Corn Yield Increases Relative to Nonfumigant Chemical Control of Nematodes[1]

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Abstract: Corn yields were measured after application of nematicides in 16 experiments, mostly in medium-to-heavily textured soil, at 12 locations in Iowa during 1973-1976. The average maximum yield increase in plots treated with nematicides was 21% over yields in untreated plots. Yields were correlated negatively with nematode numbers or nematode biomass in nearly all comparisons. Correlations of nematode numbers in the soil with yield averaged –0.56 for *Helicotylenchus pseudorobustus*, –0.45 for *Hoplolaimus galeatus*, –0.51 for *Pratylenchus* spp., and –0.64 for *Xiphinema americanum*. Correlation coefficients for numbers of nematodes in the roots and yield averaged –0.63 for *Pratylenchus* spp. and –0.56 *H. galeatus*. Correlation coefficients for yield and total number of nematodes averaged –0.65 in roots and –0.55 in soils. Negative correlations also were greater for comparisons of yield with total parasitic-nematode biomass than with numbers of individual nematodes of a species or total numbers of parasitic nematodes. *Key Words: Helicotylenchus pseudorobustus, Hoplolaimus galeatus, Pratylenchus hexincisus, Xiphinema americanum,* rootworms.

Nematodes have been associated with corn, *Zea mays* L., from the upper midwestern United States (4, 8, 14, 18). Nematicides have reduced the density of nematode populations around corn and have been associated with increased yields (7, 10). The effects of nematodes on corn production over wide areas of the upper Midwest, where medium-to-heavily textured soils predominate, have not been evaluated fully. Smolik (16) found a negative correlation of yield with parasitic nematodes at harvest in South Dakota. *Hoplolaimus galeatus* (Cobb) Thorne and *Pratylenchus hexincisus* Taylor & Jenkins were implicated in corn yield losses in sandy soils in Iowa (13). Rootworms, wireworms, earworms, or stalk rot were not present or were not affected by the treatments in these tests. This research was done to determine the role of nematodes as a factor in in-

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creased corn yields in plots treated with nematicides in medium-to-heavily textured soils.

MATERIALS AND METHODS

General procedures: The results reported are from 16 experiments at 12 locations during 1973-1976. The experiments were in all sections of Iowa except the southwestern part. Two experiments were in soil containing more than 90% sand, but all others were in loam, silt loam, or clay loam soils. Five locations were suspected of having a nematode problem. The other 11 test sites were not previously assayed. Granular nematicides applied were aldicarb, carbofuran, O[5-chloro-1-(1-methyl)-1H-1,2,4-triazol-3-yl]O,O-diethyl phosphorothioate (CGA-12223), ethoprop, fensulfothion, phenamiphos, and terbufos. Nematicides were applied in a 17.8-cm band unless specified otherwise. Granules were applied with tractor-mounted applicators or calibrated gear-driven, hand-operated applicators and incorporated into the top 5 cm of soil. Row widths were 71-76 cm. Most plots were four rows wide and 9.1 m long. The two outer rows were sampled within the row for nematodes, and the center 7.6 m of the inner rows was harvested by hand for yield. A composite of ten 2-cm core samples/15.2 m of row was sampled from each treatment about mid-June, mid-to-late July, and late August to early September. A pretreatment sample was collected from the untreated plots, but because of small nematode numbers, the data are not included. Each treatment was replicated 4 to 7 times. All tests were of a randomized block design. The number of treatments per experiment ranged from 4 to 10, including an untreated control. Cultivars varied with experiment.

The soil in each sample was mixed thoroughly in the laboratory by rolling, and 100 cm^3 was processed by the centrifugal-flotation method (9) within 2 days of sampling. Fibrous roots collected from the soil samples were processed for endoparasites by thin-layer water extraction for 7 days, with a change of water after the third day, in 1973-1974, and by a shaker method (3) for 4 days in 1975-1976. After nematode extraction, the roots were dried at 90 C for 48 h.

Correlations: Correlations were tested between corn yields and numbers of soil nematodes/100 cm^3, total nematode biomass in soil, total numbers of nematodes in roots, and total nematode biomass in roots. The higher of the two nematode counts was used for calculating correlation coefficients (r).

