HOST STATUS AND GREEN MANURE EFFECT OF SELECTED CROPS ON *MELOIDOGYNE CHITWOODI* RACE 2 AND *PRATYLENCHUS NEGLECTUS*

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ABSTRACT

Al-Rehiayani, S., and S. Hafez. 1998. Host status and green manure effect of selected crops on *Meloidogyne chitwoodi* race 2 and *Pratylenchus neglectus*. Nematropica 28:213-230.

The suitability of selected crops as hosts of *Meloidogyne chitwoodi* race 2 and *Pratylenchus neglectus* was evaluated in greenhouse and field microplots. Host status was based on reproductive factor (Rf = Pf/Pi). Sudangrass cv. Hidan 36 (*Sorghum vulgare* var. *sudanense*) and all oil radish (*Raphanus sativus* L.) cultivars were maintenance hosts ($1 < Rf < 3$). All buckwheat (*Fagopyrum esculentum* Moench) cultivars, rapeseed (*Brassica napus* L.) cv. Humus, sudangrass cv. Trudan 8 and cv. Sordan 79, horsebean (*Canavalia ensiformis* L.), velvetbean (*Mucuna deeringiana* Bort.), castorbean (*Ricinus communis* L.), and corn (*Zea mays* L.) were either poor or nonhosts ($Rf < 1$) for *M. chitwoodi.* Most crops tested were either good hosts ($Rf > 3$) or maintenance hosts ($1 < Rf < 3$) for *P. neglectus,* but buckwheat cv. Tardo, horsebean, and velvetbean were poor hosts for *P. neglectus.* Stems and leaves of crops were incorporated as green manure into sterile soil in greenhouse pots. Pots were inoculated with *M. chitwoodi* race 2 (10 J2/cm^3 soil) and a 3-week-old tomato (*Lycopersicon esculentum* Mill.) seedling was planted and left to grow in each pot for 7 weeks. Incorporation of stem and leaf tissues of all crops reduced ($P < 0.05$) the total number of *M. chitwoodi* in pots compared to the control. Amending the soil with green manure residues of horsebean, velvetbean, castorbean, sudangrass cv. Hidan, rapeseed cv. Humus, corn, or oil radish cv. Trez more effectively reduced *M. chitwoodi* populations (79% to 94%) than either barley (77%) or tomato (68%). Buckwheat green manure was least effective in reducing nematode populations. The effect of oil radish cv. Trez and rapeseed cv. Humus as green manures in potato (*Solanum tuberosum* L.) crop rotations was investigated in field plots. Green manure crops were planted after harvest of wheat in mid August and incorporated as green manure in mid October. Potato was planted the following spring. Fall fallow treatments were included as a standard. After green manure incorporation and before planting potato, nematode population densities declined in all plots. However, plots planted to oil radish had significantly lower nematode population densities than fallow. During the subsequent growing season, *M. chitwoodi* soil populations increased on potato in all plots, but green manure plots had lower ($P < 0.05$) nematode populations than fallow plots. Soil population densities of *P. neglectus* did not change in any plot. Green manure treatments increased yield of marketable potatoes by 106-185%, and reduced *M. chitwoodi* tuber infection compared to fallow.

Key words: *Brassica napus, Canavalia ensiformis,* green manure, *Meloidogyne chitwoodi, Mucuna deeringiana, Pratylenchus neglectus, Raphanus sativus, Ricinus communis, Sorghum vulgare* var. *sudanense.*

RESUMEN

Al-Rehiayani, S. y S. L. Hafez. 1998. Estado del hospedante y efecto del uso de cultivos seleccionados como abono verde, en *Meloidogyne chitwoodi* raze 2 y *Pratylenchus neglectus.* Nematrópica 28:213-230.

La capacidad hospedante de ciertos cultivos, hacia *Meloidogyne chitwoodi raza* 2 y *Pratylenchus neglectus,* fue evaluada en el invernadero y en microparcelas en el campo. La capacidad hospedante, se basó en el factor reproductivo (Rf = Pf/Pi). Pasto sudan cv. Hidan 36 (*Sorghum vulgare* var. *sudanense*) y todos los cultivos de rábano aceitoso (*Raphanus sativus* L.), fueron hospedantes de sobrevivencia ($1 < Rf < 3$). Todos los cultivos de alforfón (*Fagopyrum esculentum* Moench), nabo silvestre (*Brassica napus* L.) cv. Humus, pasto sudan cv. Trudan 8 y cv. Sordan 79, haba panosa (*Canavalia ensiformis* L.), el friho pica-pica (*Mucuna deeringiana* Bort.), higuerilla (*Ricinus communis* L.) y maíz (*Zea mays* L.) fueron muy pobres o no hospedantes (Rf < 1) de *M. chitwoodi*. La mayoría de los cultivos evaluados, fueron buenos hospedantes (Rf > 3) o cultivos de sobrevivencia (1 < Rf < 3) para *P. neglectus*, sin embargo el alforfón cv. Tardo, la haba panosa, y el friho pica-pica no fueron buenos hospedantes. Tallos y hojas de estos cultivos, fueron incorporados como abono verde en el suelo estéril de las macetas, en el invernadero. Estas se inocularon con *M. chitwoodi* raza 2 (10 J2/cm^3 de suelo) y se sembraron con una plantula de tomate (*Lycopersicon esculentum* Mill.) de 3 semanas, la que se dejó crecer por 7 semanas. La incorporación de tallos y tejido de hoja de todos los cultivos, redujo significativamente el numero total de *M. chitwoodi* en las macetas, en comparación al control ($P < 0.05$). La enmienda del suelo con residuos de haba panosa, el friho pica-pica, higuerilla, pasto sudan cv. Hidan, nabo silvestre cv. Humus, maíz y el rábano aceitoso cv. Trez, como abono verde, redujo las poblaciones de *M. chitwoodi* más efectivamente (79% a 94%), que con cebada (77%) o tomate (68%). El alforfón como abono verde, fue menos eficiente para la reducción de poblaciones de nematodos. También se investigó, el efecto del nabo aceitoso cv. Trez y el nabo silvestre cv. Humus como fertilizantes verdes en la rotación de cultivos de papa (*Solanum tuberosum* L.), en parcelas en el campo. Los cultivos utilizados como abono verde, fueron plantados después del trigo a mediados de Agosto, e incorporados como fertilizante verde a mediados de Octubre. La papa fue plantada en la primavera siguiente. Los tratamientos con barbecho del otoño, fueron incluidos como control. Después de la incorporación del abono verde y antes de plantar la papa, las densidades de las poblaciones de nematodos declinaron en todas las parcelas. Sin embargo, las que se sembraron en el suelo con el rábano aceitoso, tuvieron poblaciones significativamente más bajas que el barbecho. Durante la temporada de crecimiento subsiguiente, las poblaciones de *M. chitwoodi* del suelo, aumentaron en la papa, en todas las parcelas, sin embargo las parcelas con abono verde tuvieron poblaciones de nematodos significativamente menores que las parcelas con barbecho ($P < 0.05$). Las poblaciones en el suelo, no mostraron ningún cambio para *P. neglectus* en ninguna parcela. Los tratamientos con abono verde, aumentaron el rendimiento de la papa entre un 106-185%, y en comparación al barbecho, redujeron la infección del tubérculo por *M. chitwoodi.*

