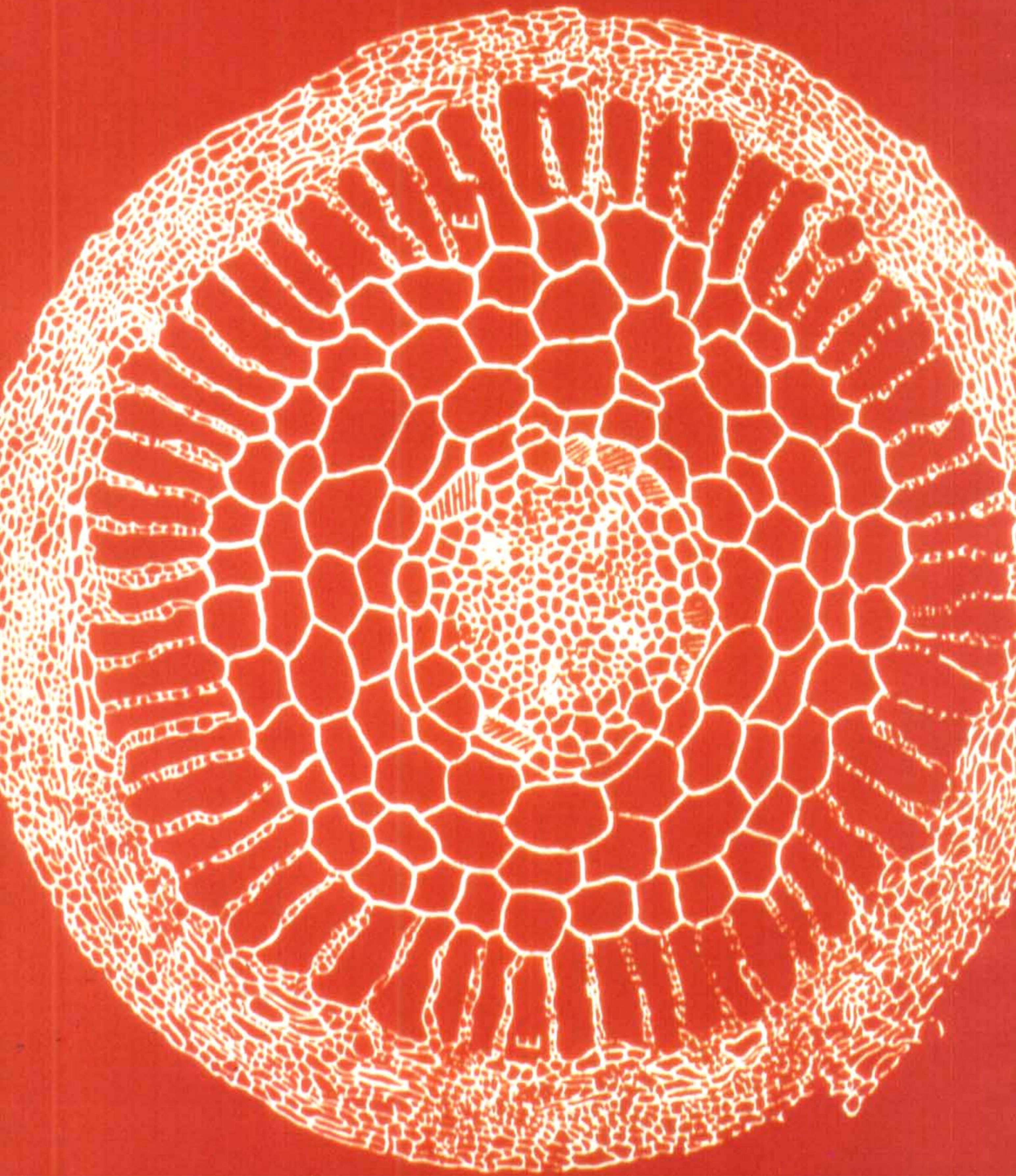
Can Mycorrhizae Control Root Disease?



