Managing *Meloidogyne chitwoodi* on Potato with Rapeseed as Green Manure

H. MOJTAHEDI, Research Associate, G. S. SANTO, Professor and Nematologist, J. H. WILSON, Agriculture Research Technologist III, and A. N. HANG, Associate Agronomist, Departments of Plant Pathology and Crop and Soil Sciences, Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, WA 99350-9687

ABSTRACT

Mojtahedi, H., Santo, G. S., Wilson, J. H., and Hang, A. N. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. Plant Dis. 77:42-46.

Leaves of the rapeseed (*Brassica napus*) cultivar Jupiter used as a soil amendment effectively reduced *Meloidogyne chitwoodi* population densities at the zone of incorporation. Soil in the zone of incorporation was protected from nematode colonization for 6 wk. Stem and root tissues of rapeseed were also effective when homogenized before being used as an amendment. Greenhouse-grown plants accumulated more glucosinolates and became more effective in suppressing *M. chitwoodi* with age. Second-stage juveniles were more sensitive than egg masses, with ED_{50} of 10 and 23 mg of green leaves of 4-mo-old rapeseed per gram of soil, respectively. For two consecutive years, planting Jupiter rapeseed in the fall and incorporating it in the spring as green manure limited *M. chitwoodi* damage on potato (*Solanum tuberosum*) tubers in field experiments. Augmenting green manure amendment with ethoprop further reduced nematode damage to potato tubers and resulted in commercially acceptable tubers similar to those obtained from plots treated with 1,3-dichloropropene.

Additional keywords: Columbia root-knot nematode, organic amendment

The Columbia root-knot nematode, *Meloidogyne chitwoodi* Golden et al, is a significant pest of potato (*Solanum tuberosum* L.) in the Pacific Northwest. The nematode causes warts on the tuber surface and brown spots within the tubers (1). Blemished tubers may be downgraded or rejected for processing or fresh market. This nematode is controlled primarily by fumigating soil with 1,3-dichloropropene (1,3-D) or metham sodium (17). Because of health and environmental concerns, the continued availability and use of the soil fumigants are uncertain, and the search for alternative measures to manage *Meloidogyne* spp. on potato and other vegetable crops has become increasingly important.

Previously, we demonstrated (12) that soil incorporation of rapeseed (*Brassica napus* L. 'Jupiter') reduces *M. chitwoodi* population densities. Amending the soil with rapeseed and other members of Cruciferae also is reported to be effective against *Rhizoctonia solani* Kühn (6) and *Aphanomyces euteiches* Drechs. (13). Glucosinolates, organic anions commonly found among cruciferous plants, are implicated in biological activities of these plants as green manure. Glucosinolates are hydrolyzed enzymatically and release a number of biologically active compounds, including isothiocyanates (20). Ellenby (7) reduced population densities of the potato cyst nematode by treating soils with extracts of several cruciferous plants in vitro and with allyl-isothiocyanate (mustard oil). Recently, Brown et al (2) presented direct evidence for the production of isothiocyanate and ionic thiocyanate in soil after amendment with rapeseed meal.

M. chitwoodi can occur deep in the soil profile (19), and second-stage juveniles (J_2) have the capability of migrating upward to recolonize the nematicide-treated zone and damage potato tubers (11). Thus, the depth and duration of control achieved by green manure play an important role in the success of green manure treatments.

The objectives of these studies were: 1) to evaluate the efficacy of different amounts of Jupiter rapeseed green manure on the survival of different life stages of *M. chitwoodi*, 2) to determine the duration and depth of control achieved by green manure treatments under greenhouse conditions, and 3) to evaluate the use of rapeseed as a soil amendment in managing *M. chitwoodi* on field-grown potato. A portion of these studies has been previously published (18).

PPNS Paper No. 125, Project No. 0650, College of Agriculture and Home Economics Research Center, Washington State University, Pullman 99164-6240.

Accepted for publication 12 September 1992.

