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SOIL FUMIGATION: How and Why It Works

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The quality and yield of a crop depend, to a large extent, on what happens in the soil. Nematodes, fungus diseases, weeds or soil-inhabiting insects can sap your best acreage of its profits. However, fumigation with nematocides, fungicides, herbicides and insecticides helps control soil pests. Cultural practices, such as crop rotation, working the soil at the right time to destroy germinating weed seeds, and timely planting, are also helpful.

Soil fumigation is not a substitute for proven and accepted cultural practices for crop production; rather, it is one more tool that can be used in an attempt to improve the quality and yield of crops.

Soil is a mosaic of rock particles, plant roots, microorganisms, decaying organic matter, soil solutions, and interconnecting air passages. It is, therefore, a very complex medium in which plants grow. A fumigant, when applied to soil as a stream of liquid, reduces to a vapor of separate molecules that move through the soil according to factors of soil content and condition.

Most of the fumigant molecules dissolve in the soil water; some remain in the air spaces in the soil (soil air). In addition, some fumigant molecules in the soil water are either "sorbed" or react with the soil organic matter. (The term "sorbed" refers to two distinct phenomena: adsorption and absorption. Adsorption means that an extremely thin layer of molecules of gases, dissolved substances, or liquids adheres to the surfaces of solid bodies with which they are in contact. Absorption means that the materials become a part of the solid bodies, and thus may be altered chemically, or broken down and rendered noneffective.)

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As far as is known, fumigant molecules are not sorbed by sand, silt or clay particles except when the soil is very dry, nor do fumigants react and decompose with the mineral fractions of the soil as they do with the organic fractions.

For the purposes of soil pest control, fumigant that is sorbed or decomposed by reaction with organic matter is rendered noneffective because the fumigant can no longer move through the soil by way of the soil water or soil air. This movement, of course, is fundamental and essential to the effectiveness of fumigation as a soil pest control.

MOVEMENT OF FUMIGANTS IN SOIL

The rate of movement of the fumigant molecules through the air spaces is approximately 1,000 times faster than through the water films. This is because fumigant molecules in water keep bouncing into closely spaced water molecules and thus just can't move anywhere in a hurry. In soil air there is so much empty space that fumigant molecules hardly hit air molecules at all, so fumigant molecules move through the air passages without much interference.

Equilibrium between the concentrations of fumigant in soil air and soil water is always changing. Therefore, some fumigant molecules in soil water will pass into soil air when concentration of fumigant in soil water gets too high in relation to concentration of fumigant in soil air. Conversely, when concentration of fumigant in soil air is high in relation to concentration of fumigant in soil water, some fumigant dissolves into the soil water.

It is the magnitude of this ratio that determines the rate of movement of fumigant through soil. If a large proportion of fumigant is in soil air, the fumigant will move through the soil rapidly; if a small proportion of fumigant is in soil air, then the fumigant will move through the soil slowly.

Many factors influence this ratio of fumigant in soil air to fumigant in soil water, and therefore the rate of movement of fumigant through soil. Some of these factors are:

1. Solubility of the fumigant in water
2. Soil moisture
3. Soil compaction
4. Soil temperature
5. Soil type
6. Organic matter

Although these factors occur simultaneously when soil is being fumigated, each factor should be discussed individually to demonstrate its influence on fumigant movement through soil.

1. Solubility

Each fumigant differs in its solubility in water and its tendency to vaporize in air, so for each fumigant a certain rate of application under average conditions must be determined. For example, if we have two different fumigants, we may find 15 molecules of fumigant A and 85 molecules of fumigant B in the soil air for every 100 molecules of soil water. In this case, fumigant B moves through the soil much more rapidly than fumigant A, because fumigant B inherently retains more molecules in the soil air and is less soluble in water.

2. Soil Moisture

In dry soils, the proportion of air spaces to water is much greater than in wet soils and more fumigant is in soil air than in soil water. Consequently, fumigants move through dry soil much faster than through wet soil.

When soils are saturated with water (in other words, when there is little or no air space in the soil), fumigant movement is extremely slow, since almost all movement must take place through soil water. Rapid diffusion won't occur until the water evaporates or drains down into the soil, so that the soil pores can open up.

