Differential Vertical Movement of Nonvolatile Nematicides in Soil[1]

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Abstract: When incorporated in the top 5-cm of Tifton sandy loam at 11.2 kg/ha in the field, B-68138 [ethyl 4-(methylthio)-m-tolyl isopropyl phosphoramidate] prevented galling of tomato roots by *Meloidogyne* sp. down to 20 cm. A similar application of 16.8 kg/ha of V-C 9-104 [0-ethyl S,S-dipropyl phosphorodithioate] was 99% effective down to 20 cm. Aldicarb [2-methyl-2-(methylthio) propionaldehyde 0-(methylcarbamoyl) oxime], B-25141 [0,0-diethyl 0-{p-(methylsulfinyl) phenyl}phosphorothioate], and carbofuran [2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate] prevented galling only in the zone of incorporation (top 5-cm of soil). When aldicarb (11.2 kg/ha) was applied to the surface of Ontario fine sandy loam contained in clay pots in the greenhouse, it prevented galling of tomato roots down to 20 cm deep. V-C 9-104 and B-68138, applied similarly, were 100% effective to a depth of 5 cm. B-25141 was 100% effective in the zone of incorporation only. D-1410 [S-methyl-1-(dimethylcarbamoyl)-N-[(methylcarbamoyl)oxy] thioformimidate] did not control 100% of the root-knot nematodes at any depth. *Key Words:* Organic phosphates, Carbamates, Root-knot, Chemical control, Dispersion of nematicides, Tomato (*Lycopersicon esculentum*), *Meloidogyne incognita, M. hapla, M. arenaria, M. javanica.*

Most nematicides are contact poisons. A lethal concentration of the toxicant must reach the target organism. Consequently, some knowledge of the physical activity of nematicides in soil is prerequisite to their efficient use.

Factors which govern the dispersion of nematicidal soil fumigants have been recently reviewed (4). Soil temperature, moisture, and soil type greatly influence the dispersion of soil fumigants (7, 8). Only circumstantial evidence is available to explain the apparent good dispersion of nonvolatile nematicides in soil (4). Excellent nematode control with surface application of certain nonvolatile nematicides on established turfgrass suggests rather extensive downward movement of the nematicides (2, 11). Limited studies on movement of nonvolatile nematicides in soil indicate they move downward as a result of rainfall or irrigation (4, 5, 10). They are apparently sorbed as they move and do not penetrate as deeply as water. Soil type undoubtedly influences the extent of downward and lateral movement by governing the amount of sorbtion. This is indicated in experiments designed to test the efficacy of certain nonvolatile nematicides. Differences in dosage rates required of a particular nematicide to produce similar results in different geographical areas vary greatly (6, 9). Moreover, differences in the degree of nematode control obtained with several nonvolatile nematicides used at the same dosage rate in the same soil type indicate that nematicides differ in their ability to penetrate soil (1, 2, 6, 9, 11).

In this study I measured the degree of control of root-knot nematode, *Meloidogyne* spp., at different soil depths to determine the extent of vertical downward movement of selected nonvolatile nematicides.

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MATERIALS AND METHODS

Field studies were conducted in Tifton sandy loam (85% sand, 7% silt, and 8% clay) heavily infested with a mixed population of *Meloidogyne incognita* (Kofoid and White) Chitwood and *M. javanica* (Treub) Chitwood. Each plot was 1.8 m × 15.2 m. Nematicide applications were arranged in a randomized complete block design replicated four times. The nematicides used were aldicarb [(2-methyl-2-(methylthio) propionaldehyde 0-(methylcarbamoyl) oxime)]; B-25141 [0,0-diethyl 0-{p-(methylsulfinyl) phenyl} phosphorothioate]; B-68138 [ethyl 4-(methylthio)-m-tolyl isopropyl phosphoramidate]; V-C 9-104 [0-ethyl S,S-dipropyl phosphorodithioate]; D-1410 [S-methyl-1-dimethylcarbamoyl)-N-{(methylcarbamoyl)oxy}thioformimidate]; and carbofuran [2,3-dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate.] A 10% granular formulation of each nematicide was applied to the soil surface with a Gandy® fertilizer spreader, and immediately incorporated in the top 5 cm of soil with a disk harrow. Each nematicide was applied at 6.7, 10.0 and 16.8 kg active ingredient per ha except B-68138 which was applied at 4.5, 6.7 and 11.2 kg/ha.

