PESTICIDES IN FOREST NURSERY SOILS

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The chemical revolution in American agriculture has presented us with spectacular short-term gains in productivity. It is now evident that use of pesticides on our soils may bring problems of a long-term nature; viz., side effects on soil fertility, water supplies, and on various organisms including subsequent crops and even man himself.

The practice of applying chemicals to soil for pest control on an extensive scale is new to forest nursery culture. Petroleum oils and Bordeaux mixture have been used for weed and fusiform rust control, but innovations, in general, have come only in the past decade. The 65 issues of Tree Planters' Notes since November, 1950, list 25 pesticides, used at one time or another in nurseries (2). Although this is a sizeable number of materials, the data indicate that their use has not yet become widespread and common. In the light of recent developments it is apparent that the approach of forest nurserymen to problems of pest control has been both conservative and wise.

In the future we will see an increased use of chemicals and of problems which arise as man attempts to prevent adverse changes in his environment. The soil is a porous medium of organized complexity and its biological and chemical forces have constituted our first line of defense against harmful effects of chemicals. We now know that the soil is a fully equipped laboratory in which we can learn how to control the use of chemicals in our environment. If the story of chemistry is how the world is made, the story of chemicals added to soil is one in which man is remaking the world.

Regulatory aspects

The bulk of research and development in the pesticide field has come since the 1954 Miller Pesticide Residue Amendment (Public Law 518) to the Federal Food, Drug, and Cosmetic Act of 1938, and has been mostly for the purpose of obtaining clearances for use of chemicals on food crops. The manufacturer is required to prove how much residue, if any, will remain on each crop and that it will be safe in food. These are the data used by the Food and Drug Administration to establish its tolerances. The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 is the law that requires manufacturers to prove to the U.S.D.A. that pesticides are effective. This law also requires labeling to indicate which pests the chemical will control, the crop or livestock on which it can be used and in what amounts and to give adequate warnings of hazards to users.

These Acts provide important legal guidelines for the use of pesticides on food crops but it is obvious that nurserymen producing non-food crops must exercise a high degree of individual or collective initiative in their choice of materials, and in the absence of complete knowledge of long-term effects of pesticides, a considerable amount of prudence.

Greatly expanded research on the overall problem of pesticide residues is now being conducted in the State Experiment Stations and in laboratories of the Agricultural Research Service, U.S.D.A., individually and cooperatively, through five regional herbicide residue projects. In addition, private industry, the U. S. Public Health Service, and State and local government agencies are attacking many aspects of the broad problem of chemicals in our environment.

Behavior in soil

Everyone recognizes that the topic of "pesticides in forest nursery soils" is of both technical and public interest. A cross-section of available evidence on chemical-soil interactions has been reviewed. Two questions arise. What are the facts about pesticides in soils? What are the restraints, if any, which these facts impose upon us in selection and use of pesticides in our nurseries? It is hoped that a brief story of the behavior and fate of pesticides in soil will point up certain principles which will help nurserymen find specific answers to these questions.

The principal factor affecting fate and persistence of pesticides in soil is dosage. Dosages range from 1-ounce in a seed treatment to several hundred pounds for nematocides and broad-spectrum materials. A seed treatment with Dieldrin for insect control at the rate of 1-ounce per acre would not be expected to create a residue problem, although it is suspected this compound, or its products, may be quite persistent in soil (8). The thiolcarbamates, known from microbiological data and results Eptam, to decompose in several weeks in soil, can be applied frequently at rates up to 300 pounds per acre, as demonstrated with Vapam, without serious residue effects.

Commonly used pesticides (table 1) are listed as to type of compound, pests controlled, and persistence in soils in weeks, exclusive of leaching effects. The values are ranges derived from tests reported from a variety of soils, climatic zones, and inferences from chemical relatedness and microbiological data (1,_2, .2). No specific data were available to the writer for estimates of persistence listed with question marks or as "prolonged" or "temporary"; but they reflect the weight of available evidence and in cases where decisions have to be made regarding the use of these chemicals, such estimates are better than none at all.

