Nematodes are one of the major pests that can seriously limit sugar beet production in Idaho and eastern Oregon. The severity of damage depends on the nematode species present and population densities in the soil at the time of planting. The most common sugar beet nematodes in Idaho and eastern Oregon are the sugar beet cyst nematode (*Heterodera schachtii*), root knot nematode (*Meloidogyne hapla*), and stubby root nematode (*Paratrichodorus* or *Trichodorus* species). For more information about these nematodes, refer to CIS 1072, "Sugar Beet Nematodes in Idaho and Eastern Oregon," http://info.ag.uidaho.edu/Resources/PDFs/CIS1072.pdf.

This publication deals only with the cyst nematode (*Heterodera schachtii*). Over half of the sugar beet acreage in Idaho and eastern Oregon is infested with the sugar beet cyst nematode at a level that requires treatment.

Cyst nematodes generally have limited host ranges compared to root knot nematodes or stem nematodes. However, the sugar beet cyst nematode can parasitize a number of vegetable crops such as red table beet, broccoli, radish, Brussels sprouts, mustard, kohlrabi, and rapeseed, and weeds such as chickweed, nightshade, and goosefoot. Growers can reduce damage from sugar beet cyst nematodes by using a variety of crop management practices such as crop rotation, weed control, early planting, use of green manure, and proper fertilization. For more information on using green manure trap crops, see CIS 1071, "Management of Sugar Beet Nematode," http://info.ag.uidaho.edu/Resources/PDFs/CIS1071.pdf.

Soil fumigation is one way to manage the sugar beet nematode. Soil fumigation is an exacting procedure that must be done properly if satisfactory results are to be obtained. To control sugar beet cyst nematode and optimize sugar beet yield, fields should be fumigated if the soil contains 5 or more viable cysts per 500 cubic centimeters of soil, and the period between sugar beet crops is 3 years or less. These recommendations are based on University of Idaho diagnostic nematology lab results. For more information on soil sampling, refer to CIS 1056, "Sampling Procedure to Diagnose Nematode Infestations,"

usually injured so severely that control measures are ineffective in correcting the damage. Therefore, control procedures are normally based on pre-plant application (mostly fumigant compounds) or at-planting application (non-fumigant compounds).

Soil fumigants will not completely eradicate nematodes. The objective of such treatments is to reduce nematode populations to a level where serious crop damage will not result.

Types of Fumigants

Two classes of soil fumigants are available. The first class includes the true fumigants. True fumigants are volatile compounds that rapidly convert from liquid to a vapor or gas state. True fumigants move as a gas through the soil airspace by diffusion, whereby molecules of gas spread uniformly throughout available space. True fumigants include Telone II and Telone C-17.

The second class of fumigants includes the non-true fumigants such as Vapam (metam-sodium). Non-true fumigants are extremely water-soluble and move easily in the soil as a liquid. Metam-sodium will move from a region of high concentration to one of lower concentration and during the final stage of conversion, as gas in the soil air space, similar to true fumigants.

Factors Influencing the Effectiveness of Soil Fumigation

Nematodes are aquatic animals that live in the water films surrounding soil particles. To be effective, fumigants must penetrate and diffuse into soil pores to contact the nematodes and, in addition, must penetrate the moisture film surrounding the nematodes. Several factors can influence the effectiveness of soil fumigation.

The grower must consult with the sugar factory agronomist to select the correct fumigant nematicides. This depends on the availability of application equipment, time of year applied, and the cost/benefit ratio. Knowledge of biology and habitat of the nematode pests involved will help determine the appropriate chemical and optimum time, rate and method of application.

Many environmental factors can positively or negatively affect the activity of fumigants. Soil type, soil temperature, soil moisture, organic matter content, and certain soil cations can affect the rate of chemical conversion, distance moved, and the rate of movement.

Clay soils tend to restrict movement of all types of fumigants. Although clay soils slow the conversion of Telone II to the gas phase, they actually increase the rate of metam-sodium conversion to MITC, the liquid biocidal state. In fine-textured clay soils, pore spaces are much smaller than those in sandy or sandy-loam soils. Such small pores are likely to be blocked by excess moisture or compaction, making it more difficult for vapors to diffuse. As a consequence, fumigation may be incomplete, especially if the nematicide is highly volatile or short-lived in the soil. Sandy soils, however, contain large pores that are less likely to be blocked by excess moisture or compaction; but an effective surface seal, necessary to prevent rapid loss of vapor, is more difficult with such coarse-textured soils.

High organic matter tends to restrict movement and tie up fumigants, sometimes necessitating the use of higher rates. For effective nematode control, peat and other organic soils require two to three times the amount of nematicide needed for mineral soils. The high rates are necessary to compensate for the adsorption of the nematicides on the organic matter of the soil.

Temperature and weather conditions also influence the effectiveness of fumigants. As soil temperature increases, the rate of conversion of both Telone II to the gas state and metam-sodium to MITC increases. High soil temperature speeds the gaseous diffusion, thus shortening the exposure of nematodes to the toxic fumes. The result is poor fumigation and more nematode damage to plants. Low soil temperature increases the retention of the gas, thus prolonging exposure of nematodes to toxic fumes and resulting in more effective fumigation and less nematode damage to plants.

Freezing temperatures during the winter after fumigation will kill more nematodes that have survived the fumigation treatment, making fumigation more effective. On the oinflunemathe

tfterure7sate and min more effdats. atter of the

season. The number of surviving nematodes will increase faster, and the population may climb high enough to cause damage.

Soil Preparation

Proper soil preparation is vital to maximize product performance.

