Effects of Management Practices on *Meloidogyne incognita* and Snap Bean Yield[1]

D. A. Smittle[2] and A. W. Johnson[3]

Abstract: Phenamiphos applied at 6.7 kg ai/ha through a solid set or a center pivot irrigation system with 28 mm of water effectively controlled root-knot nematodes, *Meloidogyne incognita*, and resulted in greater snap bean growth and yields irrespective of growing season, tillage method, or cover crop system. The percentage yield increases attributed to this method of *M. incognita* control over nontreated controls were 45% in the spring crop, and 90% and 409% in the fall crops following winter rye and fallow, respectively. Root galling was not affected by tillage systems or cover crop, but disk tillage resulted in over 50% reduction in bean yield compared with yields from the subsoil-bed tillage system. *Key words:* root-knot nematode, phenamiphos, tillage system, cover crop, nemagation, *Phaseolus vulgaris*.

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The southern root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, is a serious pathogen of snap bean, *Phaseolus vulgaris* L., in temperate and tropical regions (2,13). In addition to reduced plant vigor due to root-knot nematode damage (13), plants attacked by nematodes are more susceptible to root-rot fungi (1,6,10). Populations of *M. incognita* are suppressed by summer fallow (3) or by rotation with less susceptible crops (5); however, even with these measures the nematode population may still remain sufficiently high to require chemical control methods to prevent yield reduction.

Phenamiphos (ethyl 4-[methylthio]-*m*-tolyl isopropylphosphoramidate) has been effective in nematode control through inhibition of motility (7), attraction to bean roots (8) and root penetration (9). Foliar application of phenamiphos was ineffective in inhibiting nematode penetration and was phytotoxic at high concentrations (9). An efficient application method that would enhance the normal acropetal movement of a nematicide in roots while providing an inhibitor effect on root-knot nematode motility and attraction is needed.

Preliminary evaluations of phenamiphos (6.7 kg ai/ha) applied to cucumber at the blossom stage through a center pivot irrigation system with 8 mm of water was not phytotoxic. Applied this way it appeared to inhibit plant damage from root-knot nematodes, even though yields were reduced from nematode infection prior to the application (unpublished data). The objectives of this study were to determine the effects of irrigation system-applied phenamiphos and different tillage systems on varying levels of *M. incognita* and the resultant growth and yield of snap bean.

MATERIALS AND METHODS

Spring 1980: The experiments were conducted on Lakeland sand (93.5% sand, 2.9% silt, and 3.6% clay, pH 6.0–6.7) naturally infested with *Meloidogyne incognita.* The experimental design was a split plot with tillage methods as main plots 5.5 m wide and 6 m long, and nematicide treatment as sub-plots 5.5 m wide and 6 m long. Main plots and sub-plots were replicated four times. A rye winter crop was incorporated into the soil to a depth of 10–15 cm with a disk harrow before moldboard plowing or subsoiling and planting on 1 April. The moldboard plow was used at a depth of 28–30 cm for complete inversion of rye residue. The subsoil plant system consisted of introducing subsoil shanks spaced 91 cm apart to a depth of 36–38 cm. The surface of the fractured area was leveled with rolling cultivators, leaving most of the rye residue on or near the soil surface at planting. All plots received 22, 73, 173, 174, and 55 kg/ha of N, P, K, S, and Mg, respectively, after tillage. Seeds of snap bean (*Phaseolus vulgaris* cv. Eagle) were planted (175,000 seed/ha) in rows 91 cm apart on 2 April. Phenamiphos (ethyl 4-[methylthio]-*m*-tolyl

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[2]Associate Professor, Department of Horticulture, University of Georgia, Coastal Plain Station, Tifton, GA 31793-5401.

[3]Supervisory Research Nematologist, USDA SEA ARS, Coastal Plain Station, Tifton, GA 31793-5401.

isopropylphosphoramidate) was injected at 6.7 kg ai/ha into the center pivot irrigation system during the application of 28 mm of water on 3 April. Control plots were covered with plastic during nematicide application. The plastic covers were removed from the control plots and EPTC (*S*-ethyl dipropylthiocarbamate) was injected at 3.4 kg ai/ha into the irigation system during application of 5 mm of water for weed control. All plots received 123 kg N/ha as 30% nitrogen solution through the irrigation system in six applications during plant development. Nitrogen applications were based on uptake rates for snap bean (11). Scheduling of irrigation was by pan evaporation using crop factor values developed by Stansell and Smittle (12). Soil water status was monitored by tensiometers throughout plant growth.

