Soil Fertility and Management for Culturing Hardwood Seedlings

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Davey, C.B. 1994. Soil fertility and management for culturing hardwood seedlings. In Landis, T.D.; Dumroese, R.K., technical coordinators. Proceedings, Forest and Conservation Nursery Associations. 1994, July 11-14; Williamsburg, VA. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 38-49. Available at: http://www.fcnanet.org/proceedings/1994/davey.pdf

Abstract—Nursery production of hardwood seedlings and cuttings is different than the production of pine seedlings in several important ways. Hardwoods need approximately twice as much water and significantly more of most nutrients, especially nitrogen and calcium. Hardwoods are generally produced from open-pollinated, wild seed. This results in large within-seed source variability in seedling size and vigor. Seed orchard seed has tended to reduce this variability some and to increase the average seedling size. Hardwoods are particularly sensitive to soil physical properties. Soil compaction, which results in high soil bulk-density, is very deleterious. This is due to impeded root growth and impaired gas and water movement in the soil. Some hardwoods are ectomycorrhizal, some are endomycorrhizal, and a few can be either or both. Most hardwoods must be grown at a much lower seedbed density than most pines. When this fact is coupled with higher irrigation and fertilization costs per acre, the cost per seedling becomes much higher for hardwoods than pines.

Keywords: mycorrhizae, nitrogen fixation, irrigation, fertilization, lime, temperature.

INTRODUCTION

The nursery manager who has devoted his or her career to the production of pine seedlings and is suddenly confronted with the need to produce hardwoods finds that it is a completely different world. This is true in several respects. We have already heard about the differences in weed control between pines and hardwoods. Now, let us consider various aspects of soil management necessary for the production of quality hardwood seedlings. Topics for consideration will include: water, nutrients, soil testing, soil physical properties, mycorrhizae, seedbed density, and vegetative propagation.

Water

The first rule in growing hardwoods is to separate them from the pines. The reason for this is that hardwoods require almost twice as much water as pines and if you try to use one irrigation schedule for both you will either drown the pines or desiccate the hardwoods. This fact was demonstrated dramatically with a single collection of green ash seed. Because of a study we wanted to run in two nurseries, this seedlot was carefully mixed and divided in half with one half going to each nursery. About a month after the seed had been planted, I called both managers to see how the crop was developing. The first manager said that it had been an excellent seedlot and that if anything our seedbed density

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was bit high. The second manager said that the seedlot had been bad and that he estimated only about 3% germination. This prompted a visit to the second nursery. There I found that the green ash seed had been planted in one bed in the middle of a field of loblolly pine beds. The pines were growing beautifully and the green ash was exactly as described - very sparse. Subsequent observations have confirmed that whereas pines may do well with about one inch of water per week, hardwoods need about two inches per week. This is especially critical during germination and emergence of the hardwoods. These general amounts of water include rain plus irrigation and must be used only as a general guide. If a nursery receives a big rain of four inches in a few hours, that does not mean that no irrigation will be needed for two weeks. Interestingly, over the years, I have had more trouble getting people to use less water than to use more water. In some nurseries, I have wondered why there weren't cattails growing in the beds. The bottom line on this is that irrigation needs to be done correctly and hardwoods do demand more water than pines.

Nutrition and Soil Fertility

In the sections that follow, I will attempt to not only give some notion about hardwood seedling nutrition but also for some key nutrients, how hardwoods differ from pines. However, it must be recognized that soil fertility is only one significant factor in a suite of three factors. The other two are soil physical factors and soil biological factors. Although we will stress fertility management, it cannot be considered in a vacuum. Thus the other two legs of our three-legged stool will also be covered.

There are sixteen elements that are known to be essential for the growth of all tree seedlings and one additional one for the growth of nitrogen-fixing species. Of these elements, four come from the atmosphere and the rest from the soil. These essential elements are conveniently divided into two groups, those that are needed in the plant in fairly large amounts (called macro-elements) and those that are needed in very small amounts (called micro-elements). The micro-elements have sometimes been called the minor elements, but that gives the false impression that they are somehow less important than the macro-elements. They are all absolutely essential for tree growth.

