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Host–Parasite Relationship of *Meloidogyne chitwoodi* on Potato[1]

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Abstract: The soil fumigant 1,3-dichloropropene gave good to excellent control of the Columbia root-knot nematode, *Meloidogyne chitwoodi,* on potato, *Solanum tuberosum* L. Nonfumigant nematicides (aldicarb, fensulfothion, carbofuran, ethoprop, and phenamiphos) were less effective in controlling *M. chitwoodi,* since the nematode affects tuber quality more than quantity. Soil temperature during the growing season affected parasitism of *M. chitwoodi* on potato more than did the initial nematode population. There were positive linear correlations between degree-days and infected and galled tubers ($r = 0.92$), degree-days and nematode generations ($r = 1.00$), and infected and galled tubers and nematode generations ($r = 0.91$). Differences in degree-days and resultant nematode reproduction caused great variability in infection and galling of potato tubers during four growing seasons: 89% for 1979, 0% for 1980, 13% for 1981, and 18% for 1982, giving positive linear correlation ($r = 0.99$) between final nematode soil population (Pf) and percentage of infected and galled tubers. Corresponding increases in the soil populations of second-stage juveniles (J2) during the growing season were 9,700% in 1979, 170% in 1980, 552% in 1981, and 326% in 1982. There was a negative linear correlation ($r = -0.87$) between initial soil J2 populations (Pi) and the degree of parasitism (infection and galling) of potato tubers, Pi being of secondary importance to degree-days.

Key words: Columbia root-knot nematode, *Solanum tuberosum,* soil temperature, reproduction, generations, degree-days, chemicals, population densities, control.

The Columbia root-knot nematode, *Meloidogyne chitwoodi* Golden et al. (3), occurs throughout the Columbia River Basin of Washington and the Snake River regions of Idaho (9,10). It has been found parasitizing several plant species including potato, and it is known to cause severe crop losses (4,8). Many potato growers have had their potatoes rejected because nematode infection and galling exceeded that allowable by potato processing firms.

Soil temperature has a major influence on development and reproduction of root-knot nematodes (5,7,9,11), and summer temperatures influence the number of nematode generations per year. Since soil temperatures vary from one year to another, the adverse effect of the nematode on salable potatoes also varies annually (10). A 5-year study was conducted to determine 1) the efficacy of using fumigant vs. nonfumigant nematicides for control of *M. chitwoodi* on potato and 2) the effect of soil nematode populations, soil temperature, and nematode reproduction on the host–parasite relationship of *M. chitwoodi* and potato.

Materials and Methods

Adjoining fields located on the Ft. Hall Indian Reservation near Blackfoot, Idaho, were chosen for this study. The fields were

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cropped alternately with potatoes, *Solanum tuberosum* L. cv. Russet Burbank, and wheat, *Triticum aestivum* L. cv. Nugaines. Fields were treated with nematicides only before planting potatoes to avoid the possibility of chemical treatments affecting soil nematode populations the following year. The soil was a sandy loam (6% silt, 7% clay, 87% sand, 4% organic matter, pH 7.4). Plants were grown under a center pivot sprinkler irrigation system. Each experimental unit consisted of six-row plots, 5.5 × 120 m in 1978 and 5.5 × 37 m in 1979–82, with treatments arranged in complete randomized blocks and replicated four times. Each plot was sampled with a 2.54-cm core sampler on 1-m centers to 30 cm deep, and the initial (Pi) and the final (Pf) soil nematode populations were determined, immediately before planting and immediately after the soil was plowed following harvest. Soil samples were processed using an elutriator–sugar flotation method (2).

Agronomic practices were consistent for the area in relation to fertilization, weed control, and irrigation. Soil temperature at a depth of 30 cm was monitored with thermographs during the growing season.

Fumigant nematicide was applied with applicator chisels on 30-cm centers at 30 cm deep. Nonfumigant nematicides were applied 15 cm to the side of the row and 15 cm deep with a chisel applicator. Potato seed pieces were planted 10 cm apart in rows 90 cm apart.

Chemical control

Chemical treatments were as follows.

1978: 1,3-Dichloropropene (1,3-D) was applied at 135, 180, and 224 kg/ha 23 days before planting. Soil temperature at 30 cm deep was 11 C. Nonfumigant nematicides, aldicarb (2-methyl-2-[methylthio] propionaldehyde *O*-[methylcarbamoyl] oxime) and fensulfothion (*O,O*-diethyl *O*-4-[4-(methylsulfinyl) phenyl] phosphorothioate), were applied at 5.6 kg a.i./ha at planting time when the soil temperature was 18 C at 30 cm deep.

