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Effects of Fertilization and Vesicular–Arbuscular Mycorrhizal Inoculation on Growth of Hardwood Seedlings[1]

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ABSTRACT

Eight hardwood species were grown in fumigated soil without vesicular-arbuscular mycorrhizae (VAM) or in soil infested with a mixture of *Glomus mosseae* and *Glomus etunicatus*. Three fertilizer treatments of 140, 560, and 1,120 kg/ha of 10-10-10 fertilizer were established in combination with the two mycorrhizal treatments. Ten equal applications of NH_4NO_3, totaling 1,680 kg/ha, were added to all the treatment plots during the growing season. For six of the eight species, the VAM seedlings showed greater height and diameter growth and dry weight production than nonmycorrhizal seedlings. Sugar maple (*Acer saccharum* Marsh.) and walnut (*Juglans nigra* L.) displayed no height growth differences. Only boxelder (*Acer negundo* L.), of the inoculated seedlings, consistently responded to increases in fertilizer level. Nonmycorrhizal seedlings generally showed increased growth with increased fertilizer applications. The growth of the nonmycorrhizal seedlings at the higher fertilizer levels was not sufficient to produce plantable seedlings for artificial regeneration. A difference in host preference for the *Glomus* spp. symbionts is suggested by the large difference in infection between species. Infection values varied from a high of about 80% for sycamore (*Platanus occidentalis* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and boxelder to a low of 40% for sugar maple and sweetgum. The growth data suggest that high quality seedling stock of most of these hardwood tree species can be obtained in nurseries as long as cultural practices in the nursery encourage VAM development.

Additional Index Words: **nursery practices, seedling production, black cherry, black walnut, boxelder, green ash, red maple, sugar maple, sweetgum, sycamore.**

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THE ESTABLISHMENT of vesicular-arbuscular mycorrhizae (VAM) usually increases plant growth, especially on infertile soils (Mosse, 1973; Gerdemann, 1968). The VAM occur on numerous genera of trees such as *Liquidambar, Platanus, Ulmus, Juglans, Fraxinus, Acer,* and *Liriodendron* (Marx, 1977). Although these species are known to be endomycorrhizal, little work has been done to investigate specific symbiont–host interactions. Recent work on sweetgum seedlings indicates a strong symbiont–host interaction with large growth differences being reported among half-sib sweetgum progeny that were infected by a mixture of *Glomus* species (Bryan and Kormanik, 1977; Kormanik et al., 1977). Growth differences were not found among the nonmycorrhizal progeny, nor were any significant growth responses found at levels of 140, 280, 560, and 1,120 kg/ha of 10-10-10 fertilizer for either the mycorrhizal or nonmycorrhizal half-sib progeny. Significant differences in total nutrient contents of the foliage, stem, and roots have also been reported among the VAM sweetgum families (Schultz et al., 1979). Nutrient concentrations of VAM seedlings were generally lower than for nonmycorrhizal seedlings, but significant differences in total nutrient contents per seedling varied between families of VAM seedlings. Although all seedlings reponded favorably to mycorrhizal establishment, these differences between half-sib families suggest a specific symbiont–host interaction. Such interactions should be considered in nursery seedling production. By testing the progeny of selected mother trees with various potential VA fungi under nursery conditions, the most promising combinations can be selected to improve seedling production. Sweetgum, in general, is very sensitive to the VAM symbiosis, and this sensitivity can be further differentiated between seed sources. It is not clear whether the general species response displayed by sweetgum occurs in other

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hardwood species, nor whether seed source differences could be expected.

This study was done to determine whether seven other hardwood species show a similar general species response to the same mixture of *Glomus* species and soil fertility levels that were used in the previous studies with sweetgum. Because of limited plot size, no attempt was made to define the variability between seed sources. Further work should be initiated to define within-species variation for those species that show favorable responses in this study. The species selected for study are potentially valuable for timber and fiber production.