Macro-elements

Carbon (C), hydrogen (H) and oxygen (O) come from the atmosphere as water, oxygen, and carbon dioxide. They are the elements that are needed in largest amounts for tree growth. However, we seldom include them in a discussion of fertility management. For this discussion we will assume that there will be adequate air and water to take care of those needs.

Nitrogen (N)

Hardwood seedlings come in two groups in regard to their N needs. The first group, which include a majority of hardwoods require a source of fertilizer N. They need about 50% more N than most pines. Thus, they are heavy N feeders. The second group of hardwoods associate with certain microbes, form nodules on their roots, and provide their own N. Certain leguminous species, such as black locust, associate with bacteria called *Rhizobium.* while other species such as alders, Russianolive, or casuarina associate with an actinomycete called *Franki*a. The result is the same in both cases. The microbes live in nodules on the plant roots and convert atmospheric N into forms that the plant can use. In practice, we usually do not apply fertilizer-N to the N-fixing species until the middle of June. If they are well nodulated and growing up to expectations, we continue to refrain from fertilizing with N. However, if there is a lack of nodulation and growth is sub-par, we simply pick these species up on the regular N fertilization schedule for the rest of the growing season. A lack of nodulation may occur in the year following soil fumigation.

Nitrogen is needed for growth. But sometimes it can also stimulate seed germination. Studies by Auchmoody (1982) suggested that certain recalcitrant seed can be stimulated to germinate through the action of nitrate. He applied either urea or calcium nitrate to cherry *(Prunus pennsylvanica*) seed and observed a strong germination stimulation. Rates of application of 50 lbs. N/acre (56 kg N/ha) were effective. Since both nitrogen sources were equally effective, he concluded that the stimulation was related either to the direct action of the applied nitrate in the calcium nitrate or to nitrate derived from the urea via nitrification. Both phosphorus (P) and potassium (K) were included in the treatments but neither stimulated germination above that produced by the N alone.

Some authors have shown a strong clonal response to fertilization. Curlin (1967) grew 22 clones of cottonwood *(Populus deltoides* Bartr.) cuttings, using a single rate of ammonium nitrate fertilization. He found a strong clonal response to the fertilizer in plant height, diameter, and volume. Since most hardwood seed being planted today is still open-pollinated, this strong interaction manifests itself in large seedling-to-seedling variation in growth. The small amounts of improved seed from hardwood seed orchards which have been available for planting almost always show a reduction of variation in seedling size. Until we have genetically uniform seed or use clonal vegetative propagation (Ike,1969), real uniformity among hardwood seedlings will be very difficult to achieve.

The potential advantages of slow-release fertilizers in forestry have been recognized for more than 25 years (Hauck, 1967). One early study of the effect of slow release magnesium ammonium phosphate (MagAmp) and coated oxamide was carried out with tulip-poplar *(Liriodendron tulipifera*) seedlings (White and Ellis, 1965). The authors reported an increase in N uptake but a decrease in survival. They also found that high rates of N application depressed potassium uptake. Deines (1973) compared ammonium nitrate, urea, and sulfur-coated urea (SCU) on the growth of sycamore *(Platanus oxidentalis)* and sweetgum *(Liquidambar styraciflua*) seedlings in two nurseries which had contrasting soils. Seedling growth, when evaluated at the same rate of N application, was better with urea than either the SCU or the ammonium nitrate. He cautioned, however, that the SCU had been applied in one preplant application, whereas the other two sources had been split into five equal applications during seedling growth.

