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Characteristics of Principal Nematicides [1]

Robert A. Dunn and Joseph W. Noling[2]

Chemical products used to control nematodes have generally fallen into two major classes, fumigants and non-fumigants or "contact" nematicides, based on their chemical and physical characteristics. After the brief introduction in the next paragraphs, each of these groups of nematicides are discussed in detail in the following sections.

The first economically effective nematicides were **soil fumigants** . These are chemicals that, when applied to soil, generate fumes that spread through the soil pores to treat a volume of soil reasonably uniformly. Their key characteristic is that they are locally redistributed in the soil by diffusion as gases. Some are economically effective against several kinds of pests (among nematodes, fungi, bacteria, insects, and weeds), and are thus often called " **multi-purpose** " or " **broad-spectrum** " fumigants. Others that have been used primarily for nematode control, lacking significant effects against any other important pest group, are the **fumigant nematicides** .

Since the 1960's, a completely different group of products, usually termed " **non-fumigant** " nematicides, has been developed. All are organo-phosphate or carbamate pesticides; most have significant insecticidal and/or acaricidal properties. Most are extremely toxic to humans (acute oral and dermal toxicities). In contrast to the fumigants, these chemicals depend heavily on initial mixing with the soil and local redistribution in solution in the soil water. Some are systemically absorbed and redistributed within plants. They are commonly formulated as granules to which the active ingredient has been adsorbed onto the surface of a sand, clay, or organic grit of a specific particle size at a rate of 5% to 20% of the total weight of the formulated product. Many are also available in more concentrated emulsifiable or water-soluble spray liquids.

Land preparation is important to success with any nematicide. The soil should be turned, tilled, or thoroughly disked at least 4 to 6 weeks before treatment, to encourage decay of roots and other plant trash that could protect nematodes from the chemical and interfere with application equipment. Intact organic matter can also directly adsorb ("tie up") soil fumigants so that not all of the product applied to the soil is actually free for pest control. Soil should be worked deeper than the actual intended depth of treatment, to be sure that no compaction layer interferes with nematicide movement. Heavier soils may need to be worked again about 1 week before treatment or planting, to be sure that there are no soil

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2. Robert A. Dunn is a Professor of Extension Nematology in the Department of Entomology and Nematology and Joseph W. Noling is an Associate Professor of Nematology at the Citrus Research and Education Center in Lake Alfred, Florida, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

clods that might interfere with uniformity of fumigant diffusion or incorporation of a non-fumigant nematicide. Soil should be in good seedbed condition, with adequate but not excessive moisture through the entire tilled depth when either fumigant or non-fumigant nematicides are applied to the soil. Irrigate during the week before treatment if necessary to achieve this.

Multi-Purpose Soil Fumigants

These products are intended to reduce populations of other soil-borne pathogens, insects, and weed seeds in addition to nematodes (activity against different kinds of pests often depends on the application rate). Offsetting their wider spectrum of activity are greater expense per acre, more complicated application equipment and methods, and greater potential hazard. Because of their costs, they are generally used where the crops have especially high value (seedbeds, golf course greens and tees, nurseries, some fruit and vegetable crops).

By far the greatest portion of multi-purpose soil fumigants used in Florida are formulations of methyl bromide with varying concentrations of chloropicrin (Table 1). All **methyl bromide** products used for soil fumigation should contain a small percentage (0.5 - 2%) chloropicrin to warn of free fumigant in the atmosphere, such as from torn plastic tarps, equipment leaks, etc. Methyl bromide is deadly but has no odor itself; chloropicrin is a powerful tear gas that is easily detected in low concentrations. Higher proportions of chloropicrin are usually chosen to increase fungicidal activity, since it is a far better fungicide than is methyl bromide. All methyl bromide products are **extremely toxic** and must be handled with utmost respect and care to avoid injury to those who used them or come near areas where they are used.

A range of **methyl bromide/chloropicrin** formulations registered for various crops, planting media, and planting sites are listed in Table 1 . Not all brands of any given formulation are registered for all of the same uses, so this table is only a guide to available mixtures. It is the **user's responsibility** to be sure that a product is legally registered for the crop/site for which it is being applied.

Because of their great volatility at normal temperatures, most methyl bromide products and concentrated chloropicrin formulations are sold and handled in gas cylinders. Small quantities (1 or 1.5 lb) of 98% methyl bromide/2% chloropicrin are sold in sealed cans which are used for treating small areas of seedbed or individual planting sites.