1979 (Field 1A): Treatments were similar to those applied in 1978. The fumigant was applied 41 days before planting at a soil temperature of 11 C. Cool, rainy weather delayed planting from the normal 14-day waiting period to 24 days. Nonfumigants were applied at time of planting when the soil temperature was 16 C.

1979 (Field 1B): Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) at 3.4 and 5.6 kg a.i./ha, aldicarb at 5.6 kg a.i./ha, fensulfothion at 5.6 and 11.2 kg a.i./ha, ethoprop (*O*-ethyl 5,5-dipropyl phosphorodithioate) at 5.6 kg a.i./ha, and phenamiphos (ethyl 3-methyl-4-[methylthio] phenyl [1-methylethyl] phosphoramidate) at 5.6 kg a.i./ha were applied at time of planting, when the soil temperature was 14 C.

1980–82: 1,3-D was applied in 1980, 1981, and 1982 at rates of 100, 135, and 170 kg/ha 38, 36, and 13 days before planting at soil temperatures of 8, 10, and 8 C, respectively; soil temperatures at planting were 14, 16, and 16 C, respectively.

Plants were grown for 159, 134, 136, 145, and 142 days during 1978–82, respectively. Sections 25 m long of the two center potato rows were harvested, tubers graded for size, and yields obtained. Tuber samples (25 kg/plot) were collected at random from each plot and examined for galling. Another 10 kg tubers with no external galling were collected from each plot and stored at 7 C, a normal potato storage temperature, for 70–100 days; these tubers were then examined internally for nematode infection and externally for nematode galling.

Nematode reproduction

One day after field planting in 1979–82, potato seed pieces were planted in methyl bromide-fumigated soil in 3.8-liter plastic containers, one seed piece per container. The soil in each container was inoculated with 1,000 *M. chitwoodi* second-stage juveniles (J2), and the containers were inserted to soil level in guard rows in the experimental field at Ft. Hall, Idaho. Starting 4 weeks later, four containers chosen at random were harvested each week and the potato roots were examined for nematode reproduction. As soon as viable eggs were found, the remainder of the containers in the field were removed and 6-week-old noninoculated potato plants from the greenhouse were transplanted into fumigated soil in other containers, the soil was inoculated with 1,000 J2, and the new con-

TABLE 1. Effect of 1,3-D and nonfumigant nematicides on control of *Meloidogyne chitwoodi* on Russet Burbank potato.

Soil treatment*	Rate (kg/ha)	Yield (quintal/ha)† 1978	Yield (quintal/ha)† 1979	No. 1 tubers (%)‡ 1978	No. 1 tubers (%)‡ 1979	Galled tubers (%)‡ 1978	Galled tubers (%)‡ 1979
1,3-D	135.0	435	419	56	63	12	<1
1,3-D	180.0	426	417	59	55	11	3
1,3-D	224.0	406	419	57	64	6	2
Aldicarb	5.6	380	378	43	31	23	54
Fensulfothion	5.6	356	393	32	24	30	58
Nontreated		348	363	30	6	66	89
LSD ($P = 0.05$)		38	35	19	12	11	19

* Fumigants applied 23 days before planting in 1978 and 24 days in 1979 at a soil temperature of 11 C, 30 cm deep. Aldicarb and fensulfothion—kg a.i./ha.
† Tubers harvested 159 days after planting in 1978 and 134 days in 1979.
‡ Combined data collected at harvest and after storage at 7 C for 100 days.

tainers were inserted in the field. The new containers were removed beginning 2 weeks after inoculation and at weekly intervals thereafter, and the potato roots were examined for viable nematode eggs. Using this procedure, it was possible to determine the number of nematode generations produced per year; this was equated with the percentage of infected and galled tubers harvested from nontreated plots in the nematicide experiments and related to soil temperature at 30 cm deep during the growing season. Soil temperature was converted to degree-days (maximum daily temperature + minimum daily temperature ÷ 2) − 5 C × number of days (1). In a preliminary study, J2 began invasion of potato roots at about 5 C.

