to root when they are still in the juvenile stage. Stem cuttings were made from such shoots when they were 1 to 3 inches long (see sketches) and rooted in a greenhouse with intermittent mist, 70°F bottom heat, in vermiculite and perlite (1:1). Regardless of IBA concentration used, all of the cuttings rooted in two weeks. The 1,000 ppm IBA (quick-dip) treatment had the most vigorous root system. Higher IBA concentrations caused deterioration at the base of the cuttings, and less vigorous root growth.

Rooting of adventitious shoot from a root cutting (¼ actual size).

Adventitious bud formation on root cuttings was most active from late December to mid-June although bud initiation occurred throughout the year (graph 2). Root segments, 3 to 18 inches long and ⅛ to 2 inches in diameter, were used in various tests. Segments of approximately ½-inch diameter produced the highest number of adventitious buds (up to 600 from one 18-inch-long root cutting taken in April); however, the percentage of these buds that will form viable shoots for rooting is unknown.

High variability in adventitious bud initiation was found among different clones. New methods are being sought to improve bud initiation on root cuttings since this material may prove most feasible for commercial propagation of Quaking Aspen.

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Eight-month-old tree from adventitious bud cutting.

Soil desiccation and fumigation for

ARMILLARIA ROOT ROT IN CITRUS

R. L. RACKHAM • W. D. WILBUR • T. E. SZUSZKIEWICZ • J. HARA

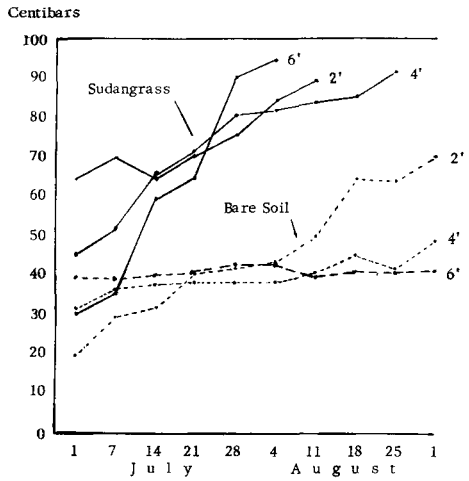
NUMEROUS UNSUCCESSFUL attempts have been made to replant sites in citrus groves where trees have been infected with *Armillaria mellea*. The original rootstock, sweet orange, is susceptible. Some sour orange rootstocks are resistant to the disease, but cannot be recommended because of susceptibility to tristeza (quick decline). Troyer citrange and trifoliate orange are most commonly replanted now, but both are extremely susceptible to *Armillaria mellea*. An Ichang hybrid has shown resistance in greenhouse tests and is now being field tested.

When old infected roots remain in the soil, roots from newly planted trees can grow in close enough proximity to become infected. The fungus moves up some of the roots, eventually girdling the crown just beneath the soil surface. The infection then continues to spread throughout the rest of the root system and eventually to the roots of adjacent trees. Troyer replants planted in infected soil have been observed to survive from four to eight years before becoming girdled. By this time, much money and effort have been expended with only limited crop returns.