Most of the research on soil-chemical interactions has been conducted with organic herbicides applied at pre-emergence dosages. These compounds generally remain active at toxic levels in the soil for less than

Table 1.--Pesticides at normal dosages per acre, and their approximate range of persistence in time in a variety of soils, exclusive of leaching and other effects

Pesticide (Common name)	Type of compound	Pests controlled	Persistence[1] in soil (weeks)
Varsol	Petroleum oil	weeds	usually none
Dichloropropene	Halogenated hydrocarbon	nematodes	1 - 2?
Ethylene dibromide	Halogenated hydrocarbon	nematodes	2 - 4?
Dibromochloropropane	Halogenated hydrocarbon	nematodes	4 - 6?
D.D.T.	Halogenated hydrocarbon	insects	prolonged
Benzene hexachloride	Halogenated hydrocarbon	insects	>500
Chlordane	Halogenated hydrocarbon	insects	>500
Endrin	Halogenated hydrocarbon	insects	prolonged
Dieldrin	Halogenated hydrocarbon	insects	prolonged
Allyl alcohol	Aliphatic alcohol	weeds	2 - 4?
Trizone	Halogenated hydrocarbon	several	<1?
Methyl bromide	Halogenated hydrocarbon	several	<1?
Chloropicrin	Halogenated hydrocarbon	fungi	<1?
Eptam	Thiolcarbamate	weeds	3 - 8
Vapam	Thiolcarbamate	several	temporary
Ferbam	Thiolcarbamate	fungi	temporary
Thiram	Thiolcarbamate	fungi	temporary
Captan	Cyclohexene	fungi	temporary
Cycloheximide	Cyclohexyl	fungi	temporary
Mylone	Thiadiazine	several	temporary
Maleic hydrazide	Pyridazine	weeds	4 - 10
Diuron	Dimethylurea	weeds	>250
Monuron	Phenylurea	weeds	>500
Simazine	Triazine	weeds	>-50
Atrazine	Triazine	weeds	prolonged
Propazine	Triazine	weeds	prolonged
Sesone	Phenoxy acid	weeds	2 - 4
2,4-D	Phenoxy acid	weeds	1 - 4
MCPA	Phenoxy acid	weeds	8 - 14
2,3,6-TBA	Phenoxy acid	weeds	10 - 26
2,4,5-T	Phenoxy acid	weeds	20 - 48
Dalapon	Chlorinated propionic acid	weeds	7 - 10
CIPC	Carbamate	weeds	2 - 8
Monsanto 553-T	Benzylthiolcarbamate	weeds	>300

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[1] Data from Alexander (1), Audus (3), and Klingman (5). Values with question marks and those listed as prolonged or temporary were estimated from persistence of related compounds or from characteristics of the chemical and microbiological degradation of compounds.

one year (6). Exceptions are the substituted ureas--Monuron, Diuron, and Monsanto 553-T. Extreme persistence, as a result of off flavors in the edible portions of plants, is well known for the chlorinated, aromatic insecticides--chlordane and benzene hexachloride. The triazine herbicides are intermediate and the thiolcarbamate and aliphatic chlorinated hydrocarbons are of low persistence in toxic forms in soils. The phenoxy acids are variable, depending on the position of substituent chlorine and other groups on the phenyl radical. Residual chloride and bromide can cause toxic effects on plants following applications of dichloropropenes and ethylene dibromide (i).

Persistence of chemicals in soils is determined by microbiological decomposition, chemical decomposition, adsorption on soil collids, leaching, and volatility. Depth of placement is also important in terms of the above factors. Herbicides act primarily in the upper 1/2-inch of soil; insecticides, fungicides, and nematocides are applied at depths ranging from 1/2-inch to 8 inches. Chemicals move by diffusion in soil water, in air spaces, and in flowing water (A).

Diffusion in air, even by compounds of high water solubility and low volatility, is much more important than diffusion in water. Only compounds existing in a non-volatile ionized state will not diffuse in air, and these are few in number. Complex situations exist with the thiolcarbamates and with mylone, which are carried down by water flow, but which decompose to release the toxic and highly volatile methyl isothiocyanate, which is rapidly transferred by diffusion in the soil air.

Most pesticides are abundantly adsorbed to the soil colloids and only a small fraction exists in the freely dissolved state in the soil water. This has two important consequences. The first is that movement in flowing water is limited and in spite of repeated heavy rains, a chemical may resist leaching and persist in the upper layers of soil. Secondly, adsorbed chemical is exposed over an enormous surface area and this is believed to accelerate breakdown reactions, whether it is a slow hydrolysis (natural chemical reaction) as in the phenylureas and substituted triazines or a rapid microbiological decomposition as in the aliphatic halogenated hydrocarbons. Adsorption complicates the problem of dosage because most of the chemical is held in reserve on the colloids. Only a small proportion is active against pests in the soil water and atmosphere at any one time.