3. Soil Compaction

The comparison between diffusion in loose versus compact soil is quite similar to the comparison between dry and wet soil. Loose soil has a higher ratio of fumigant in soil air to fumigant in soil water than does compact soil; therefore, fumigants move through loose soils faster than through compact soils. When the soil becomes very compact, most of the air spaces become disconnected from each other and air spaces become encircled with a water film. Then fumigant movement is very slow because of the slow diffusion through the water films.

4. Soil Temperature

When soil temperatures are low, the tendency of fumigants to vaporize decreases while solubility in water increases. Then there is more fumigant in soil water than in soil air and the rate of fumigant movement through the soil is decreased.

5. Soil Type

Clay and sandy soils have about the same amount of **total** air space, but air spaces in clay soils are usually much smaller and more disconnected than in sandy soils. Furthermore, clay soils usually contain higher amounts of organic matter that sorb and decompose fumigants. Thus the rate of fumigant movement through clay soils, especially poorly prepared clay soils, is usually slower than through sandy soils and more fumigant is usually required for pest control.

It has often been assumed that fumigants do not diffuse through clay soils as well as through sandy soils because the fumigant is sorbed on the clay. Actually, very dry clays **do** sorb fumigants strongly, rendering them ineffective as a soil pest control, but it is doubtful that moist clays sorb fumigants to any appreciable extent. There would be no difference in rate of movement through clay and sandy soils if air spaces were the same and continuous, and if the soils contained equal amounts of organic matter.

6. Organic Matter

Fumigants are sorbed by and react with soil organic matter. This sorbed or reacted fumigant is not toxic to soil pests.

Sorption and reaction between organic matter and fumigant is greatest in very dry soils. In very wet soils, on the other hand, the rate of reaction of fumigant with organic matter is slower, but the fumigant movement is so slow that the fumigant has lots of time to react with organic matter. Thus, soil high in organic matter should be moist and relatively loose for best diffusion and pest control.

In optimally moist soils that have an open, continuous air space network, the rate of reaction of fumigant with organic matter is relatively slow and the fumigant can diffuse through the soil quite rapidly. However, because of the reaction of a fumigant with soil organic matter, regardless of moisture conditions, more fumigant is required to obtain the desired movement pattern in a high organic matter soil.

RATE OF REACTION WITH PESTS

Soil pests are found in both soil water and soil air. The fumigant molecules react with the physiological functions of the pests and destroy several life processes.

In addition to the **rate of movement** of the fumigant, the **rate of reaction** with the pest is important. The rate of reaction with the pest is generally proportional to the concentration of fumigant. Thus, a high concentration will kill the pest in a short time, and a low concentration will take a longer time. However, keep in mind the economics of fumigation—striving for pest control at a minimum cost. To be most efficient, the fumigant should remain in the soil zone as long as possible.

When the rate of fumigant movement is very rapid, high concentrations in soil water are required to kill the pests. However, because crops often are planted soon after fumigation, fumigant cannot remain too long in the soil or plant toxicity will occur.

The fumigant's inherent toxicity thus influences the amount that should be used, as well as the degree of pest control obtained. Toxicity is also affected by temperature. One fumigant may be effective over a wide temperature range, while another may be effective only in a limited range. A compromise in soil conditions is required to result in both good pest control and no plant toxicity.

THE GENERAL PATTERN OF FUMIGANT MOVEMENT AND PEST CONTROL IN FIELD SOILS

If a fumigant of known toxicity and solubility were injected deeply into a uniformly moist, porous soil of an optimum type, temperature and organic content for pest control, the **rates of movement and reaction** of the fumigant would be equally rapid and maximally effective in all directions. Under such optimum conditions, a single stream of fumigant would give a cylindrical pattern of movement and pest control. This pattern would get larger as the rate of fumigant movement decreased, and control would be uniform, economic and effective throughout the area.

If the fumigant were applied in streams quite far apart, say 4 feet as in a row treatment, a number of cylindrical patterns of movement and control would be obtained. If the streams were quite close together, say 1 foot apart as in a broadcast treatment, the fumigant movement and pest control patterns would overlap and coalesce, but fumigant concentrations would be horizontally uniform and would vary only in the vertical direction through the soil.