Palabras claves: Abono verde, *Brassica napus, Canavalia ensiformis, Meloidogyne chitwoodi, Mucuna deeringiana, Pratylenchus neglectus, Raphanus sativus, Ricinus communis, Sorghum vulgare* var. *sudanense.*

INTRODUCTION

Plant-parasitic nematodes are common in Idaho potato (*Solanum tuberosum* L.) fields, and several nematode species damage potatoes (Hafez and Thornton, 1992). The Columbia root-knot nematode, *Meloidogyne chitwoodi* Golden, O'Bannon, Santo, and Finly, 1980, is the most serious nematode problem because it deforms and blemishes tubers. When 10% or more of the tubers are blemished, the crop may be rejected for processing or fresh market. The root-lesion nematode, *Pratylenchus neglectus* (Rensch) Filipjev and Schuurmans Stekhoven, which occurs in mixed populations with *M. chitwoodi* in Idaho potato fields, currently has minimal effect on potato (Hafez and Thornton, 1992); however, *P. neglectus* could be important at high population densities (Ferris *et al.*, 1994).

Current management of *M. chitwoodi* and *P. neglectus* in potato fields is primarily accomplished by treatment of soil with nematicides. Alternatives to nematicides are needed, due to increasing concerns about the impact of these chemicals on the environment and on human health. For potato, these may include prevention of nematode spread, crop rotation, clean fallow, early harvest, and nonhost green manure crops (Santo, 1994). In the last decade, there has been increased interest in using nonhost and green manure crops to control root-knot and other nematodes in vegetable production systems (Davis *et al.*, 1996; Ferris *et al.*, 1993; Johnson *et al.*, 1992; McSorley *et al.*, 1994; Mojtahedi *et al.*, 1993b; Rodríguez-Kábana *et al.*, 1992). Some of the green manure crops used successfully for nematode management in the United States include rapeseed (*Brassica napus* L.), sorghum-sudangrass (*Sorghum bicolor* L. *Moench*), velvetbean (*Mucuna deeringiana*), oil radish (*Raphanus sativus* L.), and yellow mustard (*Sinapis alba* L.). Sudangrass and sorghum-sudangrass grown as green manure crops reduce population densities of *M. chitwoodi* in the soil of potato fields (Mojtahedi *et al.*, 1993a). Sudangrass cv. Piper incorporated in the fall and rapeseed cv. Jupiter incorporated in the spring reduce potato tuber infection comparable to ethoprop at 13.4 kg a.i./ha (Santo, 1994). Velvetbean as a nonhost green manure crop suppressed *M. arenaria* (Neal) Chitwood population densities in peanut crop rotations, and reduced yield losses caused by *M. arenaria* and *Heterodera glycines* Ichinohe in soybean (Weaver *et al.*, 1993). Oil radish and yellow mustard green manure crops have been effective for management of sugarbeet cyst nematode, *H. schachtii* Schmidt, populations in Idaho (Hafez and Hara, 1989).

However, little is known about the use and effectiveness of green manure crops for management of *M. chitwoodi* in Idaho potato rotation systems. The length of growing season limits potato growers in southwestern Idaho to one crop a year. The production season is constrained by snow and frozen soils during winter. Average length of the growing season ranges from 70 to 160 days in southwestern Idaho. Frost may occur beginning in September. Conditions become suitable for soil tillage and planting in April and the potato crop is usually harvested in September. Principal rotation crops in southwestern Idaho are alfalfa, barley, corn, or wheat. Unfortunately, this type of rotation does not provide acceptable nematode management because these crops are good hosts for *M. chitwoodi.* At present, soil fumigation with nematicides or long rotation with clean fallow are the most effective means for *M. chitwoodi* management. The use of nonhost green manure crops could shorten rotations by decreasing the time between potato crops and reduce dependence on nematicides.

There is a need to find a suitable green manure crop for *M. chitwoodi* management that fits Idaho potato rotation systems. The following characteristics are ideal for green manure crops in Idaho potato rotations: 1) the green manure crop should not serve as a good host for *M. chitwoodi;* 2) it should grow quickly and produce abundant biomass; 3) it should not be sensitive to frost; 4) it must be agriculturally and economically feasible—that is, it must not hamper operations needed to optimize the yields of the preceding or subsequent crops; 5) it must not shed seed if this would lead to a weed problem; and 6) the green manure crop can be planted as a second crop in late summer after the harvest of an early-maturing rotation crop and incorporated as green manure in the fall. The objectives of this research were 1) to determine the host suitability of selected crops and cultivars to *M. chitwoodi* and *P. neglectus*; 2) to evaluate the effect of green manure from selected crops on *M. chitwoodi*; and 3) to determine the effect of selected green manures on potato yield in the presence of *M. chitwoodi* and *P. neglectus.* A portion of these studies has been published (Al-Rehiayani *et al.*, 1995; Al-Rehiayani and Hafez, 1996; 1998).