N. C. Schenck
University of Florida, Gainesville

The answer to "Can mycorrhizae control root disease?" would require a crystal ball or a soothsayer. Past and current research indicates that mycorrhizal fungi can deter or significantly reduce the effects of some pathogens on the host. Most of the evidence, however, is from laboratory, greenhouse, or microplot studies. Little work has been done in the field, and no deliberate effort has been made in commercial agriculture to control root disease with mycorrhizae. In my opinion, preliminary results of greenhouse studies look promising and justify further investigations.

What Are Mycorrhizae?

Plant roots form mycorrhizae with certain fungi, resulting in a mutually beneficial symbiosis. Most plants have a fungus-root (myco-rhiza) rather than roots per se; only a few plant families do not form mycorrhizae. The three general types are ectomycorrhizae, endomycorrhizae, and ectendomycorrhizae; only the first two types have been studied for effects on root-infecting fungi and the diseases they cause.

Ectomycorrhizae are formed predominantly on forest tree species, particularly those in the Pinaceae, Fagaceae, Betulaceae, and Myrtaceae, by fungi in the Basidiomycetes and Ascomycetes. The fungus forms a dense layer of hyphae over the root, called the mantle (Fig. 1), and becomes established intercellularly in the root cortex. Ectomycorrhizal roots characteristically have a thickened, branched appearance (Fig. 2), compared with roots without mycorrhizae.

Endomycorrhizae are formed on roots of plants in many families by fungi in the Zygomycetes and Basidiomycetes. The predominant and most widespread group are the vesicular-arbuscular (VA) mycorrhizae in the Endogonaceae (Zygomycetes). These fungi form vesicles (terminal hyphal swellings considered to be storage organs; Fig. 3) and arbuscles (intracellular haustorialike structures). No mantle is produced and no change in root morphology occurs as with ectomycorrhizae. Both ectomycorrhizal and endomycorrhizal fungi are ubiquitous,

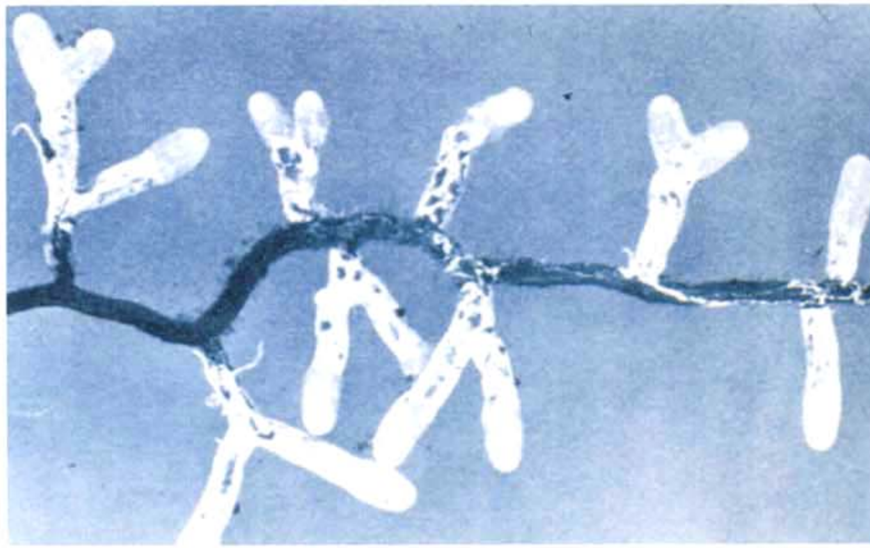


Fig. 2. Thickened, branched roots resulting from ectomycorrhizal fungus on *Pinus* sp.

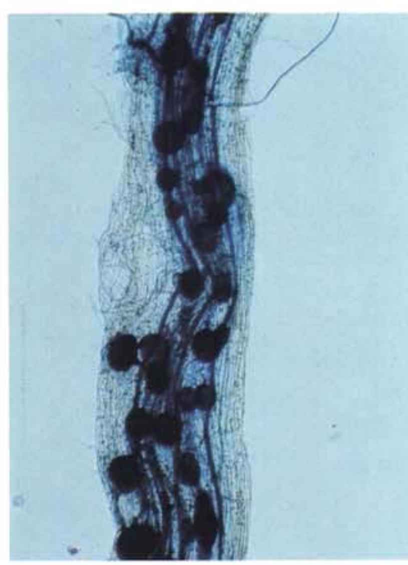


Fig. 3. Stained plant root containing vesicles (dark blue inflated objects) of vesicular-arbuscular (VA) mycorrhizal fungus.

