rooting of plants. My work, I think, is vital in the rooting of plants. I couldn't help but reflect upon it at the time he made his presentation. My work at VPI is in the field of plant pathology and nematology, that particular field of proper protection from various plant diseases.

Dr. Osborne presented the following paper.

SOIL STERILIZATION AND FUMIGATION

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Plant diseases become a limiting factor where plant propagation areas are used intensively. There are four general groups of causal agents of plant diseases; fungi, bacteria, nematodes, and viruses. Following are some pertinent characteristics of each of these disease producing organisms. Fungi - generally microscopic, filamentous organisms that reproduce by spores (seeds), commonly air borne. Spores produce germ tubes that may penetrate directly into the plant tissue or through natural openings or wounds, and cause infection. Bacteria - microscopic, one-celled organisms which cannot withstand desiccation. None of the plant disease bacteria produce spores, thus they cannot remain alive while being carried great distances in the air as can fungi. Bacteria enter plants through natural openings or wounds. Nematodes - Eel-shaped, microscopic organisms that may inhabit the soil in immense numbers. They require water for movement. Most frequently injury is caused by feeding in or on the roots but some can infect the upper part of the plant. Nematodes reproduce by eggs. They are not commonly transported by wind as are fungus spores. Viruses - Sub-microscopic entities which must be transported from plant to plant by man's activities or by insects or mites. Viruses cannot penetrate directly but must be placed into a wound or injected during insect feeding. So far as is known, viruses cannot multiply outside their host plants or insect vectors and in some cases become non-infectious when the host plant dies.

Many disease causing organisms referred to as soil inhabitants are capable of residing in the soil for a period of several years, without access to its host. This is especially true of certain fungi; notable examples being *Rhizoctonia* the principal cause of seedling camping-off and stem canker, *Fusarium* and *Verticillum* which cause wilts and *Pythium* which causes damping-off and root-rot of seedlings and cuttings of susceptible plants. Other organisms, called soil invaders, do not persist as long in the soil. Many of them survive only as long as the host material, either living or dead, persists as a substrate for their existence. When these disease organisms are not eliminated from the soil plant growing, at best, is an inefficient operation that does not realize the maximum profit potential.

PEST CONTROL WITH HEAT

Heat is considered by many authorities to be the most effective disinfectant for the destruction of pests in soils. Nematodes are killed when exposed to 120° F. for 30 minutes. Most plant disease-causing fungi are killed at 140° F. for 30 minutes. All disease-causing bacteria and most viruses are killed at 160° F. after the same period. Weed seeds are usually killed at 180° F.

Dry Heat Treatments

Dry sources of heat such as flame and electricity are being used to a limited extent. Newhall and Nixon (3) discuss methods of disinfesting soils by electric pasturization when steam is not available. Portable oil or kerosene burning "flame pasturizers" are now being marketed. One such apparatus consists of a heated, hexagonal, slightly sloping cylinder, 20 inches in diameter and 8 feet long, that revolves about 40 times a minute. A flame is directed into the lower end of the cylinder against the direction in which the soil moves. Soil shoveled in the upper end reaches a temperature of 175° to 190° F. as it drops from the lower end of the cylinder.

Steam Treatments

Steam is a very efficient source of heat and, therefore, is the best method of heat treating soil. It quickly kills all disease causing organisms, without causing injury to nearby plants or humans. Cole (2) reports that "While there are many methods of applying steam to soil, in each case its movement is by diffusion through the continuous pores of the soil to the cold area where it condenses. Although a temperature of 180° F. for 30 minutes is recommended to destroy pests, to reach a 180° F. in the coldest corner of a stationary soil mass, most of the soil will have had to reach 212° F. To steam soil at less than 212° F., moving soil and mechanical mixing of steam and soil must be used, or equipment must be built for producing steam-air mixtures of less than 212° F.

