The major disadvantage of the teats is that they cost some 25¢ each and, since they break down in light, are not re-useable. We are currently working on an injection moulded equivalent which should cost only a few cents each.

MYCORRHIZAL FUNGI — THEIR ROLE IN PLANT ESTABLISHMENT

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Abstract. Mycorrhizal fungi are beneficial soil fungi associated with the roots of plants. In forming a symbiotic association with the plant root, these fungi can: (a) increase nutrient uptake and improve plant growth in nursery and field soils, (b) reduce transplant injury, (c) assist rooting and survival of cuttings and (d), deter infection of roots by soil-borne fungal and nematode pathogens. Inoculation of horticultural plants with suitable mycorrhizal fungi in the nursery results in the beneficial mycorrhiza being carried with the roots when the plants are set out in the field, thereby improving plant establishment, survival, health, and growth.

INTRODUCTION

Horticulture is currently in the midst of a widespread boom. This is due partly to the introduction of new crops, but also to the adoption of new techniques in plant breeding, container production of plants, tissue culture methods for bulk propagation and pathogen elimination, and in the use of fertilisers, pesticides, herbicides, and soil fumigants. However, despite the obvious advantages associated with some of these progressive changes, problems still exist in growing horticultural plants. Plant pathogenic bacteria and fungi often cause concern and the control of some pathogens, particularly those below ground, is sometimes unsatisfactory or impossible by chemical means. Furthermore, the use of pesticides and herbicides, or soil sterilisation, can upset the delicate balance of micro-organisms present in the soil, often creating nutritional or pathogen imbalances and thereby adversely affecting plant growth. In the future, increasing costs and depleting energy resources could reduce fertiliser production, an industry essential to horticulture and agriculture.

Most soils contain a variety of fungi and other micro-organisms. Some of these are pathogens and are harmful to plant growth. However, there are others that are beneficial to plants. There is an increasing range of naturally-occurring soil bacteria and fungi which have found commercial use either as biological fertilisers or as agents for biological control of plant pathogens (1).

One such group of beneficial micro-organisms are the mycorrhizal fungi. The fungi involved form a symbiosis with the roots of plants. It is a beneficial association where both parties benefit: the host provides carbohydrates for the growth of the fungus and, in return, the fungus supplies nutrients to the host. Mycorrhizal fungi invade plant roots virtually forming an extension of the root system and thereby improving the uptake of nutrients by plants (14).

At present, four types of mycorrhizas are associated with different groups of horticultural crops (5). Ectomycorrhizas occur naturally on the fine feeder roots of many valuable trees — pine, spruce, beech, oak, pecan. Another group associates with plants of the heath family (Ericoid mycorrhizas). A third, very widespread group associates with a range of horticultural and ornamental plants, ranging from cereals to tomatoes to citrus and subtropical tree crops (Vesicular-arbuscular (VA) mycorrhizas). A fourth group associates only with orchids (Orchidaceous mycorrhizas).

The purpose of this article is to point out where mycorrhizal fungi (in particular the VA mycorrhizal group) can contribute to the establishment and production of horticultural plants.

Vesicular-arbuscular (VA) mycorrhizas: VA mycorrhizas are the most widespread of all the mycorrhizal associations. The fungi involved associate with a range of horticultural and ornamental plants, such as cereals and grain crops, tomatoes, legumes, citrus and subtropical tree crops, vegetable crops, and ornamentals. Roots become infected from very small spores (<1 mm diameter) which are present in the soil either singly or in groups. These fungi can benefit the establishment and growth of plants in several ways:

1) *Improve plant growth in nursery and field soils.* The most striking effect of VA mycorrhizas is their ability to improve the growth of plants, particularly in low or medium phosphate soils. The same effect could be achieved by adding quantities of phosphate fertilisers (Figure 1). However, it is possible to replace some of that fertiliser with mycorrhizal fungi and still produce the same increase in plant growth.

Phosphorus has consistently been shown to be involved in mycorrhizal-assisted nutrition. However, mycorrhizal fungi also increase the selective uptake of other minor elements, such as zinc, sulphur, potassium, and copper, and have been shown to relieve symptoms of zinc deficiency in peach, citrus, and apple (5).

