Observations on the Mechanics of Soil Fumigation

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MUCH HAS BEEN SAID about the conditions under which soil fumigants can be effectively applied. You recall them all: tilth, well cultivated to 10 inches; moisture, ideal for seed germination; temperature, 35° to 85° F.; a minimum of undecomposed plant residue; apply at 12-inch spacing and 6 to 8 inches deep, using a railroad iron drag for sealing.

Perhaps, if we look closely at the soil, we may see why these factors are important.

Soil, and we shall speak primarily of mineral soil, is composed of particles ranging in size from small rocks down to minute particles, distinguishable only under a microscope. Soils composed primarily of large particles we call either gravel or a coarse sand. If the particles are primarily all very small, we call the soil a clay.

If we carefully scrutinize a handful of soil, we find that the particles fit together rather loosely and that there is between these particles a considerable open or pore space. The volume of this pore space varies from one soil to another. For a coarse sand, pore space is 35 percent; but for a clay, it may reach 53 percent. This means, of course, that in 1 cubic foot of sandy soil (1,728 cubic inches), 605 cubic inches is air space.

Now, if we could take all the particles in a cubic foot of sand and measure the surface area of them, we would find that it covered 8,318 square feet. If we used a cubic foot of clay, we would find that the surface area of all the particles totaled 173,900 square feet, or about 4 acres.

When soil is properly tilled, particles of the soil fit loosely together and, upon cleavage, will break apart into individuals rather readily if the soil is a sand or a sandy loam. If the soil is a fine-textured clay, the minute particles, sometimes as small as .0049 millimeters in diameter, or a little larger than a bacterium, will group themselves together into a crumb. Several hundred of them may combine into these crumbs, and even the crumbs may combine, forming clods; but under normal conditions these crumbs cleave one from another rather readily. If soil is worked too wet and under heavy pressure, the particles, either of a sand or of a clay, are mechanically compressed; and the irregular surfaces become interlocked, holding the particles together into a hard, compact clod. When this is done, the pore space of that soil is materially reduced.

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Of course, soil is never completely dry. In it, there is always a certain amount of moisture, even when the soil may appear dry. This moisture is held not only in a thin film surrounding the points of contact between particles but is held also as imbibed moisture. This latter may be imbibed or it may actually be held in the cleavage plane spacing, according to the amount of moisture present. This latter accounts for the shrinkage and cracking of clays upon drying. If the soil is completely saturated, or waterlogged, all the pore space is filled with water and air is completely excluded. However, the soil under normal conditions will not long remain saturated, for gravity will remove the larger portion of the water, leaving again only a thin film of moisture around each particle or imbibed within the colloids. This water, removed by gravity, percolates slowly down through the soil to gravel strata, through which it may flow to natural stream drainage or to underground lakes.

If the sandy loam soil contained sufficient moisture to assure germination, there would be approximately 12 percent moisture present. This would be the equivalent of 6,700 cubic feet per acre foot of soil. In an acre foot of sandy loam, there would be 15,200 cubic feet of pore space. This, reduced by the 6,700 cubic feet of water, would still leave a total of 8,500 cubic feet of pore space. If we consider a clay loam soil or a clay, we would have approximately 25 percent moisture present for good seed germination. This would be 875,000 pounds of water, or 14,000 cubic feet of water. The pore space in a clay loam would amount to 23,200 cubic feet. From this let us deduct the volume occupied by the water; and we would find a total of 9,200 cubic feet of pore space remaining. It is interesting to note how closely the actual pore or air space in clay loam soils corresponds to the pore space in a sandy loam soil, when we consider the additional moisture present.

Temperature and temperature changes have a profound effect on soil. Of most interest to us is the movement of soil air under temperature changes. During the night, the air in soil is comparatively cold. In the morning, when the sun again reaches the soil, it warms slowly; and the cold air in the pore space gradually expands, forcing a portion of it out of the soil. Then, as evening comes, the air in the pore space contracts and fresh air is drawn in from the soil surface. We get, then, a sort of soil breathing that gradually circulates the soil atmosphere. During the winter months, these temperature changes are much less than during the summer; hence, a much slower air circulation takes place. This breathing, of course, changes the moisture content of the soil, depending upon the humidity of the air at the time air is drawn into the soil complex.

Let us consider now the injection of a soil fumigant into a soil in proper tilth and of proper moisture content. Injected at a depth of 6 inches, the fumigant volatilizes rather slowly. An application of 20 gallons of D-D completely volatilized yields 660 cubic feet of D-D vapor. (D-D, incidentally, is a registered trade-mark of Shell Chemical Corporation). This would fill but 6 percent of the pore space in an acre foot of normal soil under a normal moisture content, or but 3 percent of the pore space if we consider, as we must, that we are fumigating at least 2 acre feet of soil.

If, now, we increase the amount of moisture present in either of these soils up to, or nearly to, complete saturation, there will be little opportunity for the penetration of the 660 cubic feet of D-D vapor present due to the pore passage blockage by the increased volume of water. We can expect, therefore, that the rate of D-D vapor penetration will not only be greatly reduced and the completeness of penetration limited but the effective control of the soil-borne organisms will be thereby influenced.

