the spring test and nine times between 30 October and 30 November during the autumn test. The fruit were graded by size and quality according to USDA grading standards (11). At each harvest, fruit were examined for insect damage and culled if holes bored by *D. hyalinata* were found. Yield, insect, and nematode data were subjected to analysis of variance for a two-way classification, followed by Duncan's new multiple-range test. Yield was analyzed as a function of nematode and insect population densities on the various sampling dates by means of a stepwise multiple regression analysis (8).

RESULTS

The nematodes *Helicotylenchus dihystera* (Cobb) Sher, *Quinisulcius acutus* (Allen) Siddiqi, and *Rotylenchulus reniformis* and the insects *Diaphania hyalinata* and *Myzus persicae* were present in both the spring and autumn tests. The effects of the treatments on populations of *Q. acutus* and *R. reniformis* in both tests are shown in Table 1. Permethrin alone had little effect on nematode population levels, and no significant control of *Q. acutus* or *R. reniformis* was achieved by any treatment in the spring test (when the lower rate of oxamyl was used). During the autumn test, when the higher rate of oxamyl was used, populations of both *Q. acutus* and *R. reniformis* were significantly reduced on several sampling dates in the plots treated with oxamyl alone or in combination with permethrin, compared to untreated plots.

The effects of the treatments on populations of *D. hyalinata* and *M. persicae* are shown in Table 2. In general, little control of *M. persicae* was achieved. However, treatments containing permethrin gave significant ($P = 0.05$) control of the melonworm, *D. hyalinata,* compared to untreated control plots on two sampling dates in each test. Population levels of *D. hyalinata* in plots treated with oxamyl alone were intermediate.

Other nematode and insect pests, such as *H. dihystera, Meloidogyne* spp., *D. nitidalis, D. balteata,* and *L. sativae,* were present in very low numbers and showed little response to treatment.

Yield differences by treatment for the

Table 1. The effect of oxamyl and permethrin on soil populations of the nematodes *Quinisulcius acutus* and *Rotylenchulus reniformis* on several sampling dates in the spring and autumn tests.

Treatment†	Nematodes per 100 cm^3 of soil*											
	Spring test, sampling date						Autumn test, sampling date					
	1–30	2–13	2–27	3–12	3–27	4–11	9–25	10–3	10–17	10–31	11–14	11–30
							Q. acutus					
Oxamyl + permethrin	13a	4a	10a	8a	3a	7a	112a	126b	82a	59a	101a	28a
Oxamyl	3a	3a	5a	3a	5a	16ab	89a	72ab	116ab	43a	97a	55a
Permethrin	3a	5a	9a	1a	8a	31b	104a	52a	246b	188ab	518b	400b
Control	1a	15a	8a	9a	6a	27ab	121a	77ab	248b	338b	738c	468b
							R. reniformis					
Oxamyl + permethrin	64a	76a	136a	28a	64a	222a	418a	196b	37a	24a	58a	48a
Oxamyl	115a	62a	112a	31a	25a	163a	547a	88ab	73ab	33ab	149ab	91a
Permethrin	50a	84a	95a	76a	91a	447a	458a	58a	141c	64ab	263bc	483c
Control	57a	78a	125a	57a	66a	185a	541a	97ab	120bc	74b	362c	331b

*Mean of six replications. Means in each column followed by the same letter are not significantly ($P = 0.05$) different, according to Duncan's new multiple-range test.

†Treatment rates—Spring test, oxamyl = 0.56 kg ai/ha; permethrin = 112 g ai/ha. Autumn test, oxamyl = 1.12 kg ai/ha; permethrin = g ai/ha.

spring test (Table 3) were likely due to *D. hyalinata,* the only pest consistently affected by the treatments in this test. The weight of USDA #1 small fruit (highest commercial value) per plot was inversely related to the numbers of this insect pest. In the spring test, the significant difference in fruit weight in this grade between oxamyl-treated and untreated plots can be attributed not to nematode control, but to the limited effect of oxamyl on *D. hyalinata.* Damage to yellow squash by *D. hyalinata* is twofold, consisting of loss in the number and weight of fruit resulting from foliar feeding (indirect loss), as well as loss caused by the insect feeding directly on the fruit. Indirect damage by this pest accounted for a 23.4% yield reduction in total small-fruit weight in the spring test (12,933 g from control plots compared to 16,890 g from plots treated with both oxamyl and permethrin). Additionally, a 9% reduction in total small-fruit weight occurred from direct damage by this pest, resulting in culled fruit (1,842 g insect-damaged fruit in control plots minus 328 g insect-damaged fruit in plots treated with both oxamyl and permethrin = 1,514 g net direct loss = 9% of 16,890 g). Thus, total loss in weight of small fruit attributed to *D. hyalinata* was 32.4% in this test. Note that in this test, when insect control alone was achieved, the yields of plots treated with oxamyl alone were between those of the control plots and plots treated with permethrin (alone or in combination), a more effective insecticide than oxamyl.

