Effects of Initial Population Densities of *Heterodera schachtii* on Yield of Cabbage and Table Beets in New York State

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ABSTRACT

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Relationships between initial population density (P_i) of *Heterodera schachtii* and total or marketable yields of table beets, direct-seeded cabbage, transplanted cabbage, and sweet corn grown in field microplots were determined in 1975 and 1977. Total and marketable yields of table beets and cabbage (direct-seeded and transplanted) but not sweet corn were inversely correlated with P_i of *H. schachtii*. A P_i as low as six to nine viable eggs and larvae per gram of soil decreased marketable yields of table beets and cabbage. In 1975, marketable yields of table beets were decreased by 23, 25, 42, and 54% at P_i of 9, 18, 34, and 68 eggs and larvae of *H. schachtii* per gram of soil, respectively. These same P_i's lowered marketable yield of direct-seeded cabbage by 21, 28, 46, and 54% and that of transplanted cabbage by 25, 31, 34, and 42%, respectively. Table beets produced in soil with the greatest P_i's were misshapen and of undesirable size, and cabbage heads were smaller and less firm. Also, fibrous roots of table beets and cabbage plants growing in soil at the greatest P_i's were discolored and reduced in size. Final population density (P_f) of *H. schachtii* were affected by the crop grown and also the P_i. Number of cysts remained approximately the same and the number of viable units was smaller in microplots planted to sweet corn, a nonhost. On both hosts, the greatest buildup of *H. schachtii* occurred at the smallest P_i, whereas the least buildup occurred at the greatest P_i. Transplanted cabbage supported the greatest reproduction of *H. schachtii* at all P_i's. In 1977, significant reductions in marketable yields of both direct-seeded and transplanted cabbage occurred only at the greatest P_i of *H. schachtii* tested, 12 eggs and larvae per gram soil. Marketable yields of table beets were not significantly affected by any P_i tested.

The sugar beet-cyst nematode, *Heterodera schachtii* Schmidt, was first discovered in New York State in 1961 and caused damage to table beets grown for beet greens on a fresh market vegetable farm near Syracuse, New York (10). In 1971, a heavy infestation of *H. schachtii* was discovered in a 5.3-ha table beet field near Lyons, New York where beets had been grown in short rotations for many years (12). Results of a survey conducted in 1970–1971 (12) and subsequent field observations and analysis of many soil samples have shown that this nematode is widely distributed throughout the table beet- and cabbage-growing areas of central New York State. Except in small heavily infested areas in a few fields, population densities of *H. schachtii* on most of the known infested farms are low. High densities of this nematode, however, have caused considerable economic losses to table beets on two farms. As a result, production of table beets was discontinued on one of these farms, whereas the other grower was forced to practice a long rotation with nonhost crops. Densities of *H. schachtii* as high as 190 eggs and larvae per cubic centimeter of soil were found in two fields. In greenhouse tests, top and root weights of table beets were reduced in soil infested with 19.1, 9.8, and 4.9 eggs and larvae per cubic centimeter of soil; smaller nematode numbers had no measurable effect on top or root weights (12).

Heterodera schachtii has a wide host range (21), attacking many weed and crop plants in the families Chenopodiaceae and Cruciferae. Yield losses to numerous crops of these families by *H. schachtii* under field conditions were demonstrated with nematicide-soil treatments (7–9,17). Jones (6) was the first to report the relationship between densities of *H. schachtii* and yield of sugar beets grown in microplots under field conditions. He reported that the economic threshold level of *H. schachtii* in sugar beet fields in England is six to eight larvae per gram of soil. In microplot studies, Olthof (14) found that an initial population density (P_i) as low as 1.7 larvae per gram soil retarded top and root growth of sugar beets. Olthof et al (16) studied the effect of five densities of *H. schachtii* on yields of table beets, cabbage, cauliflower, rutabagas, and spinach grown in microplots in Ontario, Canada. They reported that marketable yields of cabbage and table beets decreased 24 and 30%, respectively, at a P_i of 18 larvae per gram of soil; whereas, yields of either crop were not affected at a P_i of six larvae per gram of soil.