Examples of chemical breakdown independent of micro-organisms in soil are: dalapon - slow hydrolysis; sesone - breaks down to 2,4-D, and then micro-organisms destroy its herbicidal properties. Photodecomposition of monuron in quartz tubes occurred in sunlight to the extent of 83 percent in 48 days (i).

Volatility is important in loss and removal of pesticides from the soil in surface applications and leaching is a factor in soils of low clay and organic matter content and porous sub-soils when a compound such as trichloroacetic acid, which is not strongly adsorbed on negative micelles, is employed.

Decomposition by micro-organisms is the most prevalent and important type of breakdown of pesticides in soils. Micro-organisms break down all types of organic matter including organic pesticides. Hydrocarbons occur commonly in soil. Approximately 0.02 percent of higher plant composition is of hydrocarbon-type compounds. It is not surprising that micro-organisms break down halogen-substituted hydrocarbon pesticides. Addition of a paraffin substrate results in 10^5 bacteria per gram of soil decomposing this substrate (1). Allyl alcohol, for example, is broken down successively to acrolein, acrylic acid, and lactic acid by Pseudomonas (1)

The breakdown of chemicals involves a lag period in the buildup of responsive organisms. This is an induction period for adaptive enzymes in nondividing cells of a segment of the population, rather than a selection of mutants from the populations. The soil, now enriched with a new bacterial population, continues to metabolize the chemical at a rapid rate, so long as the chemical is supplied to it. It is of interest that this state even continues for a time after the chemical is exhausted, as shown in soil columns previously treated with chemical, then perfused for long periods with distilled water. Additions of more chemical results in a very rapid buildup, with little or no lag phase.

We know very little of adaptive responses of soil bacteria to newer chemicals or of duration of adaptation from treatment to treatment. We do know that cross-adaptations in culture is an important phenomenon (3.). Adaptations to a given substrate involves simultaneous adaptation to all intermediates in a breakdown chain. By this same argument, adaptation to one molecule brings about simultaneous adaptation to a number of homologous molecules.

Micro-organisms have become adapted to the decomposition of aromatic ring compounds by their breakdown of lignin and humus constituents, which have structures based on the aromatic nucleus. Some amino acids and many herbicides and insecticides have an aromatic nucleus.

The true bacteria, Actinomycetes, and fungi are involved in breakdown of chemical in soils. Bacteria attack the chlorinated aliphatic compounds by first removing the chlorine, leaving elementary compounds such as acetic and propionic acids, which in turn are then converted to carbon dioxide and water.

Decomposition of 1, 2, 3 benzene ring compounds, including the phenoxy acid herbicides, is accomplished by species of Pseudomonas, Mycobacterium, Achromobacter, and Bacillus. Species of actinomycetes are important, and under some conditions, fungi also participate. Side chains are oxidized first, then ultimately the benzene derivative is converted to a noncyclic molecule related to its aromatic precursor. Cathechol and one or two related compounds are the last cyclic compounds preceding ring cleavage. Succinic and acetic acids are then produced and these two acids are in turn oxidized to carbon dioxide and water (1).

Microbiological degradation is dependent on soil pH, moisture, depth, and organic matter level. It is more rapid under neutral than acid conditions and at higher temperatures and after liming. Chemical specificity is often of great importance. For example, 2,4-D disappears in 1 to 4 weeks, whereas 2,4,5-T, which differs only by a third chlorine on the benzene ring, may remain in nonsterile soil for 6 months to a year or more (1).

Simazine is attacked only by fungi and actinomycetes, for the nitrogen in the molecule. Best effects result if high carbon supplements are added to the soil in order to maintain a favorable C/N ratio (2).

It is of interest that many herbicides undergo decomposition in the plant. Thus, the crop itself including weeds controlled must be added to the list of active organisms GO

Of greatest interest are the effects of pesticides on important soil micro-organisms and on processes which regulate soil fertility. Dichloropropenes stimulate certain bacteria in their growth and amino acid production (2). Substituted ureas block photosynthesis and hence inhibit unicellular green algae. Halogenated aliphatic acids, phenoxy acids, and thiolcarbamates cause temporary reductions in numbers of bacteria. It is significant that marked inhibitory effects of soil pesticides on micro-organisms are generally not observed at normal recommended dosages (2).