MATERIALS AND METHODS

Crops and cultivars: Twenty cultivars of 10 crop species were included in these studies. They are oil radish (*Raphanus sati-*

vus) cvs. Melodie, Trez, and Adagio 5a-3; buckwheat (*Fagopyrum esculentum*) cvs. Kendo, Prego, Rondo, and Tardo; white mustard (*Sinapis alba*) cv. Martegina; rapeseed (*Brassica napus* L.) cv. Humus; corn (*Zea mays* L.) Hybrid AP622; sudangrass hybrid (*Sorghum vulgare* var. *sudanense*) cv. Trudan 8; sorgum-sudangrass hybrids (*Sorghum biocolor* x *S. vulgare* var. *sudanense*) cvs. Hidan 36 and Sordan 79; castor (*Ricinus communis* L.); horsebean (*Canavalia ensiformis* L.); velvetbean (*Mucuna deeringiana* Bort.); barley (*Hordeum vulgare*) cv. Steptoe; and tomato (*Lycopersicon esculentum* Mill.) cv. Payette.

Seeds of the various crops were obtained from the following sources: Buckwheat, oil radish, and mustard cultivars, P. H. Peterson Saatzucht, Lundsgaard, Germany; castorbean, horsebean, and velvetbean, Dr. Rodríguez-Kábana, Auburn University, Auburn, AL; sudangrass and sorghum-sudangrass cultivars, Northrup King Co., Minneapolis, MN; barley, tomato, and corn, commercial and private seed companies in Idaho; and rapeseed, Department of Plant, Soil, and Entomological Sciences, University of Idaho.

Nematode inoculum: The Columbia root-knot nematode, *Meloidogyne chitwoodi* race 2, and the lesion nematode, *Pratylenchus neglectus,* were used throughout this research. The population of *M. chitwoodi* originated from a potato field near Parma, Idaho, and inoculum for experiments was obtained from infected tubers that were kept in cold storage. *M. chitwoodi* J2 were extracted from infected Russet Burbank potato tubers. Infected tubers were dipped in a 0.26% NaOCl solution for 1 minute, peeled to a depth of about 10 to 12 mm depending on the depth of nematode infection. Peeled tuber tissue was macerated using a mixer. The macerated tissue was placed in Baermann funnels under a mist chamber and the hatched J2 were collected every 24 hrs for 10 days. Inoculum was also cultured on tomato cv. Payette in the greenhouse.

The *P. neglectus* population originated from a potato field near Parma, Idaho and the inoculum was cultured in the greenhouse on barley cv. Steptoe. Juveniles and adult females of *P. neglectus* were extracted from barley roots. The roots were dipped in 0.26% NaOCl solution, cut into small pieces (1-2 cm), placed in a mist chamber, and nematodes were collected daily for two weeks.

Greenhouse evaluation of host status: An experiment was conducted to test the suitability of the previously mentioned crops and cultivars as hosts of *Meloidogyne chitwoodi* race 2. Seeds from each crop and cultivar were planted in 15.2-cm plastic pots containing 1 500 cm^3 of sterilized sandy soil (sand 64%, silt 44%, clay 10%, organic matter 0.8%, and pH 7.9). After germination, the seedings were reduced to six per pot. Each pot was infested with an initial population (Pi) of 15 000 freshly hatched *M. chitwoodi* J2 race 2. Each crop was replicated 10 times. The pots were arranged in a completely randomized design on a greenhouse bench. Pots were watered daily and fertilized every 2 weeks with a commercial solution of 5 g of NPK (20-20-20) in 100 ml water per pot. Plants were grown at soil temperature of 23-25°C and received 14 hrs of light per day, supplemented with fluorescent lamps. The experiment was terminated 8 weeks after inoculation.

Soil from each pot was separated from roots and a 500-cm^3 sub sample was placed in a 3 liter-pan with water. Roots were washed in a second pan to remove soil particles and the resulting suspension was added to the pan containing the soil and stirred thoroughly. Nematodes were extracted from the soil suspension by differential sieving using 250- and 38-µm screens (60 and 400, mesh respectively). Sieving through 400 mesh was repeated three times to collect smaller nematodes that had passed through the first and second times. The sieving procedure was followed by sugar flotation (Jenkins, 1964). Root systems were washed free of soil and rated for nematode galling on a 1 to 5 scale: 1 = no galls, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% of roots galled (Taylor and Sasser, 1978). The roots from each pot were chopped and placed in Baermann funnels in a mist chamber for 10 days. Root systems were removed from the mist chamber and oven dried at 65°C for 7 days. The nematode suspensions were concentrated using a 25-μm (500-mesh) sieve. The number of eggs and juveniles were counted from 1-ml aliquots and results were extrapolated to the total volume of the suspension. Final nematode population densities (Pf), root-gall indices, number of J2 per gram of dry root, and reproductive factors (Rf, where Rf = Pf/Pi) were subjected to analysis of variance, and differences among treatment means were compared using Fisher's least significant difference (LSD). Based on the Rf values, four groups of hosts are defined as follows: good hosts supporting large increases in nematode population (Rf > 3), maintenance hosts supporting the nematode population without substantial increases (1 < Rf < 3), poor hosts resulting in population decreases (0.1 < Rf < 1), and nonhosts resulting in elimination of the nematode population (Rf < 0.1). The gall rating was regressed against the Pf. Final nematode population data were log transformed before analysis.

The crops listed above were also tested against *P. neglectus* in the greenhouse, using the same soil and growing conditions described previously. Corn hybrid AP622 was used as a standard host. Ten days after planting, soil in each 6-inch plastic pot was infested by adding water suspension of mixed age groups of *P. neglectus* (1 500 per pot). Pots were randomized in eight replicates on greenhouse benches. The experiment was terminated 10 weeks after inoculation. Roots were separated from soil and nematodes (males, females, and juveniles) were extracted from roots and soil as described for *M. chitwoodi*. The host status was determined as in the previous experiment. Data were analyzed with analysis of variance, and differences among the treatment means were compared using the LSD test.

