Irrigating and Fertilizing To Grow Belter Nursery Seedlings[1]

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Abstract - At the time of loblolly pine seed sowing, we recommend soil nutrient concentrations (in parts per million) of: 350-400 for Ca, 80-90 for K, 80 (Brayll) for P, 50 for Mg, 0.3-3 for Cu. 3-8 for Zn, and 0.5-l .2 for B. Soil pH should be 5.1-5.9. An Initial N apptlcalon of 10-15 kg/ha (11-17 lbs/acre)should be made when the elongating stems above the cotyledons are 2.5 to 3.5 cm(1 to 1-1/2 Inches) long. A second equal N application is needed 10 to 14 days later. Three applications of 15-30 kg/ha N shoutd be made at Intervals of 10 to 14 days, Seedlings from late sowings require more N than those sowed earlier. If rains are frequent, N'applicattons should be skipped or reduced. By mtd-July. seedttngs heights should be 15-20 cm (6-8 Inches), and N applications should be suspended. In late September, seedlings should be undercut and 22 kg/ha (20 lbs/acre) of N should be applied.

Between germination and the first N apptlcation, water should be applied daily to avold any moisture stress. After seedttngs are estabttshed, beds should be watered when tendon meters at 20 cm (8 inches) read 30 centibars. After mid-July, water when readings reach 50 centibars, or when there ts danger of scorch on exceedingly hot days.

In this paper we describe a system for producing excellent loblolly pine seedlings for planting in southern forests. The system, which has taken years to develop, appears to be working well. Proof of that will depend upon results of outplanting tests, but there are strong indications that the seedlings we are producing will be better than those coming from most southern forest nurseries. One reason they will be better is because they are being graded to get rid of inferior individuals. Another reason is that top/root (T/R) ratios are near ideal. In our approach, irrigation and fertilizer applications are less generous. The seedlings that are produced have smaller tops, and do not require pruning. And because less fertilizer and water are applied, there is less possibility of polluting groundwater under the nursery.

We present the findings with no details on metabolic pathways or complex root morphology. In the main, however, we describe a system for growing loblolly pine nursery seedlings and in less detail present current practices that appear to be equally effective for producing a good and consistent crop of hardwood seedlings.

BACKGROUND

This new approach to growing loblolly pine seedlings began with research on sweetgum and other species of hardwoods. Nursery-grown hardwood seedlings were performing erratically in the field. Some were growing quite well and others were growing very, very poorly. Some of those early research findings with sweetgum are summarized at the outset.

A decade ago, we were observing uneven results of sweetgum plantings. A fair proportion of the seedlings that were being planted were growing quite well, but the proportion was not high enough to make a satisfactory stand. And many of the planted trees were growing slowly, if at all. Our conclusion was that good performers had to differ from the poor performers in some major way. that would be recognizable in nursery seedlings. Our goal, therefore, was to separate potentially good and poor performers through grading in the nursery.

There was little new about the idea of grading nursery seedlings. People have been trying to do that for as long as there have been forest tree nurseries. There was, however, no detectable enthusiasm among nurserymen, who had become comfortable with the practice of selling all of their seedlings rather than culling and discarding some of them. We heard some comments about culling being impractical or inappropriate in a 1980's nursery operation. We ignored the comments and plunged ahead.

Our research showed that the number of strong, first-order lateral roots (FOLR) a nursery seedling possessed was a strong

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indicator of its probable performance after outplanting. Individuals with the fewest FOLR were least competitive both in the nursery and in forest environments (Kormanik 1986, Kormanik and Muse 1986, and Ruehle and Kormanik 1986).

We suspected that the proportions with high and low performance potential in seed lots from individual mother trees were genetically controlled, but to test that theory we had to be able to produce a consistent crops of seedlings regardless of the nursery in which they were grown. We wanted sweetgum seedling that fell within a specific size range, and we wanted differences in performance potential to be fully expressed after a year in nursery beds.

During the late 1970's and early 1980's we had developed a protocol for growing sweetgum in our experimental nursery when the original work on lateral root development was done (Kormanik 1985, Kormanik and Ruehle 1987). With that protocol, number of strong FOLR was a meaningful measure of probable field performance of sweetgum (Kormanik 1986).