Fig. 4. Effect of VA mycorrhizal fungi on growth of citrus rootstock (rough lemon) seedlings (left to right) inoculated with *Glomus etunicatus*, inoculated with *G. mosseae*, and noninoculated. (Courtesy A.-C. McGraw)

but VA mycorrhizae occur on a much greater number of plant species and thus are more common.

What Are the Attributes?

Mycorrhizae have received considerable attention in recent years because mycorrhizal plants have several advantages over nonmycorrhizal plants. Mycorrhizal plants grow better in infertile soil (Fig. 4), largely because of increased uptake of nutrients that are relatively immobile in soil, such as phosphorus. The volume of permeated soil is much greater with the hyphae of a mycorrhizal fungus than with plant root hairs, and for this reason many plants with short or rudimentary hairs depend more on mycorrhizae than do plants with finely branched roots and long and abundant hairs (14). Mycorrhizal fungi enhance water transport in plants (10), decrease transplant injury (6), help plants withstand high temperatures (5), promote establishment of plants in wastelands (4), and reduce the effect of root-infecting fungi (3,11). These

Florida Agricultural Experiment Station Journal Series No. 2622.

(Opposite page) Fig. 1. Cross section of ectomycorrhizal root of pine showing thick outer layer of fungus tissue called the mantle.