When steam under pressure is released into a stationary soil mass which is at 70° F., the steam expands and drops to atmospheric pressure and 212° F. temperature. It condenses quickly on the cool particles at its point of entry. Condensation continues and the temperature of the soil at that point rises, from the heat being released, until 212° F. is reached in the area next to the outlet, the steam accumulates and moves on through the soil pores to condense on the next cooler zone. The temperature rises as the air is pushed out until 212° F. is reached, at which time the pores contain all steam.

Steam moves upward through soil about twice as fast as it does downward or sideways. A given soil has a maximum rate for condensing steam and, if the steam input exceeds this rate, "blow outs" occur. Once a "blow out" of steam from the soil occurs, steam is bled from the rest of the treatment area and heating is greatly reduced. Greatest efficiency is obtained at just below this point, through balancing the steam flow rate and the quantity of the soil treated.

Since steam penetrates very poorly into compacted soil, benches or beds should be thoroughly cultivated to the desired treatment depth. All clods and lumps should be broken up. Soil moisture, in excess of that required for good planting tilth, decreases efficiency because wet soil requires more heat to reach the same temperature and the reduced pore space slows steam passage.

Treatment Methods

Buried Tile Method

This is a very efficient method of treating soil in greenhouse benches, beds, or outdoors. It consists of placing three or four inch clay drain tiles in rows 18 inches apart and 12 to 16 inches deep in soil to be treated. Steam is released into the tiles until a soil temperature of 180° F. is maintained in the coldest corner for 30 minutes.

Surface (Thomas) Steaming

Steam is applied to a covered area of the soil surface, and diffuses downward through the pores. Disadvantages in this method are: 1) steam moves less rapidly downward than upward through the soil, 2) soil conditions must be ideal for effective penetration of the steam, 3) provisions must be made for the escape of air from the soil pores as it is displaced by steam, therefore, this method is generally not as effective as the buried tile method.

Vault Steaming

Containers of soil are steamed in a chamber tight enough to hold steam but not so tight as to allow a pressure build-up. Containers should be separated by ½ inch in each direction to permit ready flow of steam. The chamber can be modified for bulk soil steaming by placing tiers of steam pipes throughout the chamber. The design should be such that no soil is more than six inches from a steam outlet.

Steam Rake

Steam is released into the soil through pipes attached to vertical chisels mounted eleven inches or more apart on a hollow steam header pipe. A powered winch draws the device through the soil at the rate of 6-8 inches per minute. Baker and Olsen (1) have found this device to have the following disadvantages: "Because steam is released at points eleven inches or more apart, the rake must not be moved forward so fast that the expanding spheres of steam do not have time to meet, or else strip treatment will result. Practically, this means moving only 6-8 inches per minute. The large volume of steam is injected into a small volume of soil and the condensing capacity of the soil is frequently exceeded, with consequent "blow outs". In clay soils the trailing pipes tend to form mud tubes which conduct the steam to the rear and away from the area to be heated. It is impractical to increase forward speed by decreasing the distance between chisels, because this would increase the mechanical drag and cause soil to pile up ahead of the header pipe. This device, although presently much used, is likely to be dropped because of its deficiencies."

Steam Blade

This device is currently being developed in Holland and California. Steam is released from the trailing edge of a horizontal flat blade which is moved through the soil at depths of 12 to 16 inches. The soil surface is heated by steam released under a trailing surface tarp. Forward speed of the steam blade can be increased over that of the steam rake because of the large area of contact between soil and steam released from the blade. The steam blade is reported to have a high thermal efficiency.

PEST CONTROL WITH CHEMICALS

Steam sterilization is recognized as the most effective means of disinfesting soil; however, the use of chemicals has gained wide acceptance under certain conditions. Fumigants offer an effective and practical means of controlling certain soil-infesting pests in large outdoor areas and locations where steam sterilization is not available.

Chemical soil fumigants are not effective against all types of disease organisms. The value of fumigants used to control certain wilt diseases caused by fungi such as *Verticillium* or *Fusarium* is doubtful except where chemicals are used at high concentrations. Generally the efficacy of a fumigant also is governed by soil type, temperature, and moisture. Most fumigants are toxic to animals and plants and cannot be used in enclosed areas. Fumigants generally require a waiting period to elapse between treatment and planting. Several fumigants, even after an adequate airing or waiting period, leave a residue which is toxic to certain crops. One major disadvantage of fumigants is that generally they are not effective when used at a soil temperature below 50° F.