METHODS

Seeds were collected from the following tree species: (i) *Acer negundo* L. (boxelder); (ii) *Acer rubrum* L. (red maple); (iii) *Acer saccharum* Marsh. (sugar maple); (iv) *Fraxinus pennsylvanica* Marsh. (green ash); (v) *Juglans nigra* L. (black walnut); (vi) *Liquidambar styraciflua* L. (sweetgum); (vii) *Platanus occidentalis* L. (American sycamore); and (viii) *Prunus serotina* Ehrh. (black cherry). The sugar maple, black walnut, and black cherry came from trees in Vermont, North Carolina, and Tennessee, respectively. All other seed came from trees in northeastern Georgia. Only sweetgum, red maple, and sycamore were of known mother tree origin; the other species represented mixed seed lots. This precluded only within-species comparisons so seed from each species was treated as a mixed lot. The sweetgum seeds were stratified in water at 2 to 4°C for 24 days prior to sowing, and the other seven species were stratified as recommended in Agriculture Handbook no. 450 (U.S. Department of Agriculture, 1974).

The study used a 4 by 3 by 2 factorial design consisting of four replications of three fertilizer levels and two levels of mycorrhizal inoculum. Seedlings were grown in 24 redwood boxes 1 by 1 by 0.6 m at the Whitehall Experimental Forest of the School of Forest Resources, University of Georgia, Athens. The bottoms of the boxes were constructed from 2 cm marine-grade plywood to prevent contamination from the soil beneath. Drainage was enhanced by placing 15 cm of gravel in the bottom of each box and by drilling a series of 2.54 cm holes at the base of the sides. The empty boxes were fumigated in place under polyethylene plastic with methyl bromide (Dowfume MC-2, Dow Chemical Co.) for 48 hours. The boxes were then filled with a similarly fumigated 2:1:1 mixture of a sandy loam forest soil, coarse sand, and finely ground bark. Analysis of this mixture before fertilizer treatment revealed the following amounts of extractable ions in kg/ha: NO_3-N, 39; P, 26; K, 77; and Ca, 366. Hydrated lime [$Ca(OH)_2$] at the rate of 174 g per box was spread on the surface and watered in just before sowing the seed to bring the elemental calcium of each box up to 1,120 kg/ha.

All boxes were inoculated with 2 liters of coarsely chopped sorghum roots taken either from pot cultures of sorghum mycorrhizae and a mixture of *Glomus mosseae* (Nicol. & Gerd.) Gerdemann & Trappe and *Glomus etunicatus* Becker & Gerdemann or from nonmycorrhizal control sorghum pots. This resulted in about 850 spores of the *Glomus* spp. mixture in each box. The inoculum was spread evenly over the surface and worked into the top 15 to 20 cm of soil. Root washings from the pot cultures were passed through a 45-μm mesh sieve (openings smaller than the minimum spore diameter of the *Glomus* spp.). The VAM soil received filtrate from nonmycorrhizal sorghum pot cultures, and the control soil received filtrate from the pot cultures of the mixture of *Glomus* spp.

Three treatment levels of 10-10-10 fertilizer consisting of 11.7, 47.0, and 93.8 g per box (equivalent to 140, 560, and 1,120 kg/ha) were randomly assigned to each of the two mycorrhizal treatments. The fertilizer was incorporated into the top 7 to 10 cm of soil before the seeds were sown. Ten equal applications of NH_4NO_3, totalling 1,680 kg/ha, were made to all the treatments during the growing season.

Seeds from the eight species were sown in the boxes during the last week of May. Each box had 40 planting locations, five of which were randomly assigned to each of the eight species. Several seeds were planted at each location to ensure that at least one plant was available per location. After planting, the boxes were lightly covered with fumigated pine needle mulch. After germination, seedlings were thinned to one per planting spot.

It was recognized that specific nursery requirements of individual species could not be optimized for all species in a single experiment within the constraints of the facilities available. The concern, however, was not absolute growth of the seedlings, but rather their response to mycorrhizal infection under specified nutrient regimes. Randomization controlled interspecies competition and thus controlled the effects of fast and slow growing species being adjacent to each other.

The seedlings were harvested in early November. Heights and root collar diameters were measured, and root, stem, and leaf weights were obtained after drying to a constant weight at 70°C. The presence of VAM infection was determined from root samples collected from each seedling by the Phillips and Hayman procedure (1970), except that lactophenol was used in place of chloral hydrate.

The roots were observed under a dissecting microscope after clearing and staining. Four classes of root infection were recorded: 0 to 24, 25 to 49, 50 to 74, and 75 to 100 percent of the sampled root. The intensity or degree of infection within individual roots was also classified: (i) low intensity—small infection sites widely scattered along the entire root; (ii) medium intensity—larger sites more uniformly distributed throughout the infected roots but rarely coalescing; and (iii) high intensity—feeder roots almost solidly infested. Finally, roots were evaluated for the percentage of the total infection made up of hyphae, arbuscules, and vesicles per unit volume of root segment.