The first in-depth evaluation of slow release fertilizers in hardwood nursery production was conducted by Villarrubia (1980). He evaluated both soluble and slow release N sources over a range of application rates on sweetgum and green ash seedlings. The soluble N sources were ammonium nitrate (AN), ammonium sulfate (AS), sodium nitrate (SN), and urea (U) and the slow release N sources were isobutylidene diurea (IBDU) and two slow-release forms of sulfur-coated urea (SCU). They were called SCU-11 and SCU-24. The numbers represent the dissolution percentages in water after seven days. Thus, the SCU-24 released its N approximately twice as rapidly as the SCU-11. Rates of fertilization were the equivalent of 200, 300, and 400 lbs. N/acre with the slow release forms being incorporated with the soil prior to planting the seed. The soluble forms were topdressed during seedling growth.

Height growth for both species was greatest with SCU-24 (Fig. 1). This was followed by a group consisting of AS, U, SCU-11, and AN. These were followed considerably by IBDU and lastly by SN. Since most of the better performing N sources contained sulfur (S), a second experiment was conducted using AS, U, and U plus elemental S (U+S) at the same rate of S as is in the AS. Results were clear, with both height and root collar diameter being significantly greater with the S-containing forms (AS and U+S) than with the U. This response is likely to be soil-specific. However, note the comments on phosphorus below, where S again becomes an important consideration.

The N sources had large effects on soil acidity. At the beginning of the study (before any N fertilizer was applied), the soil in the plots ranged from pH 5.6 to pH 6.5. By September, across all plots, the SN plots averaged above pH 7 while the AS plots were all near pH 4.5.

Results showed that there were no differences in seedling growth attributable to N rate. Thus, the lowest rate tested (200 lbs. N/acre) was adequate and represented a considerable reduction in fertilizer costs, since the highest rate had been the standard for the nursery where the tests were run. Growth response to N source formed two distinct groups with AS, SCU-24, AN, SCU-11, and U being better than IBDU or SN. The AS and SCU-24 gave the best early and rapid growth. This reduced weeding costs due to rapid shade development. Neither source nor rate of N application affected seedbed density of either species.

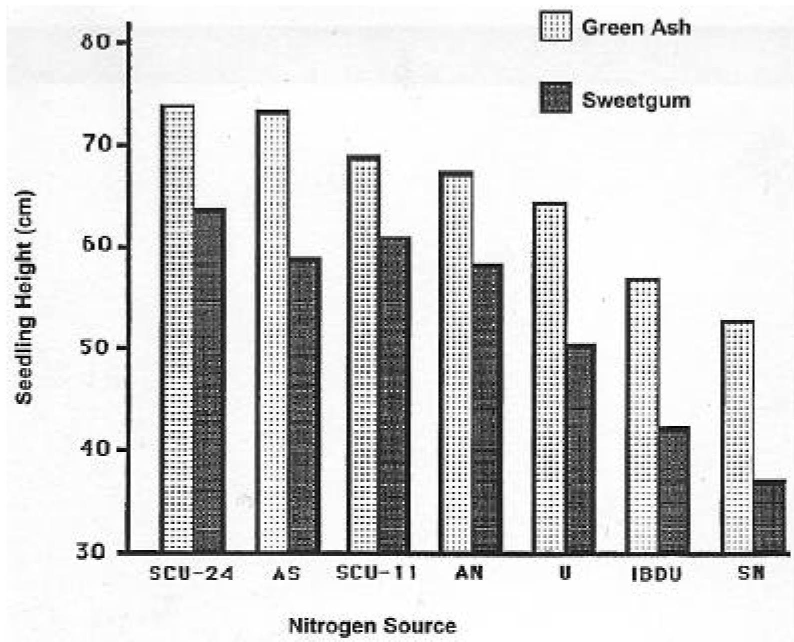

Figure 1. Effect of nitrogen source on height of green ash and sweetgum seedling at lifting (data summarized from Villarrubia, 1980).

The fact that the slow release forms of N were as effective as the soluble forms, and that they were applied all in one application at the beginning of the season, seemed to offer some advantage. However, an assessment of the cost of the materials made it at least as economical to use the soluble forms, even when the added cost of fuel and labor for repeated application were included. In addition, the soluble forms offer the advantage of being flexible in the amount used in any given year. This allows adjustment for year-to- year climatic variation. Currently, several nurseries are doing custom application of soluble N fertilizers that are composed of ammonium nitrate and urea, with varying amounts of ammonium sulfate or ammonium thiosulfate added.