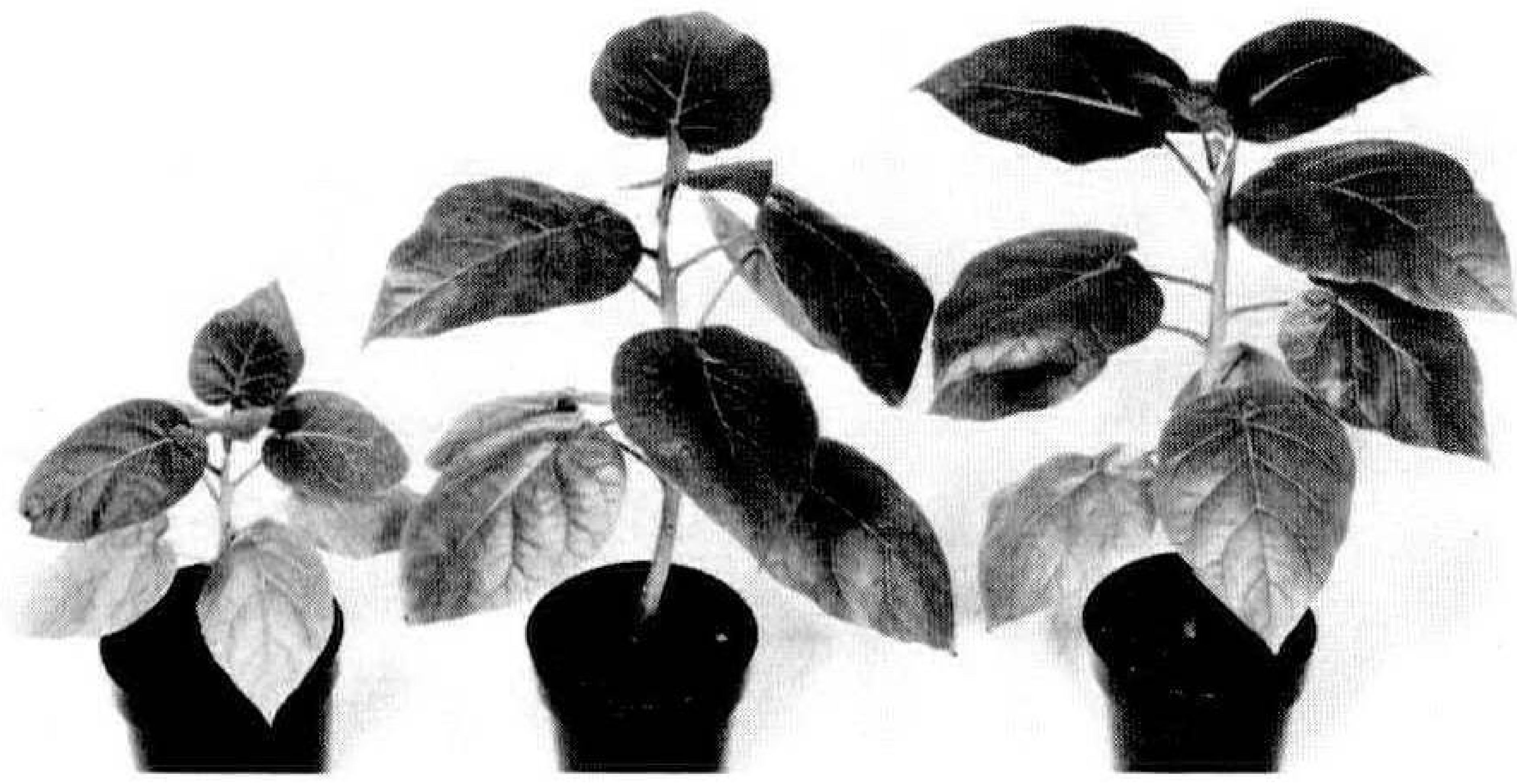

Figure 1. Effect of VA mycorrhizal fungi and added phosphate fertiliser on the growth of tamarillo *(Cyphomandra betacea)* plants in field soil. Growth in field soil is poor and indigenous fungi are slow to infect roots **(plant on left)**. Plant growth is improved by the addition of mycorrhizal fungi **(middle plant)** or phosphate fertiliser (60 kg P/ha) **(plant on right)**.

Although VA mycorrhizal fungi are present in most field soils, these naturally-occurring fungi are not necessarily the best at improving plant growth. Many of the field mycorrhizal fungi are slow to infect roots and are inefficient at improving the growth of transplanted stock (Figure 1.)

Figure 2. Avocado *(Persea americana)* plants infected with VA mycorrhizas (left) show greater resistance than uninfected plants (right) to wilting after transplanting.