0191-2917/81/03023005/$03.00/0

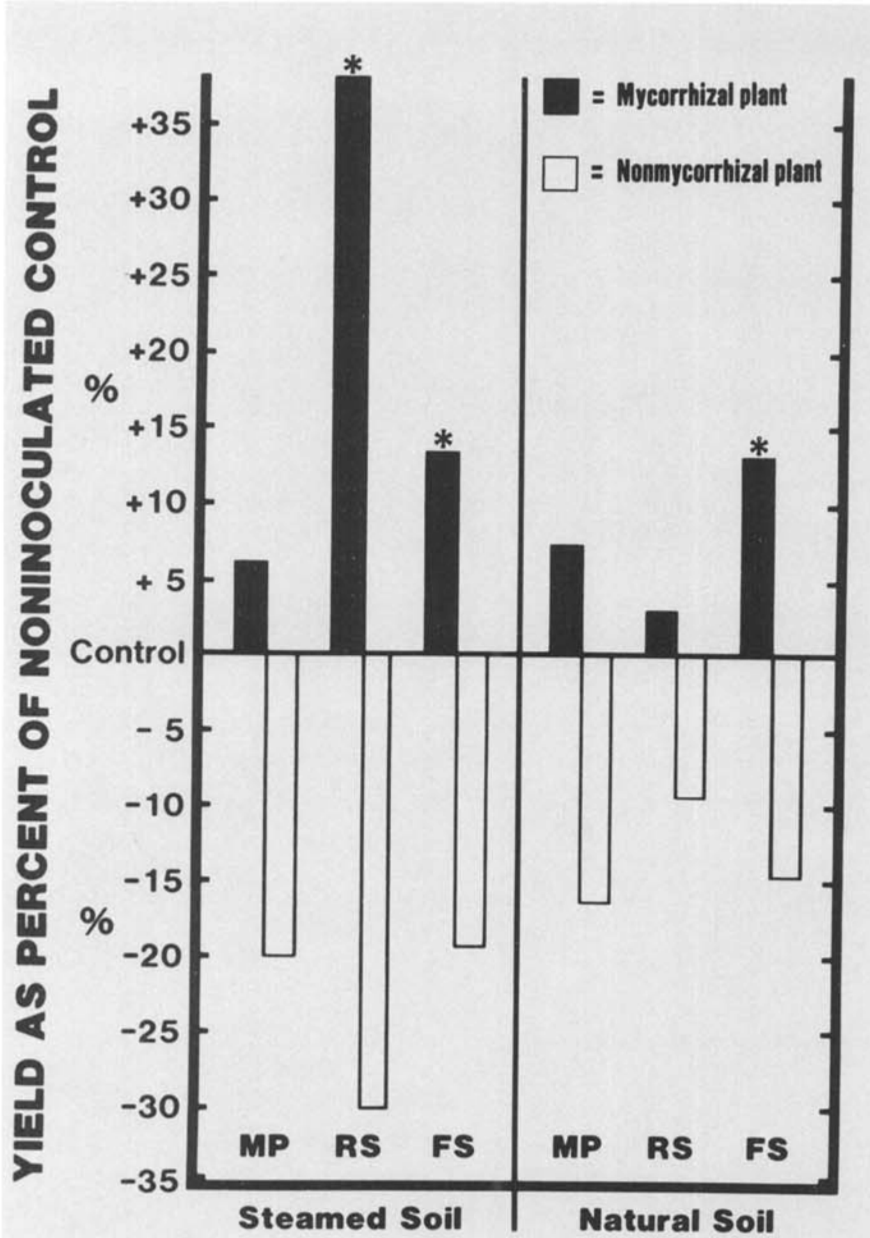


Fig. 5. Effect of *Macrophomina phaseoli* (MP), *Rhizoctonia solani* (RS), and *Fusarium solani* (FS) on yield of soybean plants with and without mycorrhizae, compared with noninoculated control plants. * = Yield differences between plants with and plants without mycorrhizae significantly different ($P = 0.05$). (From dissertation of L. Zambolim, University of Florida, 1980)

attributes of mycorrhizae are being recognized as important in modern agriculture (9).

What Are the Effects on Disease?

Early field observations that trees with ectomycorrhizae were damaged less by pathogens than trees with few or no mycorrhizae suggested that ectomycorrhizae decreased disease severity, but a cause-and-effect relationship has been difficult to establish. In his review of tree feeder root diseases, Marx (3) presented research evidence clearly demonstrating that ectomycorrhizal fungi protect trees from infection by root pathogens and reduce effects of the pathogens on plants. This was shown for *Rhizoctonia solani* on loblolly pine and *Phytophthora cinnamomi* on shortleaf pine (Table 1). Mycorrhizae formed both by *Pisolithus tinctorius* and by *Cenococcum graniforme* not only protected shortleaf pine from *P. cinnamomi*, enabling the plants to equal or surpass the growth of noninoculated plants, but also reduced the number of propagules of the pathogen recovered from soil.

In greenhouse studies (11), VA mycorrhizal fungi reduced the effects of several pathogens on their hosts (Fig. 5). *Thielaviopsis basicola* on tobacco and alfalfa, *Fusarium oxysporum* f. sp. *lycopersici* on tomato, *Phytophthora megasperma* var. *sojae* on soybean, *Pyrenochaeta terrestris* on onion, and *R. solani* and *Pythium ultimum* on poinsettia were all reduced in studies using several different species of VA mycorrhizal fungi, including *Glomus mosseae, G. macrocarpus, G. etunicatus, G. fasciculatus,* and *Gigaspora margarita* (Table 1). In most instances, growth of diseased mycorrhizal plants was equivalent to that of noninoculated control plants.

VA mycorrhizal fungi have similar effects on nematodes, especially the root-knot nematode. Several species of mycorrhizal fungi suppressed root knot on tomato, cotton, soybean, tobacco, carrot, and oats. Most plants with mycorrhizae had fewer galls (Fig. 6) and/or larvae than plants without mycorrhizae, and growth of mycorrhizal plants inoculated with root-knot nematodes was equivalent to that of noninoculated plants without mycorrhizae.

Not all reports indicate that mycorrhizae decrease disease (12). In some studies, VA mycorrhizal fungi had no effect on either pathogen or disease; in others, disease was actually worsened. Davis et al (1) noted that the incidence of *Verticillium dahliae* was greater in cotton plants with mycorrhizae than in those without, and Ross (8) reported the incidence of Phytophthora root rot on soybeans in microplots was significantly higher on plants with mycorrhizae (Table 1). Reports concerning mycorrhizae and *P. megasperma* var. *sojae* on soybean are conflicting, ranging from little or no effect to disease increase or suppression (11). The reasons for these apparent incongruities are unknown but may be related to differences in soybean cultivars, pathogen races or biotypes, soil types, and investigative procedures.

