Avoiding the Staking Dilemma **Published in the International Plant Propagators Soc.**

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Introduction: If trees in nature only grew upright when staked and supported, our forests would be a mass of horizontal entanglement and the lumberjack would never have to yell “timber”. When a seed germinates, the primary root or radical quickly extends downward to support the developing new plant. In nature the tip of the taproot suppresses secondary root development until its vigor begins to decline as oxygen and conditions for root functions deteriorate with depth. The tip of the taproot controls branching below ground much like the terminal bud controls branching above ground. If you want the top of a tree or a side limb to branch, cut off the tip. Roots respond the same way.

The young tree branches, but except for the occasional rabbit or deer damage, the branches remain present and functional until surrounding trees or other vegetation provides sufficient shade to cause their death. By the time the lowest horizontal branches have been killed by lack of light, generally several years have passed and successive layers of branches above have been formed.

When a tree, growing without the interference of man, grows among other trees, the horizontal root growth is greatly restricted. This is because a given quantity of soil can only support a given quantity of roots. If the soil in an area is already occupied by Tree A, then the roots of Tree B will be greatly restricted. Only when a root of Tree A dies is there an opportunity for expansion of the roots of Tree B into that area.

Background: For years the argument has been that trees grow tall when surrounded by other trees because they “stretch or reach” for light. Trees do need light and grow more on the sides or top exposed to light compared to shaded areas. The limited flexing of the stems also contributes to the vertical growth. But, I do not believe light and movement are the only factors involved. I have grown thousands of trees in a variety of placements and spacings and studied their responses (Whitcomb 1988). Trees grow taller and more slender when restricted on two sides by other trees in a nursery row, much like what occurs in the forest. But one major difference is the fact that the other two sides of the trees are exposed to full sun and are **not** restricted in their development. On the other hand, the roots are restricted on two sides by adjacent trees and often on the other two sides either by cultivation and root-pruning or grass and weed vegetation between the rows.

The reason the trees in the nursery rows in the field grow tall and slender seems to be as much about root space and development as light distribution to the foliage and flexing of the stems. In further support of this view, consider that light saturation of leaves (the maximum amount of light a leaf can use in photosynthesis to produce energy) of most tree species is in the range of 1000 to 1500 foot candles whereas full sun in most areas of North America is 10,000 foot-candles or more. This means that even somewhat shaded leaves are still working at or near full efficiency.

When I compared light to leaves of trees in a field nursery and spaced on 24-inch, 36-inch, and 48-inch centers in the row and eight feet between rows, I found none of the leaves received less than 800 foot-candles on a sunny day. Even as evening approached, there were only small differences between the amount of light the most shaded leaves received with the 24-inch spacing compared to leaves on trees with the 48-inch spacing. Yet the growth of the tops of the trees with the 24-inch spacing were more slender compared to those with 36-inch spacing and especially more slender compared to those with 48-inch spacing. From this and other experiences, it appears that root functions play a significant role in top development, branching, and stem strength.

The flexing by wind of the tops of trees stimulates stem diameter development and stem strength. One need only travel from North Carolina to Oklahoma and observe that further west the trees are shorter and generally with more branching. Soil conditions and soil depth have often been cited as the reason. On my farm in north central Oklahoma I have many acres where the topsoil is six feet or greater in depth and quite fertile. Even on these soils, and with drip irrigation, my trees are shorter and have more branching and larger stem development that the same species grown in Arkansas, Tennessee, or North Carolina.

A classic study of the effect of movement of the top of a tree on stem strength and development was done by Neel and Harris. They studied young trees in a greenhouse. The tops of half of the sweetgum (*Liquidambar styraciflua)* trees were connected to a mechanical apparatus that would turn on thirty seconds each day and shake the trees. The other half of the trees was not disturbed. The trees that were shaken had larger diameter stems and 30% less height growth, thus demonstrating that wind plays a role in height and stem growth. Jacobs (1954), Leiser, et al. (1972), Larson (1965), and Telewski and Pruym (1998) showed that trees that are staked grow taller and have smaller diameter stems compared to those not staked. Clearly staking does not solve the problem but contributes to the problem.