The objectives of our microplot study were to determine the economic threshold density of *H. schachtii* for table beets and cabbage (direct-seeded and transplanted), and also to determine the influence of hosts (cabbage and table beets) and a nonhost (sweet corn) on soil densities of this nematode.

MATERIALS AND METHODS

Soil (Ontario loam to Lima silt loam, pH 7.1) used in this study was obtained from a vegetable farm near Geneva, New York. Cabbage and table beets are the only vegetable crops grown on this farm and are generally alternated in the same fields. Soil was collected from a field heavily infested with *H. schachtii* and also from a noninfested field (in which *H. schachtii* is below the recovery level). Each soil was passed through a 16-mm mesh screen, mixed thoroughly, and the number of *H. schachtii* was determined. Initially, eight randomly collected composite samples (each consisting of about 30 subsamples) were taken from each soil source and analyzed for numbers of cysts and numbers of eggs and larvae per known volume of soil. Initial counts obtained were used as a guide in preparing the densities to be tested by mixing the proper amount of *H. schachtii*-infested and noninfested field soils. Greater P_i's of *H. schachtii* were tested in 1975 than in 1977 (Table 1). Prepared soils were covered with plastic sheets and stored in an open barn until use (usually about 1 wk).

Field microplots, similar to those previously reported by Olthof and Potter (15), were used. They consisted of nonglazed clay drainage tiles (25-cm in diameter and 30-cm long) placed in a field which was fumigated the preceding fall with Telone® C-17 (76.3% dichloropropene and 17.1% chloropicrin; The Dow Chemical Company, Midland, MI 48640) at a rate of 374 L/ha. The hole for each tile was dug with a tractor-mounted posthole digger. Soil

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around each tile was packed firmly and the top of each tile was about 2–3 cm above the soil surface. Tiles were arranged in rows 1.5 m apart and the spacing of the tiles within the row was also 1.5 m. About 15 kg of soil were added to each tile and firmed lightly. Within 24 hr after the tiles were filled with soil, twelve, three, or four Thiram (tetramethylthiuram disulfide; E.I. duPont de Nemours & Co., Wilmington, DE 19898)-treated seeds of table beet cultivar Ruby Queen, cabbage cultivar Round Up, or corn cultivar Jubilee, respectively, were planted per tile. One 6-wk-old cabbage seedling was transplanted into each tile. The direct-seeded cabbage and corn were later thinned to one and two plants per tile, respectively. Microplots were watered only when needed during the first 6 wk after planting and were cultivated once. All other cultural practices including planting, fertilization, and insect and disease

