Relative Efficacy of Selected Volatile and Nonvolatile Nematicides for Control of *Meloidogyne incognita* on Tobacco[1]

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Abstract: Root-knot nematode control and tobacco yields in plots infested with *Meloidogyne incognita* and treated with the nonvolatile nematicides, aldicarb, Mocap ®, or Nemacur ® were greater than those on similar plots treated with volatile nematicides such as DD, DD + MENCS, SD14647 or tetrachlorothiophene. Root-knot control and tobacco yields in plots treated with carbofuran or Dasanit ® were equal to that obtained with DD + MENCS, but less than that obtained with the other volatile soil nematicides. The most efficient dosage was 3.4 kg/hectare active ingredient for aldicarb and Mocap ® and 10.0 kg/hectare for Dasanit ®. Carbofuran and Nemacur ® were equally as effective at 4.2 kg/hectare as they were at higher dosages. The most efficient dosage of DD and SD14647 was 84 liters/hectare. Aldicarb and Dasanit ® resulted in better nematode control and tobacco yields when incorporated into the top 15-20 cm of soil than when incorporated into the top 5-10 cm of soil. Nemacur ® and Mocap ® performed better when incorporated into the top 5-10 cm of soil, and carbofuran performed better when applied in the seed furrow (placed 15-20 cm deep in a 5-cm band and bedded). *Key words:* organic phosphates, carbamates, soil fumigants, root-knot nematodes, chemical control, *Nicotiana tabacum.*

When organic phosphate and carbamate nematicides were introduced, it became important to measure their effectiveness in relation to the volatile soil fumigants already in use. Because the organic phosphate and carbamate nematicides are relatively nonvolatile, new methods of application had to be explored. We evaluated several volatile and nonvolatile nematicides in 5-year field trials for dosage level, method of application and efficiency against *Meloidogyne incognita* (Kofoid & White) Chitwood on tobacco (*Nicotiana tabacum* L. 'NC-2326'). A preliminary report has been given (7).

Volatile soil fumigants in the chlorinated C_3 hydrocarbon group have long been standard treatments for control of root-knot nematodes on tobacco (17). More recently, mixtures of these compounds with fungicides to obtain a broader spectrum of activity were investigated and found to be effective in areas where disease complexes were evident (14). Finally, the introduction of nonvolatile organic phosphate and carbamate nematicides brought a new era in chemical control of nematodes (9). These nematicides effectively control *Meloidogyne* spp. on tobacco (8, 10, 12, 15, 16), *Trichodorus christiei, Pratylenchus brachyurus* and *Tylenchorhynchus martini* on sugarcane (2); *M. incognita* on gardenia (13); *Rotylenchulus reniformis* on cotton and sweet potatoes (1, 3); and *Belonolaimus longicaudatus* and *T. christiei* on vegetables (4, 5, 17). In many cases, treatment with organic phosphate and carbamate nematicides resulted in greater crop yields than did the commonly used soil fumigants DD, DBCP and EDB (1,3-dichloropropene, 1,2-dichloropropane; 1,2-dibromo-3-chloropropane; and ethylene dibromide) (1, 2, 8, 11).

MATERIALS AND METHODS

Field evaluations were done in Tifton sandy loam (85% sand, 7% silt, 8% clay) which was naturally infested with *M. incognita*. Plots were single rows 15.2 m long and 1.2 m apart. Nematicides were applied in a randomized complete block design replicated seven times. Volatile soil fumigants used were DD (1,3-dichloropropene and 1,2-dichloropropane mixture); DD + MENCS (80% DD + 20% methyl isothiocyanate mixture); SD-14647 (95.2% DD + 4.8% methane sulfonic acid mixture); and tetrachlorothiophene. Nonvolatile nematicides used were aldicarb (2-methyl-2[methylthio] propionaldehyde O-[methylcarbamoyl] oxime); Dasanit ® (O,O-diethyl O-[p-(methylsulfinyl)phenyl] phosphorothioate); Mocap ® (O-ethyl S,S-dipropylphosphotodithioate); carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl

Received for publication 14 February 1972.

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methylcarbamate); and Nemacur® (ethyl 4-[methylthio]-m-tolyl isopropylphosphoramidate).

Soil fumigants (liquid formulations) were applied 2-3 weeks before planting. They were injected (one chisel/row) 20 cm below the soil surface and bedded to 30 cm above the point of injection. At planting, the top 7.5-10 cm of soil on the bed was pushed into the row middles ahead of the planter. During application of soil fumigants, the 15-cm-deep soil temperature averaged 25 C, and the soil moisture averaged 5% by weight.

Nonvolatile nematicides (granular formulations) were applied just before transplanting. They were either spread on the soil surface in a 76-cm-wide band and incorporated into the top 5-10 cm of soil with a disk harrow or into the top 15-20 cm of soil with a power-driven rototiller, or in some cases were placed 15-20 cm deep in a 5-cm band and bedded to 30 cm above the band. In the latter case, the top 7.5-10 cm of soil on the bed was pushed into the row middles ahead of the transplanter.

