to see it incorporated within 24 hours. I would not want to see it go longer than that, even on dry soil.

BRUCE USREY: Do you have any recommendations for spotted spurge control in juniper?

CLYDE ELMORE: No, I don't. You can use the preemergence herbicides. Dacthal is much better as a preemergent than any of the other common herbicides for spotted spurge control. There is no easy answer for spurge control in any of our junipers. But preemergence Dacthal has looked better than anything else. If you have heavy soils, you could even use simizine, but you'd have to be extremely careful with it.

BRUCE BRIGGS: At what time of year and at what temperature should TOK be applied—what sort of weather conditions?

CLYDE ELMORE: We've applied TOK mostly under cool conditions—cool weather when the temperature has been below 75° F. There doesn't seem to be as much difference in temperature as there is on how well the weeds are growing and the stage of growth If you get them at the two to three leaf stage, and the weeds are growing rapidly, temperature does not make that much difference. If you use it at higher temperatures, you're going to increase the injury to the ornamental plant.

MODERATOR BROWN: Clyde, we appreciate your taking time to share this up-to-date knowledge with us. We are looking forward to the Proceedings coming out so we can use the information you have presented here today. Thank you.

Our next speaker will be talking on disease-free propagation in relation to standardization of nursery stock. He is a gentleman who has contributed a great deal to the nursery industry and to all plant propagators; he is known to all of you. Dr. Kenneth F. Baker, of the Department of Plant Pathology, University of California, Berkeley.

DISEASE-FREE PROPAGATION IN RELATION TO STANDARDIZATION OF NURSERY STOCK

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It is a truism that there are two sources of plant disease organisms — the soil (including organic matter and water) and the host plant. Thus disease control in the nursery comes down to (a) the use of treated or pathogen-free soil, (b) use of pathogen-free propagules or planting stock, and (c) routine sanitation to keep them both clean.

DISEASE-FREE PROPAGATION

Soil. Although man has been growing plants in containers for at least 4000 years, only in the last 40 has he examined the bases for the practices employed. The development of nursery soil mixes has been discussed in detail elsewhere (1), and need not be repeated here.

Many troublesome pathogens of nursery stock carry over in soil, and means of combating them have passed through several phases. Before the problem was understood growers had necessarily devised, by trial and error, means of living with such pathogens. For example, very careful manipulation of soil moisture provided useful disease control. With knowledge of the existence of soil microorganisms, the use of soil treatments soon began. The philosophy at that time resembled that of many early settlers in the West, "There aren't any good Indians." Soil treatment by fumigants or by steam has been, and still largely is, based on the idea of overkill It is now clear that we have gone too far in this direction, and that our treatments have eliminated friends as well as foes (3). The contamination hazard in the nursery or the the final planting site is the price we are paying for creating a biological vacuum.

It is a fortunate biological fact that pathogens, because of the specialization necessary for successful parasitism, are easier to kill than some soil saprophytes. The means are now available, furthermore, to make a start in selective killing of pathogens in soil. There are two approaches to this problem:

> (a) Drastic soil treatment may be used, followed by inoculation with selected antagonists which will inhibit the pathogens. Here again the philosophy has progressed from the complex and difficult to a simpler and easier program. At one time it was thought best to isolate individual antagonists and reintroduce them, either singly or a few of them, into soil of near sterility. This would almost require a research program for each new situation. It is now realized that this also produces an unstable situation, and that a natural soil flora that includes many kinds of antagonists is to be preferred (6). How might such a program work? First, it is necessary to locate a soil in which the pathogen is unable to establish or to produce the disease in question. This is not as difficult as it sounds, for as any nurseryman knows, disease in plants is the exception rather than the rule. Such a soil can be freed of all plant pathogens by treatment with aerated steam at 140° F. for 30 minutes, leaving a balanced flora of antagonists. This soil may be used for inoculation of the propagation medium or container mix which has been reduced to near-sterility by

treatment with fumigants or by 212° F. steam. There are many points still to be worked out for this general method, but the results so far appear promising.

