DEVELOPMENT OF NURSERY TECHNIQUES

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Abstract. Major landmarks in the development of modern nursery techniques are outlined The John Innes Horticultural Institute in England demonstrated in 1934-39 that, with slight modifications, a single roughly standardized soil mix could be used for a wide variety of plants The first unified comprehensive approach to the special problems of plant growth in containers was evolved at the University of California in 1941-57 The U C. mixes were the first truly standardized, light weight, inert, well-aerated media that could be steamed without production of phytotoxicity Many modifications have since appeared, based on the principles presented in Manual 23, in which the mixes were described The U C System was uniquely evolved under stress of war conditions, with shortages of labor and materials; it was the result of the combined effort of many growers, research scientists, extension workers, and commercial laboratories, and was continually referred back to growers for modification. There was emphasis on using soil and plants free of pathogens, and practicing intensive sanitation Major advances in the System in the past 27 years are: aerated steam treatment of soil and propagules; addition of selected microorganisms (antagonists) to propagules or to treated soil for biological control of accidentally introduced pathogens and to increase plant growth through bacterization, use of minute meristems, cells, and protoplasts in propagation to improve pathogen control, prolonged mild heat therapy of plant propagules to decrease virus transmission; prevention of pathogen transmission in irrigation water, holding seed in polyethylene glycol following thermotherapy to permit metabolic damage to be repaired and the seed thus to recover from treatment

Although man was growing plants in containers in Egypt at least 4000 years ago (2), only in the last 50 has he examined the scientific bases for the practices developed. At first he probably used the soil from the area where the plant was obtained, but he later added various amendments to improve growth. The soil mix of an especially successful crop thus became the standard for that plant, even through the soil may not have been responsible for the success. Different mixes eventually came to be thought of as necessary for each crop, and the idea was reinforced by prevalent secrecy that prevented comparison with other mixes. Growing practices were long determined by rote, prescribed in the apprentice system then used. Some of these routines were compiled and published (13) as late as 1930 for growers to follow without considering the rationale involved.

This rule-of-thumb system continued until the twentieth century, and still persists among some untrained growers. "Root action," evidenced by new white roots when plants were knocked out of the container, was emphasized in growing, particularly in fertilizing and watering practices. This useful

concept, unfortunately, has declined with greater technical knowledge and methods.

SOIL MIXES

Although plants had been grown in sand culture by 1840, and in water culture in the 1860s, it was 90 years before these techniques affected grower practice. Hydroponics was widely and extravagantly publicized in the 1930s in the U.S., but commercial application was generally unsuccessful because of difficulties of adequate control of nutrient levels, aeration, glasshouse humidity, and root disease, and because of equipment cost. Laurie and Kiplinger tried sand and gravel culture in Ohio after 1931. Post and Seeley used constant-level subirrigation of soil in benches in New York about 1940, but slight change in water level led to inadequate moisture or to waterlogging. These methods are still used in special situations.

The John Innes Horticultural Institute in England developed a roughly standardized soil medium in 1934-39. Their demonstration that, with slight modifications, a single soil mix could be used for growing a wide range of plants is an important landmark in container culture. These mixes consisted of composted turf (especially grown on loam soil for this purpose), peat, coarse sand, hoof and horn meal, superphosphate, sulfate of potash, and chalk. These mixes were widely used despite the disadvantages of variability in and frequently unavailability of composted turf soil, the expense, labor, and space required for composting, excessive weight, toxicity when steamed together, and failure to eliminate pathogens when only the turf was steamed.

The first unified comprehensive approach to the special problems of container growing was made at the University of California in 1941-57. Leaf mold, horse manure, and fine sandy loam were used at first, but this mixture was abandoned because of salinity injury, post-steaming toxicity, variable results, and shrinkage. By 1947, Canadian peat, fine sand, and mineral fertilizers were used. Attempts to improve the mixes and to understand why some were better than others led to the U.C.-type mixes, the first truly standardized, light-weight, inert growing media. The concepts evolved have proved, as predicted, of greater permanent value than the five basic formulations presented. These principles apply to the many variations in the System that have since appeared [e.g., Peat-lite and Jiffy Mix (perlite or vermiculite with sphagnum peat); redwood sawdust, fine bark, perlite or pumice with fine sand; sphagnum peat with perlite, heat-processed montmorillonite clay, or sand; composted pine or hardwood bark with sand, perlite, pumice, expanded shale, or Styrofoam]. The trend ev-

erywhere is now toward inert, lightweight, standardized, artificial mixes, and away from the use of soil.