Data were analyzed by analysis of variance and Duncan's Multiple Range Test using the Statistical Analysis Systems procedures of Barr et al. (1976).

RESULTS AND DISCUSSION

Growth

The VAM seedlings of all species were significantly larger than nonmycorrhizal seedlings for all variables except height (Table 1). Only the heights of black walnut and sugar maple showed no significant differences between VAM and nonmycorrhizal seedlings. Throughout the study, sugar maple never grew well. Although there was a drastic difference between the latitudes of the seed source and study areas, these first-year results are not much different from those obtained in many forest tree nurseries (U.S. Department of Agriculture, 1974). Sugar maple seedlings are extremely sensitive to high temperatures, and even in their natural range, they must be shaded during the early part of the growing season until established. It is not unusual for seedlings of this species to be transplanted at 2-0 in forestry plantings or even 2-2 for horticultural purposes to ensure adequate size for successful outplanting. Of interest in this study is the relatively large difference between root weights of VAM and nonmycorrhizal sugar maple seedlings. Further work should be done with this species to assess the influence of VAM on seedling production.

The lack of height growth differences between mycorrhizal and nonmycorrhizal walnut seedlings is probably the result of the large carbohydrate reserve in the nut which appears to sustain these seedlings until late June or early July. All walnut seedlings grew rapidly in height following germination, and there were no measurable height differences between the treated and control plants. The nonmycorrhizal walnut seedlings, however, set their terminal buds by mid-July and became quiescent. Their leaves became chlorotic by early August and began to abscise in mid-August. The VAM-infected walnut seedlings ceased growing when their nonmycorrhizal counterparts stopped growing; their foliage, however, did not become chlorotic but remained active throughout most of the growing season. This continued

Table 1—Growth responses of seedlings from eight hardwood species grown in a soil-sand-bark mixture containing a *Glomus* spp. mixture (GM) or no mycorrhizal inoculum (NI) at three levels of 10–10–10 fertilizer. GM seedlings were significantly larger than NI seedlings for all variables except height of sugar maple and walnut.

Species	Height		Diameter		Root dry weight		Stem dry weight		Leaf dry weight	
fertilizer	GM	NI	GM	NI	GM	NI	GM	NI	GM	NI
kg/ha	cm				g					
Black cherry										
140	33.3 a*	5.0 a	0.40 a	0.15 a	5.60 a	0.16 b	3.90 a	0.05 b	4.08 a	0.06 a
560	45.5 a	5.2 a	0.53 a	0.18 a	7.37 a	0.29 b	4.72 a	0.07 ab	4.14 a	0.12 a
1,120	24.7 a	5.9 a	0.32 a	0.19 a	2.94 b	0.70 a	1.80 a	0.13 a	1.46 a	0.08 a
Boxelder										
140	41.2 b	11.9 c	0.96 a	0.29 c	10.49 b	0.25 b	6.83 b	0.21 b	3.20 a	–†
560	46.5 ab	16.5 b	1.01 a	0.48 b	13.85 ab	1.25 b	9.72 b	0.93 b	3.45 a	–
1,120	56.2 a	26.7 a	1.13 a	0.72 a	18.86 a	4.73 a	14.45 a	3.26 a	3.41 a	–
Green ash										
140	31.4 a	6.8 c	0.82 a	0.19 b	12.41 ab	0.13 b	5.03 b	0.07 b	4.07 b	–
560	35.9 a	8.7 b	0.92 a	0.22 b	14.97 a	0.26 b	7.56 a	0.13 b	6.25 a	–
1,120	33.1 a	11.0 a	0.80 a	0.29 a	10.45 b	1.05 a	5.01 b	0.38 a	3.46 b	–
Red maple										
140	32.4 a	7.5 b	0.63 a	0.18 b	4.26 b	0.08 a	2.08 b	0.04 b	3.37 b	0.03 a
560	32.7 a	8.6 b	0.61 a	0.23 b	3.78 b	0.55 a	2.29 b	0.14 b	3.52 b	0.15 a
1,120	42.3 a	14.0 a	0.71 a	0.34 a	6.71 a	1.89 a	4.22 a	0.42 a	5.83 a	0.58 a
Sugar maple										
140	7.0 a	7.2 a	0.26 a	0.25 b	0.86 b	0.38 b	0.09 a	0.15 b	0.50 b	–
560	7.7 a	7.4 a	0.28 a	0.26 ab	0.98 ab	0.48 b	0.25 a	0.16 ab	0.45 b	–
1,120	8.6 a	7.7 a	0.29 a	0.29 a	1.28 a	0.74 a	0.30 a	0.19 a	0.73 a	–
Sweetgum										
140	27.4 a	4.1 b	0.72 a	0.16 b	6.32 a	0.19 a	3.10 a	0.04 a	3.53 a	0.02 a
560	28.4 a	5.3 ab	0.70 a	0.22 ab	4.81 a	0.34 a	2.71 a	0.10 a	3.23 a	0.12 a
1,120	33.8 a	6.3 a	0.72 a	0.28 a	6.26 a	1.40 a	4.12 a	0.29 a	4.21 a	0.26 a
Sycamore										
140	51.1 a	15.9 c	1.03 a	0.34 c	24.76 a	1.06 b	13.32 a	0.61 b	8.80 a	0.40 b
560	57.9 a	21.1 b	1.22 a	0.50 b	32.49 a	2.68 b	19.47 a	1.56 b	12.81 a	0.88 b
1,120	57.7 a	31.7 a	1.27 a	0.65 a	43.92 a	5.06 a	27.11 a	3.31 a	17.48 a	1.91 a
Walnut										
140	22.4 a	20.8 a	0.67 a	0.59 a	48.35 a	14.90 a	3.28 a	2.61 a	–	–
250	22.9 a	22.4 a	0.67 a	0.61 a	43.67 a	15.82 a	3.11 a	2.71 a	–	–
1,120	23.6 a	21.0 a	0.67 a	0.60 a	42.39 a	16.67 a	3.45 a	2.68 a	–	–