MATERIALS AND METHODS

Greenhouse studies. *Soil amendment.* An isolate of *M. chitwoodi* race 1 (WAMC1) was obtained from the root-knot nematode collection at the Washington State University Irrigated Agriculture Research and Extension Center, Prosser (15). Potting soil was a loamy sand (84% sand, 10% silt, 6% clay, 0.5% organic matter, pH 6.9) previously treated with methyl bromide. Soil was infested by adding finely chopped tomato roots infected with *M. chitwoodi* in a cement mixer that was rotated for 1 min. Except for that used for tests on sensitivities of *M. chitwoodi* life stages, the infested soil was incubated for 10 days at 18 C to obtain a mixture of egg masses and J_2. Then, 500 g of infested soil was amended with 2–3 cm of chopped leaves (blades and petioles), stems, or roots of 1- to 4-mo-old Jupiter rapeseed. Unamended soil served as a control.

In two experiments, the concentration of aliphatic glucosinolates (gluconapin, progoitrin, glucobrassicanapin, and napoleiferin) in rapeseed tissue was determined by Daun and McGregor's method (5). All treatments received 15 g of nonfumigated field soil (starter) to facilitate decomposition of plant tissue during the incubation period. Treated soils were placed in 7.5-cm-diameter clay pots and incubated on a greenhouse bench for 10 days before 3-wk-old tomato (*Lycopersicon esculentum* Mill. 'Columbian') seedlings (one per pot) were planted. After 3 wk, the root systems were washed free of soil and stained with acid fuchsin (4), and nematodes within the roots were counted.

Five pots per treatment were arranged in randomized complete blocks. Data based on nematode counts were log transformed before being subjected to analyses of variance, and means were separated by Duncan's multiple range test. All experiments were repeated at least once, and the effects of treatments that were significant at $P < 0.05$ were presented or discussed.

Plant age and parts. Jupiter rapeseed was grown in the greenhouse for 1, 2, 3, and 4 mo before 20 g of leaves of all ages and stem and roots of only 4-mo-old plants were tested as green manure. The concentration of aliphatic glucosinolates in leaves, stems, and roots of these plants was also determined. For comparing plant parts, leaves, stems, and roots were either chopped or homogenized before being mixed with nematode-infested soil. Plant tissues were homogenized in 80 ml of water with a Sorvall homogenizer running at high speed for 1 min. Chopped tissue was mixed with soil and placed in pots, and 80 ml water was added. An unamended treatment was included as a control.

Effects on inoculum sources. The effects of different rates of chopped leaves from 4-mo-old Jupiter rapeseed as green manure (0, 5, 10, 15, 20, 25, and 30 g/515 g of soil corresponding to 0, 10, 19, 29, 39, 49, and 59 mg/g of soil, respectively) on eggs within egg masses and J_2 of *M. chitwoodi* as inoculum sources were evaluated. Initially, eggs were freed from egg masses by NaOCl (9) and placed on a hatching screen to obtain J_2 (21). Soil in plastic bags was mixed with green manure plus 2,000 J_2 in 5 ml of water. The bags were shaken gently before the soil was placed in clay pots. For egg masses, the soil was infested with galled tomato root pieces (harboring unknown numbers of eggs) and immediately mixed with green manure. Juvenile population densities in a portion of untreated soil were determined. The data for the different rates of green manure were subjected to probit analysis (8) to calculate an ED_{50}.

Protection of amended zone. The depth of control achieved by green manure and the duration of control within the zone of incorporation were determined in polyvinyl chloride (PVC) soil columns (16). The 15-cm-high columns were constructed by taping three PVC rings, 8.25 cm in diameter and 5.0 cm high, end to end. The columns were packed with soil to attain bulk density of 1.4 g/cm^3. A fourth ring, sealed on one end with 25-μm-pore nylon screen that allowed nematode passage but confined the amendments and root growth, received 515 g of soil plus 20 g of chopped leaves of either 4-mo-old rapeseed or wheat. Five soil columns per treatment were arranged in randomized complete blocks and placed on the surface of dry soil in 10-cm-diameter clay pots.

To determine the depth of control, the columns received soil that had been infested with chopped galled tomato roots for 10 days. Another set of columns received 1 ml of metham sodium in 50 ml of water (equivalent to 468 L/ha of metham sodium in 1 cm of water). Unamended soil served as a control. The soil columns were incubated at 18 C and irrigated daily with 50 ml of water for 3 wk before the content of each ring was