In 1984, we began work with loblolly pine to determine whether any of our findings with sweetgum would be applicable to it and other conifers. At that time, and to this day, there is no generally accepted protocol for nursery production of loblolly pine seedlings. Seedbed densities, soil fertility, fertilizer application schedules, and irrigation schedules vary widely among nurseries and among fields within nurseries. As we began to study loblolly pine seedlings, it became apparent that these variations in nursery conditions were influencing FOLR development of loblolly seedlings. Differences in cultural techniques also were frustrating our attempts to obtain seedlings within a narrow range of sizes for our research.

At that time, our specific research objectives were: (1) to develop frequency distribution *curves* of seedling FOLR numbers for mixed seedlots and lots from specific mother trees, (2) to correlate height and root collar diameter with number of FOLR, and (3) to determine heritability values for FOLR development. To complete those objectives, we needed to produce seedlings within a specific size range without clipping tops or wrenching roots. We wanted seedlings ranging from 25 to 36 cm (10 to 14 inches) tall.

EARLY OBSERVATIONS

It didn't take long for us to realize that production nurserymen had a conflicting set of. objectives. We wanted loblolly pine seedlings to grow at apace that would permit expression of differences in outplanting potential. Nurserymen wanted to grow seedlings of uniform size with little or no culling. To meet their objectives, they were, and still are, providing luxurious quantities of nutrients and water. Under these conditions, inherently superior loblolly seedlings get too large, so nursery workers expend considerable effort clipping tops and wrenching roots to get a final product that is small enough to plant. Their procedures are described in the Nursery Handbook (USDA 1984).

Thirty years before, Wakeley (1954) recognized that such improvements in nursery culture hampered the development of a morphologically based grading system for southern pine seedlings. The purpose in nurseries, however, was not to make a grading system work, it was simply to eliminate the need to grade seedlings.

We found that all nurseries were clipping seedling tops and wrenching roots several times during the year to produce seedlings with uniform stem characteristics. Root morphology was quite variable among these seedlings with uniform top sizes. Furthermore, even in individual nurseries, top clipping, and root wrenching schedules were varied to compensate for the differences in soil productivity of individual fields.

When we began to compare fertilization practices of different nurseries, we found little similarity among them. There even appeared to be little similarity among fields within the same nursery. It was not unusual for P, Ca, K, and Mg levels to vary by 50 to 75 percent among individual fields, and the levels were sometimes double that which we had found ideal for sweetgum. Fields considered good for producing seedlings characteristically had significantly different fertility levels and even different ratios of specific nutrients than did less-desirable fields. We also found little relationship between irrigation patterns and the seasonal requirements of the seedlings for moisture. If water was applied daily in May, it also was applied daily in August, regardless of the plants' need for water. Little consideration was given to soil texture when prescribing irrigation interval and duration and fertilizer applications.

WHAT WE DID

Early observations led to the conclusion that we needed a target **seedling** density for seedbeds and a baseline value for soil fertility. By "baseline value" we mean the nutrient content of the soil when seeds are sown. In our experimental nursery we adjusted the nursery beds to a uniform density of 258-280 seedlings/m2 (25-28 **ft2),** used the same fertility baseline we had found so effective with sweetgum, and then applied nitrogen at levels up to 280-308 kg N/ha **(250-275 lbs/** acre), which was the quantity most commonly applied in southern nurseries in the mid-1980s. We applied these in equal **increments'**on the same date that the commercial nurseries did. We avoided topclipping and root wrenching because we wanted a natural balance between roots and tops to occur.

This system produced excessively large seedlings but root morphological differences were correlated with stem characteristics. Seedling sizes were easily stratified by FOLR numbers. Seedlings were sometimes twice as large, up to 75 cm, (30 inches) as those being shipped to the field for outplanting and were more difficult to outplant. The survival of 70-80 percent under research conditions was acceptable. We did, however, question whether such good results could be **sus**tained under commercial planting conditions.

At about this time, we were able to demonstrate how **photosynthates** were partitioned between roots and tops of loblolly pine seedlings during the entire year. We were able to do so using assays for several sugar-metabolizing enzyme reactions {Sung et al. **1989, 1993).** During our physiological and morphological investigations, seedlings were excavated weekly from several different nurseries.

We found that little root **growth** occurred in June, **July,** and early August. These observations had a major impact on our thinking. Fertilizer applied at this time was being transformed into top growth. Since our tops were generally too large, we saw a need to limit fertilizer application **from** June to early August.

