EFFECTS OF *MELOIDOGYNE JAVANICA* AND ORGANIC AMENDMENTS, INORGANIC FERTILISERS AND NEMATICIDES ON CARROT GROWTH AND NEMATODE ABUNDANCE

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Summary. Nematode pathogenicity and control methods were evaluated in pot experiments. Six USDA selections (crosses of Brasilia and Nantes inbred) of carrots suppressed multiplication of *Meloidogyne javanica* and were less galled than a susceptible cultivar. Lower population densities of *M. javanica* were observed in soil used to grow rapeseed cv Dwarf Essex and sorghum/sudangrass cv Jumbo as green manure crops compared with sorghum cv Pacific Supergraze, and carrot growth was inhibited in soil used to grow the latter. Although *M. javanica* egg masses were observed on Dwarf Essex roots, and juveniles were detected in roots of both Dwarf Essex and Jumbo, growth of the subsequent carrot crop was not inhibited compared to carrots grown in fallowed soil. Lucerne pellets at high rates alone or combined with urea, poultry manure or gypsum were shown consistently to stimulate carrot growth without increasing forking and to reduce both carrot galling and *M. javanica* population density. Poultry manure also reduced galling and population density of *M. javanica* in soil but not in roots. Fenamiphos effectively controlled *M. javanica* at an initial population density of 108 J2/175 cm^3 of soil but not at 717 J2/175 cm^3. Cadusafos was highly effective in controlling *M. javanica* but it suppressed carrot emergence. Resistant carrot selections and soil amendments have potential value for the control of *M. javanica* in carrot production.

The main nematode pests of carrots (*Daucus carota* L.) in Australia are root-knot nematodes (*Meloidogyne* spp.) and, in a recent survey of South Australian carrot crops, *M. javanica* (Treub) Chitw. was the main species found. This nematode causes root galling and increases incidence of forked and defective carrots, reducing grower returns. Chemicals, mainly fenamiphos or metham sodium, are commonly used as a preventative measure against these nematodes, but enhanced biodegradation has been found after repeated use of either of these chemicals (Stirling *et al.*, 1992; Warton *et al.*, 2001). Alternative methods of control are therefore needed.

The addition of organic amendments that stimulate growth of antagonistic micro-organisms, or release toxins during decomposition (Badra *et al.*, 1979; Bradow, 1991) has been advocated as an alternative method of nematode control. Hydrogen sulphide released during decomposition of amendments is toxic to nematodes (Fortuner and Jacq, 1976) and calcium sulphate has been used to stimulate production of this compound (Spaull *et al.*, 1992). The nematode suppression following soil incorporation of cyanogenic sudangrass hybrids into soil (Widmer and Abawi, 1998) has been shown to be correlated with the amount of free cyanide released into soil (Widmer and Abawi, 2002). Brassica green manure crops have also been shown to be nematicidal (Walker, 1997) and to produce toxic isothiocyanates during decomposition (Kirkegaard *et al.*, 2000). Poultry manures also have potential to suppress nematodes whether through stimulation of antagonistic microbes (Kaplan *et al.*, 1992) or production of ammonia (Rodriguez-Kabana, 1986). Lucerne soil amendments were also reported to suppress nematodes (Mankau, 1968; Mankau and Minteer, 1962; Johnson *et al.*, 1967). Amendments with high N contents are generally recognised as being more effective against nematodes than those with lower N contents (Mian and Rodriguez-Kabana, 1982).

Recently, carrot breeders have produced lines with simply inherited dominant resistance to *M. javanica* (Simon *et al.*, 2000), opening up the possibility of using resistant cultivars to restrict nematode multiplication. These selections are derived from crosses between Brasilia and a Nantes inbred obtained from P. Simon, USDA Vegetable Crops Research Unit, Madison, Wisconsin.

This paper reports results of pot experiments using carrot field soil, naturally-infested with *M. javanica*, to evaluate alternative, non-chemical control strategies. Lucerne pellets, poultry manure and gypsum were used as soil amendments, and were compared with a locally registered nematicide, fenamiphos, and an unregistered one, cadusafos. U.S. Department of Agriculture-developed carrot selections with resistance against *M. javanica* and *M. incognita* (Kofoid *et* White) Chitw. were compared with a susceptible cultivar to determine their potential for use in soils infested with local populations of *M. javanica*.