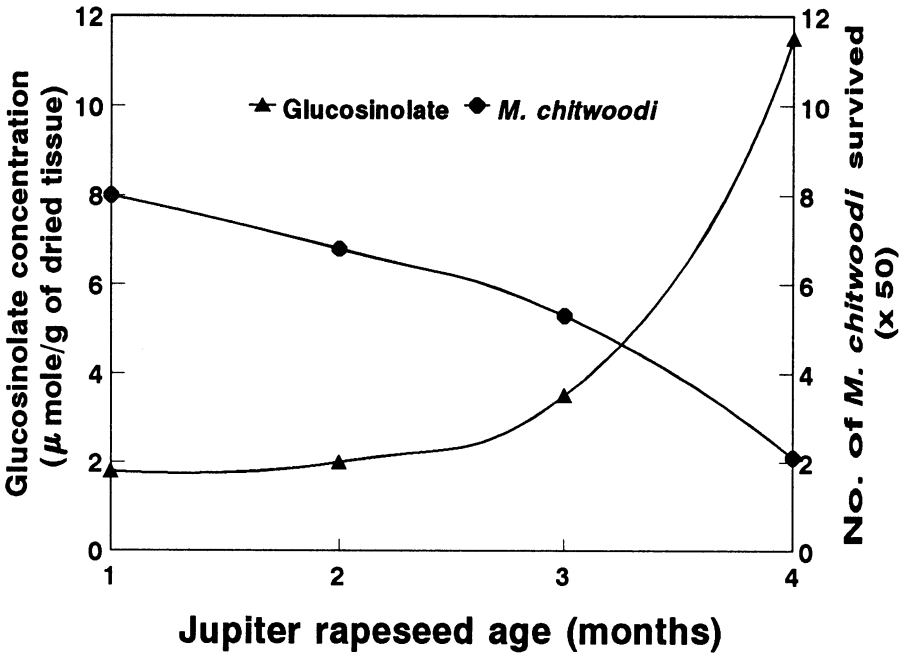

Fig. 1. Concentration of glucosinolates (sum of gluconapin, progoitrin, glucobrassicanapin, and napoleiferin) in leaves of rapeseed of different ages and effects of 20 g of leaf tissue incorporated into 515 g of soil as green manure on survival of *Meloidogyne chitwoodi*, on the basis of a tomato bioassay.

Table 1. Concentration of glucosinolates and number of *Meloidogyne chitwoodi* in roots of tomato grown in 515 g of infested soil amended with 20 g of different plant parts of 4-mo-old rapeseed that were chopped or homogenized before amendment

Amendment	Glucosinolates[y] (μmol/g)	Nematodes/root system	
		Chopped	Homogenized
None	...	387 a[z]	387 a
Leaves	11.5 ± 2.5	3 c	1 b
Stems	27.8 ± 1.7	24 bc	9 b
Roots	25.4 ± 2.8	92 ab	12 b

[y] Values are means of three observations and are sums of progoitrin, gluconapin, glucobrassicanapin, and napoleiferin determined per gram of dried leaf, stem, and root samples.
[z] Values are means of five replicates. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test.

bioassayed directly with a tomato seedling. After 3 wk, roots of tomato plants from each ring were stained, nematodes in the roots were counted, and the effects of treatments were evaluated as before.

In a second experiment, the colonization of the green-manure-amended zone by upward migrating J_2 was studied. The columns received uninfested soil and were placed on greenhouse bench, and 3-wk-old tomato seedlings were planted in the top rings containing green manure amendments or unamended soil as a control. The columns were irrigated with 50 ml of water twice a day. Through a port in the bottom ring, 2,000 J_2 were introduced 15 cm below the top ring. Three weeks after transplantation, tomato roots were gently removed from top rings and stained, and infective nematodes were counted. The disturbed soils in top rings were packed again and new tomato seedlings were planted. Freshly hatched J_2 were injected again into the bottom rings. The procedures were repeated as before until the numbers of *M. chitwoodi* invading tomato roots planted in amended soil were similar to those in the unamended control.

Field studies. *Soil amendment.* Rapeseed used as green manure to reduce impact of *M. chitwoodi* on field-grown potato was evaluated in 1990 and 1991 at the Washington State University Irrigated Agriculture Research and Extension Center, Prosser, on loamy fine Hezel sand (81% sand, 17% silt, 2% clay, 0.9% organic matter, pH 6.7).

Plots were 2.6 m wide and had three rows 7.6 m long. Nematode soil samples were taken with a 2.5-cm soil probe to a depth of 30 cm before rapeseed was planted, before potato was planted, 3 mo after potato was planted, and after tubers were harvested. Fifteen subsamples were taken and composited from each plot. Samples were mixed thoroughly and processed by the elutriation-sugar-flotation technique (3), and J_2 per 250 cm^3 of soil were counted.