Results and Discussion

Chemical control: Although infection and galling of potatoes harvested from fumigated plots in 1978 were significantly ($P =$ 0.05) less than those from nontreated controls, less than satisfactory control was obtained (Table 1) (nematode infection and galling exceeded the 5% limit established by potato processors).

1,3-D gave good to excellent control of *M. chitwoodi* in all experimental trials during the remaining 4 years of the study (Tables 1, 2). Nonfumigant nematicides always gave less satisfactory nematode control than did 1,3-D (Tables 1, 3). The percentage of infected and galled tubers exceeded the 5% level established by the potato processing companies for nonfumigants in 1978–79 (Tables 1, 3). During 1979–82, 1,3-D reduced the soil *M. chitwoodi* population to such a low level that it did not multiply sufficiently to invade and parasitize potato tubers before harvest. Nonfumigants may reduce invasion of roots and tubers by J2 to a degree, but the chemicals are unable to maintain nematode-free tubers at harvest.

TABLE 2. Effect of soil 1,3-D on control of *Meloidogyne chitwoodi* on Russet Burbank potato.

Soil treatment*	Rate (kg/ha)	Yield (quintal/ha)† 1980	Yield (quintal/ha)† 1981	Yield (quintal/ha)† 1982	No. 1 tubers (%)‡ 1980	No. 1 tubers (%)‡ 1981	No. 1 tubers (%)‡ 1982	Galled tubers (%)‡ 1980	Galled tubers (%)‡ 1981	Galled tubers (%)‡ 1982
1,3-D	100	423	416	420	69	63	56	0	0	0
1,3-D	135	453	428	382	62	65	53	0	0	0
1,3-D	170	461	442	392	67	64	47	0	0	0
Nontreated		428	405	366	61	47	0	0	13	18
LSD ($P = 0.05$)		70	58	62	18	19	11			

* Fumigants applied 38, 36, and 13 days before planting at soil temperatures of 8, 10, and 8 C during 1980, 1981, and 1982, respectively.
† Plots harvested after 136, 145, and 142 days growth during 1980, 1981, and 1982, respectively.
‡ Combined readings made at time of harvest and after storage at 7 C for 90 days.

TABLE 3. Effect of nonfumigant nematicides on control of *Meloidogyne chitwoodi* on Russet Burbank potato, 1979.

Soil treatment*	Rate (kg/a.i./ha)	Yield (quintal/ha)†	No. 1 tubers (%)‡	Galled tubers (%)‡
Carbofuran	3.4	404	37	54
Carbofuran	5.6	426	32	60
Aldicarb	5.6	328	43	41
Fensulfothion	5.6	383	40	44
Fensulfothion	11.2	382	42	39
Ethoprop	56	415	34	61
Phenamiphos	5.6	377	66	19
Nontreated		376	6	86
LSD ($P = 0.05$)		41	12	19

* Nematicides applied at time of planting.
† Plots harvested after 134 days growth.
‡ Combined readings made at time of harvest and after storage at 7 C for 70 days.

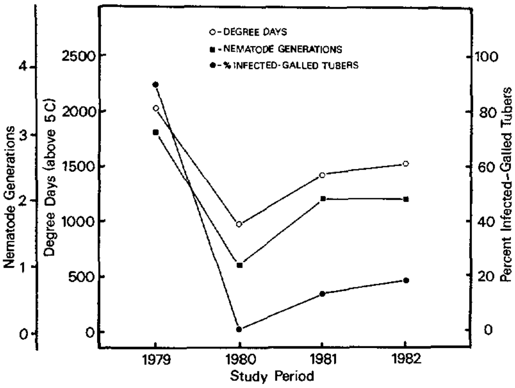

FIG. 1. Interrelationship of soil temperature (degree-days), nematode reproduction (generations per year), and infection and galling of Russet Burbank potato tubers by *Meloidogyne chitwoodi.*

Effect of soil temperature on nematode reproduction and infection and galling of tubers: Annual differences in infection and galling by *M. chitwoodi* were especially notable between 1979 and 1980 (Tables 1, 2). The 1979 growing season was unusually warm in the Ft. Hall area with more than 2,000 degree-days recorded. This resulted in the development of three nematode generations and 89% infected and galled potato tubers in nontreated plots (Fig. 1). In 1979, swollen potato roots were first seen 28 days after planting, and the first nematode generation was completed 47 days after planting; the second generation was completed 36 days later, and the third generation in another 45 days. Hence, 2,012 degree-days during 128 calendar days were required for the three nematode generations, the third generation being completed 8 days before harvest. In contrast, the 1980 growing season comprised 979 degree-days, over 96 calendar days during which one nematode generation developed, and there were no infected or galled tubers; the first swollen potato roots were observed 49 days after planting. The one nematode generation in 1980 was completed 30 days before harvest.