Ammonification was not significantly affected by 2,4-D, simazine, and other triazine compounds. The effects of aliphatic acids, chlorinated ring compounds and carbamates on nitrification was inhibitory, but temporary, disappearing in about 3 weeks (1).

Nitrogen fixation by Azotobacter was inhibited by phenoxy acids in high concentrations, but not at normal dosages. The phenoxy acids and maleic hydrazide had effects at very high concentrations on nodulation of legumes in laboratory tests by nitrogen-fixing bacteria (Rhizobium). However, some evidence suggests the effect of 2,4-D is more on the legume than on the bacteria (2). Furthermore, low concentrations in field tests have reduced nodulation, and generalizations from laboratory tests may be dangerous.

Literature cited

1. Alexander, M.
1961. Introduction to soil microbiology. John Wiley & Sons, Inc., New York, 472 pp.

2. Altman, J. and Sue Lawlou
1964. The effect of chlorinated C3 hydrocarbons on growth and amino acid production of indigeneous soil bacteria. (Abs.) Phytopath. 54:886.

3. Audus, L. J.
1964. Herbicide behavior in the soil. II. Interactions with soil microorganisms. The Physiology and Bio-Chemistry of Herbicides, pp. 163-206. (Ed. C. J. Audus) Academic Press, London, 555 p.

4. Hartley, C. S.
1964. Herbicide behavior in the soil. I. Physical factors and action through the soil. The Physiology and Bio-Chemistry of Herbicides, pp. 111-161. (Ed. C. J. Audus) Academic Press, London, 555 p.

5. Klingman, G.
1961. Weed control. Asaa Aci. John Wiley & Sons, Inc., New York, 421 p.

6. Klingman, G. C.
1962. Persistence of 2,3,6-trichlorobenzyldiisopropyl-dithiocarbamate, or its residues, in North Carolina soil. Weeds 10:336-337.

7. Martin, J. P. and P. F. Pratt
1958. Fumigants, fungicides, and the soil. J. Agr. Food Chem. 6:345-348.

8. Reynolds, H. T.
1958. Recent advances in seed and soil treatment with systemic and nonsystemic insecticides. Adv. in Pest Control Res. 2:135-182.

9. U. S. Department of Agriculture
1950-1964. Tree Planters' Notes, Issues 1 - 65. Forest Serv.

DISCUSSION TO: Eugene Turner and John P. Hollis

Q. What rate did you apply methyl bromide?

A. (Turner) We applied that at 1 pound per 400 square feet of bed space. On the Eptam, it was 6 pounds per acre.

Q. Has anybody done any work with flame cultivators? Like heat on the bed after it has been tilled to kill out seed or something like that. Does anyone have any knowledge of its affect on the useful organisms or organic matter? Also, heat on the pre-bed surface area might cause early germination of weed seeds or make them go through whatever they go through just before germination to get the seed to deteriorate. If we might get surface-warm seed to germinate before the last frost, we might get away from a lot of chemicals.

A. (Hollis) The only thing I know about it is they are doing a little work with it in Louisiana with cotton.

Q. Many nurserymen raise a little garden around the nursery. You said chlordane would stay in the soil for many years. How about these potatoes we might raise around the nursery? Are we not long for this world?

A. (Hollis) Well, if you applied any appreciable dosage, I think there will possibly be a residue in the soil.

Q. For white grub control the usual dosage is 3 to 4 pounds per acre. Where is the danger line?

A. (Hollis) I don't exactly know, but it is persistent for a long time.

COMMENTS by Mr. Gehron:

In regard to the flame thrower technique, I used one once. It worked fairly good but you've got to be real persistent with it. It's like your herbicide oils, you've got to get out there regular. And, I've found that in general use the oils are better.

Q. You mentioned, Dr. Hollis, about these things being tied up on negative ions. Now is there a possibility that in growing crops if you treat them with a fertilizer, lime, or something like that, you'd cause a greater quantity available for the plants to absorb at one time?

A. (Hollis) Yes, the use of lime does have an effect on persistence of these things in soil by changing the pH.