Field microplot evaluation of host status: The cultivars most effective in suppressing *M. chitwoodi* populations, based on the greenhouse study, were tested in 19-liter plastic container-microplots (Pinkerton *et al.*, 1989). The microplot experiment began early August 1994 and was terminated in mid October 1994. Microplot containers were located in an area (36.4 m × 15.2 m) near the University of Idaho Research and Extension Center at Parma, Idaho. Microplot soil was fumigated twice with metham sodium (Vapam) at 468 L/ha (50 gallons/acre). Containers were set in the bottom of holes (30-cm diam. × 30 cm deep) that were spaced 1 m apart. Each container received about 16 L of soil (sand 46%, silt 44%, clay 10%, organic matter 1.1%, and pH 7.8). A drip irrigation system with a single emitter at each container was used to irrigate the microplots. Poor and nonhost cultivars were planted in each container. Tomato was planted as a standard host. The containers were arranged in a completely randomized design with five replicates. Plants in each container were inoculated with 50 000 freshly hatched *M. chitwoodi* J2. The containers were weeded when necessary and fertilized weekly with 28 g of NPK (20-20-20) in 500 ml water per container. After 2 months, the experiment was terminated. The roots were separated from soil and a 20-g subsample from each container was placed in the mist chamber. The Pf and host status were determined as described in the greenhouse experiment. Data were analyzed with analysis of variance and LSD was used to separate treatment means.

Greenhouse evaluation of green manure effects: Five grams dry weight (equivalent to 4.9 t/ha) of leaves and stems of the above cultivars were incorporated as a green manure into 500 cm^3 of sterile soil (sand 64%, silt 44%, clay 10%, organic matter 0.8%, and pH 7.9). Four grams of nonfumigated field soil was added to each pot to facilitate decomposition of plant tissue. A three-week-old tomato cv. Payette seedling was planted in each pot immediately after green manure incorporation, and the soil was infested with 5 000 freshly hatched *M. chitwoodi* J2. Plants were grown under previously described temperature and light conditions. A completely randomized design was used with five replications for each treatment.

Seven weeks after inoculation, the final nematode populations were determined for each pot as described previously and the percentage of nematode reduction was calculated for each pot. Data were analyzed with analysis of variance, and differences among treatment means were compared using LSD.

Field plot evaluation of green manure effects: Oil radish cv. Trez and rapeseed cv. Humus were used as green manure to evaluate the impact of *M. chitwoodi* on field grown potato. These two cultivars were selected based on previous growth performance and frost tolerance tests conducted at the field site in 1995. Field trials were conducted in 1996 to1997 near the University of Idaho, Parma Research and Extension Center, on a sandy loam soil (sand 56%, silt 19%, clay 24, organic matter 1.5%, pH 8.0) naturally infested with *M. chitwoodi* race 2 and *P. neglectus*. Initial numbers of *M. chitwoodi* and *P. neglectus* averaged 250 and 3 500, respectively in 500-cm^3 soil. Two weeks after harvesting winter wheat in July 1996, a herbicide (pyrazon, 67.7% ai, 2.3 L/ha) was applied to eliminate the established weeds and volunteer wheat. The field was disc-harrowed 20 cm deep three times and fertilized with urea at 146 kg/ha. The field was irrigated prior to planting. The experiment was arranged in a randomized complete block design with six replications. Each experimental plot was 3.7m × 13.7 m. The sequence of crops following wheat included (i) oil radish-potato, (ii) rapeseed-potato, and (iii) fallow-potato. Oil radish and rapeseed were planted in mid August at 28 kg/ha and 10 kg/ha, respectively. A non-green manure treatment (fallow) was included as a control. The crops were rototilled 15 to 20 cm deep in early October. The soil was disc-harrowed, plowed 25 to 30 cm deep, and shaped into four rows per plot (0.9 m/row). The amount of oil radish and rapeseed green biomass incorporated per square meter was determined and the tonnage of biomass incorporated per hectare was calculated. In mid-April, the field was planted to certified potato seed pieces cv. Russet Burbank. Tuber pieces were mechanically planted 20 cm deep and 30 cm apart within rows. All pest management practices followed recommendations of the University of Idaho Extension Service. Soil samples for nematode assay were obtained by collecting 12 soil cores, 2.5-cm–diam. × 30 cm deep, from the two center rows of each plot before green manure crops were planted, before green manure crop incorporation, before potato planting, and at potato harvest. Plant-parasitic nematodes were extracted, identified and counted from 500 cm^3 soil as described for the greenhouse experiments. In mid-September, the middle two rows of each plot were harvested, and the tuber yield was calculated. Tubers per plot were counted, weighed, hand peeled, and examined for *M. chitwoodi* infection sites. A tuber with at least one infection site was considered cull (non-marketable). Total yield of tubers was separated into three grades: 1 (>228 g), 2 (113 to 228 g), and cull (<113 g or with at least one infection site). Marketable tubers were those in grades 1 and 2. All data were subjected to analysis of variance followed by mean separation ($P < 0.05$) with LSD. Nematode count data were transformed to $\log_{10}$ (x + 1) values before analysis, although non-transformed arithmetic means are presented in the tables. Single degree of freedom contrasts were used to test for significant changes in nematode populations among sampling dates for each treatment.

RESULTS

Greenhouse evaluation of host status: In the first experiment, crop species and cultivars differed in host status to *M. chitwoodi* race 2 (Table 1). *Meloidogyne chitwoodi* race 2 reproduced on tomato cv. Payette, barley cv. Steptoe, and mustard cv. Martigena, which were good hosts with heavy galling and Rf values >3. The three oil radish cultivars were maintenance hosts with Rf values <3 and low levels of galling. Rapeseed cv. Humus and corn hybrid Ap622 were poor hosts with Rf values of 0.2 and 0.6, respectively. The four buckwheat cultivars were poor to nonhosts with gall rating less than 2. No galls were detected on sudangrass hybrids. However, cv. Sordan 7 and Trudan 8 were poor hosts while cv. Hidan 36 was a maintenance host (Rf = 1.7). Castor, horsebean, and velvetbean were nonhosts (Rf = 0.01) with no root galls. Root galling and nematode reproduction were not highly correlated ($r = 0.62$), therefore, root galling was not rated in the microplot study.

All cultivars were either good or maintenance hosts of *P. neglectus*, except buckwheat cv. Tardo, castor, horsebean, and velvetbean, which were poor hosts (Table 2). The highest ($P \leq 0.05$) Pf per pot for *P. neglectus* were on rapeseed cv. Humus and mustard cv. Martigena, and the lowest Pf per pot were on horsebean and velvetbean.