Prominence value: Used to ascertain relative quantitative values among nematodes was the prominence value, PV = density $\sqrt{\text{frequency}}$ (2). Values were calculated from mean numbers of nematodes in untreated plots in the mid-to-late-summer samplings.

Biomass: More juveniles than adult nematodes were present in mid-to-late summer in Iowa. To estimate biomass, 25-30 nematodes of each species were picked at random from midseason samples and measured, and the biomass was calculated by the formula of Andrassy (1). The biomass for individual nematode species used in this study was: *Helicotylenchus pseudorobustus* (Steiner) Golden, 0.183 μg; *Hoplolaimus galeatus*, 0.792 μg; *Pratylenchus* spp., mostly *P. hexincisus*, 0.072 μg; *Paratylenchus projectus* Jenkins, 0.032 μg; *Longidorus breviannulatus* Norton and Hoffmann, 4.657 μg; *Quinisulcius acutus* (Allen) Siddiqui, 0.154 μg; *Trichodorus* sp., 0.659 μg; *Tylenchorhynchus nudus* Allen, 0.125 μg; and *Xiphinema americanum* Cobb, 0.995 μg.

Rootworms: In an attempt to identify the degree of rootworm [*Diabrotica longicornis* (Say), *D. virgifera* LeConte, and *D. undecimpunctata* Barber] control by the chemicals, 10 of the 16 experiments were evaluated for rootworm damage. The amount of root damage was classified by a 1-to-6 visual rating, from little to almost-complete root damage. Evaluations were made on five plants from each treatment plot in mid-to-late July, when maximum feeding has occurred.

RESULTS

Prominence values for the parasitic nematodes/100 cm^3 soil in all replications of the untreated plots for all tests were: *H. pseudorobustus*, 698; *H. galeatus*, 342; *Pratylenchus* spp., 318; *X. americanum*, 104; *T. nudus,* 33; *L. breviannulatus,* 0.2; *P. projectus,* 0.1; *Q. acutus,* 0.1; and *Trichodorus* sp., 0.1. Prominence values/gm dry root were: *Pratylenchus* spp., 3,960; and *H. galeatus,* 833.

The average percentage yield increase in chemically treated plots compared with no treatment ranged from 2 to 20% (Table 1). In comparison with controls, the maximum yield increases in the 16 experiments averaged 21%, with the greatest increase in any experiment being 72%, for carbofuran at 1.12 kg/ha. In general, however, carbofuran generally resulted in greater yield increase at 2.24 kg/ha than at the lower rates.

The nematicides were selective in reducing nematode numbers (Table 2). For example, CGA-12223 performed well against *H. galeatus* in the roots but did poorly against *X. americanum* in the soil. Carbofuran generally performed best against *X. americanum.*

The yield increases obtained with nematicides (Table 1) and reductions in nematode number after nematicide application (Table 2) give supportive evidence that nematodes may be limiting corn production in the Midwest. Measures of the degree of nematode infection were correlated negatively with corn yields for 58 of 60 such comparisons made with individual species. Correlation of nematode numbers in the soil with yield averaged −0.56 for *Helicotylenchus pseudorobustus,* −0.45 for *Hoplolaimus galeatus,* −0.51 for *Pratylenchus* spp., and −0.64 for *Xiphinema americanum.* Correlation coefficients for numbers of nematodes in the roots and yield averaged −0.63 for *Pratylenchus* spp. and −0.56 for *H. galeatus.* Numbers of *Pratylenchus* spp. and *H. galeatus* combined were more closely correlated with yield than were numbers of either considered singly in 71% of the instances where these measures were compared. Numbers of *H. pseudorobustus, H. galeatus, Pratylenchus* spp., and *X. americanum* in the soil were less closely correlated with yield than were all nematodes combined in 46, 60, 50, and 30% of such comparisons, respectively.

Nematode biomass of individual species was more closely related to yield than nematode numbers in 61% of the comparisons. Total nematode biomass was more

TABLE 1. Average yields and average percentage yield increases in corn plots treated with granular nematicides in Iowa (1973-1976).