MATERIALS AND METHODS

Soils and greenhouse conditions. Soils for greenhouse

experiments were collected from an organic farm (agrochemicals not used for thirteen years) and a 'conventionally-managed' carrot farm (agrochemicals used, including soil fumigation with metham sodium before planting carrots) after harvest of carrots. Soil was thoroughly mixed and stored in sealed containers at 10 °C until use. Both soil types were sandy loams with similar characteristics (Table I). To establish initial population densities of nematodes, five replicate 175 cm^3 sub-samples were extracted for five days on trays (Whitehead and Hemming, 1965) just before starting the experiments. The organic farm soil contained 108.2±15.2 (standard error of mean, SE) second-stage juveniles (J2) of *M. javanica*/175 cm^3 of soil, and 7.5±3.5 and 4.6±0.8 of *Hemicycliophora saueri* Brzeski and *Scutellonema brachyurum* (Steiner) Andrassy respectively. The conventionally-managed farm soil used in experiments 4 and 5 respectively contained 184.5±20.3 (SE) and 716.8±35.1 *M. javanica*/175 cm^3 of soil, and 76.6±15.4 (SE) and 14.3±2.6 of *H. saueri*/175 cm^3 of soil. Soil was dispensed into 175-mm-diameter pots (2.5 dm^3 soil/pot), and five replicate pots per treatment in each experiment were arranged in a randomised block design on a plastic-house bench. Plastic-house temperature was maintained at 22±8 °C, and pots were fertilised every three weeks with an aqueous solution of complete fertiliser (NPK, 27:5.5:9%) unless otherwise indicated, and watered as required. Before planting, carrot seed was coated (2 ml/g seed) with Apron XL350ES (Syngenta; 350 g/l metalaxyl-M) fungicide to control damping-off caused by pythiaceous fungi. Carrot seed (20/pot) cv. Baby, unless otherwise indicated, was planted at a depth of 6 mm. After three weeks, per cent emergence was recorded and seedlings thinned to five/pot. Carrots were grown for 21 weeks after seeding before harvesting (except for experiment 4 with a fifteen-week growing period); fresh and dry (three days at 70 °C) root and shoot weights were determined. Root galling was assessed by counting the number of galls on secondary roots or by using a 0-5 root gall index for either secondary roots (Sasser *et al.*, 1984) or primary and secondary roots (Huang and Charchar, 1982). Nematodes were extracted from a 175 cm^3-subsample of soil/pot on trays as described above, and from carrot secondary roots from each pot in a mist chamber as described above.

Pot experiments using organic farm soil

Experiment 1. Six selections (636-7, -8 and -13; 637-5, -14 and -15) and a susceptible cv, Baby, were planted in the organic farm soil.

Experiment 2. Three green manure crops, two sorghum (*Sorghum bicolor* L. *et* Moench) types and one rapeseed, were grown in the organic farm soil: a) cv Jumbo (sorghum × sudangrass hybrid), b) cv Pacific Supergraze (sweet sorghum × sweet sorghum hybrid), and c) rapeseed (*Brassica napus* L.) cv Dwarf Essex. Six seeds/pot were planted, and the stand was thinned to three plants/pot (or 125 plants/m^2) after fourteen days. After weighing shoots, whole plants were coarsely chopped into pieces (25 mm-length) 58 days after seeding and mixed along with roots into the potting soil. A 1-g subsample of roots/pot was retained, examined under a dissecting microscope for presence of galls and *M. javanica* egg masses, and placed in a mist chamber for extraction of nematodes. Six weeks after incorporation of green manures, two soil cores (each containing 26 cm^3 of soil) were taken from each pot just before planting carrot seed to assess nematode densities. A fallow soil (not planted to green manure crops) was also included in this experiment as a control, and was kept moist throughout the growing period of the manure crops.