What Is the Mode of Action?

Although the means by which mycorrhizae affect pathogens and disease is far from being completely understood, several factors have been implicated with ectomycorrhizae (3). Many ectomycorrhizal fungi are known to produce antibiotic compounds that can affect both bacteria and fungi. The mantle produced by ectomycorrhizal fungi around roots forms a mechanical barrier to the pathogen, and the antibiotics presumably "protect" noncolonized root areas from infection. Ectomycorrhizal fungi also stimulate production of volatile and nonvolatile compounds in the host that are fungistatic and probably inhibit mycorrhizae development in the host and pathogen establishment in the rhizosphere. Mycorrhizae affect rhizosphere organisms selectively and could stimulate a mycoflora antagonistic to plant-pathogenic organisms.

VA mycorrhizal fungi do not produce a

Table 1. Response of various hosts and pathogens to mycorrhizal fungi[a]

Host	Pathogen	Mycorrhizal fungus	Parameter	Mycorrhizal plants	Nonmycorrhizal plants
		Ectomycorrhizae			
Sand pine	*Phytophthora cinnamomi*	*Pisolithus tinctorius*	Plant mortality (%)	36	60
Shortleaf pine	*Phytophthora cinnamomi*	*Pisolithus tinctorius*	Root weight (mg)	134	86
			Lateral roots (no.)	21	9
		VA mycorrhizae			
Cotton	*Verticillium dahliae*	*Glomus fasciculatus*	Shoot dry weight (g)	5.1	4.0
			Sclerotia/g petiole	11,010	791
Onion	*Pyrenochaeta terrestris*	*Glomus mosseae*	Roots with pathogen (%)	14	48
		Gigaspora margarita	Roots with pathogen (%)	62	95
Poinsettia	*Rhizoctonia solani* + *Pythium ultimum*	*Glomus mosseae*	Shoot dry weight (g)	3.8	1.3
Soybean	*Phytophthora megasperma*	*Glomus etunicatus*	Root weight (g)	1.5	0.6
		Glomus macrocarpus	Plants with pathogen (%)	88	17
			Plant mortality (%)	33	0
Tobacco	*Thielaviopsis basicola*	*Glomus mosseae*	Pathogen spores/plant	125	280
Tomato	*Fusarium oxysporum*	*Glomus mosseae*	Wilt index (0–4)	1.1	2.9
			Infected stem height (cm)	12.4	23.6

[a]From Davis et al (1), Marx (3), Ross (8), and Schenck and Kellam (11).

root mantle or antibiotics and thus have a different effect than ectomycorrhizal fungi on pathogens and disease (11). Possibly, increased wall thickenings in the cortical cells of mycorrhizal roots deter penetration by the pathogen. Also, chemical differences in roots of mycorrhizal and nonmycorrhizal plants have been noted. Higher levels of amino acids, especially arginine, have been recorded in mycorrhizal roots of several plant species. Arginine and root extracts from mycorrhizal plants both reduced *T. basicola* chlamydospore production. Blockage in the ornithine cycle by the mycorrhizal fungus has been proposed as the cause of increased arginine levels (2). The increased levels of reducing sugars in mycorrhizal onion roots may explain a lower incidence of pink root disease. Sikora (13) noted decreased penetration and slower development of root-knot nematode larvae in mycorrhizal roots and suggested alteration of the root physiology by the mycorrhizal fungus as the reason.

