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Damage to Italian Crops Caused by Cyst-forming Nematodes

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Abstract: Investigations were undertaken in 1982–88 to estimate yield losses of carrot, sugarbeet, wheat, and potato caused by cyst-forming nematodes (*Heterodera* and *Globodera* species) in several provinces of Italy. Soil samples were collected at planting in 0.5-ha sampling areas distributed in each crop's major production area. Yield loss estimates were based on nematode population estimates and on curves derived earlier relating nematode densities with crop yields in Italy. Estimated yield loss values were based on the average prices reported for Italy in 1989. *Heterodera carotae* caused carrot yield losses in the Foggia (20%) and Venice (12%) provinces. *Heterodera schachtii* was common in our samples, but sugarbeet yield losses were highest in the province of L'Aquila (21%), followed by Ferrara (4.2%), Ravenna (3.3%), Modena (2.7%), and Rovigo (2.6%). *Globodera rostochiensis* and *G. pallida* were widespread in only a few of the major potato growing areas, but yield losses are remarkably high at Forlì (17%) followed by Bari (9%), Catanzaro (6%), Foggia (3%), and Trento (3%). *Heterodera avenae* was common on wheat in the sampled provinces, but caused less than 1% yield reductions. Values of total estimated yield losses were 21.1 billion (Italian liras) for potato, 13.8 billion for sugarbeet, 3.2 billion for carrot, and 2.6 billion for wheat.

Key words: Beta vulgaris, carrot, *Daucus carota, Globodera rostochiensis, Globodera pallida, Heterodera avenae, Heterodera carotae, Heterodera schachtii,* nematode, potato, *Solanum tuberosum,* sugarbeet, *Triticum durum,* wheat, yield loss.

Cyst-forming nematodes in the genera *Heterodera* and *Globodera* are widespread in Italy (3,4,12) and can cause severe yield losses. Inserra et al. (12) reported *H. avenae* among nematodes associated with durum wheat (*Triticum durum*) decline in southern Italy. Carrot (*Daucus carota*) production is important in the provinces of L'Aquila, Ragusa, Foggia, Rome, and Venice, and is reduced by *H. carotae* in the latter three provinces (1,16,26). Severe yield losses may be sustained by sugarbeet (*Beta vulgaris* var. *saccharifera*) in areas infested by *H. schachtii* (10,27) and by potato (*Solanum tuberosum*) in fields infested with *G. rostochiensis* and *G. pallida* (11).

For management of these nematodes, information is required on the extent of damage they cause on a regional basis. Such estimation is problematic because it requires both large-scale soil sampling and reliable information on the relationship between nematode population densities and crop yield (18). The damage a nematode causes to annual plants is related to its soil population density at planting (20,23), and damage estimates are necessary for optimum nematode management. Tolerance limits of 0.19 and 0.8 *H. carotae* eggs/g soil were reported for carrot (2,7). Tolerance limits for other crops grown in Italy were 1.8 *H. schachtii* eggs/g soil for sugarbeet (10), 1.9 *G. rostochiensis* or *G. pallida* eggs/g soil for potato (11), and 1 *H. avenae* egg/g soil for durum wheat (8). No attempts have been made to estimate the value of crop losses caused by cyst-forming nematodes each year. Therefore, investigations were undertaken from 1982 to 1988 to estimate yield losses caused by *H. carotae* to carrot, *H. schachtii* to sugarbeet, *H. avenae* to wheat, and *G. rostochiensis* and *G. pallida* to potato, in Italy. The results will be useful to determine research priorities and funding allocations.

Materials and Methods

Soil samples were collected between the planting and plant emergence dates. Each sample, a composite of 40 cores, was collected from four rows to a depth of 30 cm

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with a 1.5-cm-d soil probe, and stored at 10 C. The samples were taken from ca. 0.5-ha plots within fields uniformly distributed in major crop production areas. Samples were then air dried and a 200-g subsample from each was processed with a Fenwick can and ethanol (21). Cysts were counted and crushed (25) and eggs were counted. To identify cyst nematode species, 10–20 vulval cones from cysts of each soil sample were mounted and examined with light microscopy.