Methyl bromide is highly effective against nematodes, weeds, and certain damping-off organisms such as *Pythium*, *Rhizoctonia* and *Fusarium*. It can be applied to beds of well prepared soil by covering the area with a plastic tarp and injecting under the cover 2 pounds of the compressed methyl bromide gas for each 100 square feet of bed surface treated. Soils containing a high content of organic matter will require double this amount. Improved liquid methyl bromide solutions may be injected into the soil using mechanized metering equipment. After application of the fimigant the plastic tarp should remain in place from 24 to 48 hours. After the cover is removed, the soil should be aired for 3 to 14 days before planting. One should read the manufacturer's directions carefully before applying methyl bromide.

Chloropicrin

Chloropicrin (trichloronitromethane) is sold as a liquid in cylinders or in aerosol self-emptying containers. Because of its high cost this material is used mostly for fumigating potting soil, or soil in greenhouse benches and seedbeds. When properly applied at adequate rates it is effective against nematodes, most weed seeds, and all except a few of the more resistant fungi. For maximum effectiveness, measures must be taken for confining the gas, such as sprinkling the treated area with water or placing over it a gas-tight cover. Chloropicrin is toxic to animals and plants; a gas mask is essential when it is used in the greenhouse and all plants should be removed from the area being treated. No harmful residues are left in the soil.

Formaldehyde

Formaldehyde is relatively inexpensive and generally available as a 40% solution in water known as formalin. A formaldehyde liquid drench may be used for treating benches, beds, and hotbeds. The drench is usually prepared by diluting 1 gallon of commercial formalin with 50 gallons of water. It is effective against most disease producing fungi and bacteria but in the usual strength is ineffective against nematodes. After application the soil should be covered with a gas-tight cover for 24 hours. After removing the cover the soil should be aired for 10-14 days. Formaldehyde may cause irritation to the skin, eyes, nose, and throat. Avoid prolonged breathing of the fumes and use in well ventilated areas.

Vapam.

Vapam is formulated as a water solution containing sodium methyl dithiocarbamate. This material can be readily diluted with water and applied as a drench, in irrigation water, or by injection into the soil. It is said to have herbicidal, fungicidal, and nematocidal properties. After application Vapam produces a gas which diffuses through the soil. Immediately after applications the soil should be watered at a rate sufficient to wet the soil to a depth of 4 inches to form a water seal and thus prevent the escape of the gas. Three weeks should elapse between treating and planting. Soil temperatures should be at least 50° F. for treatment.

Mylone

Mylone is the trade name for a white, crystalline solid, identified chemically as 3,5-dimethyl-tetrahydro-1,3,5,2H thiadiazine-2-thione. It is reported to be effective for controlling nematodes, fungi, soil insects and weeds. The usual application rate is 3/4 lb. of 85% Mylone to 100 square feet (300 lbs. per acre). Mylone may be applied to the prepared bed in the dry form using a fertilizer spreader and rototilled into the soil, or it may be suspended in water and applied to the soil surface as a drench. Regardless of the application method, the soil surface should be irrigated after chemical application with 150 gallons of water for 100 square yards of treated area. Three weeks should elapse between treatment and seeding; a longer waiting time is required when the soil temperature is below 60° F.

CHEMICALS USED ONLY AS NEMATOCIDES

One of the most recent and economically important technological advancements in plant pathology has been the discovery of nematocides which give effective and practical control of soil-borne plant parasitic nematodes. The chemicals previously mentioned possess nematocidal, fungicidal, and herbicidal properties whereas chemicals listed under this topic are effective only in controlling diseases caused by soil-borne nematodes.