Experiment 3. Soil amendments as follows were mixed with organic farm soil 14 days before carrot seeds were planted: a) lucerne (*Medicago sativa* L.) hay

Table I. Nutrient content (NPK) of organic amendments, and organically and conventionally-managed farm soils used in pot experiments, and soil pH.

Experiment/soil	Nitrogen (mg/kg)		Total N (%)	P (mg/kg)	K (mg/kg)	pH*
	NO_3	NH_4				
Experiments 1-3						
Lucerne pellets	181	54	2.7	774	20,194	-
Poultry manure	115	6,358	4.0	4,976	16,645	-
Experiments 4-5						
Lucerne pellets	nt[1]	nt	2.6	258	26,060	-
Poultry manure	nt	nt	2.4	1,572	19,680	-
Organic farm soil	8	1	0.1	54	260	7.9
Conventional farm soil						
Experiment 4	19	1	0.1	64	193	7.8
Experiment 5	17	1	0.1	74	180	7.8

* 1 : 5 soil : 0.01 mol $CaCl_2$/L (w/v)
[1] nt = not tested

pellets, 4 mm-diameter (Johnson's Pure Lucerne Fertiliser, Kapunda) at 48 g/pot, b) poultry manure (Attunga Garden Products, Dandenong) at 48 g/pot, and c) lucerne and poultry manure applied together at 24 g/pot each. These treatments were compared with granular nematicides, either fenamiphos at 0.023 g/pot (Yates Nemacur Granular Nematicide, 50 g ai/kg, Yates) or cadusafos at 0.072 g/pot (Rugby 100G, 100 g ai/kg, Crop Care), applied to the soil surface, lightly incorporated and irrigated in, 14 days before planting seed of carrot cv. Baby. An untreated control receiving neither nematicide nor soil amendment was also included in the experiment. Soil in all pots was kept moist before planting carrot seed.

Pot experiments using conventionally-managed farm soil

Experiment 4. Soil was mixed with fertilisers/soil amendments 65 days before seeding in the following separate treatments, and no additional fertiliser was subsequently applied: a) 3 g/pot of complete (NPKS, 8:3.7:10:13.8) fertiliser; b) 24 g of lucerne pellets/pot, and 0.1 g urea (46% N); c) 24 g of lucerne pellets/pot and 6.0 g of gypsum (94% $CaSO_4 \cdot 2H_2O$) and 0.1 g urea; and d) 48 g of lucerne pellets/pot and 24.1 g of gypsum and 0.1 g urea. Potting soil was kept moist during the period before seeding.

Experiment 5. Soil was mixed with fertilisers/soil amendments four weeks before seeding to provide the following treatments, and no additional fertiliser was subsequently applied: a) 3 g/pot of complete (NPKS, 8:3.7:10:13.8) fertiliser, and treated with fenamiphos as described above seven days before planting carrot seeds; b) 24 g of lucerne pellets/pot and 12 g of chicken manure/pot; c) 14.4 g of lucerne pellets/pot and 9.6 g of chicken manure/pot; d) 24 g of lucerne pellets/pot and 6 g of chicken manure/pot; e) 36 g of lucerne pellets/pot and 6 g of chicken manure/pot; f) 24 g of lucerne pellets/pot, and 0.52 g urea (46% N)/pot; g) 36 g of lucerne pellets/pot, and 0.52 g urea/pot; h) 0.52 g urea/pot; and i) 3 g/pot of complete (NPKS, 8:3.7:10:13.8) fertiliser. The soil was kept moist during the period before seeding. Root galling was assessed using the index of Huang and Charchar (1982).

Statistical analysis. Before statistical analysis, nematode densities were transformed as ln (density + 1) if plots of residuals or tests for non-additivity and normality indicated that this was required. Randomised block designs were used and ANOVA, Fisher's protected LSD, t-tests (untreated *vs* treated) or contingency tests (P=0.05) were conducted using Statistix (Version 4.1, Analytical Software, Tallahassee, Florida).