Jupiter winter rapeseed was planted in late summer and rototilled 10–15 cm deep either in the fall after the first frost or in the spring about 1 mo before certified Russet Burbank potato seed pieces were planted. The amount of rapeseed green biomass per square meter to be incorporated was weighed, and the tonnage per hectare was calculated. A treatment of 1,3-D, 187 L/ha shanked 45 cm deep, served as a soil fumigant control. Ethoprop, 13.6 kg a.i./ha, was used either alone as a nonfumigant nematicide control or in combination with rapeseed. Ethoprop was broadcasted and incorporated 10–15 cm deep in the spring, before potato was planted in three rows 86 cm apart.

The middle row of each plot was harvested, and tuber yield (metric tons per hectare) was calculated. Twenty tubers per plot were hand-peeled and examined for *M. chitwoodi* infection. An infection index was assigned to each plot according to a rating scale of 0–6, where 0 = 0, 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10+, 5 = 50+, and 6 = 100+ infection sites per tuber. A tuber with more than six infection sites was considered culled.

Treatments were arranged in randomized complete blocks with five replicates per treatment and the data were subjected to analysis of variance. Means were separated by Duncan's multiple range test.

Experiment in 1989–1990. The experimental site was cropped to potato in 1988 and rapeseed was planted on 23 August 1989. Two nonchemical control treatments were also included: a fallow treatment free of weeds and Stephen winter wheat, which is commonly grown as a winter cover crop to prevent soil erosion. The wheat and rapeseed plots were fertilized with 170 kg of N (21-0-0) and 60 kg of P_2O_5/ha just before seeding (130 and 7 kg/ha) on 25 July and 24 August 1989, respectively. Five rapeseed

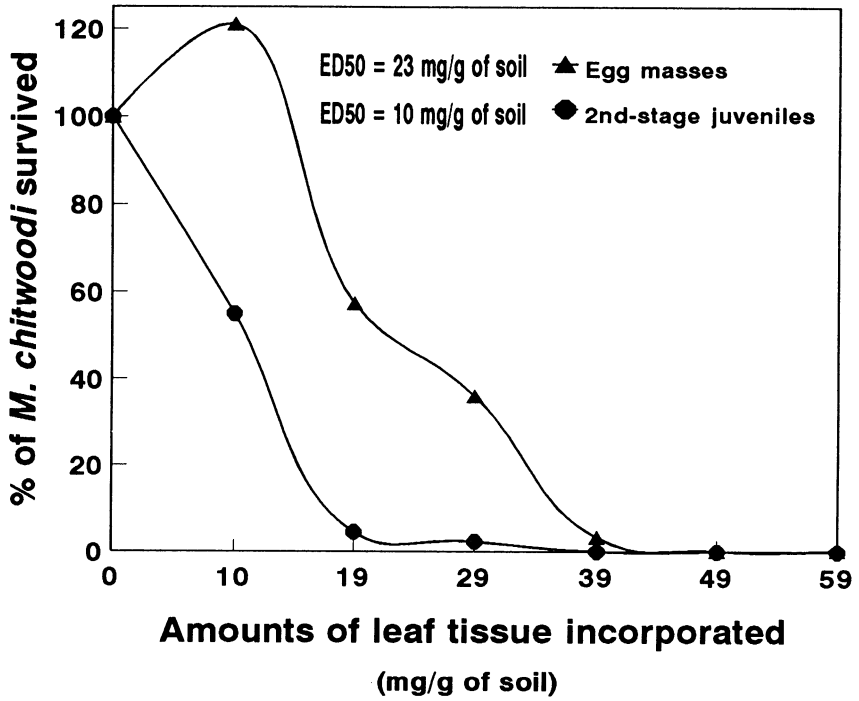

Fig. 2. Effects of different amounts of rapeseed leaves incorporated into the soil as green manure on survival of eggs in egg masses or second-stage juveniles of *Meloidogyne chitwoodi*, on the basis of a tomato bioassay.

