PRINCIPLES OF SOIL FUMIGANT DIFFUSION

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The nature of the movement of fumigants.

Soil consists essentially of a large number of very small interconnecting tubes, the solid sides of the tubes being made of mineral or organic matter. The tubes are covered on the inside with a layer of water and inside this sheath is the more or less interconnecting air-space framework of the tubes.

A fumigant, when applied to soil as a stream of liquid, evaporates to give physically separated individual molecules which move in a random direction through the soil in the same manner as do air molecules. Eventually most of the fumigant dissolves in the soil water, some remains in the soil air and some is sorbed by or reacts with the organic matter in the soil. Except for very dry soils, fumigants are not sorbed by and do not react with the mineral portions of the soil.

The rate of movement of the fumigant molecules through the soil air spaces is so much faster than the rate of movement through the water layers that for all practical purposes the latter is of minor importance in most soil situations. As the molecules move through the air spaces, movement of molecules from water into the air takes place in zones of high concentration of fumigant in the soil water in relation to the concentration in the soil air. When the relative concentration in the soil air is high some of the fumigant molecules dissolve in the soil water. Equilibriums between the soil water and the soil air are being continually established at the edge of the moving front of fumigant molecules such that for a given soil situation the ratio of the concentration of fumigant in the soil air to fumigant in the soil water is always constant. It is the magnitude of this ratio that determines the rate of movement of fumigant through the soil. If the ratio is large (i.e., a large proportion of the fumigant is in the soil air), then the fumigant will move through the soil rapidly. If the ratio is small (i.e., a small proportion of the fumigant is in the soil air), then the fumigant will move through the soil slowly. Many factors influence the ratio of fumigant in the air to fumigant in the water, and therefore, the rate of movement of the fumigant. These factors are shown below.

1. Fumigants differ as regards their solubility in water and their tendency to vaporize. Under similar soil situations there will be approximately 15, 10 and 2 molecules of the active ingredients of Telone, EDB and Fumazone in the soil air for every 100 molecules in the soil water. Thus, Telone will move more rapidly than EDB and EDB much more rapidly than Fumazone.

2. Dry soil has a much higher ratio of fumigant in the soil air to fumigant in the soil water than does moist soil and, therefore, fumigants move through dry soil much faster than they move through moist soil. Saturated soils have practically no air spaces and movement through these soils is extremely slow.

3. Loose soil has a higher ratio of fumigant in the soil air to fumigant in the soil water than does compact soil and, therefore, fumigants move through loose soils faster than through compact soils. In very compact soils most of the air spaces become disconnected from each other (i. e., surrounded by water) and fumigant movement is very slow.

4. With decreasing temperatures the tendency of fumigants to vaporize decreases and their solubility in water increases. Thus, the ratio of fumigant in the soil air to fumigant in the soil water decreases and the rate of movement of the fumigant through the soil decreases.

5. Because clays do not normally sorb soil fumigants, no difference in rate of movement through clay soils and sandy soils would be expected where the air spaces in the soils were of similar size and the soils contained equal amounts of organic matter. However, clay soils usually have smaller air spaces and more disconnected air spaces than do sandy soils. Furthermore, clay soils usually contain higher amounts of organic matter that sorbs and decomposes fumigants. Therefore, the rate of movement of the fumigant through clay soils is slower than through sandy soils and the amounts of fumigant required may be greater.

6. Organic matter irreversibly sorbs and decomposes soil fumigants. The action appears to be greatest in dry soils, next greatest in saturated soils, and least in moist soils with respect to achieving the largest possible zone of fumigant movement. Considerably higher amounts of fumigant are required to obtain the same movement pattern in a high organic matter soil as would be obtained by the normal amount of fumigant in a low organic matter soil.

The nature of nematode control.

