EFFECTS OF NURSERY PRACTICES ON VESICULAR-ARBUSCULAR MYCORRHIZAL DEVELOPMENT AND HARDWOOD SEEDLING PRODUCTION

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Abstract.--Many hardwood tree species, i.e., sweetgum, ash, sycamore, maple, and yellow poplar, that are difficult to grow in forest tree nurseries are known hosts for vesicular-arbuscular mycorrhizal fungi (VAM). Seedling quality of these species can be significantly improved if nursery practices are modified to assure proper soil environmental conditions, not only for the hardwood seedlings, but also for the VAM fungi that are indigenous to the nursery. Soil fumigation, available phosphorus levels, rate and source of nitrogen, and soil pH interact with the hardwood hosts and VAM fungal symbionts. Certain guidelines can be useful for developing specific management practices for a specific nursery.

Additional keywords: Hardwood seedling quality, herbicides, fertilization, fumigation.

Substandard planting stock is perhaps the major silvicultural obstacle to artificial regeneration of hardwood species that are hosts for vesicular-arbuscular mycorrhizal fungi (VAM). Among these species are sweetgum, ash, maple, cherry, walnut, sycamore, and yellow poplar. To a great degree the establishment of a hardwood plantation depends on the nurseryman, his practices, and his personnel. Nowhere in the growing and planting sequence is the opportunity for quality control greater than in the nursery. To establish hardwood plantations, we must employ nursery production techniques that provide quality seedlings.

During the past 5 years, the Institute for Mycorrhizal Research and Development, U.S. Forest Service, Athens, Georgia, has been developing a VAM technology for hardwood tree seedlings produced in nursery soils. When I addressed this group in 1976, I could only describe the work we were initiating and make broad recommendations--we had little practical experience or completed research. Now, 4 years later, our research results indicate that my earlier broad recommendations were, for the most part, correct. We have found that growing high quality hardwood seedlings is not the impossible job it was once thought to be. However, nurserymen will have to be flexible, willing to alter nursery practices and to develop standards for their own nursery based on specific soil and environmental conditions. A single, regionwide prescription for VAM technology transfer may not be possible.

If our research in simulated nursery beds is directly transferable to operational nurseries, most nurserymen should be able to produce large hardwood planting stock for the 1981 growing season. By 1982, nurserymen should be producing high-quality hardwood seedlings with the same consistency achieved with pine seedlings. Of course, there will be some production problems with hardwood species, but they should be no more severe than those encountered with pine. The possible adverse effects of high water tables and weed control practices may be the biggest problems to overcome.

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Some believe that large seedlings and high quality seedlings are synonymous, but this is not necessarily true. Initial results from our field performance trials suggest that a large seedling is not always a quality seedling. Our research shows that presence of VAM is the key to production of seedlings that will thrive after outplanting. Mycorrhizal technology has greater application than simply growing quality seedlings, but for the purpose of this paper other aspects will be, whenever possible, ignored. Items of direct concern to the nurseryman's immediate problem of growing VAM hardwood hosts will be discussed and, hopefully, clarified.

Today, most plant scientists realize that VAM are essential for normal development of specific tree hosts. We have had problems in forest tree nurseries producing hardwood seedlings because of cultural or management practices that, at least in the short run, reduce the effectiveness of the indigenous VAM fungi. Until recently we did not know what these practices were and, therefore, could not make the necessary cultural adjustments. Until the problem areas were isolated, we did not know how to make short-term nutritional adjustments while maintaining the long-term viability of the indigenous VAM fungal populations to assure quality seedling production.

The state of the art may change, but right now we think that efforts should be concentrated on building up and preserving whatever VAM fungi are indigenous to a particular nursery. Whatever benefits seedlings obtain from VAM, all species of VAM fungi appear to be equally effective as far as seedling development is concerned. Some VAM fungi may prove to be especially beneficial in particular circumstances. Some, for example, may be helpful in defending tree roots against disease. We are studying this possibility, but even if we found an exceptionally aggressive and beneficial VAM fungus, it would be of little immediate importance because we do not yet know how to introduce a single VAM into nursery soils. What is needed now in nursery production is a means of maintaining high population densities of indigenous VAM fungi that can infect roots early in the growing season. All hardwood nursery soils have the potential to develop and maintain a viable VAM population. Various cultural practices in a nursery, however, may significantly influence the effectiveness of VAM fungi. Cultural practices that must be considered are fumigation, weed control, fertilizer application, and maintenance of soil pH. Some of these practices affect only one member of the symbiotic partnership (host or fungus), while others affect both.