There are several misconceptions on ingredients for soil mixes that should be cleared up at this time. It has frequently been said, and is even widely believed, that peat moss is free of plant pathogens. It has even been suggested that it contains some material inhibitory to the growth of pathogenic fungi. However, many years of experience bear witness to the presence of water molds (*Pythium*, *Phytophthora*, and *Aphanomyces* spp.) in commercial peat moss from several geographical areas. For example, an azalea grower in Santa Barbara, California, sustained heavy losses from these pathogens in plants grown in nontreated German peat moss in ground beds. The pathogens were present in the peat moss as received. Canadian peat has also repeatedly been implicated in outbreaks of root rot.

The Einheitserde (Standardized Soil) was marketed in Germany after 1948 as a nontreated soil mix. It consisted of 50% peat and 50% well aggregated subsoil clay, plus mineral fertilizers. Because the peat was thought to be free of pathogens, and the clay was mined from deep subsoil, the mix was erroneously claimed to be free of pathogens. However, two German investigators showed in 1955 that the mix was infested with pathogens (2).

Similar misconceptions appeared in 1964 concerning the antagonistic effect on plant pathogens of several soils treated with aerated steam at 60 to 71°C. One of these soils was mined at considerable depth in wind-blown fine sand. Such materials, and sterile or inert media such as perlite, vermiculite, or sphagnum peat, lack antagonistic microorganisms and therefore should not be expected to inhibit pathogens following aerated steam treatment. When materials exhibit no antagonistic effect before such treatment, they should not be expected to show it after treatment; aerated steam treatments select antagonists, they do not create them (20).

THE U.C. SYSTEM

It is instructive to consider the circumstances that prompted development of the U.C. mixes. Following the Pearl Harbor attack in December, 1941, the California bedding plant industry was operated by inexperienced people under conditions of war shortages of materials and labor, but with available Army and Navy contracts for growing tomato, pepper, and pimiento transplants. Cooperation of the California Agricultural Experiment Station and Extension Service with several growers emphasized labor-saving methods, dependable production (to meet scheduled contracts), and large volume (5).

A disease complex caused large losses of seedlings and great mental confusion to growers (2). Salinity from water, leaf mold, and manures caused widespread losses, especially if soil was allowed to become at all dry. *Pythium ultimum* caused damping-off when soil was kept wet in an attempt to reduce salinity injury. *Rhizoctonia solani* caused damping-off when soil was kept at medium moisture levels trying to follow a median course. Since these factors occurred in any combination, it was impossible to consistently prevent losses by careful watering. The only available answer was to eliminate root pathogens by soil treatment. A further confusion resulted from erratic transmission of *Rhizoctonia* in pepper and tomato seed; a hot-water treatment was developed to control this (1).

Because steam treatment of soil that contained manures or leaf mold produced toxins that stunted seedlings, inert, simple, reproducible soil mixes without a clay fraction were developed that were not toxic following steaming.

War priorities made it very difficult for new nurserymen without a previous history of need to get equipment or trucks to steam or haul soil. We tried unsuccessfully to get a large fertilizer company to undertake supplying treated, fertilized nursery soil mixes. The opportunity for the first centralized soil supply service was thus lost, and did not become a reality until 30 years later in New Zealand. A mobile continuous batch soil steaming and flat-filling unit (Figure 1) was built by Wilton Abplamalp in Anaheim, California, and used by growers for several years; it was the prototype of many units used today.

By 1948 most of the components of the new system of growing had been fitted together in the operation of American Plant Growers in Lomita, California (5). A sand-peat mixture with commercial fertilizers was mixed and moistened in a concrete mixer, and placed in flats (Figure 2). The flats were treated in a cannery retort at 100°C for 30 minutes (Figure 3). When cooled, the flats were machine-sown with treated seed by a perforated vacuum plate, and then covered with thin tissue paper before being passed under an automatic sander to cover the seed. The flats were then sprayed with water and held in a germination room until seedling emergence. They were then promptly placed on glasshouse benches under humid warm conditions to promote rapid growth. Pepper seedlings required 50 days from seeding to hardening, a saving of 25-30 days over the old system. Flats were then moved on steel rollers to outdoor cold frames, and hardened-off by lower temperature and withholding water and fertilizer. The wiry plants were then hand-pulled and moved in boxes of peat