Multi-purpose fumigants other than methyl bromide/chloropicrin mixtures include dazomet, metam and mixtures of 1,3-D with chloropicrin. These products, less volatile than methyl bromide, are usually applied as liquids from drums and bulk containers rather than gas cylinders. Dazomet is a granular product that must be mixed mechanically with the soil.

Equipment

These fumigants are extremely corrosive when exposed to moisture. Carefully follow manufacturers' instructions about materials to be used to construct and maintain equipment to handle and apply fumigants. Generally, most fixtures should be of brass or stainless steel and inert plastics as specified on labels. Do not use zinc-coated (galvanized) or aluminum parts in fumigation equipment.

Soil Preparation

Land preparation is as critical for effective use of these products as any other nematicides. Their great cost per acre and the potential value of the crops for which they are generally used make it especially important that soil conditions be as recommended when they are applied.

Most multi-purpose soil fumigants require the use of a covering (tarp, usually polyethylene) or enclosure to retain the fumes in the soil long enough to be effective. In all cases, covering will dramatically increase the level of control that may be expected from a specific rate of a product.

Follow instructions for application, sealing, waiting period, and aeration listed on the label of the product being applied. Heavy soils, low temperatures, and excessive soil moisture may retard escape of the fumes from the soil, requiring a longer planting delay and perhaps mechanically disturbing the soil surface to encourage aeration. Generally, do not plant if the fumigant odor is still detectable in soil 6-12 inches deep. If in doubt, plant a few test seedlings in the treated soil and observe them for signs of injury before seeding or planting the main crop.

Use of many soil fumigants may temporarily raise the level of ammonia nitrogen and soluble salts in the soil. For most crops, only nitrate sources of nitrogen should be used until plants are well established after using multi-purpose fumigants. Consult labels for specific details and for exceptions.

Fumigant Nematicides

This group of materials was once the mainstay of soil treatment for nematode control. Three alkyl halides or halogenated hydrocarbons, EDB (ethylene dibromide or dibromoethane), DBCP (1,2-dibromo-3-chloro-propane), and 1,3-D (1,3-dichloropropene), were the principal active ingredients of most of the liquid fumigant nematicides. These compounds were relatively inexpensive and simple to apply, and were also particularly effective in the open-pored sandy soils prevalent in Florida. They provided good control of most nematodes and the first good evidence of the economic importance of nematodes as crop pests. However, registrations of DBCP and EDB were cancelled when they were found to present unacceptable health and environmental risks.Only 1,3-D remains as a commercially available fumigant registered for nematode control by EPA; it is the active ingredient of Telone ^{R} II Soil Fumigant. The multi-purpose soil fumigant, Telone C-17, is the same basic fumigant with 17% chloropicrin added to broaden its spectrum of activity.

Telone II is recommended for pre-plant nematode control for a wide range of crops (see label). It is especially desirable where root-knot nematodes must be controlled for production of annual crops.

Application

Careful attention to application practices is the key to success with soil fumigants such as Telone II. Soil preparation as outlined in the introduction to this document is critical for uniform diffusion of the fumes through the soil, and to ensure that nematodes are not protected from the fumigant by being inside of intact plant debris. The fumigant is usually injected into the soil through chisels or "knives" spaced 10-12 inches apart for wide rows or "overall" treatment and a single knife per row to treat a band about 12 inches wide. The fumigant is normally released into the soil through a tube at the back of the injection knife at between 8 and 12 inches deep, although deeper placement may be called for in some instances such as tree planting sites or nurseries for deep-rooted species.

When making an overall application, the soil is "sealed" by pulling a weighted board, heavy pipe, shallow harrow, or roller over the soil immediately behind the injection knives. This is done to break up the channels left in the soil by the knives and to compact the soil surface to slow the escape of fumigant gases from the soil. Disk-hillers, rolling cultivators, or similar equipment is used to do the same for row applications.

Another effective way to apply fumigants broadcast is to direct one or two streams of fumigant into the bottom of each furrow immediately in front of each plowshare of a moldboard plow. The next furrow slice of soil that is turned immediately covers the fumigant, leaving it buried at uniform depth throughout the field, with no channel or furrow left by an injection knife through which the fumes might escape prematurely. Acceptable control can often be obtained with lower rates of fumigant when applied by the plowshare method than by chisel injection.