(b) Minimal soil treatments of the sort mentioned above, to leave as many saprophytic antagonists as possible, have proved useful in nurseries. Treatment of container soil at 140° F. for 30 minutes avoids producing a biological vacuum; any pathogen inadvertently introduced then encounters competition or inhibition. Most surface soil exhibits such an effect. Soils mined from below the surface, or inert materials such as perlite and vermiculite, naturally contain few organisms, and this protection cannot be expected from them. The object is to select antagonists, not to create them. For this reason, the method is of less use in propagative media than it is in container soil mixes.

Propagules. There have been many methods devised for obtaining clean propagating stock. Some of these are:

(a) Propagules are produced in an area free of the pathogen, or in which the climate prevents infection of the seed or stock.

(b) The propagules are grown in such a manner that they remain uninfected. Taking tip cuttings from plants grown on trellises under non-humid conditions thus effectively produces stock free of *Rhizoctonia*, *Pythium*, and many bacterial pathogens.

(c) Cuttings may be cultured to determine those which are free of infection. The method has been a major factor in the phenomenal decrease in mum and carnation diseases.

(d) Heat treatment of propagative material has proved useful on a wide range of plants. A brief high-temperature treatment with aerated steam (4) or hot water (2) has proved useful for seed, bulbs, cormels, etc. Longer treatments at lower temperatures have been used to free many kinds of herbaceous and woody plants from certain viruses (7).

(e) Prolonged roguing of diseased plants from a stock is beneficial if the pathogen does not spread faster than it can be rogued out, and if the symptoms can be relied on to indicate infected plants. The method is best used on some virus diseases, such as rose mosaic, and is best combined with methods (d), (f), and (h).

(f) Virus indexing methods have been devised to increase the probability of detecting virus-infected stock in roguing This technique has been valuable in reducing viruses in mums, carnations, and certain woody plants.

(g) Growing plants from seed. Most viruses are not seed-transmitted (5), but accumulate during vegetative propagation. Thus, raising freesia, anemone, and ranunculus from seed produces much healthier plants than growing them from corms, roots, or claws. This method presupposes that the plant will breed true from seed. Geraniums are now rapidly changing from cutting to seed propagation, as snapdragons did many years ago.

There is a phenomenon in many kinds of seeds in which a number of adventitious embryos are developed from the nucellus or integuments. These have been found to be virus-free and identical in citrus—a sort of virus-eliminating vegetative propagation. Can ways be devised to capitalize on this phenomenon in other crops as well?

(h) Apical meristem culture is the most recent method of obtaining healthy stock, and usually produces essentially pathogen-free stock (7). The very tiny (0.02-0.004 inch or less) apical growing point is removed and grown in culture. After the plantlet has formed roots, it is transferred to thumb pots, and finally to larger pots. The method is based on the fact that the growing point under glasshouse conditions is essentially free of microorganisms, that some viruses under certain environmental conditions do not reach the growing point, and other viruses only attain such low concentrations there that they are unable to establish and are finally eliminated. This is a laboratory method, and should not be undertaken by untrained personnel

Smaller and smaller vegetative propagating units have been used in the nursery business, shifting successively downward from root divisions to cuttings, to stem tips, to growing points, to meristem-tip cultures, perhaps to single cells. One of the principal reasons for this trend is that the smaller the tissue piece used, the more likely it is to be free of pathogens. However, as the propagule size diminishes, the difficulties of propagation and indexing increase, the complexity of techniques and facilities increases, and the chance of success decreases. However, there are ever smaller worlds to conquer. Several laboratories are now studying the possibility of vegetative propagation from a single cell or tiny clumps of cells. It is probable that, for some plants, this method may eventually provide the means of obtaining pathogen-free stock

There is a very real problem of maintenance of the original pathogen-free stock, since there are no designated places to carry them on. This is now more important than developing new techniques for obtaining clean stocks. This function is being carried on by a number of commercial propagators, but there have been failures to maintain the necessary isolation, controlled sanitation, and indexing.

Perhaps a facility financially supported by industry, but under the supervision of competent plant pathologists, will be the answer.

Sanitation. It is a common misconception that in a program such as this a level of cleanliness to be found only in hospitals would be required. While this condition would be fine for maintaining the valuable mother or nucleus blocks, the cleanliness for most of the operation is more nearly that which one expects in his home, a hotel, or a restaurant. Perhaps in this day of Women's Lib we should ask wives to assist in raising nursery standards of cleanliness to those they demand in their kitchens!