Table 2. Number of *Meloidogyne chitwoodi* in roots of tomato grown in 5-cm-high soil rings from different depths below a zone amended with 20 g of chopped 4-mo-old rapeseed leaves or wheat or treated with metham sodium[y]

	Nematodes/root system			
Amendment	**Amended zone**	**5 cm**	**10 cm**	**15 cm**
None	193 a[z]	241 a	212 ab	180 ab
Wheat	132 a	191 a	440 a	357 a
Rapeseed	1 c	179 a	126 b	111 b
Metham sodium	0 c	0 b	0 c	0 c

[y]Columns were incubated at 18 C and irrigated daily with 50 ml of water for 21 days, after which soil was bioassayed with tomato seedlings.
[z]Values are means of five replicates. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test.

Table 3. Number of *Meloidogyne chitwoodi* in roots of tomato planted at different time intervals in soil rings amended with 20 g of chopped 4-mo-old rapeseed leaves or wheat and exposed to upward migrating second-stage juveniles[y]

	Nematodes/root system		
Amendment	**3 wk**	**6 wk**	**9 wk**
None	194 a[z]	154 a	108 a
Wheat	40 b	40 a	120 a
Rapeseed	4 b	22 b	63 a

[y]Columns were irrigated twice daily with 50 ml of water for 9 wk. Every 3 wk, 2,000 freshly hatched second-stage juveniles were injected 15 cm below the zone of green manure incorporation where a tomato seedling was growing.
[z]Values are means of five replicates. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test.

plots were rototilled after the first frost on 3 November 1989. One month before potato was planted, the wheat was killed with glyphosate on 16 March 1990 and rototilled on 17 April. The remaining five plots of rapeseed were rototilled on 19 March, and 1,3-D was applied on 27 March and ethoprop, on 17 April.

The whole plot received 492 kg/ha of N on 18 April, and potato seed pieces were planted on 19 April. Insects were controlled by esfenvalerate, methamidophos, and carbaryl and mites were controlled by propargite. Tubers were harvested on 26 September and graded for symptom expression.

Experiment in 1990–1991. Rapeseed was planted on 24 August 1990 after a crop of barley (*Hordeum vulgare* L. 'Steptoe'). Plot preparation and size were the same as in the 1989 experiment. Volunteer barley was allowed to grow in the control plots until killed by frost, then was incorporated by rototilling the following spring. Rapeseed plots were fertilized on 24 September, and volunteer barley plants were sprayed with fluazifop-p or hand-weeded. On 5 April, shoot samples were obtained from all 10 rapeseed plots for glucosinolate analyses, before the plots were rototilled. On 3 May, five rapeseed plots were treated with ethoprop. On 11 April, 1,3-D was applied, and on 6 May, 175 kg/ha of N was applied and potato seed pieces were planted. The postplant herbicide trifluralin and EPTC were applied on 14 May. Tubers were harvested on 18 October and stored at 5 C until 14 November, when they were graded.

RESULTS

Greenhouse studies. *Plant parts.* The concentration of glucosinolates increased sixfold as plants aged from 1 to 4 mo. Glucobrassicanapin (4-pentenyl) was the major glucosinolate detected in the leaves, stems, and roots at all sampling times (*data not shown*). During the time that concentration of glucosinolates increased, the efficacy of rapeseed as green manure on reducing soil population densities of *M. chitwoodi* also increased (Fig. 1).

Both chopped leaves and stems were effective as green manure and reduced nematode population densities. Despite the highest concentration of glucosinolates in the root system, however, chopped roots did not reduce the nematode population densities compared with the control treatment. When leaves, stems, and roots were homogenized, all equally suppressed *M. chitwoodi* infection of tomato roots (Table 1).

Effects on inoculum sources. Eggs within egg masses were more resistant to the effects of green manure than were J_2. Eggs were not affected by 10 mg of chopped leaves per gram of soil, but responses were proportionate with doses of 19, 29, or 39 mg. At 49 mg per gram of soil, most of the eggs did not yield infective J_2, and none was detected by the tomato bioassay at the 59-mg treatment. J_2 population densities declined sharply, with no nematode survival at 39 mg (Fig. 2). Probit analysis indicated that the ED_{50} for J_2 and eggs within egg masses were 10 and 23 mg of chopped leaves per gram of of soil, respectively.

Protection of amended zone. Treating the top 5 cm of soil with metham sodium eliminated all nematodes to a depth of 15 cm in soil columns. Rapeseed amendment was effective only in the amended zone (top 5 cm) (Table 2).