Nematicide	Kg(a.i.)/ha	n[a]	Average percentage increase compared with untreated plots[b]	Average yield in treated plots (kg/ha)
Terbufos	1.12	4	20	6,528
Aldicarb	3.36	2	17	10,668
Ethoprop	2.24	7	17	7,163
CGA-12223[c]	1.68	1	17	5,207
Aldicarb	2.24	2	15	6,706
Fensulfothion	2.24	6	15	6,833
Carbofuran	2.24	16	15	7,722
CGA-12223	3.36	7	14	8,967
CGA-12223	2.24-2.80	8	13	8,027
Ethoprop	1.12	7	12	6,833
Ethoprop	3.36	1	11	4,217
Phenamiphos	4.48	1	10	4,090
CGA-12223	4.20-4.48	3	9	7,163
Carbofuran	0.84-1.12	13	8	7,163
Carbofuran	4.48	2	6	7,976
Carbofuran (furrow)	2.24	3	4	9,525
Carbofuran	3.36	2	3	5,766
CGA-12223	1.12-1.40	6	2	5,588

[a]Number of tests in which the chemical was used at specified rate.
[b]Based on combined yields in all tests.
[c]O [5-chloro-1-(1-methylethyl)-1 H-1,2,4-triazol-3-yl] O,O-diethyl phosphorothioate.

TABLE 2. Percentage control of nematodes in corn plots treated with granular nematicides in Iowa (1973-1976).

		Ectoparasites						Endoparasites (roots)			
		Helicotylenchus pseudorobustus		*Tylenchorhynchus nudus*		*Xiphinema americanum*		*Hoplolaimus galeatus*		*Pratylenchus* spp.	
Nematicide	kg(a.i.)/ha	n[a]	%	n[a]	%	n[a]	%	n[a]	%	n[a]	%
Aldicarb	2.24	2	40	1	100	2	70	—	—	2	84
Aldicarb	3.36	3	55	1	100	2	92	—	—	3	92
Carbofuran	0.84	4	21	2	74	2	84	3	57	4	57
Carbofuran	1.12	8	13	3	47	5	67	3	39	10	39
Carbofuran	2.24	13	18	5	70	7	67	8	46	17	46
Carbofuran (furrow)	2.24	2	9	—	—	1	100	1	58	3	18
Carbofuran	3.36	1	29	2	76	1	68	1	23	2	81
Carbofuran	4.48	1	19	1	90	—	—	1	45	2	66
CGA-12223[b]	1.12-1.40	3	28	2	19	3	15	5	60	7	43
CGA-12223	1.68	1	19	—	—	1	28	—	—	1	58
CGA-12223	2.24-2.80	6	29	2	57	5	20	3	66	9	55
CGA-12223	3.36	6	17	2	22	3	40	1	81	8	34
CGA-12223	4.20-4.48	1	17	—	—	—	—	2	76	2	92
Ethoprop	1.12	7	27	3	54	3	55	4	73	7	33
Ethoprop	2.24	7	36	3	42	3	56	4	68	7	56
Ethoprop	3.36	—	—	1	70	1	54	1	23	2	60
Fensulfothion	2.24	5	9	2	50	2	29	4	21	6	55
Phenamiphos	4.48	—	—	1	93	1	74	1	56	2	93
Terbufos	1.12	4	34	2	10	2	9	3	17	4	79

[a]Number of tests using the chemical at specified rate.
[b]O [5-chloro-1-(1-methylethyl)-1 H-1,2,4-triazol-3-yl] O,O-diethyl phosphorothioate.

closely related to yield of corn than was biomass of individual species in 66% of the instances where this comparison was made. As an example, in a test at Ames in 1974 the correlation coefficients between yield and nematodes in the roots were respectively r = –0.78, –0.86, and –0.96 for *Pratylenchus* spp., *H. galeatus*, and both nematodes combined.

Quantitative measures of nematode presence and yield of corn tended to be most closely related at the high end of the scale measuring nematode presence. At the high end of the scale the nematodes would be more apt to be a principal factor limiting growth.