Yield differences in the autumn test followed a different pattern (Table 3). In that test, when both insect and nematode control were achieved, the yields of plots treated only with permethrin were between those of the control plots and plots treated with oxamyl (alone or in combination), since permethrin did not provide the control of the nematode component that oxamyl did. Indirect damage by insects and nematodes accounted for a 30.4% yield reduction in total small-fruit weight in the autumn test (9,002 g from control plots compared to 12,930 g from plots treated with both oxamyl and permethrin). The weight loss in total small fruit due to indirect damage by insects was estimated at 18.0% (11,326 g in plots treated with permethrin alone minus 9,002 g in control plots = 2,324 g = 18.0% of 12,930 g), assuming that permethrin alone gave the maximum level of insect control, as indicated in Table 2. The weight loss in total small fruit due to indirect damage by nematodes was estimated at 12.4% (12,930 g in plots treated with both permethrin and oxamyl minus 11,326 g in plots treated with permethrin alone =

Table 2. The effect of oxamyl and permethrin on populations of the insects *Diaphania hyalinata* and *Myzus persicae* on several sampling dates in the spring and autumn tests.

	Insects per six plants*								
	Spring test, sampling date				Autumn test, sampling date				
Treatment†	2–23	2–28	3–8	3–19	10–5	10–12	10–17	10–31	11–14
	D. hyalinata								
Oxamyl + permethrin	0a	0a	0a	0.2a	0a	0a	0.2a	0a	0a
Oxamyl	0a	0a	1.8b	6.2ab	0a	0.2a	0.5a	0.2a	14.2b
Permethrin	0a	0a	0a	0.3a	0a	0a	0a	0a	0.8a
Control	0a	0a	3.3c	15.3b	0a	0a	0a	4.2b	34.2c
	M. persicae								
Oxamyl + permethrin	0.30a	0.03a	0a	0.03a	0a	0a	0.03a	0a	0a
Oxamyl	0.10a	0.12a	0.03ab	0.03a	0a	0a	0.15b	0a	0a
Permethrin	0.15a	0.05a	0a	0a	0a	0a	0a	0a	0.18a
Control	0.68a	0.10a	0.10b	0.03a	0a	0.33a	0a	0.12a	21.93b

*Mean of six replications. Means followed by the same letter are not significantly (P = 0.05) different, according to Duncan's new multiple-range test.

†Treatment rates—Spring test, oxamyl = 0.56 kg ai/ha; permethrin = 112 g ai/ha. Autumn test, oxamyl = 1.12 kg ai/ha; permethrin = 112 g ai/ha.

Table 3. Total number and weight of fruit by treatment for various size classes and cull categories.

Test	Treatment†	USDA small fruit*							USDA small & large*	
		Marketable fruit			Culled fruit					
		#1	#2	#1 & #2	Insect damage	Fungus damage	Total	Total fruit	Total fruit	Total culled fruit
Spring 1979		Number of fruit								
	Control	125a	35a	160a	25b	4a	50b	213a	217a	56b
	Permethrin	214b	35a	249b	9a	9a	34a	284b	295b	46a
	Oxamyl	168a	42a	210ab	21b	5ab	44b	254ab	262ab	52b
	Oxamyl + permethrin	225b	36a	261b	6a	8ab	26a	287b	304b	44a
		Weight (g) of fruit								
	Control	7,550a	2,285a	9,835a	1,842b	112a	3,098c	12,933a	14,512a	4,677a
	Permethrin	12,681c	2,617a	15,298b	570a	247a	1,937ab	17,235b	20,270b	4,972a
	Oxamyl	10,088b	3,037a	13,126b	1,257b	187a	2,365b	15,490ab	18,378b	5,252a
	Oxamyl + permethrin	12,928c	2,687a	15,615b	328a	300a	1,275a	16,890b	21,162b	5,547a
Autumn 1979		Number of fruit								
	Control	123a	23a	145a	30c	13a	52b	197a	200a	55b
	Permethrin	173b	23a	196b	7a	8a	25a	221a	224b	28a
	Oxamyl	201b	30a	232c	16b	12a	41ab	272b	275c	44ab
	Oxamyl + permethrin	194b	28a	224bc	3a	10a	24a	247b	252c	29a
		Weight (g) of fruit								
	Control	5,582a	1,253a	6,835a	1,502c	324a	2,168b	9,002a	9,631a	2,796b
	Permethrin	8,910b	1,418a	10,328b	417a	222a	998a	11,326b	12,043ab	1,715a
	Oxamyl	10,152b	1,712a	11,863b	1,017b	393a	1,963b	13,830c	14,240b	2,390ab
	Oxamyl + permethrin	10,280b	1,540a	11,820b	165a	375a	1,113a	12,930bc	13,979b	2,162ab