Fall 1980: A split-split-split plot design was used with tillage as main plots, irrigation scheduling methods as sub-plots, rye winter cover crop or fallow preceding corn as sub-sub-plots, and nematicide treatments as sub-sub-sub-plots, with three replications of main plots. Each plot consisted of 10 rows 90 cm apart and 12.2 m long. The snap bean study followed a similar experiment with corn during the spring of 1980. The corn residue was cut with a flail mower, 37 kg N/ha was broadcast, and residue incorporated into the soil to a depth of 10–15 cm with a disk harrow. All plots were disk harrowed 4 days before establishment of disk and subsoil-bed tillage systems on 22 August. The disk treatment consisted of an additional disk harrowing to a depth of 10–15 cm. The subsoil-bed tillage was the same as described for the spring test. Beds were formed over the subsoiled areas with disk hillers and partially leveled before planting. All plots received 112, 73, 175, 174, and 55 kg/ha of N, P, K, S, and Mg, respectively, before seeding. Eagle snap beans were planted (178,000 seed/ha) on 25 August and chloroneb (1'4-dichloro-2,5-dimethoxybenzene) was applied as an in-furrow spray. Application methods for phenamiphos and EPTC were the same as described for the spring test. All plots were side-dressed with 45 kg N/ha 3 wk after planting. Scheduling of irrigation was by pan evaporation (12) or by tensiometers using 0.25 bar soil water tension at 15 cm depth as control level.

Soil was assayed for plant-parasitic nematodes at 4-wk intervals beginning on 17 March and 16 July for spring and fall experiments, respectively. Twenty cores of soil, 2.5 × 25 cm deep, were collected from each plot and mixed thoroughly. A 150-cm^3 sample was processed by the centrifugal-flotation method (4).

Forty plants were selected at random from each plot and indexed for galls on 14 May (spring test) and 22 September and 10 November (fall test). Galling on individual plants was rated on a scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100% of the roots galled.

Pods from a single row 3.05 m long (2.8 m^2) from the center of the plots were harvested when 15–30% attained a diameter of at least 9.5 mm (5–6 June in the spring and between 30 October and 7 November in the fall). Plants were removed from plots, counted, and weighed. Pods were removed, weighed, and a 500-g sample was graded by pod diameter (sieve size). Crop value, as reflected by pod diameter, was calculated from prevailing prices of $334/t for pods < 9.5 mm and $160/t for pods having a diameter ≥ 9.5 mm.

RESULTS AND DISCUSSION

Monitored soil water during the spring experiment showed tensions of 0.2–0.25 bar when an application of irrigation was scheduled by the pan evaporation model. During the fall, both scheduling methods required water applications the same dates. Therefore, irrigation scheduling methods did not affect snap bean response or interact with other treatment variables.

Spring 1980: Populations of *M. incognita* averaged 23 juveniles/150 cm^3 soil before treatments were applied in the spring. Nematode populations were not significantly ($P = 0.05$) affected by the previous tillage systems, although the populations in plots tilled with the moldboard plow were 39% lower than in the subsoil-plant plots. Root-gall indices, plant population, plant weight, pod yield, and crop value were not affected by tillage systems (Table 1).

Phenamiphos applied through the center

Table 1. Effect of tillage methods and a nematicide on root-gall index, stand, plant weight, pod yield, and crop value of 'Eagle' snap bean, *Phaseolus vulgaris,* (spring 1980).

Treatment	Root-gall index*	Plants/ha (× 1,000)	Plant wt. (t/ha)	Pod yield (t/ha)	Pod yield (g/plant)	Value ($/ha)
Tillage						
Moldboard plow	2.1 a†	116.2 a	23.1 a	12.8 a	110 a	1789 a
Subsoil-plant	2.0 a	134.6 a	22.3 a	13.0 a	97 a	1837 a
Nematicide						
Control	3.1 a	127.8 a	18.1 b	10.5 b	82 b	1481 b
Phenamiphos‡	1.0 b	122.9 a	27.2 a	15.2 a	124 a	2145 a

*Index on a scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled.

†Means within columns of tillage method or nematicide treatment followed by the same letter are not significantly ($P = 0.05$) different according to Duncan's multiple-range test.

‡6.7 kg a.i./ha.

pivot system controlled *M. incognita* as indicated by the root-gall indices (Table 1). Plant stand at harvest was not affected by the nematicide treatment. Plant weight and pod yield from plants in phenamiphos-treated plots were 50% and 45% greater, respectively, than those from untreated plots. The gross return from the nematicide application was $664/ha.

Root-gall indices were not correlated with plant stand at harvest (r = 0.08), but were negatively correlated with plant weight (r = –0.78), pod yield (r = –0.81), and crop value (r = –0.80). Within the range of plant populations in this experiment, plant stand at harvest was not correlated with plant weight (r = 0.13), pod yield (r = 0.27), or value (r = 0.30). There was a positive correlation between plant weight and pod yield (r = 0.97) and crop value (r = 0.94).