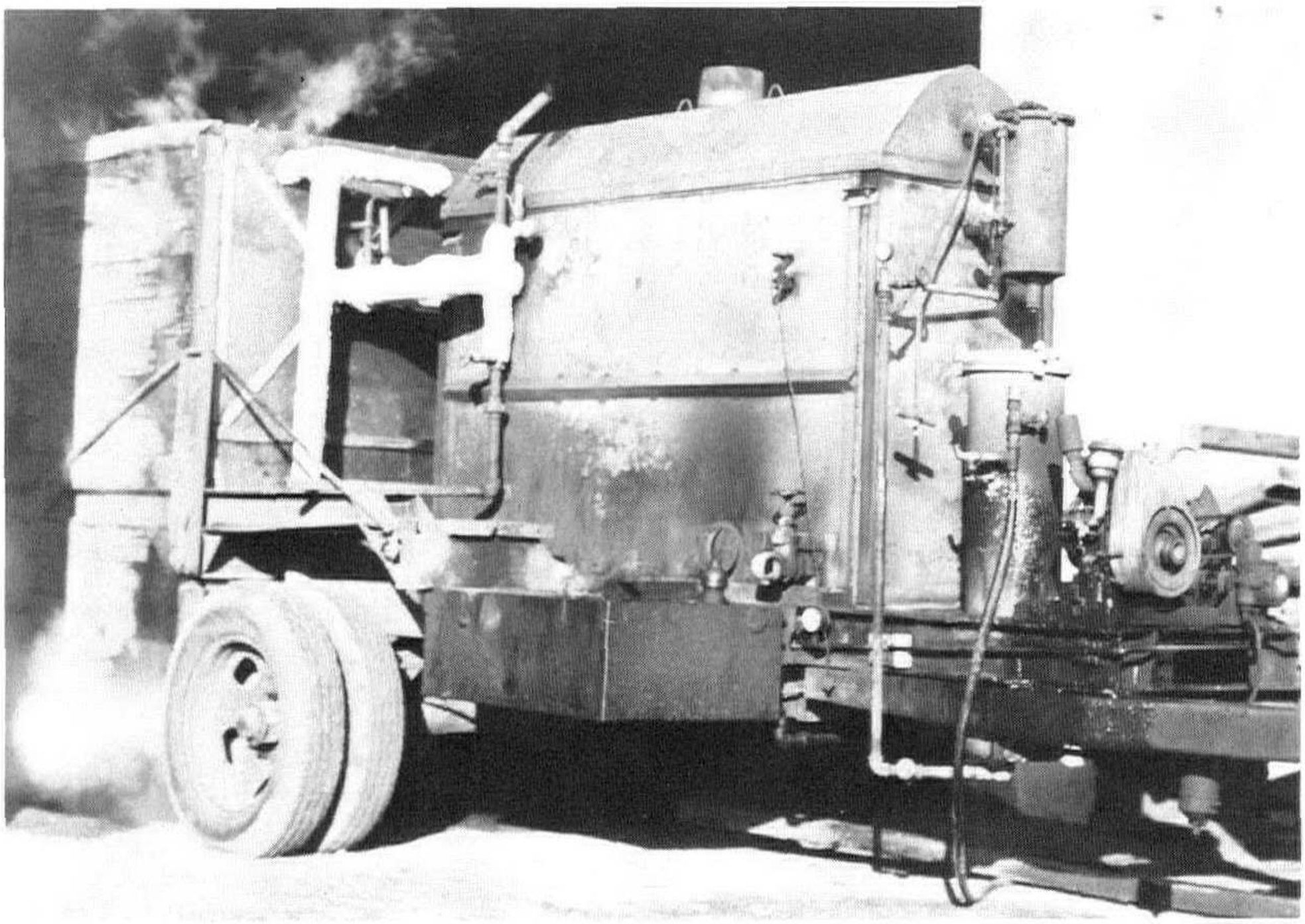

Figure 1. Mobile equipment built and used by Wilton Abplamalp, Anaheim, California, in the early 1940s for custom steaming of nursery soil. The steam generator is in front (*right*). The steam was injected into the soil in two continuous-batch type boxes at the rear (*left*). Each box held about two cubic yards of soil, and was dumped into a bin below, from which a flat-filler moved soil through an adjustable gate into flats passing below. One treatment box was heated to 100°C in 12 minutes, while the other was being filled by a conveyor belt. This unit was the prototype of many modern soil-steaming and flat-filling units. Photo courtesy of C. N. Roistacher.

moss to the field where they were machine planted. Sanitation and hygiene were emphasized throughout the procedure.