THE PROPAGATOR'S OBLIGATIONS

The propagator holds a key position in the production of nursery stock The earlier in the life of the propagule that it becomes infected with a disease organism, in nearly all cases the greater will be the damage to the resulting plant It is, therefore, especially important that the stock be kept free of pathogens while in the hands of the propagator If the plant becomes infected while in the hands of the propagator, there is often nothing that any subsequent grower can do about it. This imposes the responsibility on nurserymen to produce stock that is not only disease-free, but that is pathogen-free. There is, of course, an important difference between these states.

It is quite possible to produce infested or infected propagules that show no disease. Plants can be grown in soil too dry or at temperatures too high for development of disease. China aster seedlings may be grown, for example, at 60° F. in soil infested with the aster wilt *Fusarium* and develop no disease. When later planted in the yard at soil temperatures of 70-80° F., every plant may die. That, furthermore, is not the end of the matter. The soil becomes infested and asters can then no longer be grown there Similarly, root rot of woody plants caused by *Phytophthora cinnamomi* may be minimized by growing plants in well-drained media on the dry side. In the uncontrolled environment of the yard or orchard, the plant dies and the soil becomes permanently infested. The nursery propagator is indeed his brother's, his employer's, and the customer's keeper. The obligation, although great, is too seldom appreciated.

There is no excuse today for nurserymen to produce stock that is carrying pathogens. It is, in cold fact, immoral and unethical to do so, and short-sighted poor business practice as well. The fault is not wholly with the propagator. He is pressured by salesmen and by some research and extension workers as well, to drench the plants with chemicals when they show disease. Some of these are quite effective in suppressing disease—Dexon for *Pythium* and *Phytophthora,* and PCNB for *Rhizoctonia*. The fact is rarely pointed out that these materials do not kill the pathogens; they merely inhibit them for a time To maintain the inhibition by Dexon it must be applied at least every 10 days; PCNB has a longer life. This may be economically feasible during the brief period in the nursery, but can you imagine the owner of an avocado tree planted in his yard drenching it every 10 days for the rest of his life? Not to tell him that his plant, like a diabetic and his needle, needs an expensive elixir of life every few days is ethically even more questionable. The only answer to this is to grow clean propagules in clean soil in the nursery. It is quite as possible to pollute the environment with pathogens as with fungicides!

PATHOGEN-FREE ANTAGONIST-INOCULATED STOCK

It was mentioned earlier that treatment of soil with aerated steam at 140° F. for 30 minutes eliminates pathogens and leaves many antagonistic saprophytes. If a potent suppressive soil for the principal pathogen involved can be found and so treated, it will provide excellent inoculum for propagative beds steamed to near-sterility at 212° F. for 30 minutes Aside from protecting propagules while in the nursery beds, these antagonists would be carried with the propagules to the planting site. There is much work to be done in this area, but it now seems probable that nurseries will sometime in the future produce not only pathogen-free stock, but pathogen-free antagonist-inoculated materials as well. Work in progress indicates that direct inoculation of seed with antagonists, as with nodule bacteria *(Rhizobium)* on legume seed, is also a distinct future possibility (6).

STANDARDIZATION AND CERTIFICATION

The current interest in standardization of nursery stock has been expressed in specific standards in a number of states. These standards have in common the establishment of specifications for certain plants, without considering how the stock was produced. This trend is puzzling because nurserymen generally recognize that two plants of similar size may have vastly different growth potentials when planted out. A well-grown plant produced unchecked under constantly favorable conditions, and free of root pathogens is certainly a far better buy than a larger specimen more slowly grown under intermittently unfavorable conditions, or one infected with root-rot fungi but not yet showing disease symptoms. The first plant will rapidly equal or exceed the second in size because the latter may start growth slowly or not at all.