Field microplot evaluation of host status: The rate of reproduction by *Meloidogyne chitwoodi* race 2 on tomato and barley was lower in microplots (Rf < 5) than in greenhouse pots (Rf > 5) (Table 3). However, with the exception of oil radish cultivars, the host status rating of most crop species and cultivars to *M. chitwoodi* race 2, were in complete agreement with the ratings from greenhouse evaluations. Oil radish cvs. Melodie and Trez were nonhosts with low Rf values (0.1).

Greenhouse evaluation of green manure effects: All green manure treatments reduced the final population densities of *M. chitwoodi* race 2 ($P \leq 0.05$) compared to no green manure (Table 4). Tomato plants growing in soil amended with green manure had less galling than control plants ($P \leq 0.05$). Horsebean, velvetbean, castor, oil radish cv. Trez, sudangrass hybrids cv. Hidan 36, rapeseed cv. Humus, and corn as green manure crops were effective in reducing nematode population densities (79 to 94%) compared to barley (77%) or tomato (68%). Buckwheat was the least effective in reducing *M. chitwoodi* population densities (<65%).

Field evaluation of green manure effects: Meloidogyne chitwoodi and *P. neglectus* population densities prior to green manure planting (August 1996) did not differ ($P \leq 0.05$) among plots (Fig. 1 A, B). Soil populations of both nematode species declined significantly between planting in August 1996 and incorporation of green manure crops in October 1996 (Tables 5 and 6).

Table 1. Host status of selected crops and cultivars to *Meloidogyne chitwoodi* race 2 in greenhouse evaluations 8 weeks after inoculation with 15 000 second-stage juveniles (J2) per pot.[w]

Genus species	Cultivar	J2/g root	Gall rating[x]	J2 + eggs/pot Pf	Reproductive factor, Rf[y]	Host status[z]
Raphanus sativus						
Radish	Melodie	3 667 b	2.8 b	43 900 c	2.90 c	MH
	Trez	2 327 bcd	2.8 b	20 820 cd	1.40 de	MH
	Adagio 5a-3	2 620 bcd	2.0 b	24 785 cd	1.70 d	MH
Fagopyrum esculentum						
Buckwheat	Rondo	262 ef	1.5 cd	2 017 efg	0.10 gh	NH
	Tardo	338 cdf	1.5 cd	967 g	0.10 gh	NH
	Prego	1 187 cde	1.8 c	9 185 de	0.60 defg	PH
	Kendo	373 ef	1.8 c	5 933 def	0.40 efgh	PH
Brassica napus						
Rapeseed	Humus	501 ef	2.5 b	5 068 def	0.30 fgh	PH
Sinapis alba						
Mustard	Martigena	17 351 a	4.0 a	115 460 ab	7.70 b	GH
Sorghum vulgare						
Sudangrass	Trudan 8	244 f	1.0 e	3 055 fg	0.20 fgh	PH
Sorghum bicolor × *S. vulgare*						
Sorghum-Sudangrass	Hidan 36	1 588 cde	2.3 de	32 765 cd	2.20 d	MH
	Sordan 79	453 ef	1.0 e	9 920 def	0.70 defg	PH
Canavalia ensiformis						
Horsebean		8 g	1.0 e	198 h	0.01 h	NH

Table 1. (Continued) Host status of selected crops and cultivars to *Meloidogyne chitwoodi* race 2 in greenhouse evaluations 8 weeks after inoculation with 15 000 second-stage juveniles (J2) per pot.[w]

Genus species	Cultivar	J2/g root	Gall rating[x]	J2 + eggs/pot Pf	Reproductive factor, Rf[y]	Host status[z]
Mucuna deeringiana						
Velvetbean		1 g	1.0 e	88 i	0.01 h	NH
Ricinus communis						
Castor		1 g	2.0 e	80 i	0.01 h	NH
Zea mays						
Corn	Hybrid AP622	378 ef	1.5 cd	13 970 cd	0.90 def	PH
Hordeum vulgare						
Barley	Steptoe	13 025 a	4.0 a	138 617 ab	9.20 b	GH
Lycopersicon esculentum						
Tomato	Payette	24 823 a	4.2 a	348 802 a	23.30 a	GH

[w]Values are means of 10 replicates. Values for each replicate were log transformed before subjecting data to analysis of variance and mean separation. Means in each column followed by the same letter(s) are not significantly different (LSD, $P = 0.05$).
[x]Galls rated on a 1 to 5 scale: 1 = 0%, 2 = 1-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-100% of roots galled.
[y]Rf = (Pf/15 000).
[z]GH = good host (Rf > 3); MH = maintenance host (1 < Rf < 3); PH = poor host (0.1 < Rf < 1); NH = nonhost (Rf < 0.1).

Table 2. Host status of selected crops and cultivars to *Pratylenchus neglectus* in a greenhouse test 10 weeks after inoculation with 15 00 nematodes per pot.[x]

Genus species	Cultivar	Number of nematodes/g dry root	Pf per pot	Reproductive factor, Rf[y]	Host status
Raphanus sativus					
Radish	Melodie	466 bcd	2 704 bcd	1.8 bcd	MH[z]
	Trez	401 bcd	2 666 bcde	1.7 bcde	MH
Fagopyrum esculentum					
Buckwheat	Rondo	121 cd	2 390 cdef	1.6 cdef	MH
	Tardo	776 b	1 198 ghi	0.8 h	PH
	Prego	113 d	3 348	2.1 bc	MH
	Kendo	90 d	3 621 b	2.3 b	MH
Brassica napus					
Rapeseed	Humus	462 bcd	5 958 a	4.0 a	GH
Sinapis alba					
Mustard	Martigena	1 475 a	6 209 a	4.1 a	GH
Sorghum vulgare					
Sudangrass	Trudan 8	66 d	1 880 defg	1.3 efgh	MH
Sorghum vulgare × S. bicolor					
Sorghum-Sudangrass	Hidan 36	155 cd	2 123 defg	1.4 cdef	MH
	Sordan 7	59 d	1 498 fgh	1.0 gh	MH
Canavalia ensiformis					
Horsebean		305 bcd	568 hi	0.4 i	PH
Mucuna deeringiana					
Velvetbean		135 cd	355 i	0.2 i	PH
Ricinus communis					
Castor		637 bc	1 450 fghi	1.0 gh	MH
Zea mays					
Corn	Hybrid AP622	79 d	1 563 efgh	1.1 fgh	MH

[x]Values are means of eight replicates. Nematode number for each replicate was log transformed before subjecting data to analysis of variance and mean separation. Means within columns followed by the same letter(s) are not significantly different according to LSD ($P = 0.05$).
[y]Rf = (Pf/1 500).
[z]GH = good host (Rf > 3); MH = maintenance host (1 < Rf < 3); PH = poor host (0.1 < Rf < 1); NH = nonhost (Rf < 0.1).