Whereas most mycorrhizal fungi improve plant growth in low to moderate phosphate soils, some fungi are more effective than others. This effectiveness can vary depending on host and soil type. For example, a fungus found to be particularly beneficial to the growth of tamarillo in one soil may not necessarily be the best fungus for either citrus or tamarillo in another soil. Furthermore, some fungi can depress the growth of one host but stimulate the growth of another. Before inoculating plants with mycorrhizal fungi it is, therefore, important to select the fungus, or fungi, most appropriate to a particular host and soil type.

At high levels of soil phosphate, some mycorrhizal fungi are either killed or simply do not function (5). However, it is possible to select fungi which will infect roots even in fertilized soils (2). These fungi will be particularly useful in horticultural soils and potting mixes, many of which have been heavily fertilised and have a high phosphorus level. It is also possible to produce mycorrhizal plants at an adequate growth rate by using slow release fertilisers (5).

2) *Reduce transplant shock.* Because mycorrhizal plants are more vigorous than uninfected plants they often recover more quickly when transplanted into the field. They are usually less susceptible to wilting and slowing of growth as a result of transplanting (7; Figure 2).

3) *Assist rooting and survival of cuttings.* Mycorrhizal fungi may be able to stimulate rooting of cuttings by speeding up root initiation and subsequent root development (Table 1). Mycorrhizal cuttings also show increased survival rates compared to non-mycorrhizal cuttings when transplanted into field soil (Table 1).

Table 1. VA mycorrhizas assist rooting and survival of tamarillo (*Cyphomandra betacea*) cuttings.

	Progress of rooting after 3 weeks			Percent survival after 6 months
	roots initiated	moderate root development	good development	
No mycorrhizas	+++	0	0	54
No mycorrhizas (+ hormone)	++	+++	+	76
+ mycorrhizas	0	+++	+++	98

\+ ≤ 10% of plants
++ 11 to 49% of plants
+++ ≥ 50% of plants

4) *Deter infection of roots by soil-borne nematode and fungal pathogens.* Recent work with mycorrhizal fungi has indicated that because of their ability to colonise both roots and soil, they may have a role in the biological control of soil-borne fungal and nematode root diseases (13). Inoculation of

plants with mycorrhizas can overcome the detrimental effects on plant growth caused by root-knot nematode (Figure 3), and can also reduce the number of nematodes able to penetrate into and develop within the root. This benefit is greater when the mycorrhizal symbiosis is well established before plants are placed in nematode-infested soils.