Finally, the soluble forms offer the possibility of following the results of Ingestad (1989) and progressively increasing the rate of application over the growing season. This may also reduce the total amount of fertilizer needed since quite small application rates are used early in the season. This could have been one reason for the low rate being the best in Villarrubia's (1980) study. He used three different application rates; a light rate in June, a moderate rate in July, and a heavy rate in August.

Phosphorus (P) and sulfur (S)

In times past, we used ordinary superphosphate (OSP) (0-20-0) as our source of P. Today we use either triple superphosphate (TSP) (0-46-0) or diammonium phosphate (DAP) (18-46-0). All three are acceptable sources of P, but there has been one major change associated with switching away from OSP, and it has nothing to do with P. In the manufacturing of OSP, phosphate ore is reacted with sulfuric acid and the resulting OSP contains plenty of S. In the production of TSP, phosphate ore is reacted with phosphoric acid. Finally, DAP is produced by reacting ammonium hydroxide with phosphoric acid. Thus, neither TSP nor DAP contain any S. As long as OSP was being used nurseries seldom had need for any S additions. Since the switch to TSP and DAP, there has been a frequent need for added S. This is now provided through the use of ammonium sulfate as an N source, gypsum (calcium sulfate) as both a calcium and S source, or the application of elemental S to the soil. Both the ammonium sulfate and elemental S will acidify the soil. Thus, they need to be used with some caution. Gypsum has essentially no effect on soil acidity. All of these sources of P, S, and calcium can be used, when appropriate, on hardwoods. Hardwoods tend to use somewhat more P than conifers.

Lamar and Davey (1988) inoculated green ash seedlings in a nursery with three VAM fungi and had a non-inoculated control. They found that the P content of the foliage was considerably higher than typical coniferous seedlings. There were significant differences among all three VAM fungi and they were all better than the non-inoculated control. This study is described in more detail below, under the topic of mycorrhizae.

Potassium (K)

Since K is not a structural element in any seedlings and since nearly all sources of K are quite soluble, the only real difference between hardwoods and conifers is that hardwoods use somewhat more K than conifers. However, the difference is usually less than a 25% increase for the hardwoods.

Calcium (Ca)

Hardwoods tend to use more of almost all nutrient elements than pines, but this is especially true for Ca. According to Gosz (1984), the relative nutrient use by trees in general is N > K > Ca > P = Mg = S > Fe = Mn. However, some hardwoods, such as poplars, use more Ca than any other nutrient on the list. In general, hardwoods use about twice as much Ca as pines.

Magnesium (Mg)

According to a review by Leaf (1968), hardwoods tend to use from 50% to 200% as much Mg as pines. Sources of Mg include dolomitic lime, Epsom salts (magnesium sulfate), and a mixture of potassium sulfate and magnesium sulfate which is known by at least three different commercial names. These include: Sul-Po-Mag, K-Mag, and sulfate of potash - magnesia. They are all essentially the same product and may be interchanged without risk.

Micro-elements

Much less is known about hardwood seedling nutrition in regard to the micro-elements than is known about the macro elements. Table 1 presents a set of generalizations digested from the extensive reporting of Stone (1968) in regard to micro-element concentrations in the foliage of many species of trees. In Stone’s (1968) original tables, a wider range of values for all of these elements can be found. However, the values in Table 1 represent fairly typical ranges for pine and hardwood seedlings.

Table 1. Ranges in the foliar concentrations of the micro-elements considered "adequate" for growth of pines and hardwoods.