*Mean of six replications. Means in each column followed by the same letter are not significantly ($P = 0.05$) different, according to Duncan's new multiple-range test.

†Treatment rates—Spring test, oxamyl = 0.56 kg ai/ha; permethrin = 112 g ai/ha. Autumn test, oxamyl = 1.12 kg ai/ha; permethrin = 112 g ai/ha.

1,604 g = 12.4% of 12,930 g). The major contributor to the nematode component of yield loss was probably *R. reniformis* because it is pathogenic on related crops (6,7) but its effects could not be separated from those of *Q. acutus*. Based on the results of the spring test and relatively low numbers of other insects, *D. hyalinata* likely accounted for most of the insect component (Table 2). In addition, a 10.3% loss in total small-fruit weight is attributed to direct damage from *D. hyalinata*, resulting in culled fruit (1,502 g insect-damaged fruit in control plots minus 165 g insect-damaged fruit in plots treated with both oxamyl and permethrin = 1,337 g net direct loss = 10.3% of 12,930 g). Thus, while total weight of USDA small fruit in the untreated plots was reduced by damage from insects and nematodes, it would be further reduced by culling for insect damage. Total loss to pests in weight of USDA small fruit in the untreated plots was 40.7% (nematodes, 12.4%; insects, 28.3%) compared to the plots treated with both oxamyl and permethrin.

Because of the insecticidal activity of oxamyl, in neither test was it possible to estimate accurately nematode losses by comparing yields of plots treated with oxamyl alone with those of control plots. Because there were no differences in insect control in plots treated with permethrin alone compared to those treated with a combination of permethrin plus oxamyl, it is more accurate to estimate nematode yield losses by comparing the permethrin alone to the permethrin plus oxamyl treatments.

Multiple regression analysis: While the differential application of selective controls was useful in dividing estimated yield loss into insect and nematode components, it is difficult to subdivide individual components further by this method. For this reason, a stepwise multiple regression analysis was employed to determine which subcomponents did not have a significant effect on yield. Six separate multiple regression analyses were performed; these expressed total weight of small fruit as a function of counts of the three nematode species, using data for each of the six nematode sampling dates in the spring test (Table 4). Counts of insects on each date were also included in the analyses, provided that the insect was found in more than one of the 24 rows sampled. Insect counts were not made on the first and last dates of nematode sampling for each test, and thus are not included in the corresponding analyses. Because relationships

Table 4. Comparison of multiple regression models developed from data collected on different sampling dates.

Date of nematode counts	Date of insect counts	R^2 values†	Variables in stepwise multiple regression models‡	
			Pests evaluated	Pests eliminated
Spring 1979				
1-30	—	—	HD,QA,RR	HD,QA,RR
2-13	2-23	0.332*	HD,QA,RR,LS,MP	QA,MP
2-27	2-28	0.372*	HD,QA,RR,LS,MP	RR,MP
3-12	3-8	0.673**	HD,QA,RR,DB,DH,LS,MP	—
3-27	3-19	—	HD,QA,RR,DB,DH,LS,MP	HD,QA,RR,DB,DH,LS,MP
4-11	—	0.249*	HD,QA,RR	HD
Autumn 1979				
9-25	—	—	HD,QA,RR	HD,QA,RR
10-3	10-5	—	HD,QA,RR	HD,QA,RR
10-17	10-17	—	HD,QA,RR,DH,MP	HD,QA,RR,DH,MP
10-31	10-31	0.546**	HD,QA,RR,DH,MP	HD
11-14	11-14	0.650**	HD,QA,RR,DH,MP	—
11-30	—	0.470**	HD,QA,RR	—

†R^2 values shown for stepwise multiple regression model with highest significant R^2; asterisks (*, **) indicate significant F values at $P = 0.05$ and $P = 0.01$, respectively; dashes (—) indicate no significant regression equations for a given date.