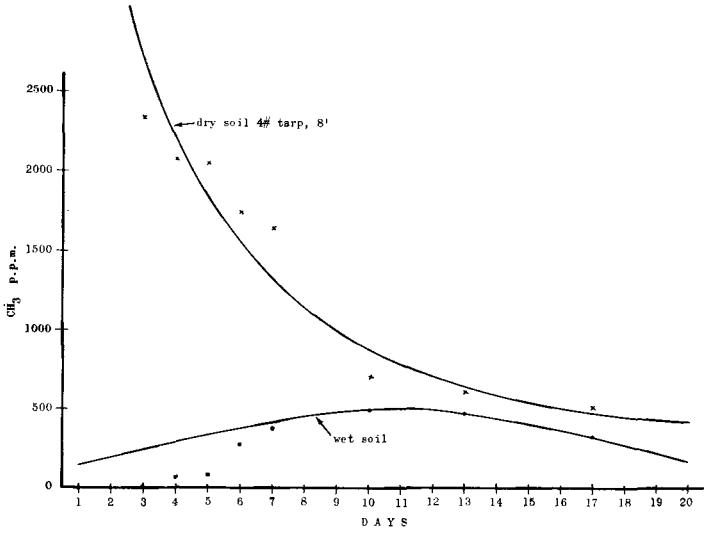
Mature trees

When mature trees are infected but not yet killed, spread throughout the grove has been controlled for many years by removal of the soil from around the base of the trunk and crown roots. Exposure of the large crown roots stops the advance of the fungus up the root system at the point where the roots are exposed to air. When excavated before being girdled, trees have continued to produce economic fruit crops for many years.

However, if the trees are not producing economic crops or are dead due to



GRAPH 1. AVERAGE TENSIOMETER READINGS AT THREE DEPTHS COMPARING BARE SOIL WITH SUDANGRASS PLANTING.



GRAPH 2. COMPARSION OF WET AND DRY SOIL IN THE PENETRATION OF METHYL BROMIDE (4 POUNDS PER 100 SQUARE FEET), AS MEASURED DOWN TO 8 FT DEPTH.

advanced Armillaria infection, fumigation is recommended. This is the only practical way known to change the soil environment, even to the extent that enough stress is placed on the fungus in the diseased roots to predispose it to biological kill. This is particularly true in the lower depths of soil (4 feet or more).

Many fumigations in past years have failed to eradicate all of the Armillaria in affected areas. This was probably due to reduced air space in the soil caused by small soil particle size, compaction, and/or high moisture. Before fumigating, the soil profile must be studied down to the maximum root depth. Only then can an estimate be made of the possibility of fumigant dispersion at concentrations high enough to eradicate all infection.

Fumigation tests

One-third acre of 10-year-old navel orange trees on Troyer roots in San Bernardino County, heavily infected with *Armillaria mellea*, was selected for a fumigation plot. To find the outer limits of infection in this site, healthy-appearing trees surrounding the dead or dying trees were inspected at the crown root area and in the root area at the drip line of each tree by digging 3-foot-deep inspection trenches. By this inspection method, several of these trees were found to be infected.

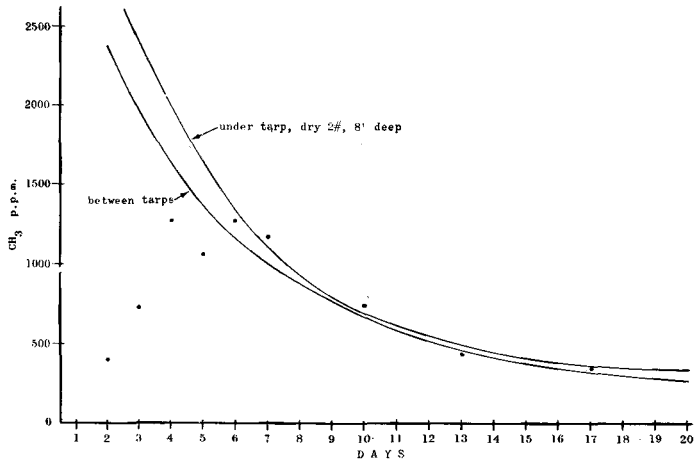
But a more complete inspection of roots from trees adjacent to known infected trees seemed important if complete eradication of the disease was to be obtained. Therefore, mapping of the infection area was completed only after pulling these trees and inspecting their total root system. If no infection was found on the root system on the side adjacent to the adjoining in-place tree, then that tree was not pulled and the infection area was assumed to be known. Otherwise, the adjoining tree was also pulled and it may or may not have been found to be infected. Fifty-five tree sites were cleared and prepared for a seed bed.

The orchard soil was a sandy loam which contained 65% sand, 26% silt, and 9% clay. It was rather uniform for 7 to 9 ft—the depth at which approximately a 6-inch layer of fine-textured soil was deposited over gravel.