Element	Pines	Hardwoods
	(foliar concentration in ppm)	
Boron	15 - 40	30 - 60+
Copper	4 - 8	5 -15
Iron	25 - 75	80 - 90
Manganese	100 - 400+	200 -1,000+
Molybdenum	0.04 - 0.10	0.05 - 0.30
Zinc	30 - 50	25 - 50

Soil Testing

Although not restricted to hardwood seedling production, it is useful to mention problems and benefits associated with soil testing. Analyzing foliage for nutrients or soil for total nutrients, while requiring good analytical chemistry, is very little trouble. On the other hand, attempting to chemically simulate in a few minutes what tree seedlings (or any other crop) will be able to extract from a soil over a whole growing season is very complex. Over the years, a number of extracting solutions has been developed for this purpose. Some are as simple as hot water which is used to extract available boron and some are quite complex, such as the Mehlich 3 extractant. The best extractant to use in any given region is still a matter for some debate. Most extractants have been named for their developer and this causes problems with pride, if not chemistry. Some typical extractants are known as Bray 1, Bray 2, Mehlich 1, Mehlich 2, Mehlich 3, Morgan, Olsen, and Truog. All but the Olsen extractant were developed for acidic soils such as exist in nearly all nurseries represented at this meeting. The Olsen extractant was developed specifically for alkaline soils.

The second aspect of the soil testing process is determining the amount of the various elements in the extract. Again, that is very routine chemistry. Finally, once we have the soil test data in hand, we get to the really tricky part of the process and that is interpreting the results in relation to the growth of some specific crop. In many states, a great deal of effort has gone into the process of correlating crop growth and yield with specific soil test levels and developing guidelines for correcting deficiencies or maximizing yield without wasting money or risking environmental pollution. Unfortunately, nearly all soil testing facilities have been developed for agronomic crops. Some work has been done with orchard tree crops, but that is about as close as we get to forest tree seedlings. One nursery manager once told me that his state soil testing lab could give him very precise suggestions for his cover crop but had no idea what to tell him about his trees.

Finally, different soil testing labs use very different ways of reporting the results that they obtain. Some express values as pounds per acre, some as parts per million, some as milli-equivalents per 100 grams of soil, some as an index value, and some are based on a volume of soil rather than a weight of soil. By the time you consider all the different extractants that might be used and all the different ways in which the results may be reported, it becomes a nightmare trying to do anything on a regional basis.

Because of the apparent babel created by the use of various soil extractants and the variety of ways of reporting results of soil analysis, a special committee, within the Auburn Nursery Co-op, was set up to try to deal with this confusion. The first decision was to select one laboratory to do all testing. This would at least eliminate the myriad of methods and results expression. No state lab was in a position, logistically or legally, to run soil tests for land owners across states from Texas to

Virginia. Consequently one commercial lab was selected and most nurseries with in the Co-op and several outside the Co-op have used this lab since the fall of 1981. By having all of the interpretation done at one location, we have built up a very substantial data bank, both in terms of soil test values, and more importantly, in terms of efficient soil management. Many nurseries in the southern region have reached the point of routine fertilization with only occasional significant adjustments of specific nutrients, soil acidity, or organic matter. The hope has been from the beginning that we could improve seedling quality and at the same time reduce seedling production costs.

Soil Physical Properties

Texture

Soil texture is an important criterion when selecting a nursery site. Ideally, pine nurseries should be located on fine sands. Coarser sands have low water and nutrient-holding capacities. Hardwood nurseries should be located on loamy sands. Finer textured soils may be fertile and hold water well but they often present severe difficulties during lifting. Root loss is often extreme and the resulting survival of seedlings in the field is reduced. There are a very few nurseries located on almost pure silt (<5% clay) on loess soils near the Mississippi River that seem to have the best of both conditions. However, just a little more clay (5 - 10%) and these soils become nearly useless for seedling production.