Rootworms: The mean rootworm damage rating was 3.2, with a range of 0 to 5.9 in treated plots in the 10 tests. Although any interaction between rootworm damage and nematodes is not clear, the correlation of rootworm damage rating and maximum nematode biomass in the roots was –0.741 (P = 0.05). The two highest rootworm damage ratings were 5.9 and 4.2, respectively in the untreated plots at Newell and Independence. Those plots had nematode biomass readings in the root of 21 and 14 μg/gm dry root in 1973 and 1974, respectively.

DISCUSSION

Negative correlations of nematodes with yield are not proof that nematodes are the cause of yield reduction. But they support the hypothesis that nematodes cause significant damage to corn. Other factors must be considered in judging the importance of individual species. For example, even though significant negative correlation coefficients were obtained with *H. pseudorobustus* and corn yield, and Taylor (17) found that this nematode disrupts cortical cells, there is other evidence that this species (12) and *H. dihystera* (15) are only moderately or slightly pathogenic to corn. Little is known about the effects of *X. americanum* on corn. In contrast, *Pratylenchus* spp. are well-known pathogens to many crops, including annuals, and evidence is accumulating that different species are detrimental to corn (5, 10). Since some of the highest yields were from plots treated with aldicarb, which is ineffective against rootworms but highly effective against nematodes, it is probable that nematode control accounts for much of the yield increases obtained when this chemical was used.

The greatest yield increases (over untreated controls) in the 16 experiments

TABLE 3. Maximum correlation coefficient (r) values in second or third samplings of nematode numbers or biomass with corn yield in Iowa (1973-1976).

		Soil		Roots	
Location	Year	Total soil nematodes	Total nematode biomass	Total root nematodes	Total nematode biomass
Fort Madison	1973	–0.23	–0.26	–0.32	–0.34
Vincennes	1973	–0.58	–0.70*[a]	–0.81*	–0.68
Ames	1974	–0.88**[a]	–0.92**	–0.86**	–0.97**
Chariton	1974	–0.45	–0.38	—	—
Fort Madison	1974	–0.70*	–0.78**	–0.50	–0.52
Garnavillo	1974	–0.32	–0.48	–0.61	–0.68
Gilbert	1974	–0.28	–0.65	–0.73	–0.85*
Independence	1974	–0.62	–0.42	–0.70	+0.17
Manley	1974	–0.50	–0.55	—	—
Newell	1974	–0.40	–0.46	—	—
Chariton	1975	–0.95**	–0.95**	—	—
Melvin	1975	–0.25	–0.10	—	—
Sanborn	1975	–0.33	–0.54	—	—
Story City	1975	–0.82	–0.71	—	—
Melvin	1976	–0.70*	–0.73*	—	—
Story City	1976	–0.74*	–0.13*	—	—

[a]Asterisks (*, **) respectively indicate significance at P = 0.05 and 0.01.

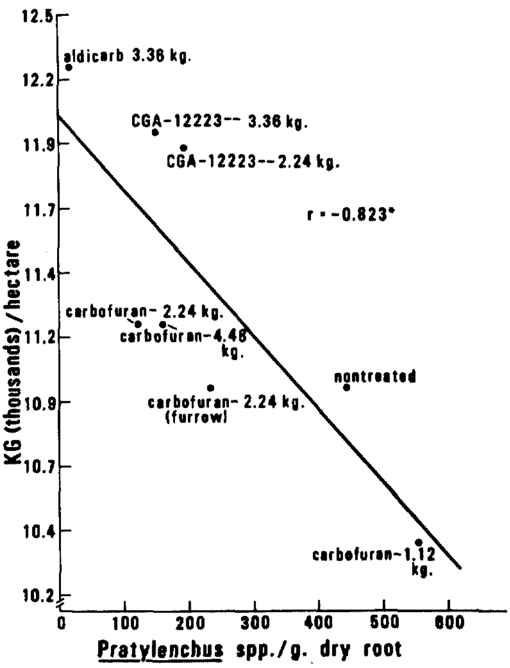

FIG. 1. Number of *Pratylenchus* spp. and yield of corn after treatment with nematicides. Melvin, Iowa (1975).

averaged 21%. Because few fields were selected for high nematode populations, there was a certain amount of randomness built into site selection. If even 50% of the yield increases were due to nematode control, the loss for Iowa would exceed the average estimate of loss due to nematodes for all corn acreage in the United States during 1967-68 (6).