We also found, as others had, that we could raise loblolly to about any size we desired, but that we could not stop rapid mid-season elongation without top clipping or root wrenching.' With information on seasonal and periodic carbon allocation and utilization patterns between roots and stems, we decided to alter our research direction. **Instead of continuing to study how to grow loblolly pine seedlings, we tried to determine how the seedlings grew.**

We soon discovered that terminal buds developed on unclipped loblolly pine seedlings in late August or early September. At that time, there was a dramatic shift of carbohydrate allocation and metabolism from stems to roots and the root systems began to expand rapidly. Late-summer clipping resulted in multiple tops

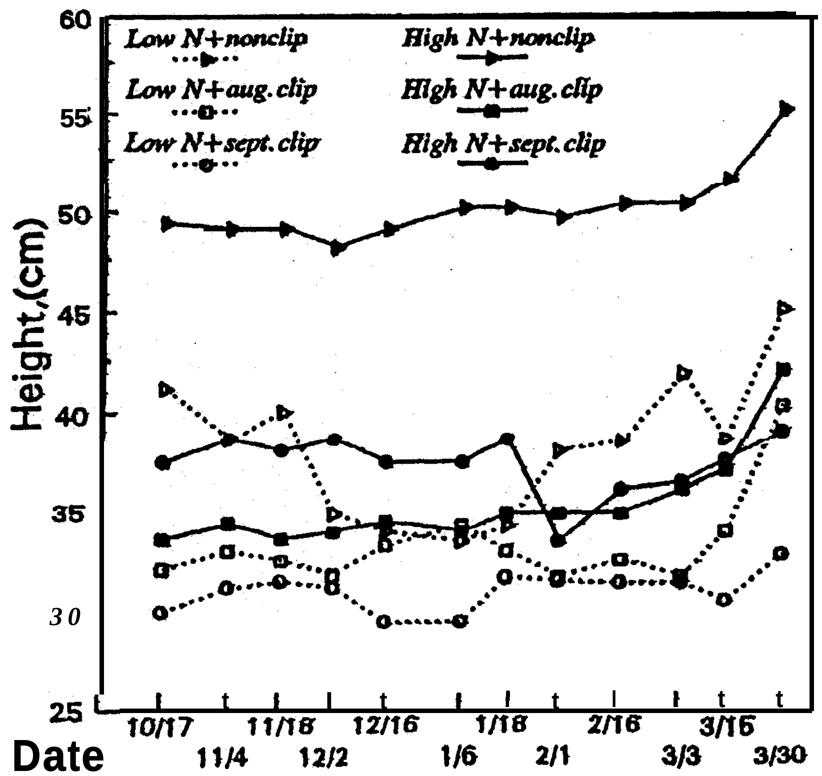


Figure 1.-Effects of high and low levels of nitrogen (308 • 84 kg/h) applied in five equal aliquots on height of clipped (August and September) and nonclipped loblolly pine seedlings.

on the seedlings, and these new tops acted as carbon sinks. They altered the normal late-summer transition from top growth to root development.

We began a series of nitrogen trials with loblolly pine using the fertility baseline developed for sweetgum. Our notion was to apply only enough nutrients to achieve our target size of 25-36 cm (10-14 inches) in seedlings that were not top-pruned or root-wrenched. Examples of our early results are shown in Figure 1. In this particular study we used 308 kg N/ha (275 lbs N/acre) as our high nitrogen level. This level was commonly used N in nurseries at that time. The low level of nitrogen was 75 lbs N/acre. The N was applied in five equal amounts whether at the high or low rate of application. No rootwrenching was done but the seedlings were clipped twice as was the policy inmost nurseries growing loblolly pine.

In Figure 1 it can be seen that whether the seedlings had high nitrogen and were clipped, or low nitrogen and were clipped or not clipped, they were of comparable sizes. It was evident that more nitrogen was being applied than the small root systems in the early season could capture and that the luxurious quantities were resulting in excessive height growth. Top/root ratios in October and November were in excess of 8:1 on these large seedlings, but by early to mid January dropped to 3 or 4:1. The T/R ratios of clipped seedlings were 3 or 4:1 beginning in early November.

