dipped in the same solution. An insurance practice which has been shown to be beneficial is to add ten drops of household bleach per pint of hormone solution. The use of hormone powders reduces the chance of cross contamination, particularly if some Captan is mixed with the powder. Dusting the powder on the base of the cutting is less apt to spread disease than dipping cutting in powder. However, the use of powder provides less uniform treatment than the liquid quick-dip.

RECENT ADVANCES IN BIOLOGICAL CONTROL OF PLANT PATHOGENS WITH RELEVANCE TO THE NURSERY INDUSTRY

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Abstract: The application of biological control of root rot diseases in nurseries is discussed. In Australia, isolates of the bacterium *Bacillus* have controlled damping-off of bedding plants caused by Pythium and Rhizoctonia. Some *Bacillus* isolates have increased the growth rate of bedding plants and given increased yields of field crops such as carrots, sweet corn and grains. Biological control of crown gall is now used commercially in Australia.

Biological control of root diseases is a reasonable reality and a growing number of people accept with guarded optimism that plant disease control by biological means in the broad sense has immense potential for the future(14). The field of biological control has recently been reviewed by Baker and Cook(2).

Aerated Steam Treatment of Soil Potting Mix. Nurseries almost universally grow their plants in steamed or chemically treated soil to reduce losses from soil-borne diseases such as *Pythium*, *Rhizoctonia* and *Phytophthora* and to control weeds and insect pests. High dosages of fumigants or steaming at 100°C for 30 minutes or longer tend to produce a "biological vacuum" and when a pathogen is accidentally introduced it may luxuriate producing severe losses.

Aerated steam treatment at 60-71°C for 30 minutes is now commonly used to kill root pathogens and leave a residual flora of saprophytes antagonistic to the pathogen. Components of mixes that are nearly devoid of micro-organisms (e.g. perlite, vermiculite, and sands mined from deep in dunes) cannot provide this protection following treatment by aerated steam.

Establishing Biological Control in the Nursery. One of the best methods of instituting biological control is to start seedlings and cuttings in propagative beds inoculated with suitable antagonists. Because the antagonists dominate the flora in the medium where the roots of the seedlings or cuttings are started, the roots and stems are infested by them. In many nurseries, environmental conditions can be readily controlled to establish antagonists around plant roots. An alternative method is to inoculate seeds with the antagonistic organism.

Biological Control of Pythium. A commercial test by Watson (See Baker and Cook,(2)) in the U.S.A., showed that chrysanthemum cuttings rooted in a steamed propagative medium inoculated with random antagonists were well protected against a high level of *Pythium* when they were transplanted to infested soil. Moist organic matter of near-sterility exposed to air-borne contamination for several days provided the inoculum of antagonists that was placed on the propagative beds. Although this method of obtaining antagonists cannot be recommended, the level of success obtained shows that empirical methods may give surprising results. At Rydalmere we(4) introduced an isolate of the bacterium *Bacillus* into steamed soil and reduced damping-off caused by *Pythium*.

Biological Control of Rhizoctonia. Biological control of *Rhizoctonia* in nurseries is more easily achieved. Saprophytic fungi and isolates of *Bacillus* and *Streptomyces* have protected seedlings both in Australia and in the U.S.A.(4,5,11). Some micro-organisms inoculated into soil however may increase the amount of disease. The ability of an antagonist to control *Rhizoctonia* damping-off varies with the strain of *Rhizoctonia*, some *Bacillus* isolates prevent pathogenicity of all isolates used and others are effective only against the extremely pathogenic *Rhizoctonia*. The effective antagonists do not influence the survival of *Rhizoctonia* in the soil, but appear to hinder infection.

Sometimes the protection afforded by an antagonist is incomplete and a single infected seedling will occur in the midst of a group of healthy ones. In punnets without the antagonist, damping-off occurs on a front affecting all seedlings. It is possible that the single infected seedling did not have the antagonist colonising its roots. Such a seedling became infected and this could be the means whereby *Rhizoctonia* moves into the aerial phase of attack when the fungus advances up the stem. Under humid conditions stem infection will then occur in plants previously protected from damping off.

Biological control of Fusarium in Carnation. Work in the United States(1) has shown that *Bacillus subtilis* isolates in the propagation medium protected the cuttings from attack by *Fusarium roseum* f. sp. *cerealis*.

Biological Control of Crown Gall. In all the above cases of biological control, an unrelated organism has achieved the control. Dr. Alan Kerr (7) at the Waite Institute found that while *Agrobacterium radiobacter* var. *tumefaciens* will cause crown gall in peaches, etc., a closely related organism, *A. radiobacter* var. *radiobacter*, a nonpathogen, will control crown gall. Biological control has been achieved by dipping roots of young peach seedlings in the antagonist and by seed inoculation.