* Values in columns for a given species labeled with the same letter are not different at the 0.05 level by Duncan's Multiple Range Test.
† Blanks indicate that leaves had been dropped prior to harvest time.

activity may be the cause for the much greater root dry weight of the VAM seedlings (Table 1).

Only boxelder, of the inoculated seedlings, consistently responded to differences in fertilizer level. As noted earlier (Kormanik et al., 1977), differences in fertilizer applications of up to 1,120 kg/ha did not stimulate height growth of VAM-infected sweetgum seedlings. Infected seedlings of boxelder, however, grew taller with each added increment of 10-10-10. A similar response was found with the nonmycorrhizal seedlings of all the species except black cherry, sugar maple, and walnut. Both sugar maple and black cherry height means increased with increased fertilizer application, but variations between seedlings were great enough to make these differences nonsignificant. The increased growth of these nonmycorrhizal seedlings with the fertilizer rates tested was not sufficient to produce vigorous and competitive seedlings needed for successful artifical regeneration. Of the three nutrients added in the 10-10-10 fertilizer, phosphorus was the most limiting. The additional nitrogen in top dressings provided from 576 to 675 kg N/ha, an amount which should be sufficient for any of these species.

Diameter growth responses for all species followed the same trend as the height responses (Table 1). In all species, VAM-infected seedlings had significantly larger diameters than nonmycorrhizal seedlings. Even the small differences indicated for sugar maple and walnut are significant at the 5% level. There was no response to fertilizer application rates among the mycorrhizal seedlings. Among the nonmycorrhizal seedlings, only black cherry and walnut failed to show an increase in diameter growth with added fertilizer. Growth of all mycorrhizal seedlings, except sugar maple, was well within the range required for high quality 1-0 planting stock, regardless of fertilizer regime.

Dry weight production of all species was greatest for the inoculated seedlings (Table 1). Leaf dry weights for walnut and nonmycorrhizal boxelder, green ash, and sugar maple are not presented because leaves had fallen off by harvest time.

Walnut produced the largest mass of roots of all the species, both mycorrhizal and nonmycorrhizal. The VAM sycamore and boxelder seedlings produced the largest stems and the largest above-ground dry weight. Green ash was consistently below these two species in above-ground dry weight. All remaining species yielded comparable dry weights for the mycorrhizal and nonmycorrhizal treatment, except for the smallest producer, sugar maple. Inoculated seedlings of black cherry, sweetgum, sycamore, and walnut showed no dry weight response to fertilizer application. Boxelder and red maple produced their largest dry weight at 1,120 kg/ha, while green ash produced its greatest mass at 560 kg/ha. Sugar maple showed a root and leaf response but no stem response to fertilizer addition.

