Fumigation of Soil in Hawaii

Walter Carter

As agricultural soils become older and cultivation continuous and more intensive, some soil amendment often is needed to offset the unfavorable effects on plants of the growing complex of pathogenic soil organisms or little known nutritional factors.

If that can be achieved by adding large amounts of organic matter—such as green-manure crops—or if crop rotations are established, the need for soil amendment is not so great as in areas where similar methods are not used.

Some crops, however, cannot be grown successfully except occasionally in a long rotation. In many places in Great Britain, potatoes can be grown on the same land only one year in seven. In Utah, sugar beets require a 4-year or a 5-year rotation with other crops. Nematodes are the limiting factor. In tropical or subtropical areas, where active organic matter decomposes rapidly, the need for a soil amender is acute.

Hawaii is no exception. Truck crops, particularly those that are susceptible to nematodes, cannot be grown profitably in succession on the same soils without the use of fumigants or other control methods. Pineapples have been grown in Hawaii for more than 40 years on the same land without the addition of organic matter other than the residues of the previous crop, and the decline of productivity before fumigation became an established practice had been noted with increasing concern. One notable exception is a plantation where grass is grown for 2 years between pineapple plantings.

An early attempt at soil amendment by fumigation in Hawaii in 1926 was directed primarily against insects and nematodes in sugarcane soil. A still earlier study, in 1910, was concerned with molasses as a fertilizer for sugarcane. Fumigants were used in those experiments. The effect of fumigation with carbon bisulfide on nitrifying organisms was recognized as significantly affecting the availability of nutrients to the plant. The chemical did not destroy the micro-organisms but caused a reproportioning of them. The term is significant: It is not considered practical to eradicate a microorganism, but its position relative to that of the other organisms can be changed.

Usually soil amendment by fumigation in Hawaii and elsewhere has been approached from the standpoint of control of nematodes and soil insects. As early as 1931, however, stimulation of the growth of pineapples was recognized as being the result of partial soil sterilization. In 1933 increased yields were recorded as having been obtained despite damage by nematodes.

The first approach to the current viewpoint on soil fumigation in Hawaii was by the late Maxwell O. Johnson in experiments begun in 1927. He got striking increases in plant growth and yields of pineapples by the use of chloropicrin—tear gas. In his first experiments he applied this liquid to pineapple fields by means of a Vermorel injector, a French device originally used for the injection of carbon bisulfide into soil and stored grain.

The first effect of the treatment was to produce a dark-green growth of the plant. Sometimes the fruit was larger. We now know that this was due, at least partly, to the killing of the nitrifying organisms in the soil by the chloropicrin. That meant that the

plant used ammonium nitrogen rather than nitrate nitrogen. The pineapple plant fortunately is well adapted to ammonium nitrogen nutrition. Johnson patented the use of chloropicrin as a soil fumigant in U. S. Patent No. 1,983,546, which makes numerous claims, all of them concerned with plant stimulation. The killing by chloropicrin of such organisms as nematodes was known previously, at least academically, and it was therefore not included among the allowed claims.

Chloropicrin has disadvantages. It is an extremely pungent and tear-making gas. It has always been relatively expensive, so that its field-scale use is limited, especially as soil cover with water seals or with more or less impermeable papers was essential to best results. Furthermore, at the time Johnson first used chloropicrin in Hawaiian pineapple soils, the favorable response to fumigation, so generally experienced now, was not consistent. Many applications failed to give economic returns.

The whole question of the field-scale use of the fumigants was completely changed by the discovery in 1940 that a mixture of 1,2-dichloropropane and 1,3-dichloropropene is an effective soil amender. The discovery of its efficacy came about in an interesting way.

The mealybug wilt of pineapple had been seen to be much less serious in virgin lands in Hawaii; the point was confirmed in other tropical countries.

As a result, a continuous search was made for soil amenders that might restore some of the qualities of virgin soil that produced more wilt-resistant pineapple plants. The study had gone on more than 5 years with no satisfactory results, when a number of chlorinated hydrocarbons were provided by the Shell Development Co. for trial. None of them had any effect on the susceptibility of pineapple plants to mealybug wilt, but one of them, the mixture I referred to, which now is known as D-D mixture, proved to be the most practical and successful soil amender known up to that time.