Figure 1. When tree seeds are timely planted, and the seedlings properly and timely spaced, transplanted, re-spaced, and fertilized and the roots are air-pruned and not allowed to circle, excellent specimens can be produced without staking. This black gum seedling is one of several thousand that were six feet tall in a three-gallon Rootmaker container. None had ever been staked.

Factors and Solutions: In the nursery several factors contribute to the problem of poor stem development: Spacing, shade, removal of lower limbs, protecting plants from wind, nitrogen nutrition, restriction of root growth and root branching all play a role.

The amount of time a tree remains at a spacing is very important. After some period of time and growth, close spacing of tree seedlings, whether in ground beds or the field, or in small, medium, or large containers horizontal root development is restricted, generally light to the inner lower leaves is reduced, secondary branch development is restricted and stem flexing is minimal with each factor contribution to stimulating vertical growth.

Seedlings of nearly all tree species begin with a single vertical stem with leaves positioned from just above the soil line to the tip. Each leaf contributes energy for growth. However, the distribution of energy is not at random, but rather is quite specific. The youngest leaves contribute mostly to terminal growth whereas the older leaves contribute mostly to stem diameter increase and root growth.

Research by Gordon and Larson (1968, 1969, and 1970) using red pine (*Pinus resinosa*) and radioactive C02 provided firm insights into this area. They found that with red pine, which holds needles for two years, the one year old needles were the prime supplier of energy for current shoot development and growth of the terminal bud, whereas the two year old needles were the prime supplier of energy for the lower stem and roots. They also reported that with *Populus deltoides* (cottonwood) energy from the upper leaves is translocated to developing tissues above. The leaves on lower limbs translocate energy to the lower stem and roots. Through a variety of research I have confirmed that their findings are true and apply to other species as well (Figure 1.) (Whitcomb 1988, 1989).

Since the older leaves and leaves on lower branches are the primary contributors of energy to support stem diameter increase and root development of trees, anything that stresses or causes those leaves to decline in productivity will affect stem development and root growth. Some of the main factors are lack of light from shading or insufficient space, but also deficiencies of nitrogen, potassium, phosphorus, or magnesium. Toxicities from excess micronutrients such as manganese, copper or boron, damage from sodium, bicarbonates, or chlorides, root problems such as being root-bound, poor drainage/low oxygen, root-rot or other disease, root insect or nematode damage, or simply over watering all cause decline of productivity of older leaves.

Starting with young seedlings, how much space is enough? It depends on the species and the length of time the trees are left at that spacing. For example, consider seeds planted in containers 2, 3, 4, and 5 inches in diameter. As the seedlings grow, those in the 2-inch containers will begin to crowd one another and restrict movement and light to the lower leaves first, followed by the 3-inch, then 4-inch, and 5-inch containers. Assuming a good root system as a result of advanced container design, at some point the tops of the seedlings in all four sizes of containers are the same. But, as time and growth progresses, the quality of the top declines and the need for staking to keep the stems upright becomes progressively more of a problem: first with the 2-inch, then the 3-inch and so on. This same crowding, reduced light to lower leaves and/or leaves on lower limbs, and reduced air movement effect can be seen on any tree in any size container if they are left too close together for too long (Figure 2). The time when trees need to be spaced further apart or shifted to larger containers and spaced further cannot be put on a calendar as it is a function of growth rate, species, time of year, fertilizer levels, and other factors.

If you doubt the importance of proper spacing and timing, conduct a simple experiment. With a block of tree seedlings of any species that have not yet overgrown their spacing and become spindly, shift 25 trees into larger containers and with more spacing well in advance of when you anticipate making the shift. Then two to three weeks later, shift another 25 and so on up to and including your normal time of shifting and spacing. Every time I have done this or have gotten others to do this simple experiment, the seedlings transplanted and spaced first are clearly the best quality and require the fewest stakes when evaluated a number of months later. Conclusion: transplant when best for the plants, not when it is most convenient for you.