‡HD = *Helicotylenchus dihystera;* QA = *Quinisulcius acutus;* RR = *Rotylenchulus reniformis;* DB = *Diabrotica balteata;* DH = *Diaphania hyalinata;* LS = *Liriomyza sativae;* MP = *Myzus persicae.*

between yield and nematode numbers can be logarithmic (10), a logarithmic transformation was performed on the nematode counts for each date and the analyses repeated. Similar analyses were performed on the autumn test data.

The R^2 values for the significant multiple regression analyses are illustrated (Table 4). Since logarithmic transformation of the nematode data increased the R^2 values in several instances and significantly improved the fit to corresponding multiple regression equations, only the regressions obtained using transformed nematode counts are shown.

DISCUSSION

A seasonal trend in R^2 values was evident in the multiple regression analyses from both tests. Early in both seasons few multiple regression equations with significant R^2 values were found. This is to be expected, since these early-season models include only nematode data; insects, important contributors to yield loss here, were not yet present in the plots in substantial numbers. As insect populations increase, the multiple regression models can account for progressively more variation. On the last sampling date in each test, when foliage was dead and no insect counts were made, the R^2 value was based on nematode counts and was greater in the autumn test, when higher populations of *R. reniformis* were present and significant nematode control was achieved.

Examination of variables included in the significant regression equations (Table 4) reveals that most produced significant effects when added to the stepwise equations. In several analyses, variables were eliminated from the stepwise regression equations for some dates, thus implying that those variables (pests) had no effect on yield, because their counts on those dates were not needed to predict yield. For example, *H. dihystera* is frequently eliminated from the multiple regression equations. This nematode was present in very low numbers and was not controlled by treatment; it also has not been reported to be pathogenic to squash.

A comparison of the multiple regression analyses from 12 March and 14 November

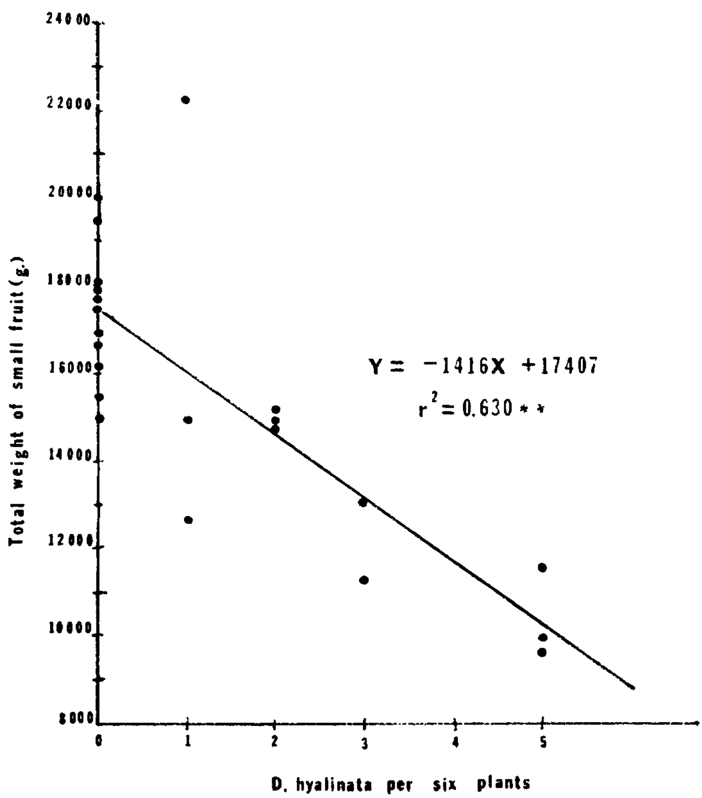

Fig. 1. Relationship between weight of small fruit per plot and the number of *Diaphania hyalinata* per six plants, 8 March 1979.

