Use of Nonselective and Mixtures of Selective Pesticides for Multiple Pest Control

Bill B. Brodie

Nematologist, Crops Research Division, ARS, USDA, Coastal Plain Experiment Station, Tifton, Georgia 31794.

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Arable soil is a complex ecosystem containing many forms of plant and animal life. Although many of these organisms are beneficial, certain nematodes, fungi, and weeds are detrimental to crop plant production. Any one of these pests poses a serious threat to crop production. When two or more pests occur together constituting "a soil-borne pathogen syndrome", ensuing crop damage can be devastating. Pesticidal chemicals have often been used in efforts to control such pathogen complexes.

Progress in the development of chemical control practices has come primarily from experiments designed to control a single pest or type of pest. Occasionally, reports have included observations on control of pests other than those for which the experiments were designed. The result has been separate recommendations for control of a large number of the major crop pests. Consequently, to implement an effective program for control of all pests necessitates repeated applications involving different types of pesticides and application procedures. However, the necessity of reducing pesticide application cost and increasing efficiency of crop production has promoted development of multiple pest control through single applications of pesticidal chemicals.

Nonselective soil fumigants.—Early in the development of chemical soil treatment, multiple pesticidal activity was recognized in several fumigant type chemicals including carbon disulfide, chloropicrin, methyl bromide, ethylene dichloride, and paradichlorobenzene (15). Much effort was expended to develop these compounds as soil fumigants for plant disease control (15, 29, 30).

Methyl bromide and chloropicrin are perhaps the best known and most widely used general soil disinfestants. Many experiments have demonstrated their effectiveness as nematicides (15, 16, 17, 28, 29), soil fungicides (15, 16, 17, 30), and herbicides (15, 16, 21). No other soil fumigants have equaled these compounds in biological activity. Reports demonstrated that mixtures of chloropicrin and methyl bromide have a synergistic effect resulting in greater effectiveness in disease control (28, 30). Due to its high vapor pressure (1380 mm Hg), methyl bromide is most effective in closed system; i.e., when applied under an air-tight seal (15, 29). Under field conditions, losses from the high vaporization rate of methyl bromide necessitates use of large amounts of the chemical for desired pest control. Thus, the cost of material and application limit the use of methyl bromide and methyl bromide-chloropicrin mixtures to treatment of plant beds, potting soil, and certain high value per acre crops (14, 30). A new formulation (in colloidal silicon dioxide gel) with a reduced vapor pressure (25 mm Hg) controlled nematodes and fungi at dosage levels as low as 40 lb/acre of methyl bromide (11, *unpublished data*). In this form, methyl bromide may eventually be accepted as a field fumigant.

The introduction of the 1,3-dichloropropene and 1,2-dichloropropane mixture (DD) in 1943 opened a new era of soil fumigation (12). The immediate success of DD as a field nematicide stimulated much interest in the development of other nematicidal compounds for field use. Within 15 years, several compounds were either being marketed or tested. These included such compounds as ethylene dibromide (EDB); 1,2-dibromo-3-chloropropane (DBCP); sodium methyl dithiocarbamate (metham); dimethyl tetrahydrothiodiazine thione (dazomet); 1,3-dichloropropene (1,3-D); and a mixture of dichloropropenes with methyl isothiocyanate (DD + MENCS) (12, 13, 24, 25, 26). Their effectiveness and widespread use has been well documented (19, Table 1).

Following the widespread use of soil fumigants for nematode control, reports of the effectiveness of certain of these chemicals against soil fungi and weeds began to appear (1, 2, 3, 5, 9, 20, 23). An extensive effort was made to determine the efficacy of certain soil fumigants in controlling nematodes, weeds, and soil fungi (4, 16, 17, 26, 27). For certain compounds (DD, EDB, and DBCP), dosages much in excess of those needed for nematode control proved necessary for control of weeds and soil fungi (1, 2, 4, 9). The most promising compounds for multiple pest control were metham, dazomet, and the DD + MENCS mixture. In several experiments, these compounds controlled several different species of nematodes, weeds, and soil fungi (Table 1). However, effective control of pests requires particular attention to methods and soil conditions at time of application. The soil must be smooth and free of undecomposed crop residue, with soil moisture 50 to 80% of field capacity; the toxicant must be applied 25-38 cm deep, and rows must be bedded 31-46 cm high; and the top 1.3-5 cm of soil must be removed from the row beds just before planting (22). This type of treatment requires 3- to 4-week intervals between toxicant application and crop planting.

Mixtures of selective pesticides.—The first attempts at multiple pest control with mixtures of selective pesticides utilized the nematicide DBCP (6). Mixtures of DBCP and pentachloronitrobenzene (PCNB) applied in the seed row at time of planting cotton were somewhat successful. Increased plant stands and early season control of root knot (*Meloidogyne incognita acrita* Chitwood) and reniform (*Rotylenchus reniformis* Linford & Olivera) nematodes have resulted from such treatment (6, 7, 8). The addition of hexachloroepoxyoctahydro endo, exo-dimethanonaphthalene (dieldrin), or *0,0*-diethyl *S*-(ethylthio) methyl phosphorothioate (phorate) to the mixture further increased cotton seedling stands by affording early season insect control (6, 7). However, root-knot indices and larval counts usually demonstrated inadequate control of nematodes from this method of applying DBCP. The effectiveness of DBCP treatment depends greatly on depth of application. In-furrow treatments of DBCP usually placed the toxicant not more than 5 cm below the soil surface. Good & Steele (18) showed that the effectiveness of DBCP diminishes rapidly when applied less than 15 cm deep. Consequently, combination treatments of DBCP with other pesticides applied in the seed row never gained widespread acceptance.