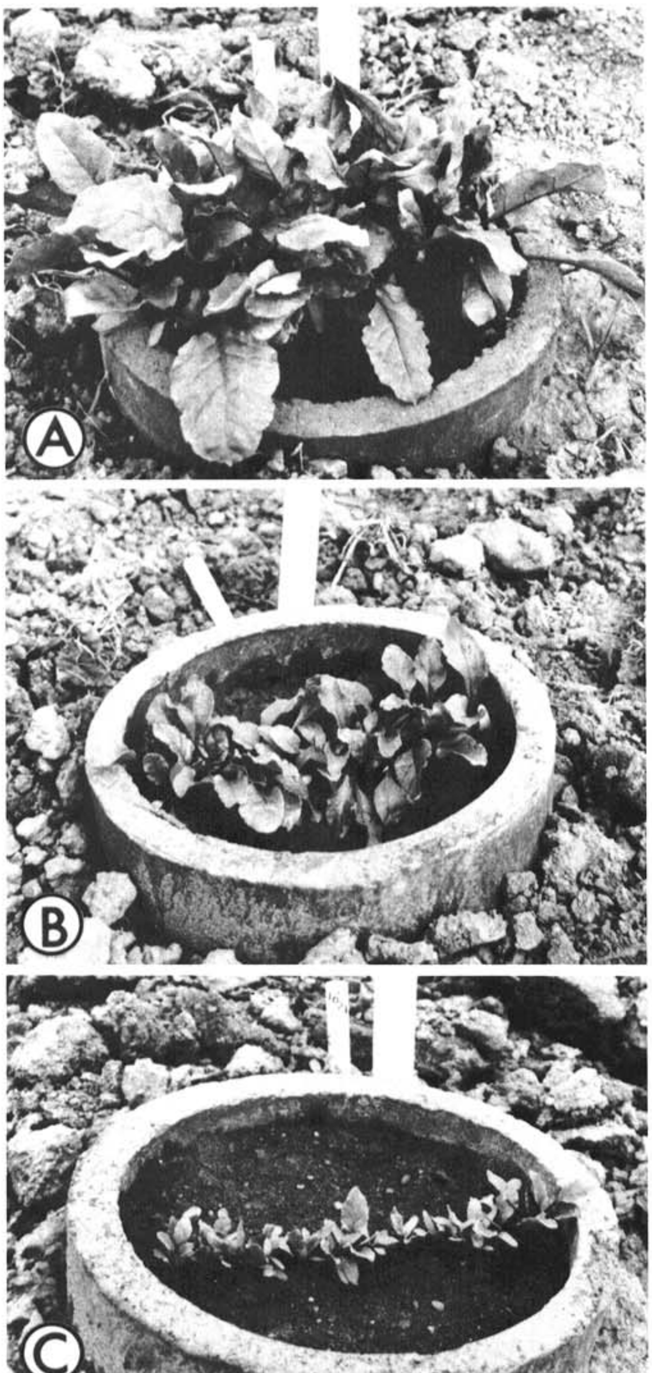

Fig. 1. Stunting of table beets grown in natural field soil infected with *Heterodera schachtii.* Initial soil population densities of the soil in microplots A, B, and C were 0, 34, and 68 viable eggs and larvae per gram of soil, respectively.

control were according to the Cornell Recommendations for Commercial Vegetable Production (Publications Office, Cornell University, Ithaca, NY 14853). The 1975 and 1977 microplot experiments were established on 13 June and 9 June, respectively. Each crop was harvested when it reached suitable maturity for commercial harvest. All treatments were replicated 10 times in a completely randomized block design.

At planting time, one composite soil sample was taken from each tile and the number of cysts and viable eggs and larvae per cubic centimeter or gram soil was determined. Total fresh weight and marketable weight of each crop were recorded at harvest time. At 2–4 wk after harvest, the tiles were dug, the soil from each tile was emptied on plastic, mixed thoroughly, and then a composite soil sample was collected. Number of cysts and also viable eggs and larvae in soil were determined; these were referred to as the final population density (P_f). Effects of the treatments on changes in nematode population were determined by comparing the P_f:P_i ratios.

Cysts were extracted from soil by a combination of the Fenwick-type extraction tank and centrifugal flotation (4). All cysts were counted. Counts of eggs and larvae were made by extracting cysts from a volume of soil containing not more than 50 cysts. All cysts extracted were transferred to a drop of water placed on a special metal plate (18) with a groove smaller than the diameter of the cysts. The cysts were then lightly crushed with a glass rod. The cyst material on the glass rod and the metal plate was carefully washed with 0.5% NaOCl (Clorox, 5.25% NaOCl) into a 50-ml beaker

TABLE 1. Effects of initial population densities of *Heterodera schachtii* on marketable and total yields of direct-seeded cabbage, transplanted cabbage, table beets, and sweet corn in field microplots during 1975 and 1977 in New York State