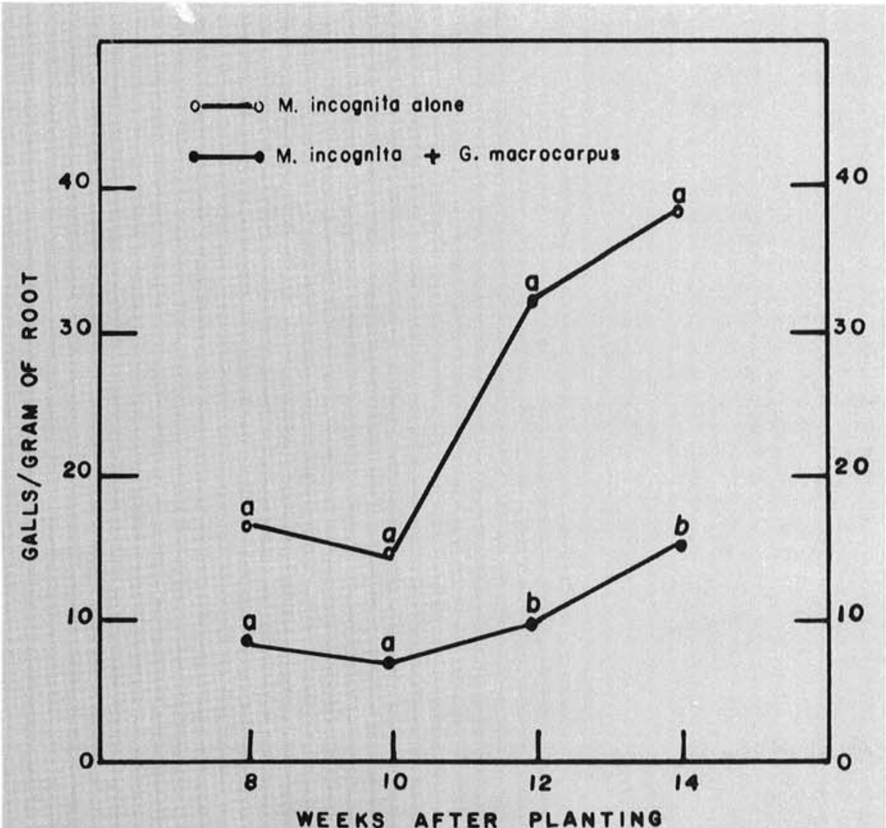


Fig. 6. Soybean roots with VA mycorrhizal fungus *Glomus macrocarpus* have fewer galls produced by *Meloidogyne incognita* than roots without mycorrhizae. Values on the same date with the same letter do not differ significantly ($P = 0.05$).

What Are the Problems . . .

Unfortunately, VA mycorrhizal fungi are obligate symbionts that must be increased on living plant roots and therefore cannot be grown on laboratory culture media for general use in agriculture. A method for commercial production of VA mycorrhizal fungi on living plant roots has been designed (7) but has not been widely implemented. Ectomycorrhizal fungi, on the other hand, can be grown on laboratory media, and limited amounts have been produced. A commercial preparation of *Pisolithus tinctorius* (Abbott Laboratories, North Chicago, IL) has successfully established mycorrhizae on pines. Thus, the possibility of widespread use of ectomycorrhizal fungi in agriculture is real, but much more research is needed on preparing inoculum of VA mycorrhizal fungi.

Both ectomycorrhizal and VA mycorrhizal fungi are affected by the other microorganisms in the rhizosphere. These organisms may prevent or hinder establishment of the desired mycorrhizal fungus on the host or reduce its effect on the pathogen and disease.

Although many species of mycorrhizal fungi reduce the effects of pathogens on many hosts, no one species can be applied to all crops in all situations. Mycorrhizal fungi vary in effect with host and environment, and a specific species may have to be prescribed according to host, soil type, location, and pathogen. Coordinated research studies among

N. C. Schenck

Dr. Schenck is a professor in the Plant Pathology Department at the University of Florida, Gainesville. He obtained his Ph.D. degree in plant pathology at the University of Illinois in 1955. He has been associated with the University of Florida since 1956, first at the Agricultural Research Center at Leesburg and after 1969 in the Plant Pathology Department at Gainesville. His current research interests include the effect of VA mycorrhizal fungi on plants and on soilborne pathogens affecting plants. The course on mycorrhizae he teaches in cooperation with several University of Florida faculty is believed to be the first in North America devoted exclusively to the subject.

several disciplines are needed to determine which situations are most conducive to obtaining benefits from VA mycorrhizal fungi in the field.