The first results with pineapple plants were available shortly after the outbreak of the Second World War, when the domestic production of vegetables became of great importance. Soil treated with D-D mixture and planted to carrots and other vegetables produced much more heavily than nontreated check plots. The result undoubtedly was due to the measure of control of nematodes that had been achieved.

D-D thus proved to be a most effective nematocide, although the discovery was purely by chance. Perhaps that was all to the good, for it gave an opportunity for the soil-amendment qualities of the material to be recognized early in its development. A logical consequence was the added recognition of growth response beyond that due to nematode control as one basic requirement for an effective soil fumigant.

HAWAII HAS ALSO PIONEERED in the development of suitable injection machinery. Injection is a problem when large acreages have to be treated and planted in a short season. Probably the first large-scale field fumigation machine was the one engineered by the California Packing Corp. for use with chloropicrin. The development of the field injectors was not easy. D-D is relatively corrosive and requires special metals. Pumps and delivery systems had to be devised—and then redesigned to get the most efficiency. The use of check rows has long been dropped as unnecessary in pineapple fields, but many an example is still provided unwittingly when application is faulty and long rows or partial rows are left untreated. From them the increasing necessity for soil fumigation, as time goes on, is demonstrated.

The methods available for small growers of truck crops have been greatly improved by the development of more effective hand injectors by firms on the United States mainland. With those new methods and new machinery, D-D and other fumigants, such as ethylene dibromide, have been found to be economical and practical as nematocides and as soil amenders.

The use of D-D mixture has become standard practice in Hawaii on pineapple lands. Some 7 million pounds are used in that way each year. The fact that in 1942, when the first results were obtained, only laboratory quantities were available as byproducts from a pilot plant used for other syntheses underscores the remarkableness of the development. Furthermore, the total volume of fumigants used on a field scale is evidence that Hawaii has pioneered in a development of vast significance to agriculture.

Perhaps a more important result of the discovery of D-D mixture was the stimulus given to the whole problem of soil amendment by fumigation for field crops in the United States and in many other countries. Other fumigants, particularly ethylene dibromide, have appeared on the market and are competitive with D-D mixture.

Some ethylene dibromide has been used in Hawaii on pineapple soils as a preplanting fumigant in place of D-D. An exact evaluation of the relative merits of the two compounds for the purpose is difficult because EDB is more sensitive to soil-moisture conditions than is D-D. With appropriate soil moisture, EDB has given excellent response. As most of the pineapple acreage is planted during dry seasons, however, D-D is perhaps the most reliable general preplanting fumigant. EDB has found a place in the postplanting fumigation of pineapple fields. Ethylene chlorobromide (ECB) is also promising for this purpose. The process involves some risk to the growing plant but growth stimulation usually has been pronounced. Sometimes profitable increases in fruit weight have followed.

Methods of testing soil fumigants have been dominated by the microbiologists' need for data on specific organisms, and the small pot test has been standard. New fumigants usually are screened by that method. Quantitative results have accrued, but the interpretation of the results in terms that the grower can use is difficult, for the method at best is artificial and of too short duration. Field-plot tests furnish a more reliable criterion for the growers because ultimate crop yield must determine the economic feasibility of the practice.

Future advances will come by understanding how fumigants affect growth.

There is, first, the effect on specific organism-nematodes, soil insects such as wireworms, and bacteria and fungi, both pathogenic and beneficial.

Second, there is growth stimulation. Plants may be stimulated because the development of root systems is hastened and improved, either by removing root pathogens or by supplying necessary factors for their growth. Possibly there is release of root-promoting hormones in the soil.

Nutrients may be more readily available because of depression of the nitrifying organisms in the soil. That is true of the early stages of growth, but growth stimulation of pineapple plants continues sometimes for the whole 4-year growth period and is often more pronounced in the second crop than in the first. Furthermore, soil fumigation after the plant has been established for several months will favorably affect the root system by stimulating or permitting new active white root tips for that portion of the whole root system that is near the point of injection of the fumigant. This suggests the possibility that soil fumigation makes nutrients available that are needed in small quantity for vigorous plant growth.

These problems of growth stimulation are closely related to a third consideration; namely, the effect of the fumigant on fertilizer practices. That is a practical point because the effects may govern dosages to be used and the economic position of the chemical in the production of the crop.

WALTER CARTER *is a graduate of Montana State College and holds advanced degrees from the University of Minnesota. He is head of the entomology department of the Pineapple Research Institute of Hawaii.*