Details of the System were presented at the Refresher Courses for Nurserymen in San Luis Obispo in 1950, 1951, 1952, and 1958, provoking controversy. Some growers denounced it as ridiculous, unnecessary, and impractical hospital cleanliness; others who had used the scheme reported it as successful. Invaluable grower reaction and feedback was thus involved while the System was being developed. There was very close cooperation between more than a dozen investigators, growers, laboratories, and extension workers in a united way, with the sole purpose of getting the job done. There is a lesson here for our present time when such cooperation is rare and there is concern about who gets the credit.

Part of all of these methods have been widely used, and many modifications developed for adaptation to perennial or woody plants.

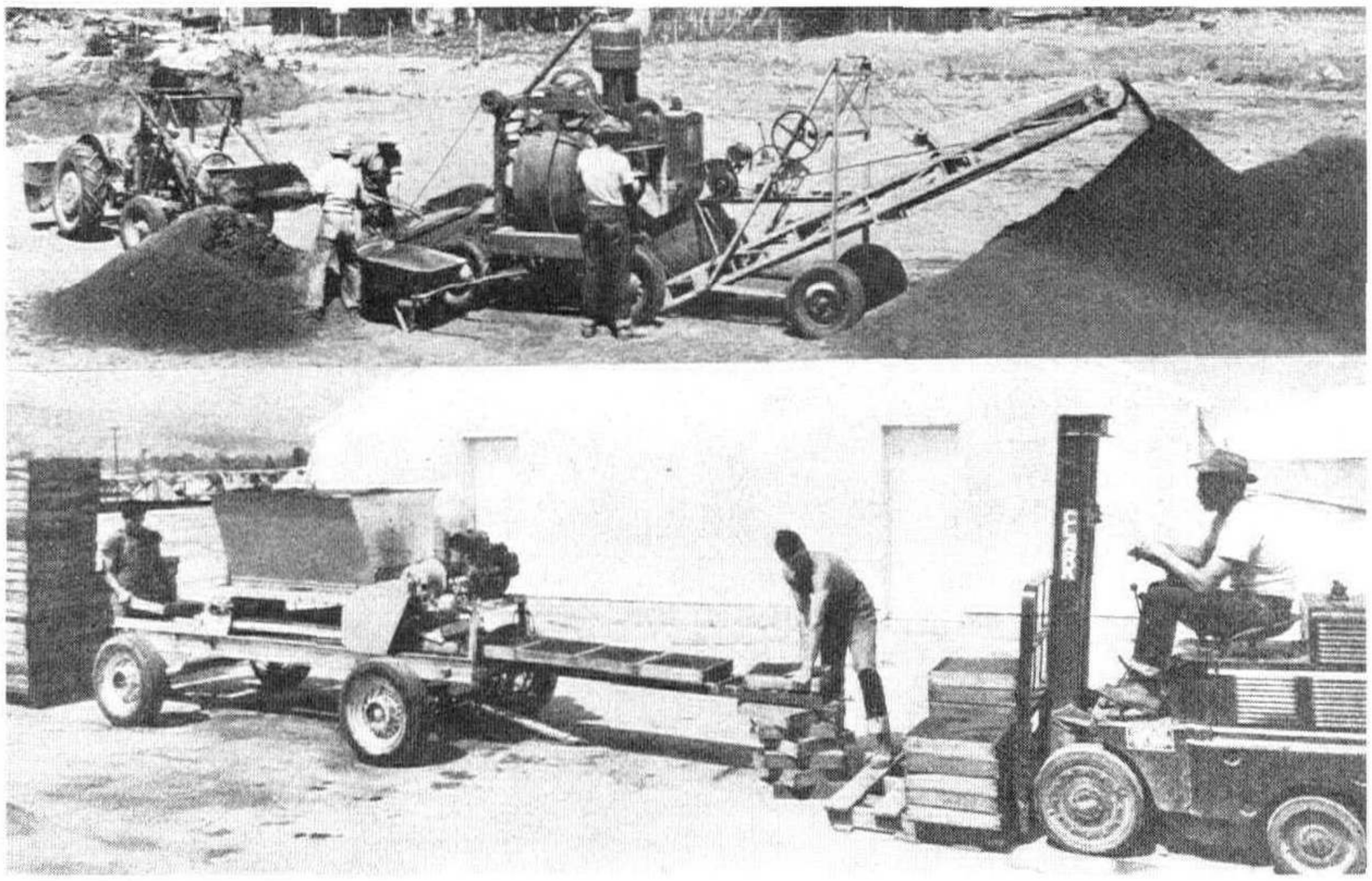

Figure 2. Soil-handling equipment in a bedding-plant nursery in the early 1940s. Upper photo shows method of blending ingredients of the soil mix and commercial fertilizer in a concrete mixer. Lower photo shows the mechanical flat filler built by Wilton Abplamalp and used by American Plant Growers, Lomita, California, for 30 years. The soil hopper was filled by a mechanical loader. This modified flat filler gave rise to many commercial units used today. Photos courtesy of American Plant Growers Inc., Carson, California.

Figure 3. Cannery retort used for soil steaming in the mid-1940s. Free-flowing steam was used, and the soil held at 100°C for 30 minutes. Photo courtesy of American Plant Growers Inc., Carson, California.

SOIL TREATMENT

Modern control of plant diseases is based on the principle that the ultimate sources of pathogens are previously infected plants and the soil, including its water and nonliving organic matter. Under the controlled environmental conditions of commercial glasshouses, application of this principle by planting pathogen-free stock in pathogen-free soil, and practicing sanitation to prevent recontamination, has practically eliminated many important diseases. Under relatively uncontrolled environment conditions of field plantings, however, the problem is more complex, and disease control therefore more complicated. A second principle, first enunciated by J. L. Jensen in Denmark in 1882, is that control of plant disease usually requires application of multiple integrated procedures, each operating in a different way or time to diminish disease, and collectively providing satisfactory control.