RESULTS

Experiment 1. Neither root and shoot biomass production nor incidence of carrot forking differed significantly between resistant selections and the susceptible control cv. Baby (Table II). Secondary roots of the susceptible cultivar were more galled and had significantly higher densities of *M. javanica* J2 than all resistant selections. This nematode was not detected in roots of selections 636-8 and 636-13. *Meloidogyne javanica* densities did not increase in soil growing resistant selections but did with the susceptible cultivar. Densities of *H. saueri* and *S. brachyurum* in soil were not significantly different between resistant selections and the susceptible cultivar.

Experiment 2. Fresh shoot weight production of green manure crops was 62.2±5 (SE), 43.2±2.7 and

Table II. Densities of *Meloidogyne javanica*, carrot growth, root galling and per cent forked roots in resistant and susceptible carrots grown in an organic farm soil[1].

Carrot cv /selection	*M. javanica**		Carrot		Dry weight (g)	
	J2/g root	J2/175 cm^3 soil	Gall index**	% fork	Carrot	Shoots
Susceptible:						
cv. Baby	3,203 a	4,752 a	3.8 a	28	5.3	1.6
Resistant:						
637-5	36 b	0.4 b	0.8 b	12	4.8	1.5
637-14	72 b	0.8 b	0.6 b	8	4.7	1.3
637-15	56 b	1.1 b	0.8 b	16	5.4	1.7
636-7	15 b	1.9 b	0.2 b	16	4.7	1.4
636-8	nd	0.3 b	0.2 b	24	4.2	1.2
636-13	nd	nd	0.2 b	16	4.4	1.4

* Transformed data [ln(x + 1)] used in statistical analysis

** Gall index of secondary roots on a 0-5 scale (0 = no galling, 1 = a few small galls, 2 = <25% of roots galled, 3 = 25-50% of roots galled, 4 = 50-75% of roots galled, 5 = >75% of roots galled)

[1] Means followed by the same letter in the same column are not significantly different by Fisher's protected LSD (P = 0.05); nd = not detected; ns = not significant.

37±2 t/ha (LSD = 4.9) for cvs Dwarf Essex, Jumbo and Pacific Supergraze, respectively. Abundant, small galls with large (external) egg masses were observed on roots of cv. Pacific Supergraze, small galls with small egg masses within roots were less commonly observed on roots of cv. Dwarf Essex and galling or egg masses were not observed on a sub-sample of roots of cv Jumbo. However, *M. javanica* juveniles were detected in roots of all three green manure crops, but densities were significantly higher in cv Pacific Supergraze roots than in cv Jumbo roots (Table III). This nematode was detected in green-manured soil treatments at planting of carrots, but not in unmanured, fallow soil. Densities of *M. javanica* J2 in soil were significantly higher after incorporation of cv Pacific Supergraze residues than after the other two cultivars. No significant difference in carrot emergence rate between treatments (range 59-69%, SE = 7) was observed. Carrots grown in unmanured, fallow soil or in soil manured with cv Jumbo residues were significantly less galled and had lower densities of *M. javanica* J2 in roots compared with the other two green manure cultivars.

Experiment 3. Carrot emergence was suppressed by the organic amendments and by cadusafos (Table IV). However, carrot (taproot) dry weight in soil with organic amendments (mean of all organic amendment treatments, 4.2±0.3 g) was significantly higher (t-test; $P<0.01$) than for carrots grown in soil without amendments (mean of untreated control and nematicide treatments combined, 3.2±0.2 g). Soil treatment with amendments did not cause significant differences in shoot biomass production or incidence of root forking (Table IV). All soil treatments reduced densities of *M. javanica* J2/175 cm^3 of soil and root gall indices; all treatments except poultry manure alone reduced densities of *M. javanica* J2/g of root (Table IV).

Table III. Effects of green manure crops on densities of *M. javanica* in both manure and subsequent carrot crops, and on carrot growth, number of root galls and per cent forked carrots in an organic farm soil[1].