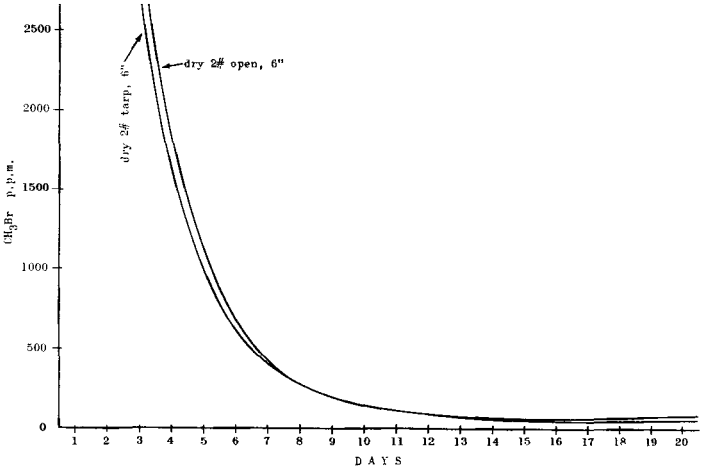
Tensiometers and gypsum electrical resistance blocks were installed to determine the soil moisture. Access tubes were installed to evaluate soil moisture and density from which porosity could be calculated.

To facilitate maximum fumigant dispersion throughout the porous fraction of soil, moisture was removed by the growth of Trudan variety sudangrass. It was planted in April and irrigated until established. Further irrigation was then withheld. During this period the grass started to head out and was mowed in July to prevent dormancy initiated by this stage of growth. When the second growth of grass had removed much of the moisture 6 ft deep, the crop was mowed (in October) and removed from the plot. This area was then ripped with a sub-soiler 24 inches deep to break up the soil com-

GRAPH 3. SIDE DIFFUSION OF METHYL BROMIDE APPLIED UNDER TARPS IN DRY SOIL, MEASURED 8 FEET DEEP.



GRAPH 4. MEASUREMFENT OF METHYL BROMIDE 6 INCHES UNDER THE SOIL SURFACE IN OPEN AREA BETWEEN TARPS.



pacted by wheel tracks between rows. Finally, the surface was disked to provide a loose soil texture which would seal the edge of the fumigation tarps.

To measure methyl bromide concentrations in the soil, samples of soil atmosphere were withdrawn into glass syringes for subsequent analysis by gas chromatography. The sample tubing, 1/16 OD stainless steel, was protected from blockage by soil particles with 64-mesh screen fixed to the buried end, while the upper end was sealed with a rubber cap that could be pierced with the syringe needle for sampling. This prevented dilution with outside air while the sample was being withdrawn. Leakage was prevented by coating the plunger and barrel of the syringe with a 1% starch solution.

To place the tubings at the sampling points, 3-inch-diameter holes were dug to depths of 6 inches, 3 ft, 5 ft, and 8 ft and the screen-protected ends inserted to the bottom of these holes. One foot of soil was backfilled and tamped. The remainder of each hole was sealed by placing a specially prepared polyethylene bag into the hole and filling it with water. The weight of water held the walls of the bag tightly against the inner surfaces of the hole. This prevented the gas from passing downward at an accelerated rate, which would give an elevated, false concentration of normal flow rates of gas in the bulk soil mass. At the end of the experiment, water was pumped out of the tubes and the stainless steel tubing and Armillaria inoculum were recovered.

When each stainless steel tube was sampled, the first 20 ml of soil atmosphere was discarded to purge the tubing. Then a sample was withdrawn into a syringe and the needle was sealed by inserting it into nonpervious soft crepe rubber. The sample of gas was transported from the field to the laboratory in this container. The same syringe was used to inject the sample into a gas sampling valve of a gas chromatograph.

Armillaria-infected roots were buried throughout the fumigation plot at each location where fumigant concentrations were measured. To evaluate gas penetration in large wood, two thoroughly infected citrus tree stumps 12 inches in diameter by 30 inches long were buried 18 inches below the soil surface in the narrow, nontarped strip between the 2-pounds-per-100-square-foot dosage treatments.