The proportion to which light, air movement, root branching and root space contribute to the superior top development is unclear. With additional space most tree species produce more side branches. As noted earlier, the leaves on the lower limbs are the primary contributors to stem and root development. A key point to remember is that spacing is a critical ingredient for the development of side branches and **these branches should not be removed** until sufficient stem diameter and taper has developed to support further growth of the top (Figure 3). Look at young pine trees growing in the wild or spaced properly in the nursery with lower limbs remaining. None are staked and all have good stem taper and strength.

When lower limbs are prevented from forming due to crowding or if they are pruned off prematurely, the stem development typically is like a piece of pipe; that is, the two sides are parallel. In these cases even as the top of the tree grows, the sides of the lower stem tend to remain parallel. This happens because the stem cannot grow without energy and the energy source is the foliage on the developing top. Energy in excess to the needs of the top moves down in the outer phloem tissues. Because this downward flow of energy is received and can be used for growth by the upper part of the stem first, normal stem taper development is restricted. Further, the more you prune off the lower limbs and reduce leaf surface, the more the top extends vertically to try to produce more needed leaf surface area.

On the other hand, once the tree has developed good stem taper like a deep sea fishing rod, the lower limbs **can** be removed, if desired and the stem taper and unparalleled sides will remain for the future. Part of this is related to the fact that the downward movement of energy supplies fewer cells in the upper portion of a tapered stem proportionate to the cells below. Further, trees with good stem taper typically have superior root systems which supply more water and nutrients to the leaves which in turn increases their efficiency and the amount of energy available for all aspects of growth.

Pruning is both desirable and undesirable, depending on when, how, and to the extent it is practiced. Nurserymen that do NO pruning end up with a high proportion of cull trees with little or no value due to such problems as double leaders, other narrow and weak major branches, or aggressive side branches leaving the tree undesirably lopsided and other factors.

The problem with most nurseries and tree farm operations is that they prune excessively and indiscriminately and without understanding the consequences of their actions. The end result is most often trees with less than desirable branching, stem taper, and root system.

Trees that require staking have poor stem taper and less desirable root systems. When wind and the weight of rain or ice flexes the top of a tree with little or no taper, the bending occurs just above the soil line. However, a tree with stem taper bends over the entire length like a good fishing pole (Figure 4).

To avoid staking while developing good stem taper and root development, you must pay close attention to early plant development (Figure 1). For example, I routinely start several thousand-tree seedlings each year for a variety of studies. Years ago I tried planting seeds in the greenhouse in December or January to get a "jump on the season". It does not work because the sun angle is low in the sky, days are short, clouds are more common and temperatures are generally cool. Yes, the seeds germinate and the seedlings grow but they are tall and spindly with large leaves as a result of low light and root systems are poorly developed. By staring "early", you create problems for the crop of tree seedlings that will require much additional staking and will never reach the quality of seedlings planted a few months LATER.

In north central Oklahoma I plant tree seedlings beginning in mid to late March in an unheated greenhouse. Our frost-free date is approximately April 15. On or about that date the tree seedlings are moved to another structure covered only with 1/4 inch galvanized hardware cloth. Wind blows freely through the structure, light intensity is nearly full sun, yet the seedlings are protected from pounding rains and hail and rodents. When rain hits the hardware cloth, large droplets are transformed into a fine mist. Using this environment and timing and Rootmaker containers designed to air-prune the roots both at the bottom and on the sides, liners of consistent quality can be produced at an economical cost and without stakes.

Fertilizer, particularly nitrogen, is essential for the growth of young seedlings. However, when nitrogen is applied in excess proportionate to the other 11 nutrient elements, top growth is typically tall and slender, leaves are large and root development is poor and staking is inevitable. The most economical decision for such a block of seedlings would be to throw them away, yet unfortunately that rarely happens.