Soil treatment began in 1869 in France with the use of carbon disulfide, and this was soon followed by application of sulfur and formaldehyde. The first modern extensive soil fumigation in the field was in Hawaii in 1932-36 using chloropicrin, and was soon followed by application of DD, a mixture of 1,3-dichloropropene and 1,2-dichloropropane. The use of DD illustrates the operation of the Law of Lesser Concessions. Growers tried this relatively inexpensive soil treatment and found that it was economically profitable. Only then were they willing to try more expensive and effective treatments with chloropicrin or methyl bromide in the hope of even greater profit. They would not have tried these more costly materials without this intermediate successful experience.

Commercial soil steaming began in 1893, but application methods remained empirical for 60 years, with little scientific study or grower inventiveness. It had been known since about 1940 that moist heat of 60°C for 30 minutes would destroy plant pathogens except tobacco mosaic virus. However, the only way to achieve such treatment was to inject steam into a moving soil mass to attain and maintain that temperature. Critical investigations of soil steaming were made in England, Norway, and California in 1954-60. The studies on aerated steam in the first two places were made by engineers in an effort to reduce fuel consumption. Our California studies were aimed at avoiding the creation of a biological vacuum and the production of phytotoxins. Mixing air with 100°C steam dilutes it and lowers its temperature to a level determined by the ratio of air to steam. At 100°C this ratio is 0:1, at 82°C it is 1.5:1, and at 60°C it is 6.5:1 by weight. Aerated steam moves through the soil in the same manner and rate as does pure

steam. It is a frequent misconception that aerated steam is more complicated to use or more expensive than 100°C steam, although the reverse is actually true. Methods of commercially producing and utilizing aerated steam have been detailed in the 1976 IPPS Proceedings (6). The advantages of aerated steam over 100°C steam are: (a) microorganisms antagonistic to plant pathogens are not destroyed and provide a measure of biological control (4); (b) phytotoxicity does not result from steaming; (c) burns and discomfort for workmen are reduced; (d) soil cools more rapidly and can be used sooner; (e) plastic containers can be treated without heat deformation; (f) smothering molds are less likely to develop on treated soil; (g) lowered cost of generating the necessary steam.

Aerated steam treatment is more often used in Australia and New Zealand than in the U.S. and England. The Aussies and Kiwis came to soil treatment in the 1960s as aerated steam was being developed, and many started their first steaming with it. The use of 100°C steam was then the accepted method in the U.S., and the inertia of an established method has delayed change here.