CHEMICALS USED ONLY AS PRE-PLANTING TREATMENTS

Dichloropropene-Dichloropropane Mixtures and Dichloropropenes

These materials, marketed under various trade names, are very effective nematocides. They are prepared as liquids and may be applied with any of the common soil chisel injectors or on the plow sole as the soil is plowed. The dosage rate is generally 20 gallons per acre (over-all treatment) at a cost of approximately $30 per acre for the chemical. Soil temperature at time of chemical application should be from 40-80° F. Two weeks should elapse between fumigation and seeding.

Ethylene di-bromide

This material is an effective liquid soil fumigant which is applied with injection chisels or plow sole applicators. Dosage recommendations range from 20 to 4.5 gallons per acre depending upon the formulation, soil type, and in the row or over-all treatments. The cost per acre is approximately the same as for the previously mentioned nematocides. A 2-3 week waiting period should elapse between treatment and planting. Soil temperatures should be above 40° F. This material cannot be used for certain bromine-sensitive plants like onions.

Chemicals Used Both as Pre-Planting and Post-Planting Treatments:

Dibromo Chloropropane

This material is sold under various trade names. Formulations of liquids emulsifiable in water, and solid granules are available. The relatively low degree of phytotoxicity of this material allows it to be used at both pre-plant and post-plant applications. It is an effective nematocide and has produced excellent results as pre-plant treatment as well as when used to control nematodes in established woody ornamentals. As with other fumigants, best results are obtained when this material is injected 6-8 inches deep in the soil. A water seal is not necessary; however, it is beneficial to slightly compact the soil surface to prevent a rapid escape of the gas. The rate of application depends upon the formulation used, soil type, species of plant being grown on the area to be treated, and time of treatment (pre-plant or post-plant). This information is generally available from the supplier or county extension agents.

Plants reported sensitive to dibromo chloropropane are beets, Fordhook lima beans, garlic, onions, peppers, sweet and white potatoes, and tobacco. This material is most effective when applied at soil temperatures in the 40°-80° F. range.

Zinophos (0,0-diethyl 0-2-pyrazinyl phosphorothioate)

This material is formulated as a solid granular, and an emulsifiable contrate. This material does not change into a gaseous state in the soil and is therefore not considered a fumigant. Zinophos is generally applied in a granular form to the soil surface and rototilled into the soil or it may be mixed with water to form an emulsion and applied to the soil surface as a drench. Recent research shows this material to be nematocidal and possess systemic properties. It is quite low in phytotoxicity and therefore may be used to control nematodes on established plants.

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1. Baker, F. B., and Carl M. Olsen, 1959. Soil steaming. The California State Florists' Association Magazine. Vol. 8; No. 9, P.P. 5-6.

2. Cole, H., 1960. Soil sterilization fumigation. Mimeograph, Agricultural and Home Economics Extension Service of the Pennsylvania State University, University Park, Pennsylvania.

3. Newhall, A. G. and N. W. Nixon, 1935. Disinfesting soils by electric pasturization. Cornell University Agricultural Experiment Station. Bull. 636: 20 p.

4. Sanderson, K. C., 1961. The use of chemical fumigants on greenhouse soil. The Maryland Florist, No. 83. Edited at the University of Maryland, College Park, Maryland.

PRESIDENT VAN HOF: Are there any questions?

MR. JOHN ROLLER (Scottsville, Texas): What type of cover crop will eliminate nematodes?

MR. OSBORNE: I don't know of any cover crop that will eliminate all nematodes from the soil. There are a number of species of the root nematodes but they find most of these species are not capable of reproducing on grasses. Grasses may be used on rotation to help control it. However, grasses are preferred host for certain species of metanematodes.

MR. PETER VERMEULEN: Have you used sugar?

MR. OSBORNE: I noticed the report which may have some merit, but the amount of sugar that would have to be used would be prohibitive in cost.

MR. ARIE JAN RADDER (Bloomfield, Conn.): I have used nematocides but the soil temperature should be above 50° F.

MR. OSBORNE: I failed to mention that most of the fumigants, the soil temperature must be 50° F. or above for the most effective control measures.