Among the noninoculated seedlings, sweetgum and walnut showed no responses to fertilizer application for any dry weight component. Red maple did not show any significant root or leaf dry weight differences with added fertilizer, but the variability within this species was large for all growth parameters. The noninoculated seedlings of all the other species showed greater dry weights at 1,120 kg/ha 10-10-10 than at the other levels with weights frequently being as much as three times greater at the 1,120 kg/ha level than at the 560 kg/ha level. There were frequently no differences between the 140 and 560 kg/ha levels. This suggests that, with some of these species, the phosphorus (P) level (49 kg/ha) in the 1,120 kg/ha fertilized microplots was approaching the concentration where seedlings could extract enough P for growth without mycorrhizae. This level of soil P, however, is still 6 to 10 times higher than normally found in many forest soils.

Consistent production of plantable-sized hardwood seedlings in southeastern nurseries has been a problem for many years, especially where soil fumigation to control weeds and other pests is practiced. Fumigation eliminates VAM fungi so that reestablishment under normal conditions can take most of the growing season. The fertility regimes in this experiment approximate the range used in many southeastern forest nurseries (unpublished data), and the importance of the VAM symbionts for many species is clear. Studies with sweetgum have shown that the amount of P in 1,120 kg/ha of 10-10-10 is insufficient to produce large nonmycorrhizal seedlings. The same results have been found in this study of seven other species. The use of high P fertilization to obtain large nonmycorrhizal hardwood seedlings is questionable, since high levels of soil P (in excess of 100 ppm double-acid extractable P) may have an adverse affect upon VAM infection. No quantitative information, furthermore, is available as to how quickly nonmycorrhizal root systems will become infected after outplanting.

Table 2—Infection responses of seedlings from eight hardwood species grown in a soil-sand-bark mixture containing a *Glomus* spp. mixture at three levels of 10–10–10 fertilizer.

Species fertilizer	Infection†	Intensity	Hyphae	Arbuscules	Vesicles
	%			%	
Black cherry					
140	47.9 a*	2.7 a	42.8 a	50.3 a	6.9 a
560	64.3 a	2.9 a	51.2 a	43.1 a	5.7 a
1,120	62.5 a	2.8 a	43.2 a	46.3 a	10.6 a
Boxelder					
140	70.0 a	2.5 a	60.0 a	37.8 a	2.2 b
560	74.6 a	2.4 a	65.5 a	31.1 a	3.4 b
1,120	80.0 a	2.6 a	59.3 a	34.3 a	6.4 b
Green ash					
140	78.3 a	3.0 a	59.3 ab	38.1 ab	2.6 a
560	82.5 a	2.9 a	67.7 a	29.1 b	3.2 a
1,120	80.1 a	3.0 a	52.9 b	45.3 a	1.8 a
Red maple					
140	68.4 a	2.4 a	69.9 a	29.6 b	0.5 a
560	68.8 a	2.5 a	55.2 ab	43.8 ab	1.0 a
1,120	67.8 a	2.5 a	49.4 b	47.6 a	3.0 a
Sugar maple					
140	41.3 b	2.1 ab	59.0 a	35.0 a	6.0 b
560	46.7 b	1.7 b	69.3 a	20.2 b	10.5 b
1,120	68.8 a	2.4 a	36.3 b	45.0 a	20.7 a
Sweetgum					
140	40.1 c	2.3 b	37.9 b	54.6 ab	2.5 a
560	56.3 b	2.5 ab	51.5 a	43.2 b	5.3 a
1,120	72.5 a	2.8 a	33.0 b	63.8 a	3.2 a
Sycamore					
140	77.0 a	2.8 a	28.8 b	67.3 a	3.9 a
560	86.2 a	3.0 a	42.5 a	52.7 b	4.8 a
1,120	85.0 a	2.9 a	53.7 a	42.9 b	3.4 a
Walnut					
140	68.1 a	2.9 a	41.8 a	37.1 a	21.1 b
560	66.1 a	2.5 ab	47.5 a	26.6 ab	25.9 b
1,120	64.0 a	2.4 b	37.1 a	21.6 b	41.3 a

* Values in columns for a given species labeled with the same letter are not different at the 0.05 level by Duncan's Multiple Range Test.

† Infection % is the % of the sampled root that was infected. Intensity is the amount of infection in a given root segment.