<u>Fumigation and Weed Control</u>

Fumigation creates problems when one is trying to retain VAM fungi because the treatment is indiscriminate--it kills beneficial as well as harmful soil fungi. The practice is necessary for control of root diseases, but it should probably be limited to the minimum necessary for disease control. Fumigation could be restricted to years when soil assays reveal a buildup of potentially harmful organisms in the soil.

Fumigation for weed control should probably be avoided whenever possible. It is an expensive practice for this purpose, and South and Gjerstad (1980) believe that few nurseries have enough weed or disease problems to justify annual soil fumigation. Nurserymen must find suitable substitutes for controlling weeds in hardwood crops. Herbicides may be a possibility. We have not undertaken any studies to determine how specific herbicides affect VAM fungi in the soil.

Management practices that increase nutrient availability in the soil are required for successful hardwood seedling production. VAM fungi are just one of the soil related factors involved in plant nutrient relationships. Any severe imbalance of essential elements is likely to adversely affect development of host and VAM fungi. Small imbalances are often more readily tolerated by mycorrhizal plants than by nonmycorrhizal plants.

Phosphorus

VAM are important in nutrient and water uptake by hardwoods. One of the most critical elements in VAM and hardwood growth in almost all soils is available phosphorus. It is not surprising that plant responses to VAM are especially dramatic when soil phosphorus is in the normal range. Most natural forest soils in the Southeastern United States have less than 8 ppm of available phosphorus. Without VAM, host trees could not become established and grow at these soil P levels. In some nonforest host plants, unusually high threshold levels of soil P are needed for the plant to develop in the absence of VAM. For about 4 years we have been trying to pinpoint these threshold levels for hardwood seedlings grown under nursery conditions.

Originally we grew hardwood seedlings requiring VAM at 25 to 30 ppm available P (Bray II). We obtained good quality seedlings at these levels with VAM, but nonmycorrhizal seedlings were stunted, seldom exceeding 7 cm in height. During the past 5 years we have run a series of experiments that standardized soil P levels at from 12 to 1000 ppm. The latter rate is equivalent to about 2000 pounds per acre of actual P. When soil P exceeds 200 ppm, VAM development can be drastically reduced, but 10 to 35 percent of the roots of most seedlings may have VAM. At soil P levels at 40 to 100 ppm, VAM roots can be somewhat reduced, but at least 40 to 75 percent of the roots of most seedlings can be colonized with VAM fungi. The latter range is the soil P threshold at which many tree seedlings grew as well without VAM as with them.

At this time, I recommend that nurserymen maintain soil P at 75 to 100 ppm. This level will permit seedlings to develop VAM even in soils where low levels of inoculum are present. We currently do not know what will happen in the long run to the VAM fungi reproduction when high levels of soil P are maintained. For example, with most VAM fungi we have worked with there is a reduction in spore production even at levels of 10 to 100 ppm soil P. With one particular isolate of *Glomus etunicatus*, spore counts declined (15,000, 2700, 800, and 125) as amount of available P increased (12, 25, 50, and 100 ppm). Other fungi did not show this reduction and, in fact, reproduced as well at 100 ppm of soil P as at 25 ppm. We can realistically hope, based on Schenk's (1980) work, that VAM fungi best adapted to the local environment and cropping sequence will be maintained and become the dominant species in a given nursery. I recommend that P not be added to the soil when cover crops are grown if soil during the seedling rotation is initially adjusted to approximately 75 ppm.