Green manure crop	*M. javanica**				Carrot		Dry weight (g)	
	J2/g root		J2 in soil from carrots					
	Manure crop	Carrot	At planting (26 cm^3/pot)	At harvest (175 cm^3/pot)	Galls	% fork	Carrot	Shoots
Fallow	–	0.3 b	nd	nd	0.1 b	12	1.2 a	0.6
Dwarf Essex	1,361 ab	2,390 a	1.2 b	87	5.6 a	4	1.3 a	0.6
Jumbo	8 b	0.9 b	0.6 b	nd	0.3 b	8	1.3 a	0.7
Pacific Supergraze	30,689 a	5,556 a	44.6 a	240	6.0 a	8	0.9 b	0.6

* Transformed data [ln(x + 1)] used in statistical analysis; roots of green manure crops sampled just before incorporation into soil; soil sampled from carrots just before planting and at harvest.
[1] Means followed by the same letter in the same column are not significantly different by Fisher's protected LSD (P = 0.05); nd = not detected; ns = not significant.

Table IV. Effects of lucerne and poultry manure soil amendments, and nematicides on densities of *M. javanica*, and on carrot emergence, growth, root galling and per cent forked carrots in an organic farm soil[1].

Soil treatment	Carrots			*M. javanica**		Dry weight (g)	
	% emerged	Gall** index	% forked	J2/g root	J2/175 cm^3 soil	Carrot	Shoots
Untreated	85 a	3.4 a	nd	3,103 a	2,088 a	3.3	1.8
Lucerne	54 b	0.8 b	25	5 b	3 b	4.7	1.6
Poultry manure	44 b	1.2 b	8	5,298 a	3 b	4.2	1.1
Lucerne + manure	39 b	0.6 b	nd	nd	2 b	3.6	1.1
Cadusafos	50 b	0.2 b	16	0.9 b	nd	3.4	1.4
Fenamiphos	85 a	1.0 b	4	173 b	25 b	2.9	1.3

* Transformed data [ln(x + 1)] used in statistical analysis
** Gall index of secondary roots on a 0-5 scale (0 = no galling, 1 = a few small galls, 2 = <25% of roots galled, 3 = 25-50% of roots galled, 4 = 50-75% of roots galled, 5 = >75% of roots galled)
[1] Means followed by the same letter in the same column are not significantly different by Fisher's protected LSD (P = 0.05); nd = not detected; ns = not significant.

Experiment 4. Carrot emergence was not significantly different between soil treatments, but carrot root and shoot biomass production was stimulated by all treatments (Table V). Significantly greater shoot production was observed with the highest rate of lucerne pellets and gypsum compared with all other treatments. Root galling was suppressed by all treatments and root forking was not observed. Soil treatments did not reduce densities of *M. javanica* J2/g of root but the highest rate of lucerne pellets and gypsum reduced the density of *M. javanica* J2/175 cm^3 of soil (Table V).

Experiment 5. Inorganic fertilisers, fenamiphos and organic amendments did not reduce carrot emergence or increase incidence of carrot forking (Table VI). The organic amendments significantly reduced root galling and four of the six organic amendment-treatments suppressed densities of *M. javanica* J2/g of root compared with the two NPK-treated (untreated and fenamiphos-treated) soils. All of the organic amendment treatments except the 14.4 g lucerne pellets + 9.6 g poultry manure/pot suppressed densities of *M. javanica* J2/175 cm^3 of soil compared with fenamiphos-treated soil (Table VI). Carrot (taproot) dry weight was significantly higher ($P<0.0001$) in soils with organic amendments (0.32±0.03 SE) than in soil without organic amendments (0.07±0.01). Carrot (taproot) dry weights were significantly and consistently higher when lucerne pellets at rates of 36 g/pot but not lower were used, compared with unamended soil (Table VI). Shoot biomass production was stimulated by all organic amendment

Table V. Effects of lucerne and gypsum soil amendments, and inorganic fertilisers on densities of *M. javanica*, and on carrot emergence, growth, root galling and per cent forked carrots in a conventionally-managed farm soil[1].