Solarization, or the entrapment of solar radiation beneath clear polyethylene tarps, is a promising means of treating moistened field soil in areas of intense sunlight. The treatment works, in part, because of the prolonged exposure to elevated soil temperature, the time being much longer (several weeks compared with 30 minutes) and the temperature much lower (37° to 50°C compared with 60 to 100°C) than with usual soil steaming. Pathogens are killed, particularly near the surface (where most of them are), or they may be stressed and rendered more susceptible to killing by antagonists. Deeper pathogen propagules are also killed by undetermined conditions at depths below the zone of soil heating. The method has been successfully used on planted pistachio groves in southern California, controlling verticillium wilt without injuring the trees.

PATHOGEN-FREE PROPAGULES

That pathogen-free propagules are important in disease prevention was recognized by the middle, and emphasized by the end of the eighteenth century, when crude methods for their production were being devised. However, the widespread commercial production of such stock appeared only in the mid-twentieth century. Tip cuttings had often been used to decrease the amount of *Verticillium* infection, on the assumption that the fungus had not advanced into the shoot tip. However, in practice this was not sufficiently dependable for commercial use. A. W. Dimock in 1943 developed a culture-

indexing technique for producing chrysanthemum cuttings free of *Verticillium* for use in research. This cultured-cutting method was soon commercialized and quickly became the standard method for producing clean cuttings of rose, carnation, and sweet potato. Continuing the earlier work on tip cuttings, studies by several workers over the world on various perennial plants found that cultures of tiny apical meristems gave plants free of some viruses. F. Quak showed in 1957 that carnations free from fungi, bacteria, nematodes, and some viruses could be obtained by growing true apical meristems in culture, and she sometimes took them from plants exposed to long heat treatments. The method was soon applied to other ornamentals, to strawberry, sweet potato, and other crops. This was soon extended to monocotyledonous as well as dicotyledonous plants, and became the commercial method for obtaining pathogen-free clones.

The Law of Lesser Concessions also seems to govern the use of propagator-grown pathogen-free stock by growers. At first, a grower may buy a small number of clean cuttings, grow them on as a mother block, and use cuttings from this stock for a few years. When the second- or third-year crop develops disease losses, he may decide to propagate from them for only one year. It finally becomes evident that it is better to have the propagator produce the cuttings, and for him, the grower, to raise the crop. New growers still tend to progress through such steps in adopting any new practice. A procedure that cannot be adapted in steps wins acceptance more slowly than one that can (9).

ADVANCES IN THE LAST TWENTY-SEVEN YEARS

There have been six major additions to nursery procedures since U.C. Manual 23 appeared: a). the development and adoption of soil treatment by aerated steam (4,6,7,11); b). addition of selected antagonistic microorganisms to treated soil or plant propagules to decrease growth of an accidentally introduced pathogen (8,14) or to increase plant growth through bacterization (12,18); c). the use of minute meristems, cells, and protoplasts in propagation to reduce pathogen transmission (17,22); d). prolonged heat therapy of plant propagules to decrease virus transmission (3,19); e). prevention of pathogen transmission in irrigation water (10,15); and f). polyethylene glycol treatments to promote repair of metabolic damage of seeds from thermotherapy (16,21). These will now be considered in turn.

The destruction of microorganisms has been the dominant idea of chemical and thermal soil treatments since 1880-90,

and recommendations have tended toward overkill rather than minimal treatment. Broad-spectrum, high-potency chemicals at high dosages have been used in field treatment, and steam at 100 to 122°C for 30 minutes for soil in containers. There is now a marked trend toward minimal soil treatment with selective chemicals, and this unfortunately has given rise to the development of resistant strains of pathogens. We have progressively "cooled it" since about 1945 from 122°C for 6 to 8 hours (autoclaves), to 100°C for 30 minutes (flowing steam), to 82°C for 30 minutes (moving soil mass), and finally to 60°C for 30 minutes (aerated steam). The central fact here is that microorganisms differ in their resistance to heat, and that plant pathogens are more sensitive than many soil saprophytes to it. Aerated steam treatment at 60°C thus leaves a group of resident adapted saprophytes while eliminating pathogens in the soil; they luxuriate because of reduced competition, and are antagonistic to accidentally introduced pathogens. Other advantages of aerated steam treatment are reduction in resultant phytotoxicity, less discomfort and hazard for workers, and lower fuel cost.