Extensive unpublished data indicates that soil P levels in many forest tree nurseries are frequently much higher than those tested here. It is not known what the effect of planting large nonmycorrhizal seedlings has on the slow initial height growth (first 1 to 3 years) frequently observed in artificial regeneration of some of these species. It is possible, however, that lower survival, and especially slow initial height growth, may be the result of an absence of VA mycorrhizae. Physiologically, root systems may not be able to sustain large tops when soil P is at normal levels until they become mycorrhizal and adequate root/top ratios develop. This physiological imbalance may be the cause of extensive top dieback as is frequently encountered with sweetgum and sycamore. Although statistics for root hair densities were not developed in this study, most nonmycorrhizal seedlings had profuse root hair development so dense that it interfered with light transmission during microscopic examination. It is not known if the nonmycorrhizal seedlings from the higher fertility microplots produced greater densities since many of the samples had been discarded before the significance of this growth feature was realized. Root hair development from the mycorrhizal seedlings occurred sporadically on individual root segments and proved to be of no consequence during microscopic examination. This further suggests that mycorrhizal development rather than massive root hair development is needed for successful growth under low P soil conditions.

The nonmycorrhizal seedlings in this study indicate a typical quiescent state consisting of stagnated growth and replacement of green pigmentation by a very dark purple, red, or yellow pigmentation, depending on the particular species involved. A mycorrhizae-moisture interaction was also noted. The nonmycorrhizal seedlings showed definite signs of moisture stress during most afternoons. Mycorrhizal seedlings showed no wilting, suggesting enhanced water uptake by VAM. Similar results have been reported for soybeans (Safir, 1972; and Safir et al., 1971).

Mycorrhizal Infection

The percentage of a seedling's root system that became infected varied between species. Sycamore, green ash, and boxelder had a high of about 80% to a low of about 40% for sugar maple and sweetgum (Table 2). This large difference in infection suggests a difference in host preference for the *Glomus* spp. symbionts. Past studies indicate a significant host *x*-genotype interaction with sweetgum progeny that is unrelated to fertilizer regime. Such information is not available for the other 7 species tested. The difference in growth and percent infection observed with these 7 species may therefore not be entirely one of host preference but may indicate a symbiont-host interaction that we are unable to determine in this test. Only sugar maple and sweetgum showed an infection response to fertilizer levels, with a low of about 40% at the 140 kg/ha rate to a high of about 70% at the 1,120 kg/ha application rate of 10-10-10 fertilizer (Table 2). These two species had infection rates similar to those of the other species at high fertilizer levels.

Sugar maple, sweetgum, and walnut also showed a response of the intensity of infection per root segment to fertilizer treatment (Table 2). There is, however, no discernible pattern in this response. The intensity of the infection was highest in two of the fastest growing species, sycamore and green ash, and least in the slow growing sugar maple.

The morphological form of the VAM infection shows some interesting responses (Table 2). The VAM follow a sequential development pattern from hyphae to arbuscules to vesicles, and the form present at any point in time is related to the growth rate or physiological condition of the host. Toward the end of the season when growth begins to slow down, there should therefore be higher percentages of vesicles, the fungal food storage organs, present. Optimum growing conditions in the nursery may significantly alter this seasonal sequential development because, except for sugar maple and walnut, the seedlings have not yet become dormant when they are harvested. These two dormant species had significantly more vesicles present than the other six species (Table 2). The rest of the species had an approximate split of 60/40 or 50/50 hyphae and arbuscules. Significant responses to fertility levels were measured but no clear patterns seem to be evident among species. It is difficult to determine the significance of these various percentages because of the relationship between season and fungal morphology. The fact that the differences do exist, however, suggests that different host-symbiont responses may be related to the overall growth of the nursery seedlings. But more refined studies will be needed to ascertain host-symbiont interaction with the individual host species.

The results from this study indicate that nursery production of seedlings from these species could be enhanced if adequate VAM fungal densities are maintained in nursery soils. The data also indicate that large seedlings might be produced with the addition of amounts of elemental P above the levels tested here. No evidence is currently available to indicate how high this level must be for the individual species tested. Most of these species have been successfully artificially regenerated. But early growth after outplanting has normally been poor and, as a result, few commercial plantings have been established. Extensive field studies are needed to determine the early growth responses of mycorrhizal and comparable-sized nonmycorrhizal seedlings to ascertain field performance. The assumption is that physiologically, large mycorrhizal seedlings would be more competitive than equally large nonmycorrhizal ones for artificial regeneration.

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