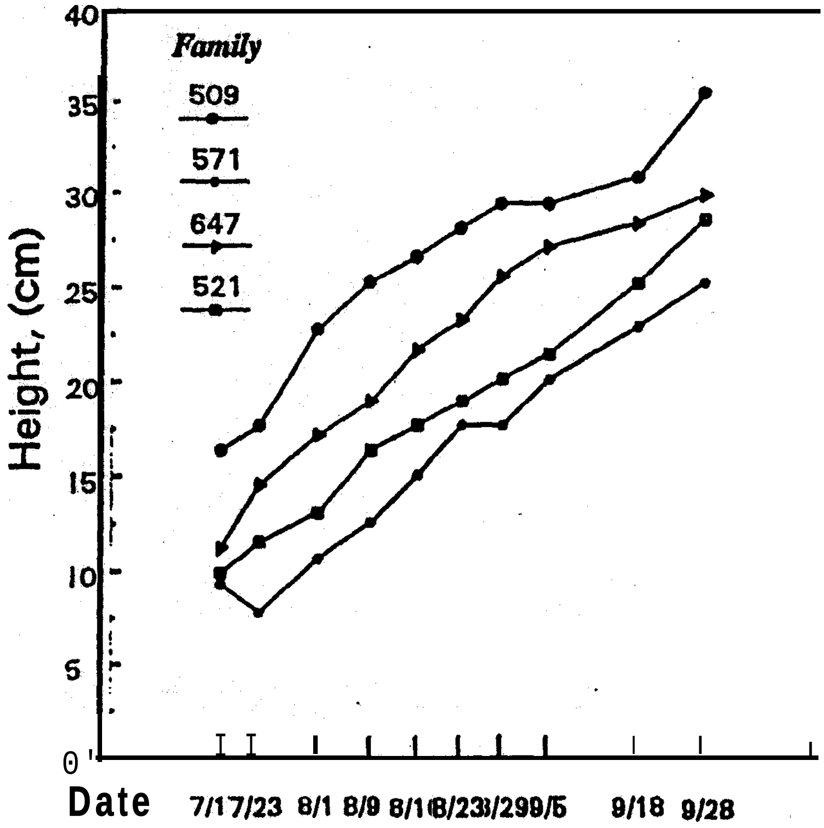


Figure P.--Heights of half-sib progeny from 27 loblolly pine mother trees In late September after normal bud set and undercutting In mid September. 23 mother-tree progenies were all distributed between families 509 and 521. Approximately 100 kg N/h were applied throughout the growing season.

FERTILIZER AND IRRIGATION PROTOCOLS

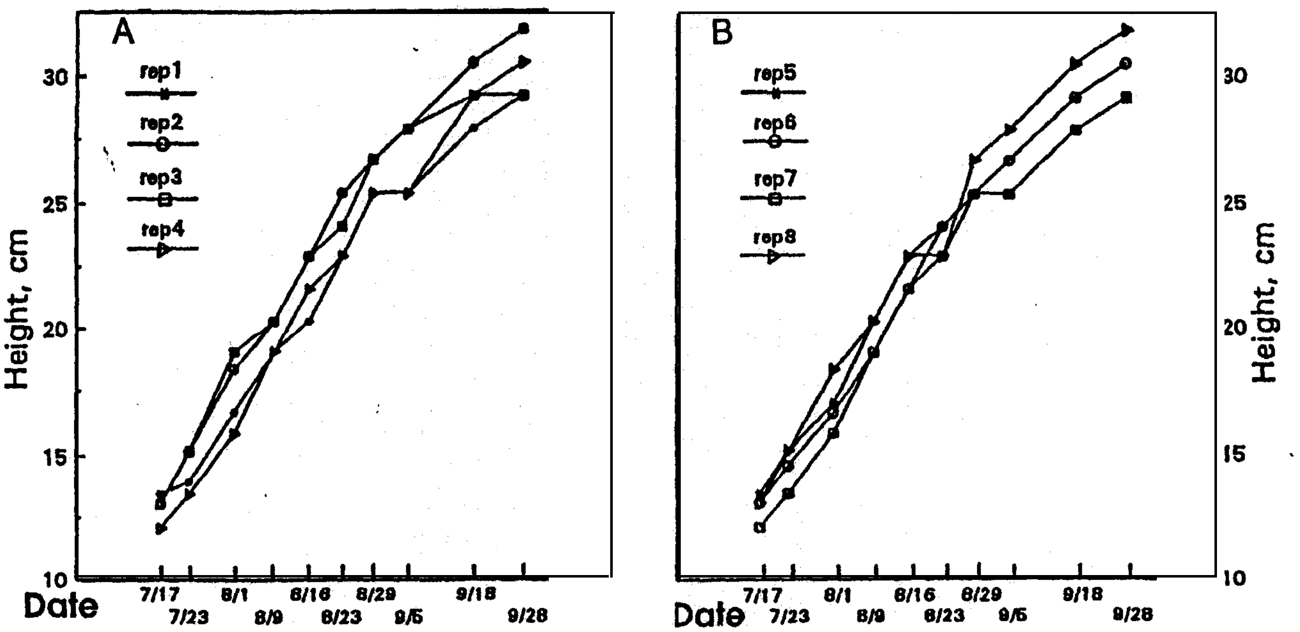
These early nitrogen trials revealed that when loblolly seedlings reach 15-20 cm (6-8 inches), whether in early June or mid July, secondary needles developed. If secondary needles appeared in June, the seedling's growth was excessively stimulated by nitrogen application. Eventually, we found that by applying nitrogen at 11-17 kg/ha (10-15 lbs N) at 10-day intervals, we could get seedlings to 15-20 cm (6-8 inches) by mid-July. We found it was good to apply one of our N applications in mid-July and then let the seedling develop until mid-September without further N application. By mid-September, at least 90 percent of the seedlings developed terminal buds. Those seedlings were undercut to 20 cm (8 inches) and a final N application of 22 kg N/h (20 lbs/acre) was made. Undercutting breaks feeder roots and stops taproot elongation. It also causes a wounding response at the time when the root system has replaced the top as the major carbon sink (Sung et al. 1993). During the next 30-45 days, fine feeder roots, mycorrhizae and RCDs increase rapidly. Tap roots do not expand appreciably, and since we began the procedure about 5 years ago we have experienced essentially no bud break after mid-September.