Tobacco seedlings NC-2326 were transplanted into the plots with a tractor-drawn transplanter, and all plots were irrigated immediately to improve transplant survival. Fertilization was consistent with established farming practices of the area. Cultivation was done without moving untreated soil into the treated row. All plots were hand-harvested. Yield was recorded as green weight and converted to cured weight on the basis of one cured harvest each year.

After harvest, 50 plants/treatment per replication were dug and rated for root-knot nematode galling. Individual plants were rated on a 1-5 scale with 1 = no galling and 5 = maximum galling. For presentation, these indices were converted to a 0-100 scale to show more clearly the differences that occurred.

Each experiment was repeated two to five times; however, to keep dosage levels consistent within types of experiments, 2 or 3 years' data are presented. To preclude residual effects of certain nematicides, the same test area was not used 2 years in succession. In alternate years, the test area was planted to root-knot-susceptible vetch in the winter and root-knot-susceptible vegetables in the summer.

TABLE 1. Root-knot indices (*Meloidogyne incognita*) and yield of tobacco on plots treated with various chemicals.[a]

Treatment	Dosage/hectare	Root-knot index[b]	Yield: Actual green leaf kg/plot	Yield: Estimated[c] cured leaf kg/hectare
Control		81	35.46	1856
Broad-spectrum soil fumigant				
DD + MENCS	47 liters[d]	72	41.11	2410
Nematicidal fumigant				
DD	84 liters	34	43.80	2568
SD-14647	65 liters	40	42.25	2477
Tetrachlorothiophene	7 liters	49	42.10	2468
Nonvolatile nematicides				
Aldicarb	6.7 kg[e]	48	47.10	2758
Mocap ®	6.7 kg	53	45.74	2682
Dasanit ®	6.7 kg	72	40.49	2374
Carbofuran	6.7 kg	78	41.61	2440
Nemacur ®	6.7 kg	42	44.66	2619
LSD = .05		23	7.19	

[a]Average of 2 years.
[b]Based on 0-100 scale with 0 = no galls and 100 = maximum galling.
[c]Calculated from one cured priming/year.
[d]Liters of technical formulation.
[e]kg active ingredient.

RESULTS

Tobacco yields were significantly greater from plots treated with DD, aldicarb, Mocap ® and Nemacur ® than from untreated plots. All other treatments did not significantly increase tobacco yields. Significantly higher yields were correlated with significantly lower root-knot indices, but highest yields were not always associated with lowest root-knot indices. Yields were 147-384 kg/hectare higher from plots receiving aldicarb, Mocap ® or Nemacur ® than from plots receiving volatile nematicides, with the exception of DD (Table 1). Yield from plots receiving carbofuran or Dasanit ® were slightly lower than from plots receiving volatile nematicides. Yields from plots receiving DD were up to 178 kg/hectare higher than from plots receiving DD + MENCS, SD-14647 or tetrachlorothiophene.

The level of root-knot nematode control and subsequent increase in tobacco yield varied with dosage levels. Yield from plots treated with DD or SD-14647 were 173-214 kg/hectare higher at 84 liters/hectare than at 64 or 47 liters/hectare (Table 2). Root-knot indices were correspondingly reduced as dosage levels increased. With the nonvolatile nematicides, there was very little correlation between postharvest root-knot indices and significant yield increase. Dosages that significantly increased yields did not always significantly reduce root-knot indices. Yields from plots treated with 3.4 kg/hectare of aldicarb or Mocap ® were as high as those from plots treated with 6.7 or 10 kg/hectare. Similarily, yields from plots treated with 4.2 kg/hectare of carbofuran or Nemacur ® were as high as those from plots treated with 6.7 or 11.2 kg/hectare.

TABLE 2. Root-knot indices (*Meloidogyne incognita*) and yield of tobacco on plots treated with various dosage levels of seven nematicides.[a]

Treatment	Dosage/hectare	Root-knot index[b]	Yield: Actual green leaf kg/plot	Yield: Estimated[c] cured leaf kg/hectare
Control		84	26.43	1549
Aldicarb	3.4 kg[d]	60	34.42	2018
	6.7 kg	53	35.09	2057
	10.0 kg	29	32.83	1924
Dasanit ®	6.7 kg	70	29.85	1749
	10.0 kg	59	36.20	2122
	16.8 kg	56	36.95	2166
Mocap ®	3.4 kg	78	36.62	2147
	6.7 kg	57	35.62	2076
	11.2 kg	40	30.78	1804
Nemacur ®	4.2 kg	53	36.93	2164
	6.7 kg	41	36.85	2160
	11.2 kg	40	37.43	2194
Carbofuran	4.2 kg	95	33.35	1956
	6.7 kg	89	31.22	1830
DD	47 liters[c]	80	28.42	1667
	65 liters	62	27.96	1637
	84 liters	37	31.37	1840
SD-14647	47 liters	42	27.86	1633
	65 liters	35	29.12	1707
	84 liters	29	31.18	1829
LSD = .05		22	6.61	

[a] Average of 2 years.
[b] Based on 0-100 scale with 0 = no galls and 100 = maximum galling.
[c] Calculated from one priming/year.
[d] kg active ingredient.
[e] Liters of technical formulation.