'Heinz 1350' tomato was direct-seeded (four double rows 35.5 cm apart/bed) to the plots 24 hr after nematicide application. Fertilizer was applied at planting in a 6.4-cm band 2.5 cm below seed depth at a dosage of 67 kg P, 39 kg K, and 67 kg N per ha. The plots were irrigated by sprinkler six consecutive days (1.3 cm/day) immediately following planting; this amount of water is recommended for obtaining maximum stands of direct seeded tomatoes in sandy soils of south Georgia. A total of 19.4 cm of rain fell on the plots during the experiment and the temperature ranged from 20–32 C. Eight weeks after planting, 50 tomato plants randomly selected from within each plot were dug and indexed for root knot. Care was taken to remove at least 20 cm of root system of each plant. Roots of 10 plants each from the medium dosage of each treatment were scored for root-knot galls at 5-cm increments to a depth of 20 cm.

Greenhouse studies were made in Ontario fine sandy loam (72% sand, 24% silt, and 4% clay) from western New York. A mixed population of *M. incognita*, *M. arenaria* Chitwood, *M. javanica*, and *M. hapla* Chitwood was added to soil in clay pots (12.7 cm dia.) at the rate of 1000 second-stage larvae per pot.

Aldicarb, B-25141, B-68138, V-C 9-104, and D-1410 [S-methyl 1-(dimethylcarbamoyl) N-{(methylcarbamoyl)oxy}thioformimidate] were applied (11.2 kg/ha) (i) to the soil surface, (ii) incorporated in top 7.6 cm of soil, or (iii) incorporated in the total soil contents of a pot (12.7 cm diam × 20 cm deep). Immediately after treatment, a 4-week-old tomato plant was set in each pot. The pots were kept in the greenhouse (25–30 C) and watered (on soil surface) daily to maintain optimum soil moisture. After 6 weeks, the plants were removed, soil was washed from the roots, and the distances from the soil surface to the first root-knot galls were recorded.

RESULTS

FIELD STUDIES: The amount of root galling in the control plots indicated an unusually uniform distribution of a relatively high infestation of *Meloidogyne* spp. in the test area. Degree of nematode control varied with nematicide and dosage level. Higher dosages controlled root-knot best (Table 1). Nematicides varied in their ability to control root-knot below the depth of incorporation. At all dosage levels tested aldicarb, carbofuran, and B-25141 prevented root galling only in the zone of incorporation. Numbers of galls below the zone of incorporation were less with these chemicals than in check plots at

TABLE 1. Galling of tomato roots in soil treated with three dosage rates each of five nematicides *vs.* untreated control.

Treatment	Kg active ingredient per ha	Root-knot index[a]
Aldicarb	6.7	2.02[b]
	10.0	1.92
	16.8	1.22
B-25141	6.7	2.12
	10.0	1.37
	16.8	1.26
V-C 9-104	6.7	1.06
	10.0	1.03
	16.8	1.01
Carbofuran	6.7	1.18
	10.0	1.48
	16.8	1.40
B-68138	4.5	1.02
	6.7	1.02
	11.2	1.00
Control	—	3.85
LSD .05		0.79

[a] Root-knot index on 1-5 scale with 1 = no galls and 5 = maximum galling.
[b] Average of four replications.

the same depth, but galling was not completely eliminated (Table 2). In general, V-C 9-104 and B-68138 were 100% effective 20 cm deep. However, root-knot galls were evident 20 cm deep on 1% of the plants in soil treated with V-C 9-104; no galls were found on plants where B-68138 was used at 11.2 kg/ha (Table 1).