Nitrogen control is complicated by the fact that weather factors cause sowing dates for stratified seeds to vary by 30 days or more between years and by 14 to 20 days in any given year. It is therefore impossible to prescribe the date when N application should begin and how often it should be applied. We found, however, that an initial N application of 10 to 15 kg/ha (11 to 17lbs/acre) should be made when the elongating stems above the cotyledons are between 2.5 and 3.5 cm (1 to 1-1/2 inches). At this time, the root system is just beginning to expand and some feeder root development can be observed. This first application is usually applied towards the end of May. A second equal application is made 10 to 14 days later. The next three applications are again at 10 to 14 day intervals, but the rates may vary *from* 15 to 30 kg/ha (17 to 27 lbs/acre), depending on when the seed were sown. Seedlings from late-sown seeds can be pushed to attain the height of seedlings from earlier sowings. If rain and accompanying thunderstorms are frequent, the seedlings may start to elongate rapidly and any of these N applications can be reduced or skipped.

The important point is that by mid-July seedling heights should be 15-20 cm(6-8 inches). Usually we find that by mid-July we only need to apply about 90 kg N/h (80 lbs/acre) to get seedlings to these desired heights. In stormy years, we have used as little as.56 kg N/h (50 lbs/acre) for the entire growing season. In a very dry season, 100 kg/h (89 lbs/acre) were needed to attain the same heights.

Irrigation protocols, which were developed simultaneously with fertilizing protocols, also were based on producing seedlings of the desired size. After the fertility baseline for a nursery is achieved, the major cause for variation in seedling development may be water availability.

Between germination and the first N application, the young succulent plants should not be subjected to any moisture stress. Initially, the beds are watered daily to assure good germination and establishment. Up to the time the seedlings are 15-20 cm tall, the beds should be watered when tension meters at 20 cm (8 inches) depth read 30 centibars. After the final mid-July N application, watering is needed only when the readings reach 50 centibars. However, irrigation of short duration may be required during abnormally hot days in midsummer. Even then, however, irrigation is seldom needed when soil tension is less than 30 centibars. Maintaining moisture at close to field capacity can result in rapid stem elongation that can only be stopped by clipping tops, wrenching roots, or imposing severe moisture stress.



Figures 3A and 3B.--Heights of loblolly pine seedlings from mixed seedlots receiving 90 kg/ha of N during the growing season In beds where the nursery fertility baseline had been established. Data are illustrated In two groups for greater legibility.

BASELINE FERTILITY

After we were satisfied with our irrigation and nitrogen protocols, we were ready to set a standard soil fertility baseline. By 1989 we were able to test half-sib seedlots of 27 mother trees to determine how baselines affected development of individual seedlots. Figure 2 contains four of these half-sib progeny seedlots. Mother tree 5.09 produced the tallest seedlings, 521 the smallest, and 571 and 647 midway between. By late September when seedlings had completed height growth, the average sizes of progeny from all families were within target sizes before the seedlings were undercut and given their final nitrogen application of 22 kg/h (20 lbs/acre). At this point we felt that we could consistently obtain seedlings within the target range and we could predict the frequency distribution of seedlings based on FOLR development(Kormanik and Ruehle 1987, Kormanik et al. 1990, Kormanik et al. 1991).