Curves relating yields of carrot, sugarbeet, wheat, and potato to cyst nematode population densities were published previously (7,8,10,11). Yield loss estimates were made based on the published curves and were expressed as a percentage of the yield in noninfested fields. Crop acreages, yields, and prices in different provinces were published for the Italian Statistic Institute (14) and the National Institute for Agriculture Economy (13). The most recent year for which data were available was 1989.

Results

A total of 202 soil samples were collected in six provinces known to be infested by *H. carotae*. It was found frequently in the provinces of Foggia and Rome (Table 1; Fig. 1), but the nematode population densities were larger in Foggia (48 eggs/g soil) than in Rome (15 eggs/g soil) province. The nematode was also widely distributed in Venice province (52% of the fields) and at Rovigo (14%). Maximum percentage of carrot yield losses were high in Foggia, Rome, Rovigo, and Venice, but the average yield loss was large only in Foggia (20%) and Venice (12%). Yield losses were highest in Venice, followed by Foggia and Rovigo provinces (Table 1). No carrot yield loss was observed at Trento, but the nematode was found in potato fields.

A total of 558 soil samples were collected in sugarbeet fields in the provinces of Alessandria, Bologna, Catanzaro, Ferrara, Foggia, Forlì, L'Aquila, Modena, Padova, Parma, Pavia, Piacenza, Ravenna, Reggio Emilia, Rovigo, Udine, and Venice (Fig. 1). *Heterodera schachtii* was very common in the province of L'Aquila, where 99% of the fields were infested, and in the provinces of Bologna (42%), Ferrara (73%), Ravenna (88%), and Rovigo (49%) (Table 2). Fortunately, with the exception of those in province of L'Aquila, the population densities of the nematode in most infested fields were below the tolerance limit of 1.8 eggs/g soil (10). Nevertheless, maximum yield losses were 90% in L'Aquila, 85% in Ravenna, 80% in Ferrara, 60% in Modena, and 30% in Rovigo. These findings were supported by control trials and field observations (27,28). In contrast, estimated yield losses averaged 21% in L'Aquila, 4.2% in Ferrara, 3.3% in Ravenna, 2.7% in Modena, 2.6% in Rovigo, and 2% in Bologna (Table 2). The provinces of Forlì, Bologna, Modena, Parma, Piacenza, Ferrara,

Table 1. Distribution of *Heterodera carotae* in Italy and estimated carrot yield losses.

Province	Samples			Yield losses (%)		Average value of yield loss‡
	Number collected	Infested (%)	Infestation >T† (%)	Maximum	Average	
Bari	20	0	0	0	0	0
Foggia	108	93	81	80	20	959
Rome	39	95	13	30	1	110
Rovigo	7	14	14	30	4	622
Trento	3	0	0	0	0	0
Venice	25	52	24	80	12	1,537
Total	202	75	49			3,228

† T = tolerance limit of carrot to *H. carotae* (= 0.8 eggs/g soil).

‡ Crop loss values are in millions of Italian liras. Total crop value for each province was reported by the Istituto Nazionale di Economia Agraria (13).

FIG. 1. Map of Italy showing provinces sampled for the assessment of damage caused by *Heterodera avenae* (■) to wheat, *H. carotae* (▲) to carrot, *H. schachtii* (○) to sugarbeet, and *Globodera rostochiensis* and *G. pallida* (△) to potato. Nematode symbols next to province abbreviation indicate the presence of the nematode in that province. Province abbreviations: AL = Alessandria, BA = Bari, BO = Bologna, BZ = Bolzano, CT = Catania, CZ = Catanzaro, CS = Cosenza, FE = Ferrara, FG = Foggia, FO = Forlì, GO = Gorizia, AQ = L'Aquila, LE = Lecce, ME = Messina, MO = Modena, NA = Napoli, PD = Padova, PR = Parma, PV = Pavia, PC = Piacenza, PN = Pordenone, RA = Ravenna, RE = Reggio Emilia, RM = Rome, RO = Rovigo, SR = Siracusa, TN = Trento, TV = Treviso, UD = Udine, VE = Venice, VR = Verona, and VC = Vicenza.

and Ravenna have the largest acreage of sugarbeet grown in Italy and, therefore, suffer the greatest annual losses (9,771 million Italian liras), followed by Rovigo and Venice (2,071 million), and L'Aquila (1,965 million) (Table 2).