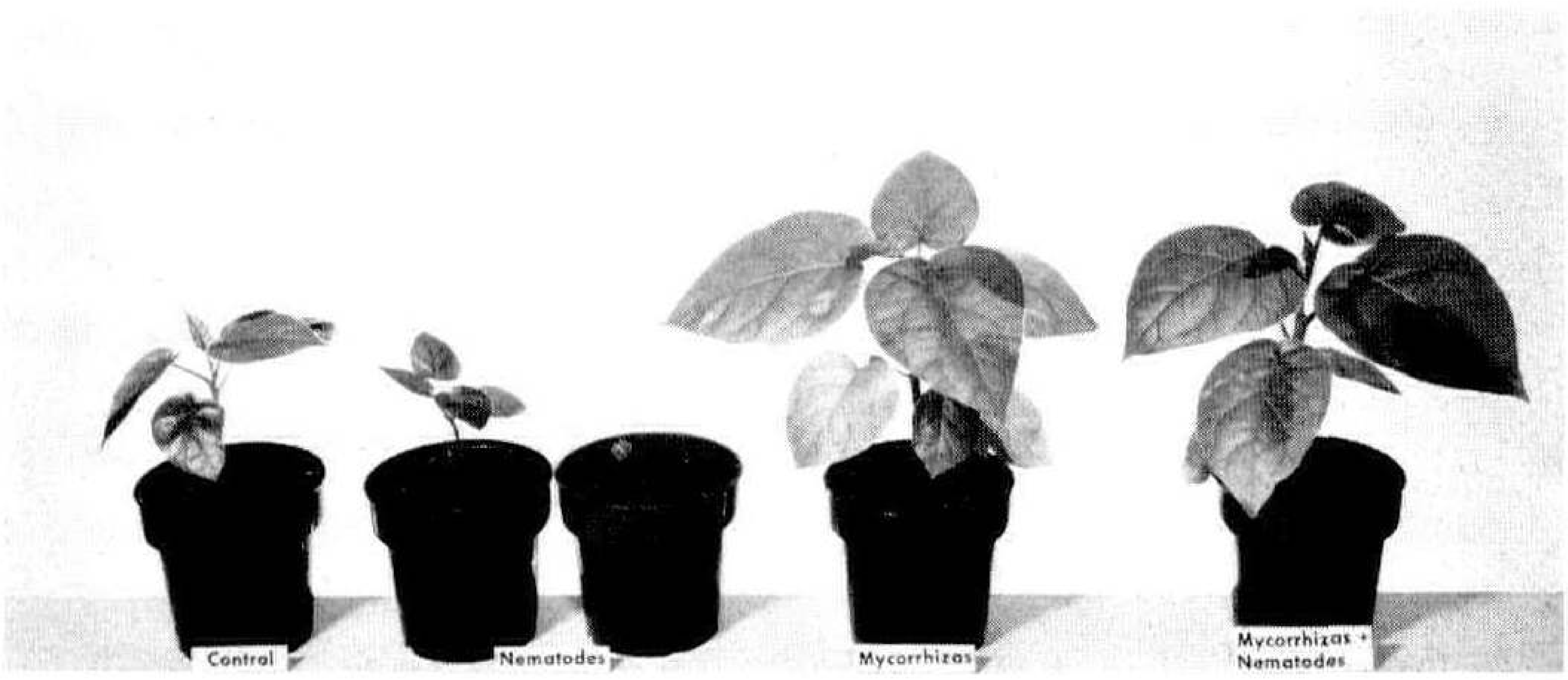

Figure 3. Inoculation of tamarillo (*Cyphomandra betacea*) plants with VA mycorrhizal fungi has overcome the detrimental effects on plant growth caused by root-knot nematode (*Meloidogyne incognita*) [data from (3)]. **Left to right:** Control, nematodes (2 plants), mycorrhizas, mycorrhizas + nematodes.

Ericoid Mycorrhizas. In natural ecosystems, plants belonging to the Ericaceae (such as *Erica*, *Vaccinium*, *Rhododendron*, and *Calluna*) are normally infected with the ericoid mycorrhizal fungus (12). These mycorrhizas influence plant growth by the absorption of nitrogren rather than phosphorus.

Ericoid mycorrhizal fungi could well have application in the improved production of ericaceous berry crops and in some ornamental nursery plants. Growth of *Rhododendron* plants in nursery soils has been improved by inoculation with ericoid mycorrhizas (19). In New Zealand ericoid mycorrhizas are becoming increasingly important with the introduction of blueberries as a significant horticultural crop. Natural mycorrhizal infection levels are very low in most of the mineral and peat soils where blueberries are now grown. This means that plants may remain non-mycorrhizal and poor croppers for several years before becoming infected. Inoculation of blueberry plants with ericoid mycorrhizal fungi has increased nitrogen uptake and has improved fruit yield in the first season by 11 to 92% (10,11).

Orchidaceous Mycorrhizas. In nature, most orchids require mycorrhizas at some stage in their life cycle and many require the association to facilitate seed germination. However, with modern sterile culture methods, orchid seed can readily be germinated on media containing inorganic salts and a carbon source (e.g. sucrose). Many of these media are inhibitory to the growth of mycorrhizal fungi (16). Some fungal isolates can infect germinating orchid seeds and may establish a symbiotic phase. However, others, such as *Rhizoctonia solani*, which may be a vigorous pathogen of non-orchid hosts, can readily infect orchids but may lead to parasitism of the seedling protocorm (4). In a commercial enterprise, where orchid seed can readily be germinated artifically, and orchids can be propagated using tissue culture methods, it is doubtful if the orchid mycorrhizal symbiosis will ever be more than a curiosity.

Ectomycorrhizas: The ectomycorrhizal association can benefit its particular hosts in ways very similar to the VA mycorrhizal association. The fungi not only improve plant growth through increased nutrient uptake, but they can also infer some degree of resistance to soil-borne pathogens, relieve plant stress under adverse conditions of extremes of temperatures, soil acidity, moisture, and salinity, and produce hormones which can assist plant rooting and development (5).