Soil temperatures for 1981 and 1982 were intermediate to those recorded for 1979 and 1980. In 1981, 1,428 degree-days resulted in two nematode generations and 13% infected and galled tubers in the nontreated plots; in 1982, there were 1,522 degree-days, two nematode generations, and 18% infected and galled tubers in the nontreated plots. The calendar days required for nematode generations were 63 and 50 days in 1981 and 56 and 49 in 1982.

Tuber infection and galling was equated to soil temperature and nematode reproduction. There was a positive correlation between the degree-days and infected and galled tubers ($r = 0.92$), degree-days and the number of nematode generations ($r = 1.00$), and infected and galled tubers and

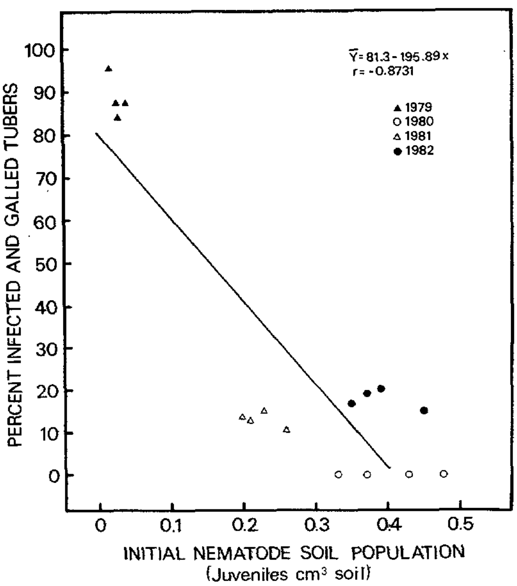

FIG. 2. Relationship of initial soil population of second-stage juveniles of *Meloidogyne chitwoodi* to infection and galling of Russet Burbank potato tubers in the field.

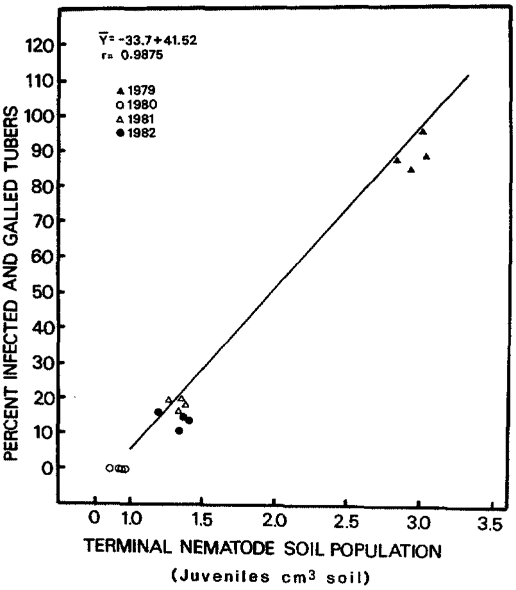

FIG. 3. Relationship of final nematode soil populations of second-stage juveniles of *Meloidogyne chitwoodi* to infection and galling of Russet Burbank potato tubers.

the number of nematode generations ($r = 0.91$) during 1979–82. A negative correlation ($r = -0.87$) occurred between the Pi and the percentage of infected and galled tubers from 1979–82 (Fig. 2), while a positive correlation ($r = 0.99$) was found between the Pf and the percentage of infected and galled tubers (Fig. 3); the Pi in 1979 was only 0.03 J2/cm^3 of soil, whereas the Pf was 2.91 J2/cm^3 soil, an increase of 97-fold , compared with a Pi of 0.40 and a Pf of 0.68 in 1980, an increase of only 1.7-fold. Results for 1981 and 1982 were similar to those for 1980.

Since *M. chitwoodi* lowers tuber quality and not yield, this problem could be partly alleviated if potato processing firms would relax their standards of grading to above the 5% infection level now established. During processing, potatoes are chemically peeled and infected tubers that are not galled are rejected as well as those showing external galling. Unfortunately, the grower cannot predict climatic conditions he will encounter during the growing season and therefore must rely on nematicides to ensure a crop of salable tubers.

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