Bulk density and soil compaction

The emergence of germinated seed from soil is affected by mechanical resistance of the soil to seedling root penetration, and by restriction of the exchange of oxygen and carbon dioxide in the seed zone (Chancellor, 1977). He reported that emergence of cotton seedlings, which are very similar to many hardwood seedlings, was directly related to air permeability of the soil and inversely related to mechanical impedance. These effects restrict root extension in the soil and as a consequence of that, the availability of water to the developing seedling. During germination and emergence, nutrient availability is not a significant problem since the very young plant is still depending on the seed for nutrients and energy. Once germination and emergence are completed and the seed energy has been used, nutrient availability becomes an additional concern. Chancellor (1977) concluded that when water is at all limiting, soil compaction reduces water and nutrient uptake. Compaction reduces seedling survival in the seedbed.

Most problems related to mechanical impedance in the nursery are related to soil compaction caused by equipment travel. The nursery manager should instruct all equipment operators to use only the paths between beds, with almost no exceptions. I have observed poor growth of cover crop in a field that had been in seedlings the year before. The poor growth was easily identified as tractor traffic diagonally across the field during lifting. Even one or two passes with a tractor leaves compaction that is difficult to totally erase during the next cycle of land preparation. The susceptibility of soil to compaction is directly related to the moisture content up to near saturation. Unfortunately, the soil is frequently very moist during the lifting season. The compacting force of a tractor tire destroys the large pores in the soil and these pores are primarily responsible for air entry into the soil and carbon dioxide escape.

Compaction leads to a high soil bulk density. The bulk density of a soil is related to its texture and organic matter content. Mitchell, et al. (1982) subjected loblolly pine seed-lings to growth in a forest soil which had been compacted to various imposed bulk densities up to 2.0 g/mL. This was done in a greenhouse where other conditions could be kept constant. Root and top growth were not greatly affected until a bulk density of 1.5 was reached. All higher bulk densities had strong, increasingly deleterious, effects on root growth, nutrient uptake, and top growth. At bulk densities of 1.9 and 2.0, growth nearly ceased. No comparable study with hardwood seedlings is known but practical observation has shown the general concept to hold. In one nursery in Virginia, high bulk density caused by equipment compaction has been found to be directly detrimental to sweetgum seedling growth in an otherwise excellent soil. There is an inverse relation between seedling growth and soil bulk density. Since soil compaction is never uniform, it also leads to increased variability in seedling size and quality. Each soil has a natural bulk density and it is affected by both texture and organic matter content. Sands have a naturally higher bulk density than clays. Daddow and Warrington (1983) have provided a very useful guide to growth-limiting soil bulk densities as influenced by soil texture. Their results show that texture must be considered when trying to decide whether excessive compaction has occurred to any given soil.

Temperature

Mycorrhizal and non-mycorrhizal green ash seedlings were grown at various root temperatures (7.5° - 20° C) (45° - 68° F) to determine temperature effects on leaf area, seedling height, and biomass production (Anderson et al. 1987). Leaf area was greater in mycorrhizal than non-mycorrhizal seedlings at all temperatures and the relative difference was greater at low temperatures. Phosphorus concentrations in roots and leaves did not differ between mycorrhizal and non-mycorrhizal seedlings. However, because of the significantly greater growth of the mycorrhizal seedlings, the P content of the mycorrhizal seedlings was always higher. The authors concluded that the mycorrhizal fungus used as inoculum *(Glomus etunicatum)* actively stimulates green ash growth at moderately low root temperatures.

Soil temperature also directly influences all reactions in the soil. There is a general temperature quotient, Q 10 = 2, which indicates that for every 10° C (18° F) increase or decrease in temperature, reaction rates will either double or be cut in half. For most chemical reactions this holds for all temperatures above freezing. For biological systems, the quotient only holds within the temperature range in which any given organism will grow reasonably well. However, it does help us understand some of the nutrient and organic matter dynamics in the soil. For example, organic matter breaks down much more rapidly in southern nurseries than it does in those in the northeast. Not only does the soil reach somewhat higher temperatures in the south, it remains well above freezing for most (in some locations, all) of the year. Thus, Q 10 = 2 tells us that the oxidation of soil organic matter will be considerably greater in the south. And in fact it is greater. The equilibrium organic matter content of sandy nursery soils in the south is generally well below 2 %. By contrast, the nursery soils of the Pacific Northwest frequently have equilibrium organic matter levels around 8%. One might expect that because of higher temperatures during the growing season, growth (photosynthesis) should be much higher in the South. Actually, it is much higher - but unfortunately- so is respiration. Thus net growth is not as much higher than might be thought at first. In fact, most of the greater growth in the South can be attributed to a longer growing season rather than to a warmer one.