Two misconceptions seem to lie at the root of this problem. Seedling diseases are thought not to persist and damage mature plants *Phytophthora cinnamomi* may be acquired by seed in fruit picked up off of the ground; when planted, they give rise to diseased rootstock seedlings and, when they are planted in the orchard, to diseased trees The pathogen may not kill the tree until years later, during a particularly wet winter, after the plant value has increased many-fold. The second fallacy is that infested or infected seedlings can be detected by symptoms or plant appearance. By inversion, this is taken to mean that if plants do not look sick or die, they must be free of root pathogens. Neither is true. Several years ago a long-term investigation at an Experiment Station to determine the effect of viruses on tree growth was upset when it was found that many of the plants had unsuspected Phytophthora root rot. Experience clearly indicates that one cannot positively assess root infection without examination and probably culturing of roots.

The basic problem is to devise specifications which can be readily established by examination but which will accurately assess the growth potential of a plant as well as measure its present size It is not enough to specify, as one state did, "Nursery stock when sold shall not be dead or in dying or seriously damaged condition."

Experience clearly shows that you can truly standardize nursery plants only by standardizing the conditions under which they are grown. This does not necessarily mean that every grower must use the same method for growing a certain plant, but that plants grown under the cleanest and best conditions will receive the best rating. *One must grow plants for standardization, not merely standardize and grade plants randomly produced.*

Many characters suggested for nursery standardization do not reflect growth potential of the plant, but merely measure the existing physical status. It is comparable to judging a car by its overall length or quantity of chrome rather than by its actual performance.

It may be possible to make some assessment of growth potential by examination of the roots. A root-bound condition from too long a period in the container can be detected, and an estimate of root condition and the presence of root rot or nematode damage thus reached.

Standards are a sort of descriptive business shorthand which tell what type of plant is involved. This is necessary for the transaction of business, particularly in mass merchandising, and should be strengthened and improved. It should not be confused, however, with measurement of growth potential.

To supplement these standards, a voluntary certification or registration scheme is needed to evaluate growth potential. Official periodic examinations could record, for example, the time the plants in a given block were grown in a certain size container, the uniformity of growth rate, whether the soil was treated or steamed, whether the lining-out stock used was pathogen-free, whether any plants had died and from what, whether specified sanitary precautions were followed, whether suppressant fungicides had been applied, and whether plants had been excessively forced to reach the prescribed size. Several state certification schemes for seed potatoes, seeds, strawberry plants, avocado and citrus trees, and others establish the necessary precedents. Grower participation should be voluntary, permitting him to decide whether he wishes to have the stock certified or merely described as to physical standards.

It would be relatively easy to apply such a certification scheme to lining-out stock and this would be a suitable place to begin. The propagator is again the key factor!

Under such a program nursery stock would always have a descriptive grade and could have an additional certification. A buyer could then decide whether a Certified No. 2 plant was a better investment for orchard planting than a plain No. 1 plant. It is as important today to assess growth potential, health, and vigor of a plant as to standardize its physical characteristics. A dual system of the sort described appears to be the only feasible way to truly standardize nursery stock. Many details remain to be worked out, but some such program is certain to evolve sooner or later.

LITERATURE CITED

1 Baker, K. F. (Ed.) 1957. The U.C. system for producing healthy container-grown plants. *Calif. Agr. Exp. Sta. Manual 23*:1-332.

2 Baker, K. F. 1962. Thermotherapy of planting material. *Phytopathology 52*:1244-1255.

3 Baker, K F. 1962. Principles of heat treatment of soil and planting material. *J. Austral. Inst. Agr. Sci. 28*:118-126.

4 Baker, K. F. 1969. Aerated-steam treatment of seed for disease control. *Hort. Res. 9*:59-73.

5. Baker, K. F 1972. Seed pathology. *In:* T. T. Kozlowski (Ed.), Seed Biology, Vol. 2, Chapter 5. pp. 317-416

6 Baker, K. F. and R. J. Cook. 1972. Biological Control of Plant Pathogens. W. H. Freeman & Co., San Francisco. (In press.)

7 Hollings, M 1965. Disease control through virus-free stock. *Ann. Rev. Phytopath. 3*:367-396

MODERATOR BROWN: Thank you, Dr. Baker. Now are there questions?

ANDY LEISER: Where are these repressive soils—in general, are they found in any particular type of agriculture?