A commercial fumigating machine was used to inject methyl bromide 18 inches deep at rates of 2 lbs per 100 sq ft on one-half of the plot. The other half was fumigated at 4 lbs per 100 sq ft. The machine laid a polyethylene tarp 10 ft wide and up to 138 ft long at the time of injection. To fumigate the entire field in one day, these strips were laid as close as mechanically possible. This resulted in strips 30 inches wide between each tarp where no fumigant was injected. Methyl bromide gas concentrations were measured in these untreated open strips, as well as under the tarped fumigated areas, to ascertain the amount of side diffusion from the adjacent fumigated strips into the untreated areas. An area 15 ft wide and 50 ft long remained wet because of a leaky standpipe up to the time of fumigation on October 21. This wet area was fumigated at the rate of 4 lbs per 100 square ft, and gas concentrations in two replicate areas were determined. Because of the limited size of this wet soil area, the 2-pounds-per-100-square-foot dosage level was not tested, nor were measurements made of side diffusion rates between these tarps.

Tensiometer readings taken at depths to 6 ft in the sudangrass cover crop reached maximum dry readings by the second week in August. Comparative readings were also taken in an adjacent area that was kept clean of any plant growth. These readings indicated that very little soil moisture had been removed from the noncropped soil during the summer (graph 1).

At the time of fumigation, the dry soil averaged 3.7, 4.6, and 4.3% moisture at the 3-, 5-, and 8-foot depths, respectively. The wet soil at the respective depths contained an average of 13.5, 13.5, and 14.0% water. Air temperature at the time of fumigation was 79.0°F, but rose to 146°F under the tarps. Soil temperatures averaged 70.5°, 72.0°, and 72.0°F, respectively, for the 3-, 5-, and 8-foot depths.

The data from the fumigant flow rates in the soil fit very closely to the statistically derived curves. In the dry soil plot, methyl bromide applied under polyethylene tarps at the 4-lb dosage penetrated 8 ft deep at the minimum lethal concentration of 500 ppm between the first and second day (graph 2). Concentrations at or above this minimum level persisted at this depth up to the 16th day. Fumigant concentrations measured at this depth in the wet soil area were considerably less, barely reaching the minimum lethal concentration level for three days. In dry soil, the gas applied at the 2-lb rate penetrated much faster and at considerably higher concentrations than double the dosage in wet soil. Side diffusion of the gases between the tarped areas in dry soil was at concentrations nearly the same as those concentrations under the tarps. This was true at the 6-inch depth, as well as the other depths down to 8 ft (graph 4).

No living Armillaria mycelium was found in the two large citrus tree stumps or in the smaller Armillaria-infected root pieces 30 days after fumigation. Armillaria-infected roots buried outside of the fumigation plot remained infected.

This experiment proves that limited pore space in wet soil impedes the speed of gas diffusion and limits the potential concentration of methyl bromide fumigant in deep-rooted crops. Instruments recently made available and techniques developed during this experiment can be used to develop similar information in other types of soil.

Conclusions

Actual methyl bromide measurements at 6 inches, 3, 5, and 8 ft indicated a high level of lethal fumigation for *Armillaria mellea* at 2 lbs per 100 sq ft in this dry soil. Only minimum lethal fumigation levels were achieved in wet soil at double this dosage. It is difficult to forecast, from this initial methyl bromide measured concentration and flow rate experiment, what levels of fumigation can be expected when fumigating either uniform clay soils or sandy soils stratified with clay lenses several inches thick. Other key types of soils are being tested to help growers forecast fumigant success in their Armillaria-infected sites.

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This cooperative Armillaria research effort was under project leaders Donald E. Munnecke and Martin J. Kolbezen, Plant Pathology Department; Lewis H. Stolzy, Irrigation Department; and Albert O. Paulus, Extension Plant Pathologist, University of California, Riverside. The Hinckley Orange Grove Company in Bryn Mawr cooperated by providing the site where the experiment was conducted; Dow Chemical Company provided the methyl bromide; Neil Maclean Company applied the fumigant; and Dr. Thomas M. Little, Extension Statistician, made the statistical analysis of the data.