MR. WELTY: I understand you have to have quite a long aeration. Isn't this something like a month or so?

MR. OSBORNE: Yes, that is another aspect I failed to mention. With the fumigants there is a waiting period required. In my own laboratory it would be at least three weeks and in a number of certain soil types and certain temperature conditions, it may be a matter of months you should wait before planting.

MR. WELTY: I understand it is longer with Vapam. At the end of three weeks by tilling it once a week after you put the Vapam on and once again before planting it is safe to plant.

MR. OSBORNE: Vapam, only three weeks.

MR. RICHARD H. FILLMORE (Durham, N. C.): I have observed among the herbaceous plants in the Sarah P. Duke Gardens, the growth of Tagetes (Marigold) doesn't seem to be inhibited in the least by nematodes. Neither does the Sempervivum or Salvia splendens. Those three will not be inhibited by nematodes. If my observations are correct, the slightest touch of a nematode on a Chrysanthemum and it just doesn't grow.

We have approximately 56 flower beds in the area in question and we try to work out a rotation so that we treat a dozen or more of those beds and plant them to Chrysanthemums and as they become infested we work them around the Salvia, Tagetes and other things. I know it is absurd to say so, but they almost seem to make Salvia grow faster, come out with enormous blossoms. For all practical purposes, they neither prohibit the plant vegetatively nor in flower. I wonder what the explanation could be for that.

MR. OSBORNE: The Dutch workers have made an extract which is being used in Holland around roses and other plants to reduce the nematode population.

MR. SHORE: Has anybody ever used red clover?

MR. OSBORNE: I think red clover is susceptible to a species of the root nematode as are most legumes. Nematodes will attack over 2,000 different plant species and legumes are quite susceptible.

MR. WILLIAM FLEMER, III (Princeton): Can you recommend a safe dip to dip the roots of bare root linears prior to planting that will kill nematodes on and in the roots?

MR. OSBORNE: I have used a number of materials as a root soak in an effort to eliminate the nematodes from the root system of living plants. Of the materials that I used so far the most effective has been the DBCP material but there was not absolute control of the nematodes. The population was greatly reduced but I didn't control them entirely. In other words, to my knowledge there is no eradicator available at the present time.

MR. RALPH SHUGERT (Neosho, Mo.): Sir, is there a relationship between crown gall and a nematode?

MR. OSBORNE: I don't know of any correlation between the two.

MR. DICK ANDREWS (Faribault, Minn.): Of the three materials, Vapam, methyl bromide, and Mylone, is any one of those superior to the others as far as weed control is concerned?

MR. OSBORNE: With my experience I have gotten better control using methyl bromide than we have using the other two materials. There may be some reports in the literature contradictory, but I know methyl bromide is very effective as a weed control.

MR. ANDREWS: Do you have to use methyl bromide stronger when you want to get rid of weeds?

MR. OSBORNE: One pound per 100 square feet would kill nematodes and give effective weed control.

QUESTION: You mentioned the nematode. Every nurseryman would not have a microscope. Would it not be feasible to take a portion of tissue that you suspect of having nematodes and put it in water 24 hours and see the nematodes?

MR. OSBORNE: I don't think I would be able to determine what species. All you would see would be a rather turgid solution or suspension of nematodes in the water.

SAME QUESTIONER: That would establish the fact that you had nematodes.

MR. OSBORNE: Most of the states now will offer a service either from a research or extension responsibility of running assays to determine whether or not nematodes are present. We offer this service in Virginia and I know a number of other states are offering this service. What would be required to determine whether or not you had a nematode problem would be your checking a plant which you think may be infested with nematodes, and digging the plant with the root system and the soil adhering to the roots. It should be enclosed in a plastic bag or some similar material that would prevent it from drying out while being transported to the laboratory. From that sample we would be able to extract the nematodes and tell you which species are present and also give control recommendations.

MR. JIM WELLS: You said, I think I am right, that steam was the best method of sterilizing and fumigating and eliminating the trouble.