GREENHOUSE STUDIES: In pot tests, where Ontario fine sandy loam was used, the degree of root-knot control varied with nematicide and depth of incorporation. All nematicides except D-1410 prevented galling 20 cm deep when incorporated in the total soil content of a pot (Table 3). Aldicarb prevented root galling 20 cm deep when applied to the soil surface. Complete root-knot control with V-C 9-104 and B-68138 extended 5 cm below the depth of incorporation. B-25141 prevented root galling only in the zone of incorporation. When applied on the soil surface, D-1410 reduced root-knot 80% to a depth of 20 cm but did not completely prevent gall formation.

TABLE 2. Galling of tomato roots at four soil depths in soil treated with five nematicides *vs.* untreated controls.

Nematicide	Dosage kg/ha	Root-knot index at[a] different soil depths (cm): 5	10	15	20
Control	—	4.0[b]	5.0	5.0	5.0
Aldicarb	10	1.0	2.2	2.9	4.0
B-25141	10	1.0	2.2	3.5	4.3
V-C 9-104	10	1.0	1.4	1.7	1.5
Carbofuran	10	1.0	1.8	2.3	2.6
B-68138	6.7	1.0	1.0	1.0	1.0

[a] Root-knot index on 1-5 scale with 1 = no galls and 5 = maximum galling.
[b] Mean of four replications.

DISCUSSION

The data indicate that the nonvolatile nematicides tested differ in downward mobility in soil and that soil type influences penetrating ability and might account for difference in nematode control obtained with the same nematicide in different geographic areas. Soil type apparently determines the dispersion of nonvolatile nematicides in soil by governing the amount of sorption. According to Goring (4), the extent of penetration of nematicides in soil is inversely related to the ratio of the amount of chemical sorbed per gram organic matter in equilib-

TABLE 3. Depth of control of root-knot infection on tomato by five nonvolatile nematicides as influenced by 3 depths of at-planting application in Ontario fine sandy loam.

Nematicide	Depth (cm) to which 100% root-knot control was obtained when nematicide was incorporated: 0 (surface)	7.6 cm deep	20 cm deep
Aldicarb	20	20	20
B-25141	—[a]	7.6	20
V-C 9-104	5	12.7	20
D-1410	0[b]	0[b]	0[b]
B-68138	5	12.7	20

[a] Plants died from apparent phytotoxicity.
[b] Complete control was not obtained at any depth studied.

rium with the amount of chemical dissolved per gram of water. Since organic matter is primarily responsible for sorption of most nematicides, they would tend to penetrate deeper into soil low in organic matter such as Tifton sandy loam. This proved to be the case with V-C 9-104 and B-68138 but not with aldicarb. This suggests that other factors may be as important as soil types in the vertical downward movement of some nematicides. It is possible that downward movement is accomplished through sorption of the chemicals by roots in the zone of incorporation and translocation downward. Aldicarb, B-25141 and B-68138 are known to move systemically in plants.

Earlier work stressed the importance of soil water in the dispersion of nonvolatile nematicides (10). Such compounds depend on percolation of water through the soil as a driving force in their movement. My experiments were not designed to measure the influence of water on movement of the nematicide. Sufficient water was applied (approximately 25 cm) to favor good penetration into the soil. Differences in depth of root-knot control among nematicides applied to identical soils could be a function of their water solubility. B-68138 and V-C 9-104 are about equally soluble in water (0.04–0.07%) with aldicarb being somewhat more soluble (0.09%). Greater solubility of aldicarb could result in rapid leaching from Tifton sandy loam and not allow sufficient time for sorption of lethal concentrations. Similarly, the extreme water solubility (25%) of D-1410 and/or inadequate dosage could be responsible for poor root-knot control with this compound.

The extend of penetration of lethal concentrations of certain nematicides appeared related to dosage level. Increase in dose was usually accompanied with increase in depth of penetration as measured by root-knot control. This phenomenon follows simple laws of diffusion which state that the rate of movement of a toxicant is directly related to the concentration of the toxicant and its diffusion coefficient.

These results point out the need for knowledge of the physical properties of both the nematicide and the soil before accurate predictions can be made concerning efficiency of nematode control.

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