A total of 788 soil samples were collected in the most important potato-growing regions of Italy (Table 3). *Globodera rostochiensis* and *G. pallida* were found in the provinces of Bari and Foggia, where their soil population densities were potentially capable of causing complete crop failure, and in the province of Trento, in which the estimated maximum potato yield loss was 18%. *Globodera rostochiensis* alone was detected in soil samples collected in the provinces of Catanzaro, Cosenza, Forlì, L'Aquila, and Naples. Usually, population densities of *G. rostochensis* exceeded the tolerance limit for potato (1.9 eggs/g soil) in only a small proportion of the fields. Therefore, high potato yield losses were estimated only in small areas of Forlì (17% loss overall) and Bari (9% overall), and in a large area in the Naples province (10.6%). The highest estimated values of the crop losses were high at Naples (8,971 million), Bari (6,329 million), and L'Aquila (2,273 million).

Among winter cereals, wheat is the most widely cultivated in Italy. Because crop loss assessments made in the provinces of Catanzaro, Cosenza, Bari, and Foggia in southern Italy (on durum wheat) and in several other provinces in northeastern Italy (on bread wheat, *Triticum aestivum*) (Fig. 1) revealed little damage due to *H. avenae*, the investigation was not extended to other regions. Although *H. avenae* appears to be widespread (Table 4), its population density seldom exceeds 1 egg/g soil, the tolerance limit for wheat in Italy (8). Therefore, the wheat yield loss caused by this nematode is much less than that caused by the other cyst nematodes to their hosts. The average yield loss in all of the sampled provinces was no more than 1%, although total crop value was high because of the large wheat acreage.

DISCUSSION

The cyst-forming nematode species *H. carotae*, *H. schachtii*, *G. pallida*, and *G. rostochiensis* are widespread in Italy where their economically important hosts are grown.

No samples were collected from carrot fields in the provinces of L'Aquila and Siracusa where *H. carotae* has not been found (Greco, unpubl.). However, data from sugarbeet and potato fields confirmed the absence of *H. carotae* in L'Aquila. Although *H. carotae* has also been reported from several minor carrot-growing areas (3,17), it is reasonable to assume that carrot yield

TABLE 2. Distribution of *Heterodera schachtii* in Italy and estimated sugarbeet yield losses.

Province	Samples			Yield losses (%)		Average value of yield loss‡
	Number collected	Infested (%)	Infestation >T† (%)	Maximum	Average	
Alessandria	14	100	0	0	0	0
Bologna	55	42	14	5	2	2,212
Catanzaro	5	0	0	0	0	0
Ferrara	71	73	21	80	4.2	4,262
Foggia	43	0	0	0	0	0
Forlì	18	61	6	3	0.2	56
L'Aquila	131	99	87	90	21	1,965
Modena	24	58	8	60	2.7	1,931
Padova	8	62	0	0	0	0
Parma	5	80	0	0	0	0
Pavia	16	100	0	0	0	0
Piacenza	5	20	0	0	0	0
Ravenna	58	88	17	85	3.3	1,310
Reggio Emilia	12	50	0	0	0	0
Rovigo	71	49	15	30	2.6	1,628
Udine	12	0	0	0	0	0
Venice	10	58	10	9	0.9	443
Total	558	66	29			13,807

† T = tolerance limit of sugarbeet to *H. schachtii* (= 1.8 eggs/g/ soil).

‡ Crop loss values are in millions of Italian liras. Total crop value for each province was reported by the Istituto Nazionale di Economia Agraria (13).

losses caused by this nematode to carrot in Italy are similar to those reported in Table 1. Although these losses may appear to be low on a country-wide basis, they are high in local production areas.