The development of nonvolatile organic phosphate and carbamate nematicides has stimulated interest in multiple pest control with pesticide mixtures. Nonvolatile compounds, such as 2-methyl-2-(methylthio) propionaldehyde *0*-(methylcarbamoyl)oxime (Temik®), *0,0*-diethyl *0*-*p*-(methylsulfinyl)phenyl phosphorothioate (Dasanit®), and *0,0*-diethyl 0-2 pyrozinal phosphorothioate (cynem), possess good nematicidal properties (10). During a 4-year study, mixtures containing any one of these nematicides, the herbicide S-propyl butylethylthio-carbamate (pebulate), and the fungicide PCNB controlled *Meloidogyne incognita*, *Richardia scabra* (Mexican clover), *Digitaria sanguinalis* (L.) Scop. (crabgrass), *Rhizoctonia solani* Kühn, and *Fusarium* sp. (11). Mixtures of specific pesticides containing a nematicide, herbicide, and fungicide were much superior to broad-spectrum soil fumigants (DD + MENCS, 1,D-PBC) in multiple pest control. The pesticide mixtures were spread on the soil surface and incorporated with a power-driven rototiller or a disk harrow. There was no evidence of incompatibility between any of the specific pesticides applied in this manner, as indicated by performance alone and in combination (reported in part in 11).

Further studies were made with mixtures of specific pesticides in which pebulate herbicide was replaced with α, α, α-trifluro-2, 6-dinitro-*N*,*N*-dipropyl-*p*-toluidine (trifluralin) applied as an in-the-seed row

TABLE 1. Multiple pesticidal activity of some soil fumigants against certain crop pests

Fumigant	Crop pests		
	Nematodes	Fungi	Weeds
DD	*Meloidogyne incognita*	*Pythium arrhenomanes*	
	Tylenchulus semipenetrans	*Phytophthora citrophthora* *P. parasitica*	
	Heterodera schactii	*Fusarium* sp.	*Convolvulus* sp. (bindweed) *Amaranthus* sp. (pigweed)
	Pratylenchus minyus *Tylenchorhynchus capitatus*	*Verticillium albo-atrum*	
	M. incognita	*Fusarium oxysporum*	
DBCP	*M. incognita* *M. incognita*	*Pythium ultimum* *Rhizoctonia solani*	
EDB	*P. minyus*	*R. solani*	
DD + MENCS	*M. incognita*	*F. oxysporum*	*Digitaria sanguinalis* (crabgrass) *Richardia scabra* (Mexican clover) *Mollugo verticillata* (carpetweed)
	M. incognita	*Sclerotium rolfsii* *F. oxysporum* *R. solani* *Fusarium solani*	*D. sanguinalis* *R. scabra*
	T. semipenetrans	*P. parasitica* *P. citrophthora* *Pythium* sp.	
	P. minyus *T. capitatus*	*V. albo-atrum*	
Metham	*Belonolaimus gracilis* *Hoplolaimus coronatus* *Rotylenchus robustus*	*Fusarium* sp.	
	M. incognita *Trichodorus christiei*	*Fusarium* sp.	
	M. incognita	*F. oxysporum*	*D. sanguinalis* *R. scabra* *M. verticillata*
	M. incognita	*S. rolfsii* *R. solani*	*D. sanguinalis* *R. scabra*
Dazomet	*B. gracilis* *H. coronatus* *R. robustus*	*Fusarium* sp.	
	M. incognita *T. christiei*	*Fusarium* sp.	
	M. incognita	*F. oxysporum*	*D. sanguinalis* *R. scabra* *M. verticillata*
	M. incognita	*S. rolfsii*	*D. sanguinalis* *R. scabra*

treatment at time of planting cotton. Excellent control of *Belonolaimus longicaudatus* Rau (sting nematode), crabgrass, Mexican clover, and damping-off were obtained. *Fusarium* wilt was much less evident in plots treated with pesticidal mixtures than in plots treated with broad-spectrum soil fumigants. It was not determined if this was a direct effect of fungus population reduction or an indirect effect caused by nematode control (*unpublished data*).

DISCUSSION.—In my opinion, the use of mixtures of selective pesticides to achieve multiple pest control on a field scale appears most promising. Although there is sufficient evidence of multiple pesticidal activity of certain nonselective soil fumigants, the large amount of chemical required and the exactness that must be exercised in application limit their suitability for general field use. On the other hand, mixtures of specific pesticides possess a sufficient biology activity at minimal dosages and provide the ease and versatility of application that is sought in any chemical control program. Such mixtures successfully controlled nematodes, weeds, and soil fungi when applied on the soil surface and incorporated with simple farm equipment (disk harrow) or applied as an in-the-seed row treatment at time of planting. In addition to their nematicidal value, such compounds as 2-methyl-2-(methylthio)propionaldehyde *0*-(methylcarbamoyl) oxime and *0,0*-diethyl *0-p*-(methylsulfinyl) phenyl phosphorothioate possess excellent systemic insecticidal properties. Therefore, an even broader spectrum of pesticidal activity is gained.

Thus far, studies with pesticidal mixtures have been made with physical mixtures (separately manufactured formulations) of the specific pesticides. Since there is no evidence of incompatibility among the different classes of chemicals, it seems plausible that formulated mixtures can be prepared from technical materials. When exact ratios of toxicants necessary for effective control are determined, I believe that a "super" granule (or other suitable formulations) with a nematicide, herbicide, and fungicide can be formulated and successfully applied for use in the production of many crops. Each formulation of this type necessarily will be tailored for specific crops and pest control uses under specific environmental conditions in a given location.

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