Fall 1980: Assays of *M. incognita* populations before establishment of tillage systems for the fall experiment showed a large residual effect from the previous experiment with corn. Numbers of *M. incognita* ranged from 234 juveniles/150 cm^3 soil in the disk tillage, rye, no nematicide plots to 31 juveniles/150 cm^3 soil in the subsoil-bed, no rye, phenamiphos plots (Table 2).

Plant stands, plant weights, pod yields, and crop values were similar for both rye cover crop and fallow systems preceding the corn planting. With the experimental design used, tillage methods did not significantly affect the number of *M. incognita* juveniles in the soil, root-gall indices, plant stand, plant weight, growth, yield, or crop value; although the disk tillage system resulted in 43% lower plant population, 53% less plant growth, 56% lower pod yield, and a $226/ha reduction in crop value (Table 3).

The application of phenamiphos through the solid-set irrigation system prior to planting the preceding crop of corn reduced numbers of *M. incognita* juveniles before establishment of tillage systems for snap beans (Table 3). In the snap bean experiment, the numbers of *M. incognita* juveniles in the phenamiphos plots were reduced to < 1 juvenile/150 cm^3 soil 4 wk after treatment and were near or below detectable levels 8 wk after planting. The nematode population in the control plots was lower 4 wk after planting snap beans than before the establishment of tillage systems. In the control plots, a fivefold increase in nematode juveniles occurred between the 4th and 8th wk after planting snap bean. Reduction in numbers of juveniles in soil following application of phenamiphos was reflected by fewer root galls at harvest and by greater plant populations, plant growth, pod yield, and crop value of snap beans (Table 3). The 66% reduction in crop value when nematodes were not controlled resulted from a combination of reduced plant stands and a 27% lower average pod production by the surviving plants.

A rye winter cover crop did not affect the *M. incognita* population before tillage

Table 2. Effect of tillage-nematicide-cover crop treatments on nematodes, root-gall index, stand, plant weight, pod yield, and value of 'Eagle' snap bean, *Phaseolus vulgaris*, (Fall, 1980).

Tillage-nematicide*		Cover crop†	Number *M. incognita* juveniles per 150 cm³ soil‡	Root-gall index 11 wk after planting§	Plants/ha (× 1,000)	Plant wt. (t/ha)	Pod pield		Value ($/ha)
							(t/ha)	(g/plant)	
Disk	P	R	83	1.5	32.8	5.1	1.9	59	251
Disk	P	F	99	1.6	77.1	8.5	3.0	39	401
Disk	C	R	234	4.5	29.3	2.8	0.9	31	113
Disk	C	F	78	4.5	12.6	0.7	0.2	16	34
Subsoil-bed	P	R	45	2.1	84.3	11.7	4.1	49	542
Subsoil-bed	P	F	31	1.6	90.9	15.5	5.2	57	679
Subsoil-bed	C	R	126	4.5	57.4	6.3	2.3	40	304
Subsoil-bed	C	F	99	4.3	34.7	3.2	1.2	35	178
F probability			.22	.51	.80	.14	.81	.16	.89

*P = phenamiphos (ethyl 4-[methylthio]-*m*-tolylisopropylphosphoramidate) injected at 6.7 kg ai/ha into a solid set irrigation system at planting; C = nontreated control.

†R = rye winter cover crop; F = fallow during winter.

‡Samples collected 16 July before incorporation of corn residue and establishment of tillage systems.

§Index on a scale of 1-5: 1 = no galls, 2 = 1-25%, 3 = 26-50%, 4 = 51-75%, and 5 = 76-100% roots galled.

Table 3. Effect of tillage methods and a nematicide on nematodes, root-gall index, stand, plant weight, pod yield, and crop value of 'Eagle' snap bean, *Phaseolus vulgaris,* (fall 1980).

Treatment	Number *M. incognita* juveniles per 150 cm³ soil*	Root-gall index 11 wk after planting†	Plants/ha (× 1,000)	Plant wt. (t/ha)	Pod yield (t/ha)	Pod yield (g/plant)	Value ($/ha)
Tillage							
Disk	124 a‡	3.0 a	37.8 a	4.3 a	1.4 a	37 a	200 a
Subsoil-bed	75 a	3.1 a	66.8 a	9.2 a	3.2 a	48 a	426 a
Nematicide							
Control	134 a	4.5 a	33.5 b	3.3 b	1.2 b	36 b	157 b
Phenamiphos	65 b	1.7 b	71.2 a	10.2 a	3.5 a	49 a	468 a

*Samples collected 16 July before incorporation of corn residue and establishment of tillage systems.
†Index on a scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled.
‡Means within columns of tillage method or nematicide treatment followed by the same letter are not significantly (P = 0.05) different according to Duncan's multiple-range test.

establishment for snap bean when phenamiphos was applied to the preceding corn crop (Table 4). However, numbers of nematode juveniles tended to be greater in plots of rye than in winter fallow plots when a nematicide was not applied. The winter cover crop systems had no effect on galling in the presence or absence of phenamiphos. Severe galling of snap bean roots resulted in both winter cover crop systems when a nematicide was not applied.