KENNETH BAKER: The one that I was speaking of was *Phytophthora cinnamomi:* and, I might add that *Pythiums* and *Phytophthoras* are the hardest of any of this sort to find. We have one soil staked out in Australia, of all places. It's the only one that I know of in the world that really works this way. And it is the one I was speaking of where the organism, *Phytophthora cinnamomi* is present and it is completely suppressed and has been for 30 years at least, because colossally big avocado trees are growing on it with no root rot at all. Now these are the sorts of things that you really look for, but there are many other kinds, and strangely enough they occur in a wide range of plants. For example, one of the men in Washington state is working on cereal diseases; I never thought of this as a thing that would really work there, but he has found soils there that are utterly suppressant to some of the root rots of wheat. He has a very big experiment that has just been set up that I'm waiting with great interest to see how it is going to turn out with next year's crop. What he did, in effect, was to take wheat seed and mix it with gum arabic. He has taken this suppressive soil from the fields where it retards these organisms and simply pelletted wheat seeds with suppressive soil. Now, this may sound like a long shot, and it may be, but I don't think it is for this reason. He also has shown this year in experiments that by adding this suppressive soil to a field where the disease was formerly active that it did, in fact, suppress it. Now we don't know whether this is going to continue to be a permanent thing or will be a "flash in the pan" for a year or two. But the quantity put on is really surprising. It would amount to 10 pounds of this suppressive soil put on—broadcast over the surface—per ton of the soil that you put it on, figured at a 6" depth—and it suppressed the disease. So I think that the trick is to find these different soils—and there are a number of them for different pathogens that we know of. Probably we shouldn't take time to ennumerate them here, but if you are specifically interested, I'll be glad to tell you about some of the others.

VOICE: Have any antagonistic microorganisms been recognized in these soils?

KENNETH BAKER: In these soils—definitely; and this is where the good part of it comes in, because for the most part, they withstand 140° F., if we're talking about treating soil with aerated steam. These are spore-forming bacteria. They come through—you knock out all of the fungi, and a good deal of the Actinomyces—getting rid of all pathogens while the beneficial organisms come through and actually are stimulated just because they break dormancy from heat treatments.

VOICE: Have you recognized or been able to culture them?

KENNETH BAKER: Yes, but we're going away from this idea of culturing them individually and adding them. I like to use the analogy of a pyramid If you stand a pyramid on its peak, on its apex, it's the most unstable thing in the world. It will fall over one way or the other if you do nothing about it. But if you turn it over and place it with the big side down, it becomes very stable and it stays put. I mean this as a direct analogy, because if you put a single organism in the soil, it's the most unstable thing in the world—it can either go rampant—it can stunt your plants—or it will be lost. But if you take the whole flora that is in there—that is balanced already, it has a built in stability that enables it to stick And this is why we're moving off of this deal; the reason for mentioning it here is that it's the sort of thing that you as individuals can actually do something with. There's nothing complex about it at all once you get zeroed in on the idea of what a suppressive soil is like. And I would put it this way—that if you have a soil where diseased seed has been planted—for example, it's carrying a pathogen — and you plant the seed in this soil for a few years and the disease never appears, then you have a suppressive soil, or if it's in an area where the organism is present, as in the avocado soil, out there, and it can be recovered, and still you don't get the disease. That, indeed, is a suppressive soil. There are a lot of them around—we've just got to find them and manipulate them.

FRANCES SPAULDING: Would you suggest screening for insect vectors—this sort of thing?

KENNETH BAKER: Well, certainly in the maintenance of disease-free stock. We talk about virus-free stone fruits, for instance. The ones that they maintain at U.C., Davis are kept in screened lathhouses for this reason. This is what you have to do once you get clean stock. You have to maintain it. This is where, so often, the program falls flat; they will get it clean, but then it becomes a great chore to maintain it and build it up for commercial use. I think there should be some sort of agency set up to do this; there is, in England, in the floriculture industry. They have put up a series of glasshouses at Littlehampton and the material that they get from apical meristem culture, and so on, goes in there. The support of this is from the industry. They get the material back at no cost to themselves, but it is supervised and run by experiment station people there to make sure that the plant material is kept clean.

MODERATOR BROWN: Dr. Baker, we appreciate the fine work you have done for the nursery industry and thank you very much for giving us this most thought-provoking presentation today. Thank you.