	Yield (kg fresh weight per microplot)[x]			
Initial density (P_i) (eggs & larvae/g soil)[w]	Direct-seeded cabbage	Transplanted cabbage	Table beet	Sweet corn
Marketable yield				
1975				
0	4.31 a[y]	4.68 a	1.95 a	0.95 ab
9	3.41 b	3.50 b	1.50 b	1.09 ab
18	3.09 b	3.22 bc	1.27 c	1.14 a
34	2.32 c	3.09 bc	1.14 cd	1.09 ab
68	2.09 c	2.72 c	0.91 d	0.86 b
r (Yield versus P_i)[z]	−0.593*	−0.469*	−0.734*	0.175
1977				
0.7	4.27 a	5.68 a	1.68 a	1.54 ab
1.5	4.09 ab	5.45 ab	1.54 a	1.18 b
3	3.81 ab	4.72 ab	1.59 a	1.68 a
6	3.72 ab	4.54 ab	1.59 a	1.50 ab
12	2.95 b	4.09 b	1.45 a	1.59 a
r (Yield versus P_i)	−0.130	−0.175	−0.068	−0.058
Total yield				
1975				
0	6.22 a	6.63 a	3.22 a	2.13 ab
9	5.45 b	5.40 b	2.50 b	2.41 a
18	4.77 bc	4.95 bc	2.27 bc	2.54 a
34	4.22 cd	4.72 cd	2.00 c	2.36 ab
68	3.54 d	4.13 d	1.59 c	1.91 b
r (Yield versus P_i)	−0.515*	−0.469*	−0.649*	0.125
1977				
0.7	7.26 a	9.22 a	2.68 a	2.51 a
1.5	7.22 a	9.08 a	2.23 a	2.27 a
3	6.77 a	7.95 ab	2.68 a	2.86 a
12	5.81 a	6.67 b	2.27 a	2.82 a
r (Yield versus P_i)	−0.082	−0.193	−0.056	−0.127

[w] Refers to viability counts as determined at planting time.
[x] Each crop was harvested when at commercial maturity.
[y] Means in a column followed by the same letter do not differ significantly ($P = 0.05$) according to the Waller-Duncan's Bayesian K-ratio (LSD) rule.
[z] Refers to correlation analyses between marketable or total yield and nematode density. An asterisk (*) indicates statistically significant correlation, $P = 0.05$.

and incubated for 30 min. The beaker contents were blended for 15 sec in a small Waring Blendor and the volume of the suspension was adjusted with water to 100 ml. Hatched larvae and normal-appearing eggs with distinguishable larva were counted in three 1-ml aliquots of each suspension per soil sample. Empty, dark, or oily eggs were not included. All data obtained in this study were statistically analyzed by the Waller-Duncan's Bayesian K-ratio (LSD) rule (20).

RESULTS

Initial population density and yield loss. Total and marketable yields of table beets, direct-seeded cabbage, and transplanted cabbage were significantly ($P = 0.05$) suppressed by all P_i's of *H. schachtii* tested in 1975 (Table 1). At P_i's of 9, 18, 34, and 68 eggs and larvae per gram soil, marketable yield of table beets was decreased by 23, 25, 42, and 54%, respectively. The same P_i's decreased marketable head weight of direct-seeded cabbage by 21, 28, 46, and 54% and that of transplanted cabbage by 25, 31, 34, and 42%, respectively. Direct-seeded cabbage and especially table beets (Fig. 1A,B,C) growing at the two greatest P_i's of *H. schachtii* exhibited symptoms of nematode damage as early as 3 wk after planting. These plants were stunted and were first to wilt during water stress periods (eg, early afternoons of hot, sunny days). Macroscopic symptoms on transplanted cabbage were not obvious till later in the growing season even at the greatest level of infestation. At harvest, fleshy beet roots growing in plots with the greater P_i's were misshapen and a large proportion of them were of undesirable size. Also, roots of cabbage plants were discolored and reduced in size (Fig. 2C), and the heads of such plants were smaller (Fig. 2A) and were also less firm (Fig. 2B). Total and marketable yield of the nonhost, sweet corn, were not correlated with P_i of *H. schachtii*; however, smallest yields were obtained from microplots infested with the greatest P_i of the nematode.

In 1977, significant suppression of marketable yields of both direct-seeded and transplanted cabbage occurred only at the greatest P_i tested (12 eggs and larvae per gram soil). Similarly, the lowest yield of marketable table beets was obtained at the greatest P_i of *H. schachtii*; however, the yield obtained in this treatment was not significantly different from the yield in the other treatments. Total yields tended to decrease as P_i increased but the differences generally were not statistically significant. Marketable corn yields fluctuated, but apparently this was not due to P_i of *H. schachtii*.