Biological Control of Phytophthora Root Rot. As yet we have not been able to control *Phytophthora* root rot in the nursery situation. However, field soils suppressive to *Phytophthora* root rot exist in Australia. These suppressive soils have the following properties: (a) a high content of organic matter; (b) high calcium levels (29-25 meq; (c) pH of 6.0-7.0; (d) very high populations of microorganisms; (e) a high magnesium content; (f) well drained red basaltic soils; (g) high ethylene levels; (h) high levels of ammonium and nitrate nitrogen (3).

The problem lies in establishing the microorganisms from the suppressive soil in a nursery potting mix. To do this the soil conditions in the potting mix will have to approximate those in the original soil so that the correct balance of organisms for disease control can be achieved.

Fertilizers and pH. Some root diseases are less severe and others are more severe when specific forms of nitrogen fertilizer are used. Diseases caused by *Fusarium* and *Rhizoctonia* are increased in severity by ammonium nitrogen and decreased by the nitrate form (6). Phytophthora root rot, however, is increased by nitrate nitrogen and decreased by the ammonium form.

The pH change associated with ammonium or nitrate fertilizer in most cases is not large enough to inhibit the pathogen directly or to account for the observed magnitude of change in disease severity and biological control may be involved.

Use of Microorganisms to Increase Plant Growth. Extensive commercial trials have been carries out in a N.S.W. nursery to determine the feasibility of inoculating treated soil with bacteria to increase the growth rate of bedding plant seedlings (Broadbent, unpublished). Seed germination was increased for portulaca, delphinium, eggplant, celosia, dahlia, cabbage and alyssum by *Bacillus* isolate WW27, and for portulaca, delphinium and snapdragon by *B. subtilis* isolate A13. Germination of several species was increased by 25% and that of portulaca by 133%. Seedling top weight was increased by WW27 for pepper, portulaca and celosia and by A13 for delphinium, dahlia and carnation. The weight increase frequently was 25% and that of celosia was 123%. Field experiments by Merriman and Price of the Victorian Department of Agriculture (9) have shown that A13 seed-pelleted on carrots, sweet corn, barley, wheat and oats have substantially increased yields.

Current experiments at Rydalmere have been designed to determine if A13 pelleted on the seed, or established in the nursery potting mix, will carry over to the field situation and provide growth and yield responses.

Biological Control with Ectomycorrhizae. Under field nursery and forest soil conditions the feeder root systems of trees are in a mycorrhizal condition. Mycorrhizae are feeder roots symbiotically infected by certain fungi and are considered indispensible to health and vigour of the tree host.

Mycorrhizae of most conifers and certain broadleaf tree species are formed by mushroom or related fungi and are called *Ectomycorrhizae.* Fungal symbionts of ectomycorrhizae penetrate between the cortical cells of the feeder root, replacing the middle lamellae. Additionally, these symbionts form over the feeder root surface a dense, usually compacted and continuous network of hyphae called the fungus mantle.

Ectomycorrhizae increase the absorption surface of roots, selectively absorb and accumulate nutrients and render otherwise unavailable substances in soil available to the tree host.

Work in the U.S.A. (8) has shown that ectomycorrhizae function as biological deterrents to infection of feeder roots by *Phytophthora cinnamomi* in certain pine seedlings. The ectomycorrhizae form a mechanical barrier to infection by *Phytophthora*, and they produce an antibiotic against the fungus.

Mycorrhizae of other forest trees such as poplar, sycamore and fruit trees such as citrus and pecan nuts, are formed by lower fungi, namely *Endogone* spp; and are called *endomycorrhizae.* These fungal symbionts penetrate into the cortical cells. Inoculation with *Endogone* has resulted in large growth responses in field crops as well as citrus and conifers. The role of *Endogone* in biological control is largely unknown. The stimulation of mycorrhizae on Monterey pine in New Zealand by the application of superphosphate resulted in indirect control of *Phytophthora* root rot (10).

Biological Control Following Chemical Treatment. Chemicals are often employed to control damping off and root diseases. Many of these chemicals kill the pathogen immediately and thus directly decrease or eliminate the root disease problem. Quite often, however, chemical control is significantly enhanced indirectly by soil saprophytes. Many saprophytic organisms tolerate the chemical or are able to rapidly recolonise the treated soil after other organisms have been eliminated.

Application of fungicides (e.g. captan, dexon, terrazole and DBCP) has reduced damping off of pecans due to *Pythium* spp

(12). There was no reduction in the population of *Pythium* but the fungicides caused a large increase of mycorrhizae and it has been suggested they offered protection from attack by the pathogen.

Conclusion. It is obvious that biological control does work and there are applications in the nursery industry. However, it will be some time before we completely unravel the mechanisms of biological control and manipulate them to our advantage.

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