Table 3. Host status of selected crops and cultivars to *Meloidogyne chitwoodi* race 2 in a field microplot evaluation 8 weeks after inoculation with 50 000 second-stage juveniles (J2) per microplot.[x]

Genus species	Cultivar	J2/g dry root	J2 and eggs/ microplot, Pf	Reproductive factor, Rf[y]	Host status
Raphanus sativus					
Radish	Melodie	839 c	5 160 cd	0.10 c	NH[z]
	Trez	333 b	6 300 cd	0.10 c	NH
Fagopyrum esculentum					
Buckwheat	Rondo	11 c	480 f	0.01 c	NH
	Tardo	16 c	780 f	0.02 c	PH
	Prego	41 c	12 672 c	0.30 c	PH
Brassica napus					
Rapeseed	Humus	733 b	7 620 c	0.20 c	PH
Sorghum vulgare					
Sudangrass	Trudan 8	12 c	1 740 ef	0.03 c	NH
Canavalia ensiformis					
Horsebean		11 c	960 f	0.02 c	NH
Zea mays					
Corn Hybrid	AP622	17 c		0.20 c	PH
Hordeum vulgare					
Barley	Steptoe	4 780 a	85 200 b	1.70 b	MH
Lycopersicon esculentum					
Tomato	Payette	2 579 a	234 360 a	4.70 a	GH

[x]Values are means of five replicates. Nematode number for each replicate was log transformed before subjecting data to analysis of variance and mean separation. The means in each column followed by the same letter(s) do not differ according to LSD ($P = 0.05$).
[y]Rf = (Pf/50 000).
[z]GH = good host (Rf > 3); MH = maintenance host (1 < Rf < 3); PH = poor host (0.1 < Rf < 1); NH = nonhost (Rf < 0.1).

The population densities in all but the rapeseed green manure treatments were even lower when soil samples were taken before potato planting in April 1997. After green manure incorporation in October 1996 and before planting potato in April 1997, *M. chitwoodi* soil population densities were reduced ($P \leq 0.05$) in oil radish green manure plots while population densities remained unchanged in rapeseed green manure and fallow plots (Table 5). Soil population densities of *P. neglectus* remained unchanged after green manure incorporation and before planting potato in all plots (Table 6).

Meloidogyne chitwoodi increased on potato in all plots, but population densities in plots following green manure incorporation were lower ($P \leq 0.05$) than those following fallow (Fig. 1A). Soil population

Table 4. Number of *Meloidogyne chitwoodi* race 2 second-stage juveniles (J2) in pots 7 weeks after planting tomato in soil amended with leaves of different crops, or unamended.[y]

Amendment		J2/g root	Gall rating[z]	J2 + eggs per pot	% Reduction
None		97 825 a	5.00 a	45 333 a	—
Raphanus sativus					
Radish	Melodie	24 527 cde	2.50 bc	15 798 b	65.2 cd
	Trez	17 846 cde	2.50 bc	9 550 b	79.0 abcd
	Adagio 5a-3	14 515 dc	2.50 bc	10 815 b	76.1 abcd
Fagopyrum esculentum					
Buckwheat	Rondo	46 606 bc	3.50 b	18 153 b	59.9 d
	Tardo	31 280 bcde	2.50 bc	12 315 b	72.8 bcd
	Prego	33 554 bcde	2.75 bc	14 515 b	68.0 cd
	Kendo	62 113 b	3.00 bc	16 210 b	64.2 cd
Brassica napus					
Rapeseed	Humus	16 992 cde	2.50 bc	7 253 b	84.0 abc
Sorghum vulgare					
Sudangrass	Trudan 8	44 213 bcd	2.75 bc	10 935 b	75.9 a
Sorghum bicolor × *S. vulgare*					
Sorghum & Sudangrass	Hidan 36	26 350 cde	2.25 bc	4 460 b	90.2 ab
	Sordan 7	30 046 cde	2.50 bc	10 095 b	77.7 abcd
Canavalia ensiformis					
Horsebean		9 950 e	1.75 c	2 550 b	94.4 a
Mucuna deeringiana					
Velvetbean		16 394 cde	1.75 c	2 550 b	94.4 a
Ricinus communis					
Castor		18 983 cde	2.25 bc	8 300 b	81.7 abc
Zea mays					
Corn	Hybrid AP622	25 821 cde	2.50 bc	9 203 b	79.7 abcd
Hordeum vulgare					
Barley	Steptoe	23 821 cde	2.75 bc	10 495 b	76.8 abcd
Lycopersicon esculentum					
Tomato	Payette	41 218 bcde	3.50 b	14 137 b	68.8 cd

[y]Values are means of five replicates. The means of each column followed by the same letter(s) do not differ (P = 0.05) according to LSD.
[z]Galls rated on a 1 to 5 scale: 1 = 0%, 2 = 1-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-100% of roots galled.