However, since most nurseries were using mixed seedlots, we further tested the baseline with mixed seedlots in different nurseries. Figures 3A and 3B contain the heights obtained from eight different replications from the 1990investigations. They are reported in two groups to make the graph more legible. Typically, we find that loblolly seedling crops are more uniform when grown in mixed seedlots than in mother-tree seedlots.

Fortunately, we found that a single baseline appears to be effective in all three Georgia State Nurseries for both conifers and hardwoods, even though the soil textures vary from sandy clay loam in one to almost a sandy loam in another.

In all the fields in these nurseries, the fertility is similar or soon will be. We found that it may take up to 5 years of manipulating nutrients to achieve the desired levels. Nevertheless, the effort is necessary to produce the kinds of seedlings that are needed. Once the fertility baseline is achieved, seedling size can be controlled through the scheduling of nitrogen and water applications.

Our recommended baselines in parts per million are: 350-400 for Ca, 80-90 for K, 80 (Bray II) for P, 50 for Mg, 0.3-3 for Cu, 3-8 for Zn, and 0.5-1.2 for B. These are the levels needed at sowing time. We maintain our soil pH at between 5.1-5.9. We have not encountered any serious problems of pH getting too high for our conifers, but we have substituted NH4SO3 for NH4NO3 several times as a precaution when initial soil pH was over 6.0.

HARDWOODS

Hardwoods represent a situation somewhat different from conifers. Three different elongation patterns are common to different hardwood species seedlings in southern nurseries, but these present no difficulty in scheduling either fertilization or irrigation. The patterns are multiple flushes with each flush terminating in a development of a terminal bud (example *Quercus* spp.); continuous elongation with decreasing nodal length in response to photoperiod but without a terminal bud until late fall (example sweetgum) and continuous elongation but no terminal bud development (example sycamore). The growth patterns are probably similar to different species of hardwood in the central and Rocky Mountain regions.

As distinct as these species growth patterns are, all species can be readily grown using the same preplant soil fertility levels and the same soil moisture guidelines. However, up to 3 to 4 times more nitrogen may be needed to produce competitive hardwood seedlings. It has only been during the 1993 growing season that we have developed technology of studying carbon allocation patterns in many hardwoods comparable to what was done earlier with loblolly pine. Thus our understanding of how hardwood seedlings grow is not yet comparable to loblolly pine. We do, however, have an understanding of hardwood "what" and "when" but need more information to explain "why."

Hardwood seedlings should be much larger than pines — two to four feet or more are desirable for most hardwood species. To obtain these may take from 280 to 500 kg N/H (250 to 450 lbs N/acre) a year. The N should be applied in equal amounts every 10 to 14 days to maintain continuous elongation of the seedlings. Since elongation of all seedlings aren't synchronized this regular scheduling of N must be maintained or erratic seedling canopy will develop where only those in elongation phase will benefit from N and others may prematurely set terminal buds or otherwise cease growing. With oaks, for example, we plan for 4 to 7 flushes before nitrogen fertilization is cut off in early September but can essentially stop seedling elongation by eliminating further nitrogen application once the seedlings target size is reached. It is emphasized that with many hardwoods, once elongation is inhibited during the growing season, it is sometimes very difficult to make it resume.

Irrigation is especially critical with hardwoods as they normally use more water than do pines. The watering is still, however, scheduled when the tension meters register 30 to 50 centibars during most of the growing season just as with the conifers. It is especially important that the hardwoods not be in the same field as most of the conifers or overwatering of the conifers or moisture stress in the hardwoods will occur.

It has been much easier to develop effective baselines for the hardwoods because high soil fertility levels and frequent watering does not result in undesirable siie seedlings. High soil fertility regimes can be reduced without undesirable growth affects to hardwood seedlings until a desired baseline is obtained. The great benefit of a common baseline is that fields can be readily changed from one species to another without concern to where in the nursery seedlings will be grown.

We are constantly monitoring soil nutrient status and seedling development to make any adjustments that will improve the seedling's quality. We do not consider any part of the developing technology as the ultimate procedure but rather one which can be modified as new information is obtained.

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