Plant stand response to nematicide treatment was affected by the winter cover crop system (Table 4). Fewer plants occurred following rye than fallow when phenamiphos was applied, but more plants occurred following rye than fallow in control plots. Differences in plant populations were reflected in plant weight, pod yield, and crop value. A greater pod production per plant occurred with a rye cover crop irrespective of nematicide treatment. Phenamiphos application resulted in 90% greater crop value in the rye winter cover plots and 409% in the winter fallow plots.

Populations of *M. incognita* before tillage establishment for snap beans varied among tillage practices, nematicide, and winter cover crop combinations, but reduction in galling of snap bean roots reflects only a response to nematicide application (Table 2). Root-gall indices of plants that survived until harvest may not give an accurate estimation of *M. incognita* damage when plant stand variations are great because of the increased susceptibility of *M.*

Table 4. Interaction of nematicide and rye cover crop on nematodes, root-gall index, stand, plant weight, pod yield, and value of 'Eagle' snap bean, *Phaseolus vulgaris,* (fall 1980).

Treatment	Number *M. incognita* juveniles per 150 cm³ soil*	Root-gall index 11 wk after planting†	Plants/ha (× 1,000)	Plant wt. (t/ha)	Pod yield (t/ha)	Pod yield (g/plant)	Value ($/ha)
Phenamiphos-rye‡	64	1.8	58.3	8.4	3.0	51	397
Phenamiphos-fallow	65	1.6	84.0	12.0	4.1	49	540
Control-rye	180	4.5	43.3	4.6	1.6	37	209
Control-fallow	89	4.5	23.6	2.0	0.7	30	106
F probability	.16	.24	.04	.03	.06	.38	.08

*Samples collected 16 July before incorporation of corn residue and establishment of tillage systems.
†Index on a scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled.
‡6.7 kg ai/ha.

incognita-infected roots to soilborne diseases (6,8,10,11). Stand reduction in the phenamiphos-rye treatment was the result of the disk tillage system. Rye cover crop had no significant ($P = 0.05$) effect on plant population of subsoil-bed plots receiving phenamiphos treatment. Plant stand in nontreated plots was greater with a rye cover crop than fallow for both tillage methods. Plant weights, pod yields, and crop values of the treatment combinations closely parallel plant populations. The data also indicate that the greater pod production per plant with rye cover crop was consistent with disk tillage, but occurred only when nematicide was not applied with subsoil-bed tillage. Crop values ranged from \$34/ha with disk tillage-no nematicide-fallow combination to \$679/ha with subsoil-bed-phenamiphos-fallow combination.

Moldboard plowing was not included in the nematicide-cover crop experiment in the fall. Moldboard plow tillage plots received both cover crop and phenamiphos treatments; therefore, comparisons of the three tillage systems for plots with rye cover crop treated with phenamiphos are valid. Plots having moldboard plow tillage, phenamiphos, and rye cover crop produced 110,630 plants/ha, 16.7 t/ha plant weight, 5.9 t/ha pod yield, and a crop value of \$743/ha (unpublished data). This information, together with that shown in Table 2, shows that high returns resulted from a combination of several cultural methods. A comparison of the three tillage systems for plots having rye and nematicide show that crop values were 27% lower with subsoil-bed and 66% lower with disk than with the moldboard plow tillage system in the fall, and the similar yield and return of subsoil and moldboard plow tillage systems during the spring indicate that both the nematode and soilborne diseases must be considered when attempting to identify the best tillage system.

The results of these studies indicate that phenamiphos applied at 6.7 kg ai/ha with 28 mm of water through solid-set or center-pivot irrigation system effectively controls *M. incognita* and increases plant size, pod yields, and gross returns irrespective of tillage methods, cover crop system, and growing season. Neither winter rye nor fallow provide sufficient suppression of *M. incognita* populations for production of snap beans in a corn-snap bean multiple-cropping system. Although returns from application of phenamiphos were greater when production conditions were conducive to high yields in the spring crop, the percentage yield increase attributable to phenamiphos was greater under production conditions that were less conducive to high yields in the fall crop.

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