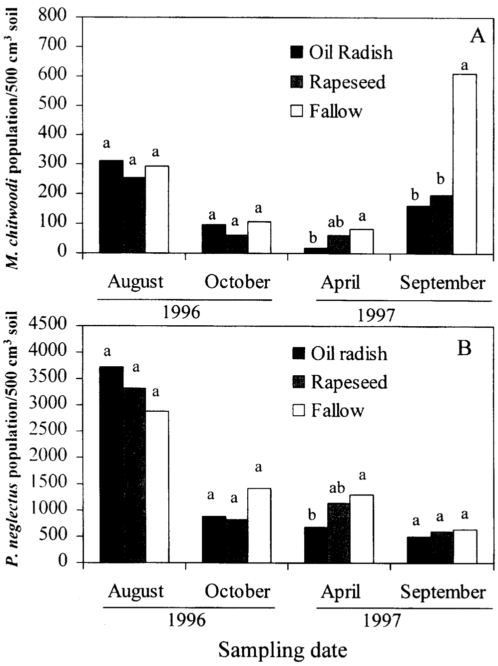

Fig. 1. Effects of oil radish green manure, rapeseed green manure, or fall fallow on (A) *Meloidogyne chitwoodi* race 2 and (B) *Pratylenchus neglectus* in soil at different sampling dates. Samples in August and October 1996 were taken prior to planting and incorporating green manures, respectively. Samples in April and September 1997 were taken prior to planting potato and at potato harvest, respectively.

densities of *P. neglectus* remained unchanged on potato (Fig. 1B, Table 6). *Meloidogyne chitwoodi* population densities increased ($P \leq 0.05$) on potato in oil radish amended and fallow plots but not in rapeseed amended plots (Table 5). Soil population densities of *P. neglectus* declined ($P \leq 0.05$) following potato in oil radish and fallow plots and remained unchanged in rapeseed green manure plots (Table 6).

Oil radish green manure treatments increased total potato yield, and total grade 1 and 2 tubers, while reducing *M. chitwoodi* tuber infection compared to fallow (Table 7). A similar trend was noted for the rapeseed green manure treatment. The total yield of marketable tubers was increased 185% and 106% in oil radish and rapeseed green manures plots, respectively, when compared to fallow plots.

DISCUSSION

Because of the potential for economic damage, an effective green manure crop for potato cropping systems must be a nonhost or a poor host of *M. chitwoodi.* Poor to nonhosts that substantially decreased or eliminated *M. chitwoodi* population densities included buckwheat cvs. Rondo, Tardo, Prego and Kendo; oil radish cv. Trez; rapeseed cv. Humus; sudangrass cvs. Trudan 8 and cv. Sordan 79; corn hybrid AP622; castorbean; horsebean; and velvetbean. Buckwheat cv. Tardo, horsebean, and velvetbean were also poor hosts for *P. neglectus.* This is the first report of these crops being poor hosts for *P. neglectus.* Sudangrass cultivars were maintenance hosts (Rf value 1 or near 1) for *P. neglectus,* which was unexpected because several sudangrass cultivars were previously reported to be poor hosts for *Pratylenchus* spp. (Dunn and Mai, 1973; MacDonald and Mai, 1963; Thies *et al.*, 1995). However, the nematode population densities in those studies were based on the root unit only, and soil population densities were not reported.

The Rf values for *M. chitwoodi* on oil radish cultivars from greenhouse trials were different from those from microplot trial. All oil radish cultivars were maintenance host for *M. chitwoodi* in the greenhouse evaluations but were nonhosts in microplots. In general, the Rf values of all cultivars were lower in microplot than greenhouse trials and could be due to the different soil types, temperature, and initial nematode populations. In the field, oil radish cv. Trez did not increase the population densities of *M. chitwoodi* race 2 and *P. neglectus* 2 months after planting, but the plants

Table 5. Single degree of freedom contrast for *Meloidogyne chitwoodi* race 2 population densities in 500-cm^3 soil from plots of oil radish and rapeseed green manures or from plots of fallow at different sampling dates.[z]

Date of sampling	Degrees of freedom	F-value	Pr > F
	Trez oil radish green manure – Potato		
August 1996 vs. October 1996	1	5.16	0.0382
August 1996 vs. April 1997	1	37.31	0.0001
October 1996 vs. April 1997	1	14.71	0.0016
April 1997 vs. September 1997	1	27.36	0.0001
	Humus rapeseed green manure – Potato		
August 1996 vs. October 1996	1	4.38	0.0537
August 1996 vs. April 1997	1	3.22	0.0931
October 1996 vs. April 1997	1	0.09	0.7680
April 1997 vs. September 1997	1	3.97	0.0647
	Fallow – Potato		
August 1996 vs. October 1996	1	4.75	0.0456
August 1996 vs. April 1997	1	9.82	0.0068
October 1996 vs. April 1997	1	0.91	0.3550
April 1997 vs. September 1997	1	25.99	0.0001

[z]Sampling dates correspond to before planting green manure crops (August), before green manure incorporation (October), after green manure incorporation and before potato planting (April), and at potato harvest (September). Overall F-tests for the analysis of variance were significant at $P < 0.05$.

were grown during fall months when low temperature may have reduced nematode activity. These results for oil radish cv. Trez agree with other reports on oil radish cultivars (Nemex, Siletta, Nova, Siletena, and Pegletta) for California populations of *M. chitwoodi* race 1 (Ferris et al, 1993). Other studies reported susceptibility of some oil radish cultivars to *Meloidogyne* spp. (Gardner and Caswell-Chen, 1994).

Rapeseed cv. Humus was a poor host to *M. chitwoodi* race 2 and did not increase population densities in the field 2 months after planting. Other studies have also reported a reduction in numbers of other *Meloidogyne* spp. in the field following rapeseed (Johnson *et al.*, 1992). The results in our study contradict those of Mojtahedi *et al.* (1991) for *M. chitwoodi* races 1 and 2 on several cultivars of rapeseed. *Meloidogyne* species may respond differently to rapeseed cultivars grown under different environmental conditions (Bernard and Montgomery, 1993).

Buckwheat cultivars were poor or nonhosts for *M. chitwoodi* race 2, as found in previous experiments for *M. chitwoodi* and *M. fallax* (Brinkman *et al.*, 1996). However, buckwheat is susceptible to a California population of *M. incognita* race 3 and *M. javanica* (Gardner and Caswell-Chen, 1994). Sudangrass cvs. Trudan 8 and Sordan 79 were poor hosts of *M. chitwoodi* and the Rf values were in agreement with those reported for Washington populations of *M. chitwoodi* race 2 (Mojtahedi *et al.* 1993a).