1. The soil must be free of clods, since fumigants are unable to penetrate them and a good soil seal is not possible with too many clods.
2. Previous crop residues must be thoroughly chopped up, incorporated into the top 4 inches of the soil profile, and allowed to decompose before fumigant is applied.
3. The soil must be loosened to aid the movement of either liquid or gas through the desired treatment zone.
4. Soil moisture must be regulated to the level specified on the label for the fumigant being used.
5. The surface seal is important to increase the concentration of the vapor in the surface inch or two of soil.
6. The soil should not be disturbed for at least 3 weeks, or approximately 1 day for every gallon of true fumigant applied per acre, after treatment.

Both soil temperature and moisture content are important to successful fumigation. The soil temperature below the surface should be between 40 and 80°F. In addition, these conditions help ensure that the target plant parasitic nematode is in a stage susceptible to the fumigant.

The depth at which volatile fumigants are applied varies with dosage, soil temperature, soil moisture, soil type, nematode fumi-

There are two major types of fumigant application methods commonly used for nematode control in sugar beet fields. In type I, solid or broadcast treatment, nematicides are applied to the whole area of a field with the intention of controlling the nematode population throughout the soil profile. Telone is injected at a shank spacing of 20-24" on broadcast applications. Fumigants should be used at the higher label rate to obtain a uniform nematode control. The depth of the application is also very critical. Deeper injection allows the gas to penetrate more soil, and prolongs the exposure time, thus increasing the effectiveness of the fumigation treatment.

Type II is a less expensive method of treating crops grown in rows, and uses simple application devices for applying the chemical along the planting row. However, row treatments do not equal overall treatment for obtaining maximum nematode control. The disadvantage of row treatment is that areas between rows left untreated create the source of reinfestation by surviving nematodes.

With either method, the application equipment of the professional fumigation company should be in good working condition to achieve a uniform application and avoid untreated strips. Figures 1 and 2 show machinery used to apply Telone II.

Sealing Soil Surface After Fumigation and Waiting Period

A soil surface seal is desirable following application of any volatile nematicide, regardless of soil type, temperature, moisture, or preparation. The seal improves nematode control in the surface inch of soil and, in addition, increases retention of the fumigant in the soil.

To create an effective seal, the shank traces left by the application equipment must be disrupted and the soil surface compacted. Disruption of shank traces can be accomplished using equipment that uniformly mixes the soil to a depth of 3 to 4 inches. A tandem disc (or similar equipment) in combination with a ring roller or cultipacker can maximize soil sealing (figure 3).

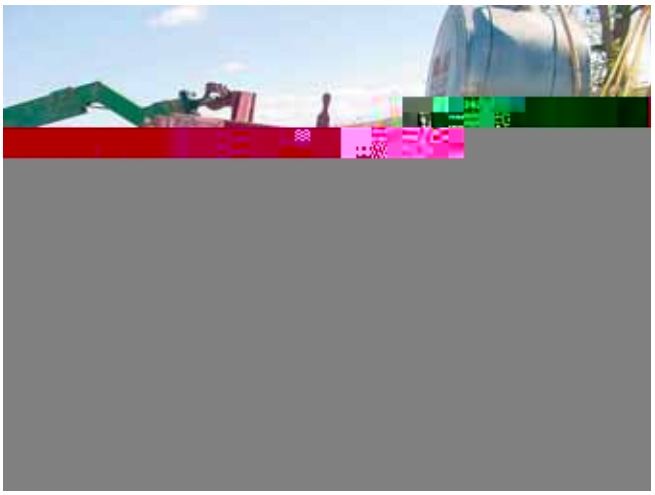

Figure 1. Ripper type soil fumigator for Telone II application

Figure 2. Ripper shank for Telone II application

Figure 3. Telone II applicator, disc and soil compacter

The waiting period between application and planting to avoid injury to the crop and increase fumigation efficiency depends on the rate at which the fumigant was applied, the type of fumigant, soil temperature, and soil conditions. The fumigant leaves the soil quickly when the weather is hot and dry, and may remain longer when it is cold and wet. Soils high in organic matter are especially difficult to aerate. Under optimum conditions, 2 to 3 weeks are usually adequate.

Reinfestation

Reinfestation may occur following fumigation if extreme care is not taken. For example, moving equipment from infested fields to treated fields without cleaning, or leaving untreated strips during fumigation, then moving infested soil from these areas into treated areas, are common sources of recontamination. Avoid using waste or runoff water. Field ends should be treated; even though not planted, they can be a source of reinfestation while performing normal cultivation practices. Weed control is important to reduce the number of nematode host plants in a given field.

Finally, even if we do our part absolutely correctly, the effects of Mother Nature, which are out of our control, on nematode survival and rate of reproduction may interact to make control less than adequate.

Summary of soil fumigation to control sugar beet cyst nematodes:

- Fields should be fumigated if the soil contains 5 or more viable cysts per 500 cubic centimeters of soil, and the period between sugar beet crops is 3 years or less.
- Consult with the sugar factory agronomist to select the correct nematicides. This depends on the availability of application equipment, time of year applied, and the cost/benefit ratio.
- Apply the recommended chemical at the proper time and rate.
- Maintain proper soil conditions (moisture and temperature) before and during the application.
- Allow a sufficient waiting period after fumigation to give enough exposure time to kill nematodes adequately.

The authors—**Saad Hafez** is an extension nematology professor and **P. Sundararaj** is a research associate. Both are with the University of Idaho Parma Research and Extension Center.

Unive

Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Charlotte V. Eberlein, Director of University of Idaho Extension, University of Idaho, Moscow, Idaho 83844. The University of Idaho provides equal opportunity in education and employment on the basis of race, color, national origin, religion, sex, sexual orientation, age, disability, or status as a disabled veteran or Vietnam-era veteran, as required by state and federal laws

July 2009