the end result is a barren growth. Simply allowing the plants a normal rest period and forcing no more than one or, at the most, two flushes of growth annually avoids these unwanted results.

There is much more to be learned about dormancy, how it is triggered, how it operates, and how it can be overcome or taken advantage of in the propagation of species rhododendrons. But the propagator who adjusts his timing or treatment of cuttings in consideration of dormancy is likely to experience success in producing these plants.

MYCORRHIZAE IN RELATION TO ROOTING CUTTINGS

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It has been stated by Zahner (1965), and probably by others before, that "In the natural environment, there exists no organism that lives like a hermit." Ponder that statement for a moment, and then let's consider plants and their associations with other organisms as a example. Certainly no plant in nature lives alone, but instead is surrounded, both above and below ground, by a myriad of microorganisms covering their roots, branches, leaves, and flowers. Some live in close association with the plants becauses of the chemical exudations from roots and leaves that support the microbe's life processes. Consider if you will, however, the intimate association that exists between plant roots and mycorrhizal fungi. Such associations are nearly universal, such that mycorrhizal associations are the rule not the exception. Healthy rootlets of most vascular plants growing in natural soil are inhabited by these beneficial fungi in a state of symbiosis. We are just now beginning to understand the nature of these fascinating associations, and what some of the implications are to the propagation, growth and survival of plants.

It is important to understand that there are two main types of mycorrhizae: ectomycorrhizae and endomycorrhizae. The key differences between these two types are that ectomycorrhizae generally form a thick mantle of fungal hyphae on the outside of the root tips, and the hyphae penetrate between the root cortical cells. (3).

These fungi are most often mushroom-type fungi (Basidiomycetes) that can be grown in culture. When they colonize roots, they often induce extensive proliferation of roots,

greatly increasing the root surface area. In addition, the fungal hyphae extend outward from the root into the nooks and crannies of the soil, absorbing water and nutrients that are translocated back to the host root.

In contrast, the endomycorrhizae, mainly vesicular-arbuscular (VA) mycorrhizae, form no outer mantle and penetrate and completely fill up the root cortical cells. The VA mycorrhizae are obligate symbionts that cannot be grown in axenic culture. They must be grown in association with living plant roots. The last stage in their life cycle is to produce large, thick-walled spores on hyphae that extend into the soil from mycorrhizal roots. The VA mycorrhizae induce little or no change in the morphology or appearance of the roots and can only be detected by clearing the root and staining the fungal structures inside the root.

Ectomycorrhizae occur mainly on members of the Pinaceae, Betulaceae, and Fagaceae; the same fungi can form mycorrhizae with members of the Ericaceae, although the morphology of the association is somewhat different, i.e. they are called ectendomycorrhizae because they form only a loose outer mantle but penetrate and fill up the outer root cortical cells. Most of the other higher plant groups form VA mycorrhizae.

We know that the plant derives a number of key benefits from the mycorrhizal associations such as increased uptake of water and nutrients. We can also observe that ectomycorrhizae exhibit a greatly changed morphology (compared to non-mycorrhizal roots) in response to growth-promoting substances produced by the fungal symbiont. One could readily hypothesize that such substances might influence the physiological process of root initiation during cutting propagation. This thought was the basis for our first experiments on mycorrhizae in relation to rooting of cuttings (2).

Rooting of cuttings of some plants is relatively easy, especially if a rooting hormone is applied at the proper time. Other plants such as bearberry (*Arctostaphylos uva-ursi* (L) K. Spreng., are not so easily propagated by cuttings and were thus chosen as test species. The hypothesis was that ectomycorrhizal inoculum grown in the laboratory and added to the rooting medium would produce growth-promoting substances that would influence the rooting process. Two months after we had added the ectomycorrhizal inoculum to flats of rooting medium and had stuck cuttings, the benefits became apparent. Cuttings of 4 cultivars of bearberry in the uninoculated rooting medium were nearly all dead, as evidenced by the lack of roots and the presence of necrotic leaves. In contrast, cuttings in the inoculated medium were green, buds had broken, and growth was

proceeding. Most had significant root systems. We visually rated the root ball size of those cuttings that had roots. It was obvious that more cuttings had rooted and root systems were larger on cuttings stuck in medium containing the ectomycorrhizal inoculum. An examination of the roots revealed, however, that in most cases the bearberry roots were not actually infected with the mycorrhizal fungi, i.e. mycorrhizae had not formed. This observation suggested that the rooting response was induced by one or more entities produced by these fungi in the medium. Further, the response was not the same for each of the four bearberry cultivars tested, i.e. one fungus-cultivar combination resulted in enhanced rooting while the same fungus with another cultivar gave no rooting enhancement.