MR. OSBORNE: I consider steam to be the best method of controlling the various disease organisms in the soil if applied properly.

MR. WELLS: Well, I read a report in an English paper recently that tests were made over there in greenhouses where they are troubled with all manner of things which indicate that Vapam is the nearest approach to steam sterilization that we have.

MR. OSBORNE: The nearest approach to steam sterilization or the comparable?

MR. WELLS: That Vapam is the nearest approach. It achieves the nearest similar effect to steam of anything yet available.

MR. OSBORNE: I don't know. I would like to read that paper. I would like to know the method of application.

MR. WELLS: It was exactly as you described it. They were putting on Vapam diluted with water, rototilled in, and sealed with water. They stated that in their opinion this achieved the same result in a greenhouse as steam.

MR. OSBORNE: I am not questioning their results but I would like to read the paper to know the method of application. Perhaps they are using certain methods that have not been used in our experiments.

MR. WELLS: Let me rephrase then. With the work you have done, would you class Vapam as being equal to steam?

MR. OSBORNE: With the work I have done I don't consider it equal to steam.

DR. JOHN MAHLSTEDE (Iowa State University): I have often been disturbed by the recommendations we make. We say, for example, on methyl bromide we take a 3 foot bed or a 5 foot bed and run our tarpaulin down and sterilize the soil with whatever chemical we might be using. What about the 3 foot path or 2 foot path you leave in between?

MR. OSBORNE: That is true, you would need to use some means to prevent bringing in of this untreated soil into the treated area. It is a matter of sanitation. In view of the limited migration activities of the nematodes, I don't think there would be a problem with the nematodes approaching the area in one year's time. It is mainly a matter of sanitation.

MR. AART VUYK: A moment ago the question was methyl bromide versus Vapam. We have tried both of them and the methyl bromide undoubtedly gives you better weed control but due to the work involved in treating a large area, the Vapam is better. You can apply it quicker and you don't have to bother with plastic cover.

PRESIDENT VAN HOF: Now we will continue with our interesting program, and it is a real pleasure to give you Dr. Wallace A. Mitcheltree to talk on Soil pH: What It Is, How to Measure It, and How to Change It. Dr. Mitcheltree is from Rutgers University.

THE MYSTERIES OF pH

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"pH" means "potenz" Hydrogen or strength for Hydrogen. It is a German term devised by a German chemist to explain the measurement of acid in a media. pH is a chemical term and when one thinks in terms of Chemistry he must think in terms of Electricity and when thinking in terms of Electricity you think in terms of "plus" and "minus" electrical charges. We go back into our high school Physics, - we learned that there was a law in the study of magnetism that said, "Like poles repel each other and unlike poles attract each other". The same law holds in Electricity that "Like charges repel each other and unlike charges attract each other." Two magnets that are placed in such position that like poles are opposite each other repel each other and force one magnet away from the other. If the magnets are so arranged that the unlike poles are opposite each other, then there is an attraction and the two magnets are immediately attracted together.

In chemistry, for instance, water has the formula of H_2O. If it were written structurally it would be written as HOH. Water is written structurally as HOH because it is made up of Hydrogen which has a plus charge H^+ and Hydroxal which has a negative charge OH^-.

Hydrogen in the gaseous form as an element is an explosive gas. Hydroxal is a white, elusive liquid very few people have had the opportunity of seeing. It is an extremely unstable ion. When the Hydrogen and the Hydroxal are brought together, the positive charge of the Hydrogen attracts the negative charge of the Hydroxal and they immediately attach themselves to each other, forming a highly essential and relatively indestructible and extremely stable compound called Water HOH.

The essential component of all acid is Hydrogen. An essential component of all hydroxides or alkalies is Hydroxal. Water, therefore, has the main components of the two absolute opposites in Chemistry. It has the main component of acid which is Hydrogen H^+ and the main component of an alkali which is Hydroxal OH^-. Water, therefore, when pure, would have a neutral pH - a pH of 7.0 because it would have the same number of Hydrogens and the same number of Hydroxals.