Table 6. Single degree of freedom contrast for *Pratylenchus neglectus* population densities in 500-cm^3 soil from plots of oil radish and rapeseed green manures or from plots of fallow at different sampling dates.[z]

Date of sampling	Degrees of freedom	F-value	Pr > F
	Trez oil radish green manure – Potato		
August 1996 vs. October 1996	1	31.71	0.0001
August 1996 vs. April 1997	1	39.06	0.0001
October 1996 vs. April 1997	1	0.38	0.5459
April 1997 vs. September 1997	1	1.64	0.2193
	Humus rapeseed green manure – Potato		
August 1996 vs. October 1996	1	34.62	0.0001
August 1996 vs. April 1997	1	21.56	0.0003
October 1996 vs. April 1997	1	1.54	0.2339
April 1997 vs. September 1997	1	4.91	0.0427
	Fallow – Potato		
August 1996 vs. October 1996	1	8.02	0.0126
August 1996 vs. April 1997	1	6.92	0.0289
October 1996 vs. April 1997	1	0.04	0.8443
April 1997 vs. September 1997	1	6.39	0.0232

[z]Sampling dates correspond to before planting green manure crops (August), before green manure incorporation (October), after green manure incorporation and before potato planting (April), and at potato harvest (September). Overall F-tests for the analysis of variance were significant at $P < 0.05$.

Horsebean, castor, and velvetbean were nonhosts for *M. chitwoodi.* There is evidence that root exudates from these plants may exert a suppressive effect on root-knot nematodes (Vicente *et al.*, 1987). Velvetbean has rhizosphere bacteria that have suppressive effects on nematodes (Kloepper *et al.*, 1991). Castor contains ricin, a toxic compound, that inhibits motility of *M. incognita* (Rich *et al.*, 1989). However, our results showed that castor was a maintenance host for *P. neglectus.* Ricin may have a smaller effect on lesion than on root-knot nematodes. Velvetbean and horsebean were poor hosts to *M. chitwoodi* and *P. neglectus* in our study and in studies involving other nematode species (McSorley *et al.*, 1994; Rodríguez-Kábana *et al.*, 1992).

Green manures of all crops tested reduced the population densities of *M. chitwoodi* in pots, but the magnitude of reduction was cultivar dependent. Green manure was more effective from cruciferous plants than from barley or tomato. All oil radish cultivars reduced the number of *M. chitwoodi,* and cv. Trez was the most effective. Cruciferous stems, leaves, and roots contain glucosinolates that break down into isothiocyanates (Sang *et al.*, 1984), which are nematicidal in solution under laboratory conditions (Lazzeri *et al.*, 1993). Presence of such compounds at different levels in stems and leaves of oil radish and rapeseed cultivars may be responsible for the effectiveness as green manures. Sudangrass cultivars were also

Table 7. Effect of green manure and fall fallow on potato yield and tuber infection with *Meloidogyne chitwoodi*.[x]

Treatment	Total yield (T/ha)	Percent of total yield				
		Grade 1[y]	Grade 2[y]	Infected[z]	Cull[y]	Marketable[y]
Oil radish	44.0 a	45.9 a	23.6 a	26.2 b	37.9 b	62.1 a
Rapeseed	42.7 ab	30.6 ab	19.9 ab	44.9 ab	53.8 ab	46.2 ab
Fallow	37.8 b	13.2 b	11.1 b	62.0 a	74.7 a	25.3 b

[x]Values are means of six replications. Means within columns followed by the same letter are not significantly different according to LSD ($P = 0.05$).
[y]Grade 1 = tubers greater than 228 g; Grade 2 = tubers greater than 113 g but less than 228 g; Cull = tubers less than 113 g or infected with nematode; Marketable tubers = Grade 1 + Grade 2.
[z]Tubers with one or more nematode infection sites.

effective as green manure in reducing *M. chitwoodi* numbers, and cv. Hidan 36 was especially effective. Our results are in agreement with previous work by Mojtahedi *et al.* (1993a). The chemical responsible for the nematicidal activity of sudangrass was reported to be hydrogen cyanide, which is produced when dhurrin, the chemical constituent of leaves, is hydrolyzed by glucosidase upon leaf tissue decomposition (MacGuidwin and Layne, 1995). Green manure from castor, horsebean, and velvetbean were most effective in reducing *M. chitwoodi* populations. Velvetbean green manure was also effective in reducing other *Meloidogyne* spp. (Crow *et al.*, 1996).

This study identified several potential green manure crops for the management of *M. chitwoodi* race 2. Sudangrass, corn, buckwheat, castor, horsebean, and velvetbean were poor to nonhosts and were effective green manures in greenhouse and microplots trials, but these crops are highly sensitive to frost damage. Horsebean and velvetbean are tropical crops that require high temperature and humidity for growth (Vicente and Acosta, 1987); therefore, these crops and cultivars were not included in our field trials.

Under field conditions, Trez oil radish and Humus rapeseed grew fast and produced a large biomass between planting in August and incorporation in mid October. They were not affected by frost in late September and a large amount (>4.9t/ha dry wt.) of stems and leaves from both crops were incorporated as green manure. Oil radish and rapeseed green manure improved yield and quality of the following potato crop. This study confirms previous reports that green manure from rapeseed plants reduces *Meloidogyne* spp. damage and increases yield of potato (Johnson *et al.*, 1992; Mojtahedi *et al.*, 1993b). However, green manure treatments had minimum effect on *P. neglectus* populations as reported by Davis *et al.* (1989). The ineffectiveness of green manure on *P. neglectus* in this study may be due to the ability of this nematode to tolerate certain chemical breakdown products from plant tissues, as indicated by Mojtahedi *et al.* (1991).

Our data showed that oil radish green manure is superior to rapeseed or fall fallow for nematode control and improvement of potato yield. Oil radish may have been more effective due to production of a larger amount of biomass than rapeseed (6.27 vs. 4.71 t/hectare dry wt), or production of a higher concentration of nematicidal compounds, such as breakdown products of glucosinolates. Oil radish planted as a second crop in early fall has many advantages over fall fallow. It reduces *M. chitwoodi* population densities more rapidly than fallow, enhances soil fertility, and may provide a niche for nematode-antagonistic organisms. Based on our results, oil radish cv. Trez, and in some instances rapeseed cv. Humus, would be effective green manure crops in cropping systems designed to reduce *M. chitwoodi* race 2 population densities and increase potato yield.

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