Much of the practical application of this association has been in forestry, and artificial inoculation of tree seedlings with ectomycorrhizal fungi is now common practice in many countries (particularly USA, Canada, Europe). Mycorrhizal plants are used to advantage in the establishment of man-made forests and in afforestation of adverse sites such as coal spoils, scree slopes, and high altitude timberline sites (6,15). They may also have application in the establishment of shelter belts, in land reclamation or stabilisation, in the production of ornamental plants, and in the establishment of commercial nut crops such as hazelnut or pecan.

PRACTICAL CONSIDERATIONS

The normal horticultural practices of commercial enterprise can affect the beneficial mycorrhizal symbiosis. The use of phosphorus fertilisers can reduce the effectiveness of many mycorrhizal fungi. Similarly, certain fungicides or herbicides can be detrimental to mycorrhizal development, particularly during the early stages of fungal establishment (8). Therefore, if mycorrhizal fungi are to be used commercially, appropriate management procedures will need to be adopted to ensure continued survival of the fungus.

Soil sterilisation effectively kills mycorrhizal fungi and recolonisation of sterilised soil is slow by natural means. Inoculation of plants with mycorrhizal fungi has potential economic importance in all situations where soil is sterilised as part of routine horticultural practice (e.g. glasshouse crops, horticultural nurseries, ornamental nurseries). Until recently, many nurseries raised their stock in field soils. Now, however, to avoid problems caused by infection with various pathogens, nurseries often raise their stock in fumigated soils or in some potting mix combination of bark, peat, sawdust, or sand. All of these mixes are usually devoid of mycorrhizal fungi. Stock from such soil-based or soil-less mixes is transplanted into the field without the benefit of a mycorrhizal association.

Commercial prospects for inoculation of plants with mycorrhizal fungi. Mycorrhizal fungi have been around a long time. People have long recognised advantages in transferring soil or humus from under a vigorous plant to developing seedlings or cuttings. This method usually does ensure mycorrhizal development, but it does create problems: the inoculum is bulky to handle and transport and there is a danger of introducing pathogens.

At present, there are three aims in infecting plants with mycorrhizal fungi:

a) to increase the plant's establishment and survival capabilities.

b) to improve plant health.

c) to increase plant growth and, if possible, production.

To achieve this, and to ensure a constant supply of pathogen-free inoculum, it is desirable to produce inoculum in culture of some kind.

Production of VA mycorrhizal inoculum is difficult. To date, the fungi involved in this symbiosis cannot be grown in pure culture — they must be raised in association with a host in sterilised soil, sand, or some suitable solid media, or in solution culture. Virtually all inoculum is currently produced from mycorrhizal-infected roots in a soil based mix. However, it is difficult to obtain sufficient quantities of pathogen-free mycorrhizal material. Production of various types of inocula is currently being investigated in several laboratories throughout the world. Unfortunately, commercial production still seems some time away, although small quantities of inoculum for citrus are currently being produced in commercial nurseries in southern California.

In contrast, the ericoid mycorrhizal fungi for blueberries and many ectomycorrhizal fungi for application in forestry and some ornamentals and nut crops can be grown very well in culture. Commercial preparations of ericoid mycorrhizal fungi suitable for inoculating blueberries are now available in New Zealand. Commercial preparations of some ectomycorrhizal fungi are currently available in the USA.

CONCLUSION

Horticultural plants are relatively easy to inoculate with mycorrhizal fungi. Mixing inoculum into sterile potting or nursery mixes, or incorporating it into nursery beds, allows the beneficial fungi to come into close contact with the roots of seedlings and cuttings. Inoculation of plants such as citrus, avocado, tamarillo, or blueberry in nursery beds or potting mixes with selected mycorrhizal fungi results in the beneficial mycorrhiza being carried with the roots when the plants are set out in the field, thereby improving plant establishment and early growth and reducing transplanting losses.

There are still many difficulties associated with the commercial production and application of mycorrhizal inoculum. Research on many aspects is still in its infancy and there is a distinct danger of rushing into commercial ventures before background information has been adequately researched.

Nevertheless, despite these difficulties and looking towards the future, it is desirable that:

1) Seedlings and cuttings should be inoculated with mycorrhizal fungi in the nursery prior to transplanting.
2) The most appropriate mycorrhizal fungus must be selected.
3) Nursery plants should be correctly managed using appropriate pesticides, herbicides, and fertilisers to ensure continued survival of the mycorrhizal inoculum in the soil.

There are tremendous potential advantages in manipulating mycorrhizas as a horticultural tool. However, it must be borne in mind that mycorrhizas are part of a complex biological system and may, therefore, be correspondingly difficult to manage successfully.

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