The addition of selected antagonists to treated soil to compete with pathogens later accidentally introduced is a very promising supportive practice still too little used, apparently because a commercial product has not yet been made available, and because it is thought that soil treatment alone will provide adequate protection. However, a single antagonist may be effective against a single pathogen in a medium free from, or with a diminished population of, other microorganisms, as in glasshouse soils. Paradoxically, there are many successful applications to crops of much lower economic value (e.g., wheat, forest and fruit trees, vegetable crops) (8,14).

Microorganisms compete for nutrients, favorable sites, and oxygen, and are selected for tolerance of unfavorable conditions of carbon dioxide, pH, water, and other microorganisms. They secrete metabolic materials, some of which (antibiotics) inhibit other microorganisms, and others stimulate microorganisms to form essential stages of their life cycles. Biological control is the retention or restoration of a disease-suppressive biological balance, achieved through increasing antagonism of a pathogen by resident organisms through modification of cultural practices, or by introducing new antagonists.

A specific type of biocontrol by inoculation of propagules with selected bacteria prior to planting is attracting much notice from commercial laboratories and research scientists. Plant growth is significantly increased, even when disease is apparently absent, because growth-inhibiting nonparasitic pathogenic bacteria present on the roots are biologically con-

trolled. Bacteria that produce broad-spectrum antibiotics have been most effective for such increased growth (12). This bacterization offers a biological means of increasing crop yields without increasing energy demands or land area, and without environmental pollution (14).

Gene manipulation or genetic engineering of microorganisms for biological control is in its infancy, but has tremendous potential for improving the level of control achieved. Microorganisms may thus be tailored for specific purposes, such as transferring a gene for production of an antibiotic effective against a pathogen, from an organism unable to survive in the given habitat to another organism that survives well in that habitat but which produces no effective antibiotic. A promising and interesting new angle on genetic engineering is the genetic modification of crop plants to make them more favorable to biological control antagonists.

In general, the smaller the plant part used for vegetative propagation the better the chance of obtaining units free of pathogenic microorganisms and viruses, but the more complex and difficult the culture technique becomes. There has been a steady decrease in size of propagules from tip cuttings, to apical meristem cultures (1957), to single cell cultures (1958), to cultures of single naked protoplasts (1975). This is a highly specialized business of tremendous potential. Old cultivars, abandoned because of virus infection, may even be rescued. *The use of sterile explant cultures in plant introduction*, pioneered in 1976, greatly simplifies intercontinental movement of propagative material. Such cultures are now accepted for introduction of large numbers of propagules into Australia, where formerly only six cuttings of a cultivar were permitted. The use of such sterile cultures in place of the old mother-block system is already in practice in nurseries, greatly reducing costs and insuring better protection from infection by microorganisms and especially by viruses. The plants must, however, be checked periodically for genetic variability and for mutations. The practical problems of maintaining and multiplying the clean mother stock usually are more difficult than obtaining it in the first place. In a successful arrangement in England, a grower association finances the development and maintenance of such material at a government research station, for distribution to grower members.

Heat treatment of planting material briefly (30 to 60 minutes) at high temperatures (43 to 57°C) to eliminate pathogens has been used since 1887. Prolonged treatment (16 to 30 days) at moderate temperatures (36 to 37.8°C) came into use after 1940 to eliminate viruses and mycoplasmas in vegetative prop-

agules. It is widely and successfully used today to eliminate many viruses in propagules of woody and perennial plants.

In situations where nursery irrigation water comes from ponds or surface drainage, it may carry fungi, bacteria, or nematodes that cause plant disease, as well as troublesome algae. Since growers are now using planting material that is free of pathogens, and are treating their soil mixes, this source of contamination requires attention. Water contamination can be controlled by injecting chlorine gas or sodium hypochlorite into water to give 0.5 to 2.5 ppm of residual chlorine at the water-discharge point from the pipes.

Heat treatment of seeds decreases and retards their germination, apparently by affecting enzyme systems, particularly in seed more than a year old. The physiological injury sustained from treatment can be repaired by holding seed in polyethylene glycol 6000 for a time at an osmotic concentration that permits metabolic processes to repair the damage, without cell elongation or radicle emergence. This make possible treatment of seed at higher temperatures than could formerly be applied, improving the eradication of the pathogen.

It can fairly be said that nursery practices have been revolutionized in the last 27 years. However, it is also a fact that no grower is using all of the many available technical advances. There are certainly going to be many more advances in the future, but even if there are not, improvements can be made simply by fully utilizing presently available techniques. At which level of advancement will you settle?

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