TABLE 3. Root-knot indices (*Meloidogyne incognita*) and yield of tobacco as influenced by method of incorporating nonvolatile nematicides into soil.[a]

				Yield	
Treatment	Dosage kg/hectare (a.i.)	Method of incorporation	Root-knot index[b]	Actual green leaf kg/plot	Estimated[c] cured leaf kg/hectare
Control		Bedded[d]	80	47.08	2759
		Harrow[e]	81	42.13	2469
		Rototilled[f]	76	45.95	2693
Aldicarb	6.7	Bedded	66	47.80	2801
		Harrow	46	57.27	3358
		Rototilled	42	58.98	3457
Mocap ®	6.7	Harrow	39	57.05	3344
		Rototilled	49	52.95	3104
Dasanit ®	10.0	Bedded	74	51.95	3045
		Harrow	69	53.89	3170
		Rototilled	40	51.39	3013
Carbofuran	6.7	Bedded	66	52.43	3073
		Harrow	70	48.92	2531
		Rototilled	67	51.39	3049
Nemacur ®	6.7	Harrow	41	54.53	3197
		Rototilled	44	52.47	3077
LSD = .05			25	7.78	

[a] Average of 2 years.
[b] Based on 0-100 scale with 0 = no galls and 100 = maximum galling.
[c] Calculated from one cured priming/year.
[d] Placed 15-20 cm deep in a 5-cm band and bedded.
[e] Spread on soil surface and incorporated into top 5-10 cm of soil.
[f] Spread on soil surface and incorporated into top 15-20 cm of soil.

A significant increase occurred with Dasanit ® only when 10 kg/hectare or more were used. In each case, root-knot indices decreased with increase in dosage of nematicide.

The effectiveness of nonvolatile nematicides also varied with method of incorporation. Best *M. incognita* control and best tobacco yield were obtained with Mocap ® and Nemacur ® when they were applied to the surface and incorporated into the top 5-10 cm of soil with a disk harrow (Table 3). Aldicarb and Dasanit ® were more effective when they were spread on the soil surface and incorporated in the top 15-20 cm of soil with a power-driven rototiller. The greatest yield increase with carbofuran was obtained when it was applied 15-20 cm deep in a 5-cm band and bedded.

DISCUSSION

Certain of the nonvolatile nematicides controlled *M. incognita* and promoted good tobacco growth just as effectively or, in some cases, slightly more effectively than did the commonly used soil fumigant, DD. This was particularly true with aldicarb, Mocap ® and Nemacur ®. The nonvolatile nematicides we used can be applied just before planting as opposed to a 2- to 3-week interval necessary between application of soil fumigants and the transplanting of tobacco. Also, soil moisture and temperature at time of application are apparently not as critical with nonvolatile nematicides as with soil fumigants. Considering the above factors, we believe that nonvolatile nematicides control *M. incognita* on tobacco more efficiently than do volatile nematicides.

The broad-spectrum soil fumigant we used (DD + MENCS) was not as effective as DD. Although DD + MENCS is effective against disease complexes of tobacco (14), our data indicate that it is not an efficient pesticide to use when root-knot nematodes only are involved.

The most effective method for application of nonvolatile nematicides varied with the compound used. The increased effectiveness of Mocap ® and Nemacur ® when incorporated in only the top 5-10 cm of soil confirms earlier studies (5) which indicated that these compounds readily move downward in Tifton sandy loam. Our data indicate that aldicarb and Dasanit ®, which required incorporation in the top 15-20 cm of soil for maximum effectiveness, moved a relatively short distance out of the zone of incorporation. The increased effectiveness of carbofuran when applied in the furrow and bedded apparently is due to the overcoming of phytoxicity that occurs when it is applied to the soil surface and incorporated. Phytotoxicity is manifested by a severe flecking and loss of lower leaves.

The lack of good correlation between yield and root-knot indices, taken after 4 months, confirms earlier studies with *M. javanica* which indicated that yield is correlated with root-knot indices 1 and 2 months after transplanting only (6).

We believe, based on our observations and knowledge of the pest situation in these experimental fields, that yield increases obtained on plots treated with the organic phosphate and carbamate compounds were attributable to control of *M. incognita* and not to other pests.

The use of organic phosphate or carbamate nematicides for control of root-knot nematodes on tobacco appears very promising. Since they are effective when applied to the soil surface and incorporated, they are better suited than volatile nematicides for application in mixtures with other pesticides such as herbicides and fungicides. Such mixtures would result in multiple pest control and could considerably lower unit production cost of tobacco.

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