Overall vs. Row Fumigation

Fumigation in the row with one or two chisels per row or bed is less expensive than overall or broadcast fumigation. It requires purchase and handling of less product and less horse-power to make the application, and subjects the environment to less of the pesticide. It should adequately control moderate populations of most nematodes. However, overall fumigation may be necessary in fields where the same crop is grown repeatedly, with especially high nematode populations, with crops that are especially sensitive to nematodes, in crops for which the period of protection must be especially long (as in some nursery situations), or when it would be difficult to locate the treated rows for planting after the waiting period.

Aeration

It may be necessary to disturb the soil carefully to encourage fumes to escape before transplanting or seeding. The process of forming beds, where they are used, usually opens the soil sufficiently for aeration following overall fumigation, but a shallow disk or harrow may be used if the soil will not be disturbed otherwise. A wait of one or two days after aeration is usually enough to clear fumigant vapors from the soil; DO NOT plant if the fumigant can still be smelled in soil from normal plant root depth.

No Residual Effect

No fumigants have any significant residual nematicidal effects. When soil is aerated enough to transplant seedlings into treated soil, there apparently is not enough fumigant left in the soil to significantly affect nematodes that might re-enter the fumigated soil. In fact, a "biological vacuum" may exist, in the sense that most of the micro-organisms that normally are antagonistic to plant nematodes have been suppressed along with the existing pest population.

Plant parasitic nematodes introduced into soil in which its natural enemies have been suppressed by fumigation may be able to reproduce more freely and rapidly than in unfumigated soil. It is extremely important to avoid re-introducing nematodes into treated soil; common risks of re-infestation include:

- deep tillage
- re-forming beds
- digging planting holes may bring up untreated soil
- infested transplants, a **very** common source
- irrigation water drawn from surface sources, especially canals that drain agricultural lands
- soil on tire treads, tools, and tillage equipment

Non-Fumigant Nematicides

Non-fumigant nematicides are essentially all organophosphate or carbamate pesticides, usually developed primarily as insecticides; some are systemic in plants; all are potent cholinesterase inhibitors and hazardous to handle; all are very water-soluble. They are generally sold in granular formulations, but more concentrated liquid formulations of most are also offered for limited uses.

Granular formulations are usually distributed in furrow at planting or in a band (width depending on crop) before or at planting; some may be applied broadcast for specific high-value crops, and some labels permit post-plant applications in specific cases (crops such as turf, tree fruits, and a few others). **Liquid** formulations may be soluble (Vydate L), emulsifiable (Mocap 6 EC), or simply stable suspensions (Furadan 4F); they are applied as most other sprayable materials, and some may also be applied as drenches (e.g., in transplant water) or via irrigation. Most labels require incorporation of the product into the soil; in heavier soils, mechanical mixing or covering is necessary, but pressure of a planter press-wheel or water application may suffice in lighter (sandier) soils.

Redistribution in soil is entirely in soil solution, so ingredients move as the soil water moves. With excessive rain or irrigation, there is risk of prematurely losing active ingredient from the root zone and water contamination by leaching or run-off. If there is too little water, the active ingredient may not move enough to reach most roots.

Organic matter and clay contents of soil also affect movement of this group of nematicides. In very sandy soils with little organic matter, low binding capacity permits excessive leaching and rapid loss of active ingredient from the root zone, where it is needed. Therefore, these products are often more effective in heavier than in lighter soils, because they are held in the root zone longer. On the other hand, some active ingredients may be so tightly adsorbed by organic matter that they are less available for nematode control.

Soil and water pH affect how long an active ingredient remains in soil. Active ingredients in the organophosphate and carbamate families are acidic, so generally degrade much faster at pH greater than 7; most nematicides degrade at least twice as fast in the lime-based soils (pH 7.5 - 8.5) of Dade County as in acid soils. Binding to soil particles and toxicity may also be affected by pH (oxamyl was reported to be more toxic at pH = 5.5 than at 6.5 or 7.5; carbofuran was toxic at 7.5 and 6.5, required higher dosage at 5.5; phenamiphos was affected less by pH).

Enhanced microbial degradation or biodegradation of pesticides are terms used to describe situations in which the normal process of biological degradation of soil-applied pesticides is dramatically increased, causing premature loss of the pesticide from the target area. When a pesticide is applied to soil, it immediately begins to disappear by at least three routes: chemical degradation, leaching, and biological degradation. The latter occurs by the process of living organisms, usually bacteria and fungi, metabolizing the active ingredient and its break-down products, to use them for their own nutrition.