Heterodera schachtii occurred in all provinces sampled. Although the nematode was not found in the sugarbeet fields of Catanzaro, Foggia, and Udine, other surveys have revealed that it caused severe damage in Foggia province on the bank of Lesina lake (where sugarbeet is rotated with crucifers). The nematode was also detected in oil radish fields in Foggia, and in wheat fields in Catanzaro and Udine. Population densities of *H. schachtii* were related to the frequency of sugarbeet production on the same land in the provinces of L'Aquila, Ferrara, Modena, Ravenna, and Rovigo. In these areas, sugarbeets are often produced in the same field every other year and, therefore, yield losses are severe. In several other provinces where the nematode is widespread, 4- to 5-year rotations are used, and *H. schachtii* population densities seldom exceed the tolerance limit for sugarbeet. Therefore, intensive sugarbeet production with crucifers in the rotation must be avoided in order to minimize yield losses caused by *H. schachtii*. The use of 3- to 4-year rotations including resistant radish cultivars is recommended (27,28). Recently, due to a surplus of sugar in the European Economic Community, the acreage devoted to sugarbeet was reduced in Italy. Production of alternative crops and adoption of longer crop rotations will probably result in reductions in *H. schachtii* soil population densities and sugarbeet yield loss.

The potato cyst nematodes, *G. rostochiensis* and *G. pallida,* occur in many Italian provinces (4). Although we did not detect the nematode in Catania, Messina, Siracusa, Alessandria, Cuneo, Torino, Rovigo, Padova, and Vicenza, our data reflect the general distribution and the average yield losses caused by these nematodes in Italy. The province of Naples appears most affected by these nematodes, where approximately 9 billion Italian liras are lost each year in crop damage caused by potato cyst nematodes. In addition, plant quarantine guidelines of many countries permit only

TABLE 3. Distribution of *Globodera rostochiensis* and *G. pallida* in Italy and estimated potato yield losses.

Province	Samples			Yield losses (%)		Average value of yield loss‡
	Number collected	Infested (%)	Infestation >T† (%)	Maximum	Average	
Alessandria	9	0	0	0	0	0
Bari	102	35	4	100	9	6,329
Bologna	9	0	0	0	0	0
Bolzano	17	0	0	0	0	0
Catania	2	0	0	0	0	0
Catanzaro	10	20	10	50	6	1,653
Cosenza	47	6	0	40	1	259
Foggia	108	40	14	72	3	125
Forlì	10	90	60	50	17	1,389
L'Aquila	123	24	3	73	3.5	2,273
Lecce	120	0	0	0	0	0
Messina	2	0	0	0	0	0
Naples	139	63	38	85	10.6	8,971
Rovigo	8	0	0	0	0	0
Siracusa	8	0	0	0	0	0
Trento	43	17	3	18	3	110
Venice	18	0	0	0	3	0
Verona	7	0	0	0	0	0
Vicenza	3	0	0	0	0	0
Total	788	28	11			21,109

† T = tolerance limit of potato to *G. rostochiensis* and *G. pallida* (= 1.9 eggs/g soil).
‡ Crop loss values are in millions of Italian liras. Total crop value for each province was reported by the Istituto Nazionale di Economia Agraria (13).

the importation of potato stocks free of potato cyst nematodes. In southern Italy, early potatoes are produced, most of which are exported to other European countries. Infested potato stocks are often rejected, thus causing additional losses to the Italian potato industry. In the areas infested with potato cyst nematodes, high losses were estimated if short-term rotations were common, such as in the prov-

TABLE 4. Distribution of *Heterodera avenae* in Italy and estimated wheat yield losses.

