

# The importance of soil fumigation for nematode control

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***Preplant fumigation is the only acceptable way to control nematodes in some crops. 1,3-D is one of the few products available to do the job.***

**S**oil fumigation was developed over a century ago in France, where carbon disulfide (CS<sub>2</sub>) was used to control phylloxera on grape roots. After World War I, it was discovered that the leftover chloropicrin, or tear gas, was an effective soil fumigant for killing insects and nematodes in pineapple-growing areas. The use of chloropicrin at that time was discontinued when surplus stockpiles were depleted and production of new material proved prohibitively expensive.

In the 1940s, scientists developed a mixture of 1,2-dichloropropane (1,2-D) and 1,3-dichloropropene (1,3-D) as a soil fumigant for preplant nematode control. These materials, marketed as DD Mixture and Telone, were relatively inexpensive and were often used by growers as precautionary measures without confirmation of nematode problems.

Later, it was discovered that ethylene dibromide (EDB), when properly applied, effectively controlled nematodes as well as wireworm and performed better than the propene-propane mixture in warmer soils. It was especially useful for such crops as carrots in California's warm interior valleys, where nematodes are a major production problem.

In the late 1940s, DBCP soil fumigant was patented as a plant growth stimulator and marketed under the trade names Fumazone and Nemagon. DBCP (1,2 dibromo 3 chloropropane) was unique in that it could be used on living plants. It prolonged the productive life of perennial crops such as citrus, grapes, deciduous fruits, and nuts.

Methyl bromide came into use at the same time. It requires plastic tarping for best efficiency and is more costly than other nematicides. Alone, or in combination with chloropicrin, methyl bromide controls most soil-borne pests. It is used on crops such as fresh market tomatoes, grapes, strawberries, and in certified nursery production.

In the 1950s and 1960s, a group of non-fumigant nematicides was developed. Primarily organophosphates or car-

bamates, these chemicals were formulated as granules or emulsifiable concentrates, applied broadcast or as a band in the seed row, and worked into the soil. Movement in the soil depends on water or mechanical soil mixing. Most are active against some insects as well as nematodes. They require extreme care in handling because of high mammalian toxicity. These materials are expensive compared to soil fumigants and have been used in California only under special conditions.

Currently, 1,3-D is under special review by the U.S. Environmental Protection Agency. We have been asked to evaluate the impact of its potential loss to California. This report summarizes our findings.

## Perennial crops

Two million acres of California farmland are planted to perennial crops such as grapes, stone fruits, and nuts. They may remain productive for a decade to a century, after which they are removed and replanted. Nematodes develop on the extensive root systems of perennials, damaging the established crop, and they persist after removal. Old roots and associated soil-dwelling pests need to be eliminated before replanting.

There are two ways to do so: rotation/fallowing for at least four years or soil fumigation. Two major soil fumigants, methyl bromide (MB) and 1,3-dichloropropene (1,3-D), are currently available to growers. Approximately 5 million pounds of 1,3-D, a third of the current California annual use, are applied for establishment of perennial crops. High-dosage broadcast applications of 1,3-D to a properly prepared field soil can provide 99.5 percent nematode control for two years after treatment and up to six years of nematode relief.

Soil fumigation at replanting sites with 1,3-D or MB in most cases returns the cost of the treatment, usually in the form of 10 to 50 percent greater initial plant growth, leading to larger, more productive plants

when they begin to bear three to seven years after planting. Of equal importance, fumigation increases the plant's life-span.

The value of 1,3-D to California agriculture is difficult to estimate, because it depends on a complex of factors such as crop, soil type, and economics. We believe that overall production efficiency might be reduced by 25 percent if this soil fumigant were not available for use at replanting. Greater amounts of other types of nematicides could be used along with more irrigation and fertilization to counteract the reduced nematode control. In some cases, low-value rotation crops, such as grains, that are nonhosts for the common nematodes of the area might be grown for four or more years.

Growers use 1,3-D in integrated pest management (IPM) programs to protect perennial crops from nematode damage during the early years of root development. Nematode attack after root establishment is usually less critical. If rootstocks are available with genetic resistance to the nematode genera present in a specific field, the grower can reduce the 1,3-D treatment by 25 to 50 percent and rely on resistance to protect the orchard for the rest of its life.

In kiwifruit, olive, apple, boysenberry, and fig, no sources of resistance to major nematode pests have been identified. In grapes, several sources of nematode tolerance and resistance are available but not widely used because of inherent growth problems to the vine. Mixed nematode species also present problems, because the rootstock may be resistant to only one nematode species. For example, Nema-guard rootstock provides excellent resistance to root knot nematode (*Meloidogyne* spp.) in peach, nectarine and almond but is highly susceptible to root lesion (*Pratylenchus vulnus*) and ring (*Criconebella xenoplax*) nematodes. Plum and prune rootstocks resistant to root knot and tolerant of root lesion nematodes are highly susceptible to ring nematode and the associated bacterial canker complex. In pistachio, some California seed sources of the common rootstock are susceptible to root lesion nematodes. Black walnut rootstocks have resistance to root knot nematode but are highly susceptible to root lesion nematodes.

The 1,3-D fumigant is a major tool in California for producing quality fruits, nuts, and vine crops. This material, 1,3-D, does not have an extended residual life, nor has it been a groundwater contami-

nant except in isolated instances where shallow groundwater exists.

### Annual crops

Root knot nematodes, the major nematode pests in California field and vegetable crops, are widely distributed in coarse-textured soils of all growing regions, and most species have a wide host range. Fortunately, such soils are well drained and aerated, and can be properly fumigated under the state's varied climatic conditions.