The trends of larger negative r-values with increased nematodes probably have biological meaning because the presence of more nematodes, and therefore a greater biomass, would result in a greater energy flow from the plant to the nematode. A greater mechanical cell destruction would also result, and might be even more important than biomass *per se.* A greater energy flow per unit of biomass is required to sustain an ecosystem of lesser diversity, as in agrecosystems, than of greater diversity, as in natural ecosystems (11). Nematodes could have a greater impact on corn production in the Midwest than on the prairie plants that corn replaced. Data are needed on production efficiencies, degree of cell destruction, and ratios of nematode biomass relative to plant biomass in the two ecosystems.

LITERATURE CITED

1. ANDRÁSSY, I. 1956. The determination of volume and weight of nematodes. Acta Zool. (Hungarian Acad. Sci. 2(1-3):1-15. *in* B. M. Zuckerman, W. F. Mai, and R. A. Rohde (eds). English translation of selected East European papers in nematology. Univ. Mass. 1967.
2. BEALS, E. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bull. 72:156-181.
3. BIRD, G. W. 1971. Influence of incubation solution on the rate of recovery of Pratylenchus brachyurus from cotton roots. J. Nematol. 3:378-385.
4. CASTANER, D. 1963. Nematode populations in corn plots receiving different soil amendments. Proc. Iowa Acad. Sci. 70:107-113.
5. EGUNJOBI, O. A. 1974. Nematodes and maize growth in Nigeria. I. Population dynamics of Pratylenchus brachyurus in and about the roots of maize and its effect on maize production at Ibadan. Nematologica 20:181-186.
6. FELDMESSER, J. (Chairman). 1971. Estimated crop losses from plant-parasitic nematodes in the United States. Soc. Nematol. Spec. Publ. 1. 7 p.
7. FERRIS, J. M. 1967. Factors influencing the population fluctuation of Pratylenchus penetrans in soils of high organic content. I. Effect of soil fumigants and different crop plants. J. Econ. Entomol. 60:1708-1714.
8. GRIFFIN, G. D. 1964. Association of nematodes with corn in Wisconsin. Plant Dis. Rep. 48: 458-459.
9. JENKINS, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.
10. JOHNSON, A. W., and R. B. CHALFANT. 1973. Influence of organic pesticides on nematode and corn earworm damage and on yield of sweet corn. J. Nematol. 5:177-180.
11. MARGALEF, R. 1968. Perspectives in ecological theory. Univ. Chicago Press. Chicago. 111 p.
12. NORTON, D. C. 1977. Helicotylenchus pseudorobustus as a pathogen on corn, and its densities on corn and soybean. Iowa State J. Res. 51:279-285.
13. NORTON, D. C., and P. HINZ. 1976. Relationship of Hoplolaimus galeatus and Pratylenchus hexincisus to reduction of corn yields in sandy soils in Iowa. Plant Dis. Rep. 60:197-200.
14. NORTON, D. C., and J. K. HOFFMANN. 1975. Longidorus breviannulatus, n. sp. (Nematoda: Longidoridae) associated with stunted corn in Iowa. J. Nematol. 7:168-171.
15. SLEDGE, E. B. 1956. Pathogenicity of the spiral nematode, Helicotylenchus nannus Steiner, 1945, in relation to selected varieties of corn. Proc. Ala. Acad. Sci. 28:123 (Abstr.).
16. SMOLIK, J. D. 1975. Nemas. S. Dak. Farm and Home Res. 26 (fall):5-9.
17. TAYLOR, D. P. 1961. Biology and host-parasite relationships of the spiral nematode, Helicotylenchus microlobus. Proc. Helminthol.

Soc. Wash. 28:60-66.
18. TAYLOR, D. P., and E. G. SCHLEDER. 1959. Nematodes associated with Minnesota crops. II. Nematodes associated with corn, barley, oats, rye, and wheat. Plant Dis. Rep. 43:329-333.