Nematodes live in the soil water and thus it is the fumigant molecules in the soil water that react with the nematodes and destroy their body processes. The rate of reaction of the fumigant molecules with the nematodes is generally proportional to the concentration of the fumigant molecules in the soil water. Thus a high concentration of fumigant molecules will kill the nematodes in a short period of time and a low concentration will take a much longer period of time. Likewise when the rate of movement of the fumigant through the soil is very rapid, higher concentrations of fumigant in the soil water are required to kill the nematodes than when the rate of movement of the fumigant is slow. The same principle applies in regard to the toxicity of fumigants to plants. Thus, for most efficient use of fumigants in killing nematodes the fumigant should remain in the soil zone being treated for as long as possible. However, because crops are usually planted soon after fumigation, the fumigant cannot be permitted to remain for too long in the soil or plant toxicity will occur. A compromise in soil conditions is thus required to satisfy both objectives (i. e., good nematode control and no plant toxicity.)

The inherent toxicity of the fumigant is also a factor that influences the degree of nematode control obtained. Two molecules of the active ingredient of Fumazone has the same killing power for nematodes at 70°F as does 5 molecules of ethylene dibromide and 15 molecules of Telone. The relative toxicity of the fumigants varies with temperature. The toxicity of EDB and Fumazone to nematodes decreases with decreasing temperature, becoming quite low with EDB at temperatures below 45-50°F. The toxicity of Telone to nematodes does not vary greatly between 40° and 90°F.

The general pattern of fumigant movement and nematode control in field soils.

If the rate of movement of fumigant through soil were equally rapid in all directions, then a stream of fumigant applied with a tractor rig would give a cylindrical pattern of fumigant movement and nematode control. Providing the organic matter in the soil were low, the nematode control pattern would get larger as the rate of movement of the fumigant through the soil decreased. If the tractor rig applied a number of streams of fumigant quite far apart (e. g., 4 feet) as in row treatment, a number of cylindrical patterns of fumigant movement and nematode control would be obtained. If the streams were quite close together (e. g., 1 foot) as in broadcast treatment, the fumigant movement patterns would overlap and coalesce so that the concentrations of fumigant would be uniform in the horizontal directions and would vary only in the vertical direction through soil. Likewise uniform nematode control would be obtained in the horizontal directions and nematode control would vary only in the vertical direction.

However, the rate of movement of fumigants through the soil is not normally equally rapid in all directions and somewhat different patterns of nematode control than those described above are obtained. In the majority of field situations the fumigant is injected only 6 to 12 inches deep. The soil above the injection location of the fumigant is usually looser and drier than the soil below the injection location of the fumigant. Furthermore, there is a lot less of it. Thus, the fumigant tends to diffuse upward more rapidly than it does downward and never maintains very high concentrations near the surface of the soil. Nematode control may not be obtained near the surface. The zone of nematode control below the injection location is usually larger than the zone above the injection location simply because there is more soil present in which to control nematodes and because higher concentrations of fumigant are maintained for longer periods of time due to the resistance of the soil to movement of the fumigant downward.

We would like to increase the resistance of the soil above the injection location to upward movement of fumigant and decrease the resistance of the soil below the injection location to downward diffusion of the fumigant in order to:

1. Increase the length of time that the fumigant remains in the soil but not so long as to cause plant toxicity.

2. Drive the fumigant deeper into the soil.

3. Maintain higher concentrations in the soil surface for longer period of time.

If we can achieve the objectives described above, we should obtain nematode control at the surface of the soil.

Nearly all of the do's and dont's of soil fumigation are based on this general principle.

Do's and don'ts of soil fumigation.

1. How to avoid plant toxicity.

Plant toxicity is the net result of a sensitivity of the crop to the fumigant and the concentration and location of the fumigant in the soil at the time the crop is planted and starts to grow. For example, some crops are very sensitive to Fumazone, others are very tolerant. Telone is not more toxic than EDB but because so much less of the latter in comparison to the former is normally used, it can generally be used with a shorter interval between treating and planting and more safely. Low temperatures, high compaction, high moisture all tend to make the fumigants linger in the soil for a longer time after application, and when these conditions occur all at the same time, the problem may be serious. This is especially true with Fumazone on sensitive crops because of its inherently slower rate of movement in comparison with the other two fumigants. The danger is present, however, for EDB and Telone as well. A most serious problem is caused by fumigating in very wet soil and then planting directly into the trapped fumigant. In such a situation, should it arise, the seeds should be planted away from the fumigation rows. In any case, under conditions where the fumigant tends to longer for excessively long periods in the soil, the interval between treating and planting should be appropriately increased.