M. chitwoodi J_2 migrated 15 cm upward in soil columns and infected tomato roots in all treatments. During the first 3 wk, the numbers of infective J_2 in the wheat and rapeseed treatments were lower than those in the control. After 6 wk, no difference was observed between the wheat and control treatments, but the rapeseed treatment had fewer infective nematodes than the control. After 9 wk, the numbers of J_2 in tomato roots planted in control, wheat, or rapeseed treated rings were similar (Table 3).

Field studies. *Experiment in 1989–1990.* The amount of Jupiter rapeseed shoots incorporated into the soil was 20 t/ha on 3 November 1989 and 44 t/ha on 19 March 1990. Potato tubers from fallow and wheat plots were heavily infected, and *M. chitwoodi* J_2 densities at harvest rose to over 2,200 and 1,500/250 cm^3 of soil, respectively. Fewer nematodes were recovered from the plots treated with rapeseed and 1,3-D during the growing season (*data not shown*) and after harvest than from the fallow or wheat-treated plots. Ethoprop reduced nematode population densities compared with fallow but did not differ from the wheat treatment.

The 1,3-D and rapeseed treatments had lower tuber infection indices and cullage than the fallow or wheat treatments. Fall incorporation of rapeseed did not differ from ethoprop but was inferior to spring rapeseed and 1,3-D (Table 4).

Experiment in 1990–1991. Because of cold injury, only 10–11 t/ha of green biomass was incorporated in the spring of 1991. The concentration of glucosinolates in leaves of field-grown rapeseed was similar to that in stems and roots (6.3 ± 0.5 μmol/g of dried tissue), and all concentrations were lower than those in the greenhouse-grown rapeseed. Glucobrassicanapin (4-pentenyl) was the major glucosinolate detected in the leaves, stems, and roots (*data not shown*).

Rapeseed alone reduced *M. chitwoodi* population densities and tuber infection (Table 5). Augmenting rapeseed treatment with ethoprop further enhanced control of *M. chitwoodi*, and culled tubers fell below 1%, a result as good as that with 1,3-D (0%). No yield differ-

Table 4. Effects of rapeseed green manure, ethoprop, and 1,3-D on potato tuber yield, number of *Meloidogyne chitwoodi* second-stage juveniles (J_2) per 250 cm^3 of soil at harvest (26 September 1990), and tuber infection, 1989–1990 experiment

Treatment	Green manure (t/ha)	Yield (t/ha)	J_2 (no.)	Infection index[x]	Culls[y] (%)
Fallow	...	45 a[z]	2,230 a	5.2 a	97 a
Wheat	...	42 a	1,560 ab	4.5 a	82 a
Rapeseed					
Fall	20 ± 1	45 a	245 c	2.5 b	50 b
Spring	44 ± 3	42 a	161 c	1.0 cd	17 c
Ethoprop	...	57 a	784 bc	1.3 bcd	20 bc
1,3-D	...	55 a	38 c	0.1 d	1 c

[x]Scale of 1–6, where 0 = 0, 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10^+, 5 = 50^+, and 6 = 100^+ infection sites per tuber.
[y]Tubers with six or more infection sites.
[z]Values are means of five replicates. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test.

Table 5. Effects of rapeseed green manure alone or in combination with ethoprop and 1,3-D on potato tuber yield, number of *Meloidogyne chitwoodi* second-stage juveniles (J_2) per 250 cm^3 of soil at harvest (18 October 1991), and tuber infection, 1990–1991 experiment

Treatment	Green manure (t/ha)	Yield (t/ha)	J_2 (no.)	Infection index[x]	Culls[y] (%)
Control	...	51 a[z]	2,129 a	4.1 a	91 a
Rapeseed	10 ± 1	54 a	231 b	0.9 b	14 b
Rapeseed + ethoprop	11 ± 1	50 a	58 c	0.1 c	<1 c
Ethoprop	...	57 a	319 b	1.1 b	21 b
1,3-D	...	57 a	2 d	0.0 c	0 c

[x]Scale of 1–6, where 0 = 0, 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10^+, 5 = 50+, and 6 = 100^+ infection sites per tuber.
[y]Tubers with six or more infection sites.
[z]Values are means of five replicates. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test.

ences were observed among the control, rapeseed, ethoprop, and 1,3-D treatments.