Data presented herein suggest that the damaging level of *H. schachtii* to both cabbage and table beets is six to nine viable eggs and larvae per gram of soil.

Effects of a single crop of cabbage, table beets, and sweet corn on population density of *Heterodera schachtii*. Data obtained in the 1977 experiment (Table 2) suggest that the P_f of *H. schachtii* was affected by the crop grown and also by the P_i. Transplanted cabbage supported the greatest increase of *H. schachtii* at all P_i's. The P_f (number of cysts or eggs and larvae) of *H. schachtii* at all P_i's were greater in soil planted to table beets than to direct-seeded cabbage. However, the latter differences generally were not significant ($P = 0.05$), and thus table beets and direct-seeded cabbage are considered to influence the increase of *H. schachtii* similarly. No increase in number of cysts occurred in soil of microplots planted to sweet corn, a known nonhost. In addition, the number of eggs and larvae per gram of soil was lowered or eliminated (below recovery level) at all P_i's as shown by the P_f/P_i ratios in Table 2.

With transplanted cabbage, table beets, and direct-seeded cabbage, the greatest rate of increase of *H. schachtii* occurred at the smallest P_i; whereas, the smallest increase occurred at the greatest P_i. At a P_i of 0.7 eggs and larvae per gram of soil; the P_f/P_i of eggs and larvae in soil planted to transplanted cabbage, table beet, and direct-seeded cabbage was about 2,992, 684, and 370, respectively. At P_i of 12 eggs and larvae per gram of soil, the P_f/P_i of these same crops was about 21, 5, and 4, respectively.

Similar results were obtained in 1975 concerning the effect of corn, table beets, direct-seeded cabbage, and transplanted cabbage on population densities of *H. schachtii*. The average P_f/P_i ratio of eggs and larvae of *H. schachtii* at all P_i's evaluated was 0.01, 2.2, 2.3, and 5.3 in soil planted to sweet corn, table beets, direct-seeded cabbage, and transplanted cabbage, respectively. The P_f/P_i ratio for soils planted to table beets, direct-seeded cabbage, and transplanted cabbage differed significantly from the P_f/P_i ratio of soil planted to corn, but they did not differ among themselves.

DISCUSSION

Results of this study show a significant negative correlation between P_i of *H. schachtii* and total and marketable yields of cabbage and table beets. Damaging levels of this nematode to both cabbage and table beets appear to be approximately six to nine eggs and larvae per gram of soil. The greatest P_i tested (68 eggs and larvae per gram of soil) induced about 50% reduction in marketable yield of both crops. Even greater populations of this nematode (191 eggs and larvae per cubic centimeter of soil) were previously detected in commercial fields in central New York State (12). The relationships between P_i of *H. schachtii* to yield of cabbage and table beets reported herein are in general agreement with previous