Because mycorrhizal fungi occur naturally on most crop plants, the present effect on plant disease may be considerable. Thus far, however, no definitive field study has determined the effect of naturally occurring mycorrhizal fungi on root disease; most research has involved greenhouse pot studies with steamed or pasteurized soils. Artificial inoculation is one means of utilizing mycorrhizal fungi more fully. In addition, perhaps cultural practices can be manipulated to increase the incidence of mycorrhizal fungi in field soil or change the predominant species to enhance their effect on disease.

. . . and the Potentials?

Interest in mycorrhizae is not restricted to disease control. Mycorrhizae may be useful as "biological fertilizers" in areas with limited phosphates or for crops that depend greatly on mycorrhizae for normal development. Species of mycorrhizal fungi resulting in good plant growth while maximizing disease control could be selected. In addition, studying mycorrhizal disease control methods may uncover new mechanisms of host tolerance to pathogens or new compounds inhibitory to root-infecting fungi. Perhaps the resistance or tolerance to plant pathogens induced by mycorrhizal fungi can be induced chemically, once the biochemical nature is known.

Many root pathogens can be controlled only with expensive physical or chemical soil treatments. Mycorrhizae offer an alternative approach, and we should pursue their potential as biological control agents despite the obstacles.

Literature Cited

1. Davis, R. M., Menge, J. A., and Erwin, D. C. 1979. Influence of *Glomus fasciculatus* and soil phosphorus on Verticillium wilt of cotton. Phytopathology 69:453-456.
2. Dehne, H.—W., and Schönbeck, F. 1978. The influence of endotrophic mycorrhiza on plant disease. 3. Chitinase-activity and ornithine cycle. Z. Pflanzenkr. Pflanzenschutz 85:666-678. (In German)
3. Marx, D. H. 1973. Mycorrhizae and feeder root diseases. Pages 351-382 in: G. C. Marks and T. T. Kozlowski, eds. Ectomycorrhizae. Academic Press, London.
4. Marx, D. H., and Artman, J. D. 1979. *Pisolithus tinctorius* ectomycorrhizae improve survival and growth of pine seedlings on acid coal spoils in Kentucky and Virginia. Reclamation Rev. 2:23-31.
5. Marx, D. H., and Bryan, W. C. 1971. Influence of ectomycorrhizae on survival and growth of aseptic seedlings of loblolly pine at high temperature. For. Sci. 17:37-41.
6. Menge, J. A., Davis, R. M., Johnson, E. L. V., and Zentmyer, G. 1978. Mycorrhizal fungi increase growth and reduce transplant injury in avocado. Calif. Agric. 32:6-7.
7. Menge, J. A., Lembright, H., and Johnson, E. L. V. 1977. Utilization of mycorrhizal fungi in citrus nurseries. Proc. Int. Soc. Citric. 1:129-132.
8. Ross, J. P. 1972. Influence of Endogone mycorrhiza on Phytophthora root rot of soybean. Phytopathology 62:896-897.
9. Ruehle, J. L., and Marx, D. H. 1979. Fiber, food, fuel and fungal symbionts. Science 206:419-422.
10. Safir, G. R., Boyer, J. S., and Gerdemann, J. W. 1971. Nutrient status and mycorrhizal enhancement of water transport in soybean. Plant Physiol. 49:700-703.
11. Schenck, N. C., and Kellam, M. K. 1978. The influence of vesicular arbuscular mycorrhizae on disease development. Fla. Agric. Exp. Stn. Tech. Bull. 798. 16 pp.
12. Schönbeck, F., and Dehne, H.—W. 1979. The influence of endotrophic mycorrhiza on plant disease. 4. Fungal parasites on aerial plant parts, *Olpidium brassicae*, TMV. Z. Pflanzenkr. Pflanzenschutz 86:103-112. (In German)
13. Sikora, R. A. 1978. Effect of the endotrophic mycorrhizal fungus, *Glomus mosseae*, on the host-parasite relationship of *Meloidogyne incognita* in tomato. Z. Pflanzenkr. Pflanzenschutz 85:197-202. (In German)
14. St. John, T. V. 1980. Root size, root hairs and mycorrhizal infection: A re-examination of Baylis's hypothesis with tropical trees. New Phytol. 84:483-488.