DISCUSSION

Jupiter rapeseed as green manure was effective in reducing *M. chitwoodi* population densities under both greenhouse and field conditions. The effects, as previously reported (12), were greater than those attributed to wheat green manure amendment. The greenhouse data suggested a direct linear relationship between the accumulation of glucosinolates and age of Jupiter rapeseed and its effectiveness as green manure. Although roots had higher concentrations of glucosinolates than did other plant parts, roots were not as effective in reducing nematode population densities unless they were homogenized before being added to the soil. These results suggest that rapeseed roots do not decompose as rapidly as leaves and stems. Nevertheless, under field conditions, roots may be a source of slow-release compound(s) that could prolong the protection of potato roots and tubers from *M. chitwoodi* infection. The protection of rapeseed green manure against upward migrating *M. chitwoodi* J_2 for at least 6 wk within the zone of incorporation is critical because no control was observed below this zone in soil columns. Results of field studies indicate that the length of protection within the zone of incorporation significantly reduced tuber infection of Russet Burbank potato. Although isothiocyanates are adsorbed to soil particles and organic matter, subsequent release of these compound(s) to provide control for at least 6 wk is questionable (2). Fall incorporation of Jupiter was less effective than spring incorporation. This response was partially due to lower amounts of green manure incorporated in the fall (20 t/ha) vs. spring (44 t/ha). Alternatively, because of its proximity to potato planting, spring treatment may provide a more effective protection than fall treatment to the potato crop. The rapeseed crop was severely injured by unusually cold weather on 21 December 1990, when temperatures fell below −19 C, and many plants were lost. Thus, the green biomass incorporated into the soil the following spring was 25% of the previous year. Despite this, the 1991 rapeseed treatment controlled *M. chitwoodi* as well as the spring treatment in 1990.

Differential sensitivities of *M. chitwoodi* inoculum sources pose another problem for managing this nematode with green manure treatments. Because eggs within egg masses are more difficult to kill, it is essential that rapeseed cultivars used as green manure are not suitable hosts for *M. chitwoodi*. Although Jupiter was classified as a host for *M. chitwoodi* in the greenhouse (12), it did not support nematode reproduction in three different field experiments (H. Mojtahedi et al, *unpublished*). With continuous culturing, however, *M. chitwoodi* may be able to infect and reproduce on Jupiter, as reported with *M. incognita* (Kofoid & White) Chitwood and *M. javanica* (Treub) Chitwood (10).

Detrimental effects of Jupiter rapeseed as green manure on *M. chitwoodi* differ from those on *M. incognita* and *M. javanica* (10). Soil temperature may also account for the different results obtained in these two studies. In Washington, the average soil temperature at a depth of 20 cm was 18.6 ± 4.3 C during the growing seasons of 1990 and 1991, compared with 27.2 ± 3.1 C in Georgia (14). Conceivably, decomposition of rapeseed tissues is delayed at cooler soil temperatures. Thus, slower decomposition and release of effective compound(s) may extend the duration of nematode control beyond that in a warmer climate.

The spring rapeseed treatment in 1990 appeared to delay potato seed germination, and the potato plants were stunted early in the season. *R. solani* and *Fusarium* sp. were isolated from stunted potato roots. Nevertheless, the plants recovered, and final tuber yield did not differ from that with the 1,3-D treatment. Delayed germination or early stunting of potato plants was not observed in 1991 plots, and the quality of tubers was better than in 1990.

Despite the significant reduction of potato tuber infection achieved with spring-incorporated rapeseed, the tubers from these plots may not be acceptable to potato processors. The tubers in the rapeseed plots in 1990 and 1991 had 17 and 14% cullage, respectively, and Washington State processors may downgrade or reject potato fields with 10% or more culls. However, augmenting green manure with ethoprop resulted in production of quality tubers that were comparable to those produced with 1,3-D. Ethoprop alone is not recommended for control of *M. chitwoodi* on potato. Similar results have been observed with ethoprop in combination with sudangrass green manure (H. Mojtahedi et al, *unpublished*).