However, the rate of fumigant movement through soil is **not** normally equal in all directions, and control patterns are not optimum. For example, fumigant usually is injected 6 to 12 inches deep. Since the soil above the injection point is usually looser and drier than soil below the injection point, the fumigant tends to diffuse upward more rapidly than it does downward, and never maintains very high concentrations near the surface. In this case, pest control near the surface may be inadequate because fumigant movement is too rapid to maintain high concentrations.

The zone of effective pest control below the injection point is usually larger, simply because there is more soil present in which to control the pests, and because higher concentrations of fumigant are maintained for longer periods of time due to resistance of the soil to downward movement.

If the surface soil is too dry, moisten it before fumigation. Light overhead sprinkling is the preferred method for moistening surface soil. With furrow irrigation, surface soil and subsoil will become wet and unless subsoil is allowed to drain freely for quite some time before fumigation, the combination of high compaction and high moisture may seal off downward movement completely.

Another helpful practice before fumigating is to loosen up the compact subsoil or hardpan by deep cultivation to about 2 to 3 feet. This practice will be effective only with soils of the right texture that have an optimum moisture content in the subsoil. To reduce fumigant loss due to dry, loose surface soil, compact the soil surface immediately **after** fumigating.

If the soil is quite dry on the surface **and** in the subsoil, excellent fumigation results can be obtained by moistening the soil from the surface downward by sprinkling or irrigation and compacting the surface after fumigation.

If the soil has a moist, loose surface and a wet, compact subsoil, let some of the moisture drain out of the subsoil before fumigating; otherwist the subsoil may be so wet and compact that the air spaces are actually sealed off and discontinuous.

Always compact surface soil after fumigation.

These practices **increase** soil resistance above the injection point and **decrease** resistance below the injection point. This control of upward and downward diffusion is important for three reasons:

1. To increase the length of time that the fumigant remains in the soil.

2. To drive the fumigant deeper into the soil.

3. To maintain higher concentrations in the soil surface for a longer period of time.

Optimum soil conditions for pest control are a moist, compact surface soil and a moist, loose subsoil.

If the surface is **wet and loose** (or compact) and the subsoil is **wet and compact**, do not fumigate, for two reasons: (1) fumigant cannot escape from wet soil and may cause plant toxicity; and (2) when the soil does start to drain, pores in the surface soil will open up first and the fumigant will diffuse upward and escape.

Low soil temperature, high soil compaction, and high soil moisture all tend to make fumigants linger in the soil. When all of these conditions occur at the same time, plant toxicity may be serious. This is one of the primary reasons why fall fumigation is preferred over spring fumigation. If spring fumigation is necessary, increase the interval between treating and planting if soil conditions will cause fumigant to linger.

Organic matter in soil is nothing but trouble as far as soil fumigation is concerned. All organic residues are detrimental.

Fresh crop residues are detrimental from two standpoints: (1) They may harbor live nematodes or eggs or fungi in protective sheaths that the fumigant cannot penetrate; and

(2) they react with the soil fumigant to an even greater extent than does natural organic matter. So, allow fresh residues to decompose as much as possible before fumigation.

Decomposition accomplishes three desirable things: (1) It releases the nematodes and fungi from their protective sheaths; (2) it reduces amount of organic matter in the soil; and (3) it forms organic matter that is usually more inert with respect to the fumigant than is fresh residue.

Use higher rates of fumigant to overcome the problem of high organic matter in the soil. Apply when soil is moist—not too dry or too wet. If the soil is too dry, the natural reactivity of fumigant with organic matter is enhanced. If the soil is too wet, diffusion is slow and the fumigant has more time to react with organic matter.

The crux of the organic matter problem is to get the fumigant to diffuse as far and as rapidly as possible before decomposition by organic matter inactivates it. This is best achieved when surface soil and subsoil are loose and moderately moist.

The **deeper** a fumigant is placed into the soil, the **slower** will be its rate of escape and the better will be the overall pest control. However, increased injection depths require a higher dosage rate to overcome the fumigant loss from reaction with soil organic matter. Applications 8 to 10 inches deep are preferred with annual crops, but injection depths up to 3 feet may be necessary in soils to be planted to perennial crops, such as orchards, brambles or grapes.

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