Nitrogen

Most nurserymen do not use enough nitrogen to obtain optimal hardwood seedling development. When a hardwood seedling has sufficient phosphorus to develop, it is biologically irrelevant whether the phosphorus is from heavy applications of phosphate fertilizer or from improved uptake through VAM. In either case, plenty of nitrogen is needed throughout the summer for optimal growth (Brown 1979). In our tests, we have found that if nitrogen is severely restricted, sweetgum seedling development is as adversely affected as if both P and VAM are lacking.

As a general rule, 1500 lbs/acre of NH_4NO_3 (500 lbs N/acre) are adequate for VAM hardwood seedlings. This total should be divided among 10 applications throughout the growing season. It is important to include 3 applications in August and 2 applications in September. We believe that these late applications are essential because it is during this period, after the seedlings' root systems are well established, that at least 60 percent of total height growth occurs. The last NH_4NO_3 application should be scheduled 45 to 50 days before the first frost.

We have experimented with 125, 250, 500, 1000, and 2000 lbs/acre of N in different studies. These rates have been applied as NH_4SO_4, NH_4NO_3, and $K\ NO_3$. The latter N source has proven to be completely unsatisfactory for sweetgum and we doubt that it would be suitable for other species. Both NH_4SO_4 and NH_4NO_3 work equally well at rates up to 500 lbs/acre. At higher rates, NH_4NO_3 is better than NH_4SO_4. However, we do not recommend using NH_4SO_4 in acid soils; it reduces pH drastically.

Some technological changes in fertilizer processing have resulted in more frequent occurrences of sulfur deficiencies in hardwood nurseries. The use of NH_4SO_4 as a nitrogen source may reduce the chances of this in some nurseries. A workable solution might be to apply 50 percent of the nitrogen as NH_4SO_4 and the rest as NH_4NO_3.

Brown (1979) found that the growth response curve for sweetgum was still increasing at 500 lbs/acre of N with both NH_4NO_3 and NH_4SO_4, but that at 1000 lbs/acre in either form a pronounced depression was observed. At 2000 lbs/acre N, the growth depression was very pronounced. We have, however, observed a doubling of sweetgum height growth when N is increased from 125 to 250 lbs/acre, and a 50 percent increase in height growth when N is increased from 250 to 500 lbs/acre. The latter increase in height growth is accompanied by a substantial increase (ca. 40 percent) in root collar diameter; this may justify the added N cost.

Soil pH

In addition to its effect on nutrient availability, maintenance of suitable soil pH may also be quite important for indigenous VAM fungi. This possibility is difficult to assess. VAM synthesis occurs on plants in soils with wide pH ranges throughout the world. Thus, it can be reasoned that soil pH *per se* is not detrimental to VAM synthesis if the VAM fungi are still effective. Our research indicates that nursery soil pH should not be raised much beyond natural pH in a specific nursery. I suggest that nurserymen in the Southeast try to keep nursery soil pH between 5 and 6 and become concerned when over half of the soil samples have a pH consistently above 6.

In one experiment (Yawney 1980), an isolate of *Gigaspora margarita* obtained from a cotton field (pH 5.4) was tested at four soil pH levels--4.5, 5.5, 6.5, and 7.5. At the two lowest pH levels, VAM synthesis was good and sweetgum seedling growth response was quite satisfactory. At the two higher levels, the growth response to VAM was negligible and the seedlings were only slightly larger than the nonmycorrhizal controls (less than 10 cm).

No information is available on how soil pH affects reproduction of other VAM fungi that occur in nursery soils. Perhaps all species of VAM fungi will not be as sensitive as this particular isolate of *G. margarita*. However, it is relatively simple and inexpensive to monitor soil pH; I suggest that nursery personnel do so during the growing season, especially after fertilizer application. The data could be important when viewed in a complete soil maintenance program and could be invaluable in determining the optimum pH range for VAM synthesis and specific hardwood seedling development in each nursery.

It must be emphasized that VAM fungi occur and form mycorrhizal associations in soils exhibiting a wide pH range. Therefore, regardless of the natural soil pH at a specific nursery, a good complement of well-adapted VAM fungi can be expected to be present. This population can be readily maintained by avoiding radical changes in soil pH.

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