LITERATURE CITED

1. Anonymous. 1986. Integrated pest management for potatoes in the western United States. Univ. Calif. Div. Agric. Nat. Resour. Publ. 3316.
2. Brown, P. D., Morra, M. J., McCaffrey, J. P., Auld, D. L., and Williams, L., III. 1991. Allelochemicals produced during glucosinolate degradation in soil. J. Chem. Ecol. 17:2021-2034.
3. Byrd, D. W., Jr., Barker, K. R., Ferris, H., Nusbaum, C. J., Griffin, W. E., Small, R. H., and Stone, C. A. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. J. Nematol. 8:206-212.
4. Byrd, D. W., Jr., Kirkpatrick, K., and Barker, K. R. 1983. An improved technique for clearing and staining plant tissue for detection of nematodes. J. Nematol. 15:142-143.
5. Daun, J. K., and McGregor, D. I. 1983. Glucosinolate Analysis of Rapeseed (Canola). 2nd ed. Canadian Grain Commission Grain Research Laboratory, Winnipeg, Manitoba.
6. Davis, J. R., Huisman, O. C., Westerman, D. T., Hafez, S. L., Sorensen, L. H., and Schneider, A. T. 1991. Cover crops and their effects on disease control and yield. Pages 65-73 in: Proc. Annu. Wash. Potato Conf. Trade Fair, 30th.
7. Ellenby, C. 1945. Control of the potato-root eelworm, *Heterodera rostochiensis* Wollenweber, by allylisothiocyanate, the mustard oil of *Brassica nigra* L. Ann. Appl. Biol. 32:237-239.
8. Finney, D. J. 1952. Probit analysis, a statistical treatment of the sigmoid response curve. Cambridge University Press, London.
9. Hussey, R. S., and Barker, K. R. 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp. including a new technique. Plant Dis. Rep. 57:1025-1028.
10. Johnson, A. W., Golden, A. M., Auld, D. L., and Summer, D. R. 1992. Effects of rapeseed and vetch as green manure crops and fallow on nematodes and soil-borne pathogens. J. Nematol. 24:117-126.
11. Mojtahedi, H., Ingham, R. E., Santo, G. S., Pinkerton, J. N., Reed, G. L., and Wilson, J. H. 1991. Seasonal migration of *Meloidogyne chitwoodi* and its role in potato production. J. Nematol. 23:162-169.
12. Mojtahedi, H., Santo, G. S., Hang, A. N., and Wilson, J. H. 1991. Suppression of root-knot nematode populations with selected rapeseed cultivars as green manure. J. Nematol. 23:170-174.
13. Muehlchen, A. M., Rand, R. E., and Parke, J. L. 1990. Evaluation of crucifer green manures for controlling Aphanomyces root rot of peas. Plant Dis. 74:651-654.
14. National Oceanic and Atmospheric Administration. 1989, 1990. Climatological data, annual summaries, Georgia. National Climatic Data Center, Asheville, NC.
15. Pinkerton, J. N., Mojtahedi, H., and Santo, G. S. 1987. Reproductive efficiency of Pacific Northwest populations of *Meloidogyne chitwoodi* on alfalfa. Plant Dis. 71:345-348.
16. Pinkerton, J. N., Mojtahedi, H., Santo, G. S., and O'Bannon, J. H. 1987. Vertical migration of *Meloidogyne chitwoodi* and *M. hapla* under controlled temperature. J. Nematol. 19:152-157.
17. Pinkerton, J. N., Santo, G. S., Ponti, R. P., and Wilson, J. H. 1986. Control of *Meloidogyne chitwoodi* in commercially grown Russet Burbank potatoes. Plant Dis. 70:860-863.
18. Santo, G. S., Mojtahedi, H., Hang, A. N., and Wilson, J. H. 1991. Control of the Columbia root-knot nematode using rapeseed and sudangrass green manure. Pages 41-43 in: Proc. Annu. Wash. Potato Conf. Trade Fair, 30th.
19. Santo, G. S., O'Bannon, J. H., Nyczepir, A. P., and Ponti, R. P. 1981. Ecology and control of root-knot nematodes on potato. Pages 135-139 in: Proc. Annu. Wash. Potato Conf. Trade Fair, 20th.
20. VanEatten, C. H., and Tookey, H. L. 1979. Chemistry and biological effects of glucosinolates. Pages 471-500 in: Herbivores: Their Interaction with Secondary Plant Metabolites. C. A. Rosenthal and D. H. Janzen, eds. Academic Press, New York.
21. Vrain, T. C. 1977. Technique for the collection of larvae of *Meloidogyne* spp. and a comparison of eggs and larvae as inocula. J. Nematol. 9:249-251.