Repeated exposure of a soil microbial population to the same active ingredient often stimulates reproduction of those organisms which are able to use that chemical, because it is an energy and/or mineral nutrient source that is inaccessible to the other microorganisms in the same soil. Nearly 300 soil-applied pesticides have been reported to have become less effective in some situation because of enhanced or accelerated the rates of their microbial degradation. Herbicides, fungicides, insecticides, and nematicides have all been affected in a wide range of locations around the world, in many soil types, and in association with many different crops. Over-use of any soil pesticide creates the risk of losing its usefulness through enhanced microbial degradation.

The most prominent example of this phenomenon among nematicides used in Florida is fenamiphos (the active ingredient of Nemacur products), which has been found to be subject to enhanced microbial degradation on many golf courses to which Nemacur has been applied frequently, over a long period of time, or both. There are examples in which fenamiphos is degraded ten to twenty times faster than the normal rate of disappearance. The effect of this remarkably rapid rate of microbial degradation of fenamiphos and its active metabolites is that the nematode "control" (suppression of activity) achieved with a Nemacur treatment is very short-lived.

Turf managers who observe that the period of satisfactory control achieved with Nemacur is much less than previously experienced should immediately cease using Nemacur on that soil and seek the best alternative methods for dealing with nematode damage to their turf. Although we do not yet know how applicable experience from other crops and regions will be to Florida turf, it seems likely that a period of complete avoidance of fenamiphos for at least one year and perhaps over two years may be necessary for the soil microbial population that is responsible for this phenomenon to revert back to normal rates of fenamiphos metabolism.

Environmental Problems and User Safety

Nearly all nematicides are classified as Restricted Use Pesticides, and most are Acutely Toxic, Class 3 poisons. Some are among the most toxic pesticides. Handle, store, use, and dispose of them with the utmost respect. Label instructions are important for knowing how to use these products safely.

Fumigants pose both acute (risk of immediate injury) and chronic hazards (long-term effects) to those who come into contact with them. Those who handle, apply, or work in connection with the application of fumigants have the greatest risks of direct exposure, through the skin or by inhalation. All safety precautions, including use of protective clothing and respiratory protection, should be followed to minimize those risks. Minimal skin protection when using any fumigant is to wear clean full-body clothing, including gloves and heavy footwear. Change and launder clothing daily, or discard daily if it is disposable. **Never** wear leather gloves or footwear, as fumigants readily soak into and through leather, which then traps the fumigant against the skin, often resulting in serious burns. Boots and gloves of heavy polyethylene or neoprene may provide reasonable protection against spills, but no material is completely impervious to fumigants. If contact occurs, **immediately** remove contaminated clothing, footwear, or gloves. Read label carefully to be familiar with and follow all safety precautions. ***High toxicity of the organophosphate and carbamate products*** makes them as hazardous to wildlife as to man. Label restrictions regarding risks toanimals or plants that are formally recognized as Endangered Species may apply to some pesticides in most of Florida, and to all nematicides.

Nematicides must be soluble in water to reach their nematode targets, which are aquatic animals. To achieve a significant concentration in soil to a reasonable root depth, high rates are often used (a concentration of 50 ppm in soil solution in a band 1 ft wide and 1 ft deep would take about 10 lb a.i./acre). The soil conditions that make crops in Florida especially sensitive to nematodes (sandy, low organic matter, nutrients readily leached by frequent rains) are also most favorable for rapid leaching and subsequent ground-water contamination by nematicides.

Table 1.

Table 1. Methyl bromide/chloropicrin formulations used on various crops.

CROP/USE	Ratio of Methyl Bromide to Chloropicrin										
	98 2	88.211.8	8020	7525	7030	68.631.4	6733	5743	5050	4555	0 100
Asparagus			*				*				
Broccoli	*	*	*	*			*				
Cauliflower	*	*	*	*			*				
Cucumber											*
Eggplant	*		*	*			*				*
Muskmelon	*	*	*				*				
Onions(bulb)			*				*				
Onions			*				*				*
Peppers	*	*	*	*			*				
Tomato	*	*	*	*	*	*	*	*	*		*
Sweet Potato											*
Vegetable	*	*				*	*				
Strawberry	*	*	*	*	*	*	*	*	*	*	*

Table 1.

Citrus	*		*	*			*				
Pineapples	*			*			*				
Grapes	*			*							*
Other fruits & nuts	*			*							
Plant Bed				*	*			*	*		*
Seed Bed	*		*	*			*	*		*	
Greenhouse	*		*				*				
Soil Fumigation			*				*				
Potting Soil	*		*				*				
Topsoil	*										
This information was compiled as a quick reference for commercial Florida growers. Since not all products of like formulation are registered for all of the same uses, the user must consult and obey the labeling of the specific product being used.											