Province	Samples			Yield losses (%)		Average value of yield loss‡
	Number collected	Infested (%)	Infestation >T† (%)	Maximum	Average	
Bari	21	52	19	6	0.4	205
Catanzaro	19	52	11	10	0.8	117
Cosenza	2	50	0	4	2	890
Foggia	245	59	5	30	0.3	548
Gorizia	10	0	0	0	0	0
Padova	14	14	14	15	1.3	266
Pordenone	15	20	20	4	0.6	6
Rovigo	19	16	11	3	0.3	127
Treviso	22	18	14	25	2	218
Udine	61	5	5	18	0.3	18
Venice	5	0	0	0	0	0
Verona	13	46	38	10	1	153
Vicenza	18	28	17	10	0.6	69
Total	464	42	9			2,617

† T = tolerance limit of wheat to *H. avenae* (= 1.0 eggs/g soil).
‡ Crop loss values are in millions of Italian liras. Total crop value for each province was reported by the Istituto Nazionale di Economia Agraria (13).

inces of Naples and L'Aquila (both with loamy-clay soil), Foggia (sandy soil), and Bari (partly sandy soil and partly clay-loamy).

In order to prevent the spread of potato cyst nematodes, potato seed tubers should be grown in nematode-free areas. When seed tubers are produced in infested areas, intensive soil sampling is required to ensure that only nematode-free fields are planted to potato. *Globodera rostochiensis* and *G. pallida* often occur in the same field. Therefore, the use of resistant cultivars to control potato cyst nematodes requires continuous monitoring of both species in order to adopt the most appropriate control measures. Frequent use of the same resistant cultivar may select for pathotypes for which no resistant cultivar is available.

In general, winter cereals such as bread and durum wheat are produced extensively in most Italian provinces. *Heterodera avenae* was widespread in all the sampled provinces. In southern Italy, where durum wheat is produced in short rotations continuously in the same fields, *H. avenae* population densities seldom exceeded 1 egg/g soil, the tolerance limit (8). Possibly the hatching behavior of *H. avenae* in southern Italy (8) and the presence of egg- and female-parasitic fungi (15) may have resulted in reduced nematode population levels and, thereby, reduced damage to wheat.

Estimated values of the yield losses caused by cyst-forming nematodes were highest for potato and sugarbeet, 21.1 and 13.8 billion Italian liras, respectively. Estimated losses for carrot (3.2 billion) and wheat (2.6 billion) were much lower; however, wheat losses refer to only 13 provinces and would be higher if estimated on a country-wide basis.

We can assess the impact of these nematodes on their host crops by considering the percentage yield loss with respect to the total yield of each crop on a national or provincial basis. Estimates of nematode damage over large areas usually show the extent of damage to be low; this can be misleading because large-scale estimates do not fully reveal the impact of the nematode in small areas. Because nematodes are usually distributed unevenly among adjacent provinces, the damage they cause may be locally severe even if of limited importance at a regional level.

Previous research revealed that the tolerance limits of potato to *G. rostochiensis* were similar in Italy (11), the Netherlands (22), and Chile (9). Tolerance limits for sugarbeet to *H. schachtii* were similar in Italy (10) and England (5,6). This confirms that, within a certain range of soil types and climatic conditions, the tolerance limit of a host plant to a given nematode species remains rather constant (22). The minimum yield, m in Seinhorst's equation (23), may vary under different cropping systems; however, it appears that this variation is within a limited range for cyst-forming nematodes. Therefore, we believe that our yield loss estimates are representative for Italy.

We also believe that 40 cores (30 cm by 1.5-cm-d) per soil sample was a reasonable number for a 0.5-ha area within a field and was sufficient to obtain a reliable estimate of the nematode population density (19). However, sampling error is expected to be larger in less heavily infested soils (24). If we assumed 100% error at low nematode population densities, sampling error would have little effect on yield loss estimation because these densities were close to the crop damage thresholds. Nematicides effective against cyst nematodes in Italy are used only to control *H. carotae*. Cost and environmental concerns do not encourage the use of chemicals, as opposed to crop rotation, for control of other cyst nematodes. Because cyst nematodes are not the only nematodes that can affect the crops considered in this study, additional research is required for a complete understanding of the role that nematodes play in Italian agriculture.

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