Soil fumigation has been the primary strategy for root knot nematode management on field and vegetable crops for over three decades. Since the other fumigants are no longer available and the high cost of methyl bromide precludes its use for most field and vegetable crops, 1,3-D is the only remaining fumigant nematicide.

Effective control alternatives to 1,3-D are limited, and for many crops are nonexistent. In particular, nonfumigant nematicides (organophosphates and carbamates) have not proved as effective as preplant soil fumigants for root knot control on most crops, because they do not provide season-long protection.

Rotation has limited value for control because of the root knot nematode's wide host range. Many of the nonhost crops provide only a low per acre return. Resistance to root knot nematodes is available in a few annual crops such as tomato, sweet potato, and beans. Resistant cultivars may be developed in the future for some crops, such as cotton. For crops such as carrots, lettuce, and melons, resistance is unavailable.

Root knot nematode (*M. incognita*) damages cotton both alone and in combination with *Fusarium* wilt, and 1,3-D is used extensively on infested fields to control the problem. Nematodes infest 250,000 acres of California's Acala cotton. The nematode/wilt problem is spreading but involves less than 10,000 acres at present. Research at the University of California and other institutions has shown that 1,3-D reduces nematode and wilt damage and increases cotton yields. Further research has shown that nonfumigant nematicide treatments do not provide adequate control and are not comparable to 1,3-D fumigation.

California produces more than 80 percent of the total U.S. processing tomatoes. Several *Meloidogyne* species attack tomato plants, and preplant fumigation has been the main nematode control method.

Recently a limited number of tomato cultivars have been released that show excellent resistance to root knot nematode, providing tolerance to damage (good yield) and reducing nematode populations without the need of fumigation. Resistance in all cultivars, however,

is based on the same single, dominant gene (Mi). Selection of aggressive isolates of root knot nematode able to develop on resistant cultivars is recognized, and aggressive isolates in California have been identified. Successful long-term use of tomato resistance will therefore require the rotation of resistant cultivars with susceptible varieties of tomato or other crops that need soil fumigation. Nonfumigant nematicides have not proved effective in controlling root knot on tomato.

Carrots, potatoes, and sweet potatoes are highly sensitive to root knot nematode, because a very few nematode juveniles can disfigure the taproot or tuber and render it unmarketable. Preplant fumigation with 1,3-D is currently the only fully protective nematicide treatment for these crops, and no resistant cultivars for carrots or Irish potatoes are available. Although damage can be alleviated by planting some carrots and Irish potatoes during the winter to avoid nematode activity, most of these crops grown on infested soils still require protection through fumigation.

Sugarbeet is also highly sensitive to root knot nematode, and infestations are common on sandy soils in sugarbeet-growing regions of the San Joaquin and Sacramento valleys. Nematode wounds allow secondary infections by root-rotting organisms. Economic yields of sugarbeet on infested soils currently are only attainable following preplant fumigation with 1,3-D. Alternative nonfumigant nematicide treatments have been found inadequate, and no genetic resistance to root knot nematode is available in commercial sugarbeet varieties.

Although it affects a more limited acreage, stubby root nematode, *Paratrichodorus* sp., is an injurious pest to sugarbeet, onion, peppers, and tomatoes, where it is successfully controlled with 1,3-D fumigation. The stem and bulb nematode, *Ditylenchus dipsaci*, can injure garlic. Preplant fumigation of infested soil with 1,3-D, along with use of clean seed stocks, can alleviate this problem.

Of critical importance to sugarbeet production in California is management of the cyst nematode, *Heterodera schachtii*, which is widespread in most of the beet-growing regions. Unlike root knot, cyst nematode occurs on all soil types, including the finer textured loam and clay soils, where it is controlled primarily by crop rotation. In some regions, however, rotations may include such nematode host crops as broccoli and cauliflower, which limit the efficacy of this control method. In these situations, the use of 1,3-D fumigation shortens the required length of rotation between sugarbeet crops by reducing cyst nematode populations on finer textured soils. On coarser soils, fumiga-

tion with 1,3-D adequately controls cyst nematode without rotations. Aldicarb, currently under special review, is a registered nematicide alternative for cyst nematode control on sugarbeet and can be effective where initial cyst nematode populations and soil temperatures are low. No commercial sugarbeet varieties are resistant to cyst nematode.

Cole crops are attacked by stubby root, root knot, and cyst nematode species. Usually two or three crops are produced annually on the same land. When the soil is infested with several types of nematodes, fumigation with 1,3-D between crops permits multi-cropping. There is no resistance to any of these nematodes in cole crops.

Many minor and specialty crops in California are grown on nematode-infested soils. Beans, onions, parsnips, celery, spinach, peppers, herbs, spices, as well as ornamentals such as roses and bulbs, are susceptible to root knot and other nematodes. Growers of all of these rely on effective preplant soil fumigation of infested soil.

In annual crops, controlling nematodes with fumigation before planting is the only acceptable method in most instances. Postplant applications after nematode infection have not proved effective.

### Summary

Twenty million pounds of soil fumigants are applied in California each year for preplant management of nematode diseases and associated disease complexes. With the relatively high cost of land and labor in California, soil fumigation permits the economic utilization of land for high-value crops and enables California growers to be competitive. The 1,3-D and MB fumigants are rapidly hydrolyzed in soil, reducing to a high degree their potential entry into groundwater.

University of California researchers recommend the use of chemicals only as a last resort in the management of nematode diseases. The first choice is the utilization of resistance, biological control, and a range of cultural and physical methods for the management of these pests. In many cases, however, such alternatives are not available nor are they likely to be in the near future. Any decision concerning the removal of 1,3-D for the control of nematodes will have a great impact on California's as well as the nation's agriculture.

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