Soil treatment (lucerne/gypsum, g/pot)	Carrots		*M. javanica**		Dry weight (g)	
	% emerged	Gall** index	J2/g root	J2/175 cm^3 soil	Carrot	Shoots
Untreated + NPK	72	2.3 a	47	55 a	0.12 b	0.08 c
(24/0) + N	56	1.6 b	15	42 a	0.26 a	0.25 b
(24/6) + N	62	1.7 b	18	39 a	0.29 a	0.25 b
(48/24.1) + N	67	1.6 b	30	7 b	0.34 a	0.39 a

* Transformed data [ln(x + 1)] used in statistical analysis
** Gall index on a 0-5 scale (0 = nil galls, 1 = ≤10 small galls on secondary roots, 2 = ≤10 small galls on both secondary and tap roots, 3 = >10 aggregated galls on secondary roots or ≤ 10 small galls on tap roots, 4 = >10 aggregated galls on both secondary and tap roots, 5 = >10 aggregated galls on both secondary and tap roots plus tap root deformation)
[1] Means followed by the same letter in the same column are not significantly different by Fisher's protected LSD (P = 0.05); ns = not significant.

Table VI. Effects of lucerne and poultry manure soil amendments, fenamiphos and inorganic fertilisers (NPK) on densities of *M. javanica*, and on carrot emergence and growth, root galling and per cent forked carrots in a conventionally-managed farm soil[1].

Soil treatment (lucerne/poultry manure, g/pot)	Carrots			*M. javanica**		Dry weight (g)	
	% emerged	% forked	Gall** index	J2/g root	J2/175 cm^3 soil	Carrot	Shoots
Untreated + N	82	6.6	2.8 a	17,564 ab	345 ab	0.11 d	0.24 e
Untreated + NPK	84	nd	2.9 a	39,219 a	309 abc	0.05 d	0.16 e
Fenamiphos + NPK	77	0.2	3.2 a	60,723 a	662 a	0.06 d	0.12 e
(24/12)	74	nd	0.9 b	4,052 bc	32 d	0.35 abc	0.69 abc
(14.4/9.6)	81	nd	1.7 b	4,460 bc	134 abcd	0.19 cd	0.72 ab
(24/6)	70	nd	2.0 b	3,008 c	43 d	0.21 bcd	0.57 bcd
(36/6)	81	nd	0.9 b	5,759 c	63 bcd	0.38 ab	0.86 a
(24/0) + N	82	4.0	1.2 b	4,384 c	35 d	0.31 abc	0.43 d
(36/0) + N	83	6.0	0.8 b	3,900 c	49 cd	0.47 a	0.52 cd

* Transformed data [ln(x + 1)] used in statistical analysis; back-converted means of J2/175 cm^3 of soil shown.
** Gall index on a 0-5 scale (0 = nil galls, 1 = ≤10 small galls on secondary roots, 2 = ≤10 small galls on both secondary and tap roots, 3 = >10 aggregated galls on secondary roots or ≤10 small galls on tap roots, 4 = >10 aggregated galls on both secondary and tap roots, 5 = >10 aggregated galls on both secondary and tap roots plus tap root deformation).
[1] Means followed by the same letter in the same column are not significantly different by Fisher's protected LSD (P = 0.05); nd = not detected; ns = not significant.

treatments (compared with both untreated and fenamiphos-treated soils) and carrot biomass production was stimulated by all organic amendment treatments except the 14.4 g lucerne pellets + 9.6 g poultry manure/pot, and the 24 g lucerne pellets + 6 g poultry manure/pot treatments (Table VI). Densities of *H. saueri*/175 cm^3 of soil were not significantly different between unamended soils and soils with organic amendments (19.4±7.2 and 16±5.2 SE), respectively.

DISCUSSION

The resistant carrot selections had useful levels of resistance to a local population of *M. javanica* but their marketability and consumer acceptance will need to be fully evaluated.