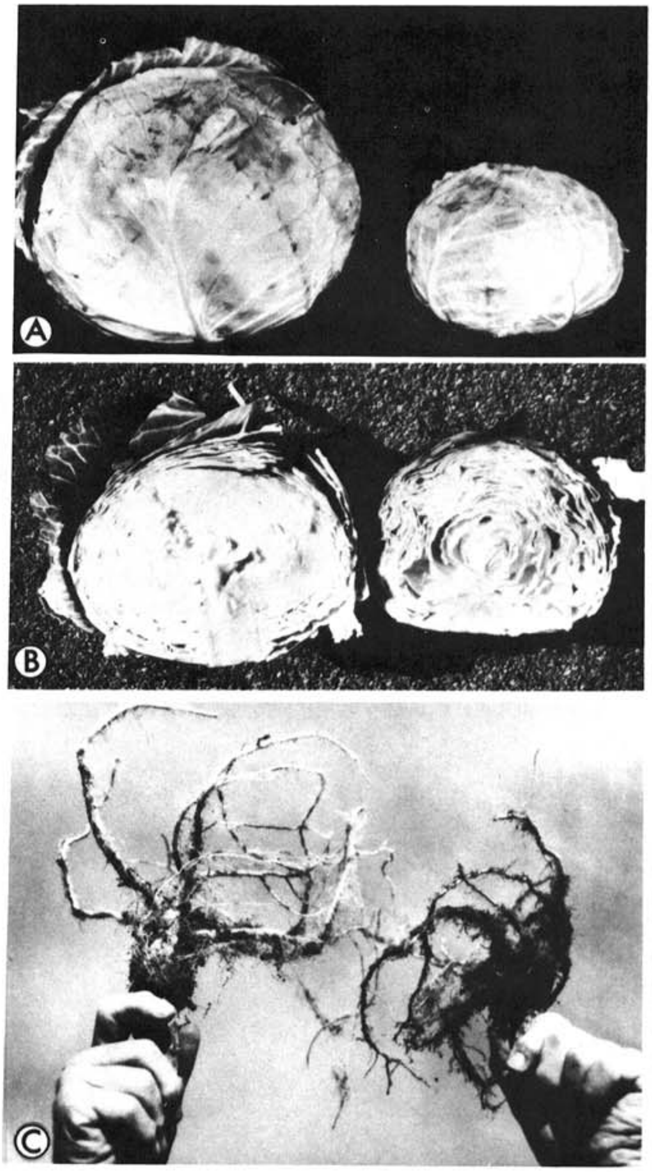

Fig. 2. Influence of *Heterodera schachtii* (68 viable eggs and larvae per gram of soil) on heads of cabbage. Cabbage heads or roots on left in each set of photographs were grown in nematode-free soil. Plants grown in infested soil produced heads which were: **A,** smaller; **B,** less firm; and **C** had roots that were discolored and reduced in size.

TABLE 2. Influence of one crop of sweet corn, table beet, direct-seeded cabbage, and transplanted cabbage grown in field microplots on changes in population of *Heterodera schachtii* during 1977 in New York State

Nematode form and crop	Ratio of final (P_f) and initial (P_i) populations of *H. schachtii* (P_f/P_i)[x]				
	0.7 (P_i)[y]	1.5	3.0	6.0	12.0
Cysts					
Transplanted cabbage	58.2 a[z]	18.1 a	5.7 a	12.1 a	5.0 a
Table beets	18.2 b	6.9 b	5.4 ab	6.3 b	2.3 b
Direct-seeded cabbage	10.4 c	4.6 b	3.6 b	4.2 b	1.4 c
Corn	1.0 d	0.9 c	0.8 c	1.5 c	0.7 d
Eggs and larvae					
Transplanted cabbage	2992.3 a	182.8 a	37.0 a	107.4 a	21.1 a
Table beets	683.9 b	45.1 ab	36.3 a	27.7 ab	4.9 b
Direct-seeded cabbage	369.8 b	24.5 b	19.3 a	24.0 b	4.1 b
Corn	0.3 c	0.2 c	0.0 b	0.0 c	0.0 c

[x]Initial (P_i) and final (P_f) population density counts were made at planting time and 2–4 wk after harvest, respectively.
[y]Refers to numbers of viable eggs and larvae per gram of soil as determined at planting time (P_i density).
[z]Column means followed by the same letter do not differ significantly ($P = 0.05$) according to the Waller-Duncan's Bayesian K-ratio (LSD) rule.

reports concerning damaging levels of this nematode to sugar beets (6,14), table beets, cabbage, cauliflower, and rutabagas (16). These similar results were obtained even though the experiments were conducted in diverse geographical areas, England, Canada, and the USA, and with different host crops, cultivars, and soil types. Although similar results were obtained in this study with direct-seeded and transplanted cabbage, yields of direct-seeded cabbage were smaller than those of transplanted cabbage at the two highest P_i's of *H. schachtii* tested.