A graduate student, C.A. Call, joined me on this project at this point to examine the phenomenon more closely. He confirmed that the response was real, using as many as 13 fungi on still a fifth bearberry cultivar, as well as on huckleberry (*Vaccinium ovatum* Pursh.). Using three fungi he found that he could dilute the inoculum 10-fold and still enhance rooting. A culture filtrate of the ectomycorrhizal fungi also enhanced rooting, but to a lesser degree than the living fungi. Inoculation of the rooting medium was most beneficial during the non-optimal period for rooting. December, than during any other time of the year including the time considered to be optimum by propagators (October). He also noted that rooting was enhanced more in well-aerated medium than in water-logged medium near the mist nozzle. When rooted cuttings were transplanted into pots, he observed a striking growth enhancement of cuttings rooted in mycorrhizal inoculum compared to uninoculated control cuttings. Some mycorrhizal inoculum was carried along with the root ball and mycorrhizae did form, a response which would account for the dramatic growth response.

Our results thus far and those reports in the literature led us to consider several possible mechanisms responsible for the rooting enhancement phenomenon. It is possible that the mycorrhizal inoculum somehow changed the physical, chemical, and/or biological composition or structure of the medium in such a way as to enhance rooting, but we have not explored those possibilities enough to comment on their involvement. Rather, we have focused on the idea that mycorrhizal fungi release certain growth factors into the medium that interact with endogenous growth substances in the cutting. It is known (4) that some ectomycorrhizal fungi can produce growth regulators such as auxins, cytokinins, gibberellins, and B vitamins *in vitro*, but none of these substances is produced by all the fungi we tested. We felt it was possible, however, that all of the fungi

might produce other materials such as ethylene and/or auxin synergists.

Another graduate student, James Graham, has demonstrated that most of the ectomycorrhizal fungi he has tested can produce variable amounts of ethylene *in vitro* if provided with the right precursor, such as the amino acid methionine. At very low concentrations, ethylene has been shown to stimulate root initiation, although other reports are contradictory (1).

We are most aligned with the idea that auxin synergists or rooting co-factors (1) are produced by these fungi. Auxin synergists are polyphenolic compounds that can control the hormone balance in plants; they can help maintain high levels of endogenous auxin in the cutting; they are known to be involved in the host infection process; and they may form auxin-phenol complexes that may predispose tissue to initiate root primordia. We are presently testing our fungi to see if they can, indeed, produce such materials. If so, we will perform experiments to demonstrate their role in the rooting enhancement phenomenon.

Among the many things we still don't know about this rooting phenomenon is how widespread it occurs, i.e. how many hosts might respond and how many fungi may be capable of inducing this response. Several cooperators have been testing inoculum of one fungus, *Pisolithus tinctorius*, on a wider host range. Dr. Wilbur Anderson of Mt. Vernon, Washington, has rooted tissue culture rhododendron cuttings in *P. tinctorius* inoculum and obtained slightly better survival, percentage rooting, and fresh weight of cuttings stuck in inoculated medium than cuttings stuck in uninoculated control medium. A commercial concern in Chicago, Illionis has been exploring this phenonmenon using mainly endomycorrhizal (VA) hosts stuck in a medium inoculated with *P. tinctorius*. In some tests they observed enhanced rooting of hosts like chrysanthemum, although there appeared to be a cultivar response similar to that which we observed for bearberry. In one case, *P. tinctorius* plus rooting hormone gave what appeared to be an additive effect on the root ball size (R.J. Steinkamp, personal communication), a response which could support the rooting co-factor idea expressed earlier. The significance of these findings, if confirmed, would be that the growth factors produced by these ectomycorrhizal fungi may influence rooting of non-ectomycorrhizal hosts (i.e. endomycorrhizal hosts) and thus broaden their potential use to propagation of many more host plants.

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THE USE OF MYCORRHIZAE IN THE PROPAGATION OF ARCTOSTAPHYLOS UVA-URSI

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Mycorrhizae have long been known to influence the growth of plants. The fruiting body of this interesting family of fungi has also been known to Europeans as truffles. I first became interested in the use of mycorrhizae when Dr. James Trappe of Oregon State University presented a lecture on the use of mycorrhizae at an Oregon State University Ornamental Short Course. He suggested that mycorrhizae fungi exist on most plants when they are growing out-of-doors in native soils. He also showed some very convincing slides that illustrated what happened to plants that did not have the benefit of the mycorrhizae fungi.

Taking the hint, I dug up a kinnikinnick (*Arctostaphylos uva-ursi*) plant from one of my mother blocks and took the soil and roots and put them in a small cement mixer, added water and let it run for about an hour. Then I strained the muddy water through a window screen sized sieve and sprayed the diluted solution over 50,000 rooted cuttings of kinnikinnick which had recently been potted into 2¼ in. pots. I know I took a chance, but the results were phenomenal. The growth at the end of the year was almost double of what I had been obtaining and the plants were in an extremely healthy condition. I showed the plants to Dr. Robert Linderman of the U.S.D.A. Ornamental Plant Laboratory at Corvallis, Oregon, and he confirmed that I did indeed have mycorrhizae fungi growing on the roots of nearly every plant examined. Unfortunately, this particular mycorrhizae grows partly on the inside and partly on the outside of the roots and there has been no success in propagating it when it is not associated with live roots.