The green manure cultivars tested were not resistant to *M. javanica* (egg masses or galling were not observed on roots of cv Jumbo so reproduction was not proven but low densities of *M. javanica* juveniles were detected in the roots) and resulted in higher densities of *M. javanica* in soil before planting carrots compared with leaving soil fallow. Nonetheless green manuring can be expected to provide other benefits to soil such as increased levels of organic matter. The rapeseed cv Dwarf Essex, and the sorghum cv Jumbo resulted in significantly lower densities of *M. javanica* in soil than cv Pacific Supergraze. The Pacific Supergraze sorghum-sudangrass resulted in reduced carrot weight and may not be suitable as a green manure crop. Despite their incomplete resistance, the rapeseed cv Dwarf Essex and sorghum cv Jumbo did not result in reduced carrot weight, and carrots grown after the latter green manure crop were no more galled than those grown in fallowed soil. Nor did this crop result in higher densities of *M. javanica* in the succeeding carrot crop, and cv Jumbo may therefore have some potential for use as a green manure, especially if it can be grown for a reduced period not allowing significant nematode multiplication. Johnson *et al.* (1992) reported that *M. javanica* did not enter or reproduce on roots of rape, including cv Dwarf Essex, in the first two crops but that a few females with eggs were found in a third crop; however, the *M. javanica* population used in my experiment did reproduce on a single crop of this cv suggesting possible differences due to nematode population.

The organic amendments, lucerne pellets and poultry manure, suppressed carrot emergence when applied 14 days before planting but not if planting was delayed for at least four weeks. A longer period (65 days) was used after application of high rates of lucerne pellets and gypsum and carrot emergence was not suppressed. Further research is needed to determine safe waiting periods under varying environmental and edaphic conditions. Lucerne pellets alone or combined with urea, poultry manure or gypsum were shown to consistently increase carrot taproot weight without increasing incidence of carrot forking, and often reduced both carrot galling and *M. javanica* densities. Since lucerne is itself susceptible to this nematode, growing it as a green manure crop instead of using it as soil amendment could risk increasing the nematode population. Increasing costs, both economic and environmental, and reduced availability of fumigants and nematicides could, however, make use of lucerne soil amendments a practical proposition for farmers. Poultry manure alone also reduced root galling and *M. javanica* densities in soil but not in roots. These organic amendments have the potential to replace inorganic fertilisers which could partially offset their costs. Lucerne pellets at or above 15 t/ha (36 g/pot) appeared to have good potential to stimulate carrot growth and reduce damage from *M. javanica*. However, field-testing will be required to confirm the results of these pot experiments. Buried crop debris has been implicated as a contributory cause of carrot forking (Rubatzky *et al.*, 1999) but lucerne pellets, because of their small size, may be less likely to cause problems. Lucerne soil amendments have also shown potential to reduce plant disease caused by soil-borne fungi (Asirifi *et al.*, 1994; Nam *et al.*, 1988; Okumura, 2000).

In these experiments, lucerne pellets and poultry manure provided the equivalent of 260-540 and 120-800 kg N/ha respectively. Very high rates of poultry manure (66 t/ha containing 3.3 t/ha N) have been used to control potato diseases and nematodes (Conn and Lazarovits, 1999), and up to 48 t/ha containing 900 kg N/ha to control *M. incognita* in ginger (Stirling, 1989). Rates of 8 t/ha (dry weight) were found to be effective against *Meloidogyne* spp. on tomato (Chindo and Khan, 1990), and 11 t/ha was effective against *Pratylenchus penetrans* (Abawi and Widmer, 2000). Rates over 20 t/ha may run risks of polluting water by leaching or soil erosion (Sumner *et al.*, 2002), although Maynard (1993) showed that poultry manure can be applied for three successive years at rates high enough (112 t/ha) to supply the fertiliser requirement of most vegetables without excessively contaminating groundwater with nitrate.

Fenamiphos at 9.6 kg/ha effectively controlled *M. javanica* in the organic farm soil with an initial density of 108 J2/175 cm^3 but was ineffective in the conventionally-managed farm soil with a higher initial density of 717 J2/175 cm^3 of soil. Cadusafos at 30 kg/ha was highly effective in controlling this nematode but it suppressed carrot emergence, and may need extended waiting periods between application and planting if it is to be used in carrots. This nematicide has previously been found to be more effective against various nematodes compared with fenamiphos (Walker and Morey, 1999).

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