Let us now consider that we introduce into a well-tilled, moisture-free soil, sections of plant residue, corn stalks, roots, undecomposed cover crop, twigs, leaves, or such material. It can be seen that the contact between the soil particles and the portions of plant residue is not as firm as though only soil were present and that air or gas movement along the plant residue would be much less unimpeded than it would be through soil only. The interchange of vapor in soil full of plant debris would be, therefore, much more rapid than it would be in pure soil. If the residue lies at an angle and one end protrudes slightly above the surface of the soil, the twigs or sticks would act similar to a chimney and would tend to ventilate the soil much more rapidly. Moisture in the soil would change this factor but little and would still permit the very rapid movement of the soil fumigant, never permitting a lethal concentration of gas to build up, particularly along the surface of the plant residue.

Should we be working in soil of comparatively low temperature, down in the range of 32 to 35 degrees, then we could expect that the movement of the vapor within the soil between day and night would be comparatively low and that the dissemination of the D-D vapors through the soil pore space would be very, very slow. In fact, measurements made and reported by Mr. C. W. McBeth, Nematologist, Shell Agricultural Laboratory, Modesto, California, indicate that under low temperatures almost twice as long is taken before a lethal concentration of D-D can be built up. With the higher temperatures, 80 to 85 degrees, the difference between day and night temperature would cause a greater change of volume; consequently, a much more rapid movement of the D-D vapors through the soil; hence, a much more rapid kill. It might be well to point out at this point that, as the D-D vapor approaches the surface of the soil, say, the top inch, the rate of dissipation would be greatly increased due to the rapid movement of fresh air through the pore interstices due to temperature changes. It is, therefore, apparent that in this surface layer of 1 inch, toxic concentrations of D-D are much less likely to be built up. Fortunately, however, this surface layer usually is subject to alternate wetting and drying, which is favorable to the demise of nematodes.

Because of the fact that D-D must penetrate through the soil pore space, we do not believe it is advisable to space D-D applications wider than

12 inches apart, thus making it unnecessary for the D-D vapors to penetrate farther than necessary. It is advisable to adopt this arbitrary distance of 12 inches to assure that the D-D vapors penetrate easily from point of injection to point of injection.

The matter of soil sealing following a D-D application is one of utmost importance. One of our reasons for soil cultivation is the loosening of the soil to increase pore space as much as possible. When soil is of proper tilth for D-D application, this pore space is at a maximum. Following the D-D application, it is necessary to pull some sort of a tool over the ground to seal the shank channels left by the injection. When soil is moist, only a light drag should be used which will smear the surface of the soil or compact and force together in a compact, thin film only the upper soil particles. This will permit the D-D vapors to penetrate through the soil pore space up to the very surface of the soil. If, however, one uses a heavier roller, the surface of the soil is not only compacted but the entire soil mass is compacted, depending upon the weight of the roller used. This not only seals the soil but reduces the pore space of the soil, limiting the ability of the D-D to penetrate through it. There are conditions under which this may be advisable, but more data must be gathered before definite recommendations can be made. Let us assume, for instance, that we may be compelled to work in a comparatively dry, loose soil; and the case must be considered only one of hypothetical interest. If we make a D-D application under these conditions, we would expect rapid volatilization of the D-D and rapid movement through the soil pore spaces. If we then use a heavy roller, compact the mass as much as possible, thereby curtailing the movement of D-D somewhat, we can expect better control than would be achieved if the soil were left loose, dry, and open.

We have purposely left to the end of our discussion reference to undecomposed root materials present in soils at the time of soil fumigation. A considerable volume of experimental work has been done on such nematode-infested materials as potatoes and galls on undecomposed roots of alfalfa and trees or vines. While we have many reports that nematodes lying within undecomposed galls are killed, observations made on commercial applications indicate that larvae lying in potatoes or undecomposed galls are not killed and are left to reinfest soil when decomposition is completed after fumigation.

No time limit for decomposition of root materials can be given, and each job to be done must be carefully inspected in order that the state of residual root materials may be determined.

In orchards, it is not possible for root materials to decompose in less than a year; hence, it is not advisable to treat old deciduous or citrus orchard land until at least 1 year has elapsed from the time the trees were pulled. Then, too, tree roots lie deep, much deeper than fumigation can penetrate normally; and decomposition must be at least partial in order that the fumigant may follow along down the root channel, giving a maximum fumigation.

Frequently, following applications of D-D during winter months, unpredicted rains fall immediately after completion of the job. Besides limiting the effectiveness of the fumigation, the gases may be completely sealed in or absorbed in the soil moisture so as to remain undissipated for a long period of time. Under these conditions, it is advisable to insist on careful aeration of soils prior to planting. The best practice would be to plow again or at least disc to a depth of 8 to 10 inches. Should this be impossible and chiseling the only cultivation given, insist on at least chiseling both ways.

Listing prior to bed planting will also be sufficient to properly aerate soils.