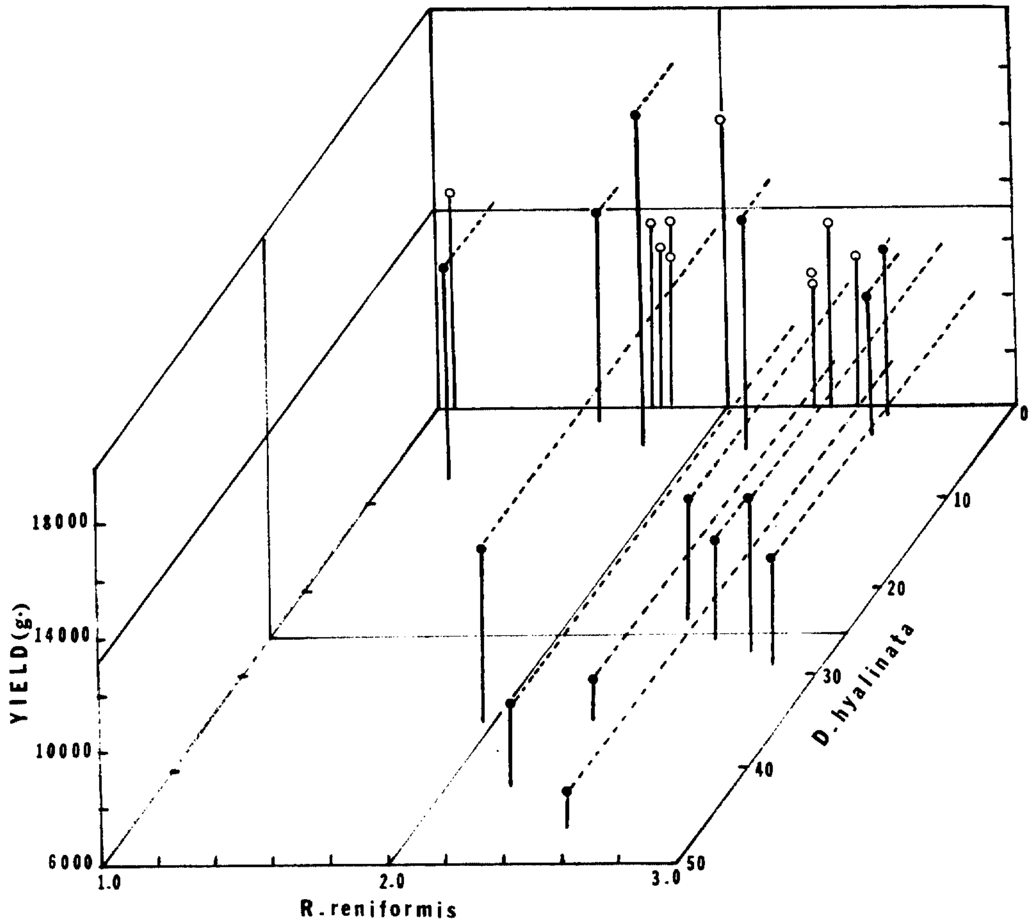

Fig. 2. Relationship between yield of small fruit per plot in grams, the number of *Diaphania hyalinata* per six plants, and $\log_{10}$ of number of *Rotylenchulus reniformis* per 100 cm^3 soil, 14 November 1979. Open circles indicate points on the plane with *D. hyalinata* levels = 0.

reveals several differences between the two tests. The highest R^2 values for the stepwise multiple regression equations were obtained on these two dates (Table 4). The relationship between yield of small fruit and *D. hyalinata* alone is illustrated for the data from 8 March (Fig. 1). The $r^2 = 0.630$ for this bivariate relationship is close to that of the best R^2 for the stepwise multiple regression analysis ($R^2 = 0.673$). In this instance, addition of other pests to the model does not substantially change R^2. This was expected, since *D. hyalinata* was probably responsible for most of the yield losses in this experiment and it was the only pest for which consistent significant control was achieved in the spring test. The relatively low R^2 values obtained when only nematodes were considered, as on 11 April, are probably a reflection of the lower nematode population pressure in this test.

In the autumn test, higher pest populations and the differential control achieved against several pests complicated the analysis. Fig. 2 depicts the relationship between small-fruit yield and populations of *R. reniformis* and *D. hyalinata,* the major pests in this system. When *D. hyalinata* counts were low and *R. reniformis* densities were greater than 100/100 cm^3 of soil, yields generally declined. When *D. hyalinata* populations increased, further declines in yield were evident. Thus, interactive effects on yield are evident even when only two pests in this multiple-pest system are considered. The bivariate r^2 value between yield and *D. hyalinata* population was 0.367, and the bivariate r^2 value between yield and *R. reniformis* population was 0.295. Both are much less than the multiple R^2 value of

0.650. This indicates that simple bivariate relationships as illustrated in Fig. 1 are inadequate to explain variation in yield in this case, and that the effects of multiple pests must be considered.

It is evident that several problems may arise in the estimation of yield loss due to nematodes in field tests involving insecticide-nematicides. For example, the present test has illustrated limited control of *D. hyalinata* and other insect pests by oxamyl. If complexes of several pests are present, it may be necessary to separate them into nematode and insect components by applying selective control measures. Multiple regression analysis may be helpful in further interpretation of the effects of the members of each component. In addition, periodic monitoring of insect populations is needed to detect seasonal population changes, since the prediction of yield as a function of pest populations varies seasonally when insects are involved.

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