2. How to evaluate and prepare soil low in organic matter for soil fumigation.

If the soil is in normal conditions it will have a moist compact subsoil and a loose dry surface. Providing the surface is not too dry and the subsurface not too wet or compact, the normal recommendation would be to compact the surface immediately after fumigating. If the surface soil is dry, it should be moistened prior to fumigation (where this is possible) and compacted after fumigation. Care must be taken in this moistening process since on irrigation we will wet both surface and subsurface and unless the subsurface has been allowed to drain freely for quite some time before fumigation, the combination of high compaction and high moisture in the subsurface may seal it off completely from the action of the fumigant. Light overhead sprinkling would be the preferred method of moistening the surface soil where this is possible. Another helpful practice is to loosen up the compact subsoil or hardpan by deep cultivation (2-3 feet) prior to fumigating (generally this practice will only be effective in soils on the dry side). All of these practices should increase the depth of nematode control and improve nematode control in the surface layers of the soil.

If a normal soil is quite dry in the surface and in the subsoil, excellent fumigation results can be obtained by moistening the soil from the surface downward and compacting the surface after fumigation. If the soil is extremely wet it probably should not be fumigated. Not only will plant toxicity occur but when the soil does start to drain free of water, the pores in the surface soil will open first and the fumigant will escape from the surface. It will not diffuse downward because the compact subsoil will still have its pores sealed off with water.

3. <u>How to evaluate and prepare soil containing large amounts of crop residues or soils high in organic matter.</u>

All organic residues, whether fresh crop residues or the natural organic matter of the soil, are detrimental to soil fumigants. Since organic matter is more or less a part of all soils, it cannot be avoide and must simply be managed.

Fresh crop residues are detrimental from two standpoints. They may harbor live nematodes or eggs in a protective sheath, and they react with the soil fumigants in most instances to an even greater extent than does the natural organic matter of the soil. In some instances, such as the reaction of EDB with fresh alfalfa residues, the type of organic matter may be more than usually detrimental to the action of the fumigant. It is recommended that fresh residues be allowed to decompose as much as possible prior to fumigation. This accomplishes three desirable things. First, the nematodes or eggs are released from their protective cover, second the organic matter content of the soil is reduced and third, the soil organic matter formed is usually more inert with respect to the fumigant than is the fresh residue.

When a soil is high in natural organic matter, special procedures are necessary to obtain the best fumigation results. With soils such as these, increased amounts of fumigants should, of course, be used. It will probably be better to loosen the subsoil than to compact the surface soil for best fumigant distribution. A loose soil throughout a depth of 2 to 3 feet would be a good objective to strive for. The soil should not be too dry or too wet. In the former case the natural reactivity of the fumigant with the organic matter appears to be enhanced, while the latter case diffusion through the soil is slow and the fumigant is reacting rapidly with the organic matter while slowly diffusing. The crux of the organic matter problem is to get the fumigant to diffuse out as far and as rapidly as possible before decomposition by organic matter inactivates it. This is best achieved in a loose, moderately moist surface soil and subsoil.

4. <u>How to get maximum mileage out of a fumigant by selection of the proper injection depth.</u>

The deeper a fumigant is injected into soil, the slower will be its rate of escape from the soil and the better will be the overall nematode control obtained. However, depending upon the dosage, too deep an injection may result in poor nematode control at the surface of the soil. For row or broadcast fumigation for annual crops, the injection depth should never be less than 6 inches. For broadcast application 8 to 10 inches is preferable and for row treatment, especially where plant beds are formed, as much as 12 to 14 inches may be desirable.

With the higher dosages of fumigant for preplant or side-dressing treatments in orchards, the fumigant should be injected at least 12 to 14 inches deep and considerably deeper injections may, if mechanically possible, be used. The best practice, if possible, would be to use two injection depths.