Red oak seedlings were grown in a greenhouse at varying day/night soil temperatures (Larson,1970). No single temperature was optimum for root growth but roots grew well at a constant 24° C (75° F). There was some decrease in root growth at 18° and 29° C (64° and 84° F). Shoot growth remained favorable at 29° C but was severely limited below 18° C regardless of a favorable air temperature. The total daily degree hours of soil heat was found to be more important for seedling growth than the difference between day and night temperatures.

Rooting depth

Rooting depth of seedlings is directly related to seedling growth. Soil depth may be actual depth or effective depth. Actual depth may be limited by a physical barrier to root growth, such as an old plow pan, or it may be effectively shallow due to a high water table or lack of oxygen penetration below a certain depth. In the latter cases there is no physical barrier to downward root growth but roots are nonetheless prevented from rooting to the desired depth.

Mycorrhizae

Most species of trees are either ectomycorrhizal or endomycorrhizal. A few spe-cies, however, can form either type. This was postulated by Lodge (1985) to offer possible advantages to those species when outplanted on variable sites. Eastern cottonwood is one species which can form both types. The results of Lodge's study showed that endomycorrhizae were prevalent on both dry and wet soils whereas ectomycorrhizal seedlings were the norm on moderately moist sites. Fine soil texture and elevated levels of soil P and K were all positively correlated with ectomycorrhiza formation and negatively correlated with endomycorrhiza formation. Evidence was found for antagonism among ecto- and endomycorrhizal fungi. In addition to cottonwood, oaks and some leguminous tree species can form either type. In general, where the option exists, superior growth of the seedlings is associated with the formation of ectomycorrhizae. However, with all known tree species, growth of mycorrhizal seedlings of either type significantly exceeds the growth of non-mycorrhizal seedlings. Also, within either type, there are important interactions between tree species and mycorrhizal species. This probably even extends to the genotype of both. However, this has not been well investigated. Tree genotype and fungus species interactions were studied for Douglas-fir by Lambeth (1979) in the phytotron and found to be important.

The effect of soil fumigation on subsequent pine seedling growth and ectomycorrhiza development has been studied fairly extensively. Snyder (1984) studied these factors as they affect sweetgum seedling growth and endomycorrhiza development. Fumigation was with 350 lbs./acre of MC-2. The concern was that while the inoculum of ectomycorrhizal fungi is air-borne and soil reinfection is fairly rapid after fumigation, endomycorrhizal fungi have spores that are only soil-borne. Thus, if fumigation damages them significantly, reinoculation can be a slow process. Snyder's results showed that sweetgum seedlings that were grown on first year, spring-fumigated soil were smaller in root collar diameter (RCD) and had lower mycorrhizal infection through much of the growing season than seedlings grown on non-fumigated soil. By lifting time, there was no significant difference in RCD's, but mycorrhizal development was still low. Graded seedlings were outplanted and after a year in the field those seedlings that had been grown on the non-fumigated soil did have larger RCD's than those grown on the fumigated soil.

One possible way to increase the endomycorrhizal inoculum in the soil might be through the growth of cover crops between fumigation and the seedling crop. This was investigated by testing both one summer and several winter cover crops and comparing them with summer fallow. Soil potassium level dropped significantly after the summer fallow and the subsequent sweetgum crop had the lowest mycorrhizal infection. The summer cover crop did not influence the mycorrhizal development of the winter cover but the winter cover did influence the subsequent sweetgum seedling crop. The best result was with a winter cover crop of rye and the poorest following lupine. Sweetgum seedlings grown after a summer cover crop of sudax were significantly taller then those grown after a fallow treatment. In a second study, sweetgum seedlings were grown in soil which had produced a crop of ectomycorrhizal water/willow oaks the previous summer. Mycorrhizal development was lower in those sweetgum seedlings than in any of the previous tests following endomycorrhizal cover crops. Thus, the possibility exists that a single crop of ectomycorrhizal seedlings may significantly lower the inoculum potential of endomycorrhizal fungi. Further elucidation is needed on that subject.