Data on the P_f's of *H. schachtii* obtained in this study, and as was shown previously (13), revealed an interaction with P_i and the crops grown, which are important for the development of a pest management control program for this nematode (2,3,13). For all crops, greatest and smallest increases were inversely correlated to the P_i in soil planted to a host crop. Transplanted cabbage supported the highest increase (P_f) as measured by number of cysts or eggs and larvae per gram soil. Although the P_f of soil planted to table beets always was greater than that planted to direct-seeded cabbage, this difference generally was not statistically significant. Transplanted cabbage had a larger root system when first exposed to inoculum than did either table beet or direct-seeded cabbage. Transplanted cabbage roots provided more infection courts, thus resulting in a greater first generation which we believe may explain the final results. Previously it was reported that *H. schachtii* complete two and possible three generations on both cabbage and table beets under field conditions in New York State (1).

Numbers of cysts of *H. schachtii* in soils planted to sweet corn (a known nonhost) remained the same and no eggs and larvae were present at the three greatest P_i's and were drastically lowered at the two smallest P_i's. A 7-yr rotation experiment conducted on a commercial vegetable farm in central New York State showed that 2 yr of corn lowered the number of cysts and eggs and larvae of *H. schachtii* (11). However, the extent of decrease in the population was not of the same magnitude obtained after 1 yr in the microplots. It is possible that the majority of cysts in the microplots were under the influence of the corn root rhizosphere, whereas a considerable number of the cysts in commercial fields lie between rows outside the corn rhizosphere and thus the enclosed eggs and larvae were not influenced by root exudates.

In 1977, the average marketable yield of cabbage in upstate New York State was 43 metric tons/ha at a value of $4,773 (19). The non-volatile and water-soluble nematicide, phenamiphos [Nemacur, ethyl 3-methyl-4(methylthio) phenyl (1-methylethyl)phosphoramidate, Mobay Chemical Corporation, Box 4913, Kansas City, MO 64120] is commercially available and has been registered for use on cabbage for the control of several nematodes including *H. schachtii*. Microplot and field studies in New York State have shown that phenamiphos (15% granular) is effective for the control of this nematode at a rate of 49 kg/ha applied as broadcast treatment shortly before planting and incorporated into the top 8–10 cm of soil (authors, *unpublished*). The total cost of soil treatment is about $191/ha ($181 for the phenamiphos and $10 for its application). Thus, the current economic loss threshold (2,5,15) for *H. schachtii* on cabbage using the 1977 market value is 4%. Olthoff et al (16) analyzed the 1970–1971 prices and found that the economic loss threshold of *H. schachtii* to cabbage in Canada was 5%. The economic loss threshold of this nematode on table beets cannot be calculated at the present time due to the lack of an effective and/or approved control program. None of the new water-soluble nematicides have been registered for use on table beets and the fumigent-type nematicides were found only partially effective in controlling *H. schachtii* in the heavy soils in New York State (authors, *unpublished*).

Knowledge gained from research on P_i's of plant parasitic nematodes is important in the development of a grower advisory program, because the P_i of nematodes are largely responsible for the damage inflicted to host crops (3). However, it is also known that nematode damage and thus economic threshold densities are influenced by several environmental and biological factors, including soil type, moisture, temperature, fertilizers, and the associated microflora. The effect of the latter factors as well as production costs and crop value on the economic loss threshold of *H. schachtii* on cabbage and table beets needs to be investigated under New York State conditions.

Development of a grower advisory program for the control of *H. schachtii* in New York State is possible at the present time, especially for cabbage. An effective and practical chemical control measure (phenamiphos) is available for use when the economic threshold density is reached. Also, a cropping sequence involving two or more consecutive years of corn or other nonhosts was shown to lower the density of *H. schachtii* below the economic threshold level (11). Combining the use of a nematicide at a low rate with the use of a nonhost may shorten the required rotation and thus warrants investigation. Information also is needed on the tolerance limit and efficiency as hosts of the available cabbage cultivars to the New York State populations of this nematode. An efficient screening procedure also is needed to identify sources of cabbage germplasm resistance to this nematode and, if it is found, to initiate a breeding program to incorporate that resistance into commercially acceptable cultivars.

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