There has been some evidence that high soil fertility, especially high phosphorus levels will reduce or even eliminate mycorrhiza development. Also, there has been speculation that vesicular- arbuscular mycorrhizal (VAM) fungi that might be effective in the high fertility environment of the nursery would not be functional in the low fertility environment of forest plantings. In order to study these potential problems, Lamar and Davey (1988) isolated three VAM fungi from roots of green ash trees in a low fertility (5-7 ppm P) forest soil and used them for inoculation of green ash seedlings in a high fertility (148 ppm P) nursery soil. Inoculation with these fungi significantly increased seedling heights, RCD's, dry matter accumulation, and phosphorus uptake, relative to control seedlings. Control seedlings received the same treatments except for the VAM fungal inoculation. Seedbeds had been fumigated with MC-2 at 300 lbs/acre. There was a significant positive correlation between foliar P concentration and percent root infection. These results provide evidence that there are VAM fungi that are capable of functioning effectively under either high or low soil fertility. That should be good news to those nursery managers producing planting stock in fertile nursery soil for outplanting in infertile forest soil. The authors concluded that the growth stimulation was probably eventually limited by the low potassium level in the nursery soil being used rather than by excessive P accumulation.

Facultative relationships

Some few tree species have the ability to form either ecto- or endomycorrhizae. It has been postulated that such an ability should offer some ecological advantage. Cottonwood *(Populus deltoides)* is one such species. A series of experiments were run with cottonwood to define this possibility (Lodge, 1985). Endomycorrhiza infection occurred under very dry or very wet conditions while ectomycorrhiza formation predominated under moderate moisture levels. Soil properties that were positively correlated with ectomycorrhiza formation and negatively correlated with endomycorrhiza formation were fine texture, potassium level, and phosphorus level. Lodge (1985) found evidence for antagonism between ectomycorrhizal and endomycorrhizal fungi.

Seedbed Density

Hardwood seedbed density varies by species, but it is almost always considerably lower than the conifers (longleaf pine is an exception). Then, since we irrigate and fertilize on an area basis, and the need for both water and fertilizer is greater on an area basis than for pines, the cost per seedling goes up considerably. Typically, the relative cost for nitrogen fertilizer for a single hardwood seedling is approximately 2.5 times as high as for one pine seedling. Likewise, the cost for water is about 3.3 times as great. Thus, it should be no surprise that the price to the purchaser is at least three times as high for hardwoods as it is for pines.

Vegetative Propagation

For several tropical hardwoods, it has been found advantageous to grow seedlings in the nursery and then just immediately before or after lifting, remove the top, leaving a root system with a stem about 6 inches (15 cm) long. This is often called a “false cutting” because it looks like a cutting after planting in the field but it has the advantage of having a fully developed root system.

Such trees can be produced as bare-root stock and survive very well where there is no dormant season. In the nursery, such planting stock can be grown either from seed or vegetatively produced from true cuttings. This last technique allows taking maximum advantage of any superior trees.

In more temperate regions, vegetative propagation has usually involved growing several coppice rotations on established root systems. The sprouts are then converted into true cuttings for establishment in the field. The fertility management of such cutting gardens in the nursery varies somewhat from seedling production. First the plant density is greatly reduced while the root systems are greatly enlarged. The frequency of fertilization of such trees can be reduced while the size of individual fertilizations can be increased over those typical for seedling production. Total nutrient demands for such trees are usually 10 to 25% greater than for seedlings of the same species. Superior selections of several hardwood species can be advantageously propagated by this method. These commonly include various poplars, ash, and sycamore.

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