To confirm that nitrogen is a key player, I did a study where tree seedlings started in small, bottomless containers with four pounds of 18-6-12 Osmocote per cubic yard in the mix and with or without Micromax micronutrients at 1 pound per cubic yard. After the seedlings were about two inches tall, every other seedling in the rows received more Osmocote 18-6-12 up to about 10 pounds per cubic yard. An experimental Osmocote coated material with a similar release rate but containing nitrogen only was applied to the other half of the containers to provide approximately the same amount of nitrogen.

The best quality seedlings with the strongest stems (in terms of holding the tops upright) were with the high level of 18-6-12 Osmocote and Micromax, followed by the high level of 18-6-12 Osmocote without Micromax, followed by the nitrogen only Osmocote and Micromax. By far the poorest seedlings were with the Nitrogen only Osmocote and no micronutrients. The difference in tree seedling quality was distinctly better with the 18-6-12 Osmocote compared to nitrogen only, with or without the micronutrients. Clearly, excess nitrogen proportionate to other nutrients is undesirable. I should also note that no deficiency symptoms were visible on any of the seedlings during the study.

Because nitrogen is mobile in the mix or soil, I much prefer slow-release fertilizers to liquids. Ideally, a small amount of nitrogen would be available continually with the slow-release, thereby avoiding the feast or famine of liquid nitrogen applications. Also keep in mind that nitrate nitrogen is preferred and ammoniacal (NH4) sources of nitrogen are generally not helpful and may be harmful to young germinating seeds and seedlings. Osmocote 18-6-12 and some formulations of Nutricote and polyon contain mostly nitrate nitrogen and work well for seedlings. On the other hand, urea formaldehyde, coated urea, and IBDU release ammoniacal nitrogen and should be avoided at the seed germination and seedling stage of development. However, once the seedlings are three to four months old, source of nitrogen is much less important.

Figure 2. These loblolly pine seedlings have been too close together for too long and will require staking once removed from the plug trays. The narrow confines of the plug tray also contribute to the vertical stretch of the seedlings. Also note that there is virtually no taper to the stems.

Figure 3. When limbs are removed from the tree trunk, the increase in trunk diameter is dependent on energy from the crown. The stem just above the soil line receives no more than just below the crown so no stem taper develops (left). On the other hand if the upper portion of the trunk is allowed to retain side branches, the trunk grows in response to energy from the crown plus energy from the side branches (center). When the limbs are left on the entire trunk, maximum trunk taper develops since energy is provided throughout the vertical axis (right).

Figure 4. A tree grown without staking in the nursery and with lower limbs in place develops good stem taper. When wind stress occurs, the entire stem flexes (left). Staked trees with little taper experience more stress at the soil line when planted

and not staked, or when the stakes are removed (right).

My first work with quart milk cartons, with or without the bottom removed, began in 1968. Clearly the root development was better with the bottom removed. Over the years we studied various aspects of nutrition, mixes, timing, spacing, and other factors. Most of the studies resulting in improved rates of top growth compared to previous work. Additional top growth came with a price; we found ourselves doing more and more staking unless the seedlings were transplanted at a relative small size.

With time, I began to investigate the root development of larger trees that had been started in milk cartons and other bottomless containers. I was not pleased with the root systems. Containers with the capacity to air-prune developing roots ONLY at the bottom, stimulate root growth downward with few or no horizontal roots. The results of excavating various trees after five years or more of growth in the field showed that the roots grew downward into a zone less and less favorable for root functions and root branching. When trees grown this way were dug with a tree spade and placed on the ground, often the 12” to 14” or more of soil at the top would fall away as there were no roots present except for what had been the original milk carton. The roots only extended downward.

In 1986 I began exploring ways to stimulate root branching at or near the base of the stem. After making assorted models with various configurations and watching their influence on root branching, it was clear that for best growth and quality of both tops and roots, air-root-pruning was necessary on the sides of the containers as well as the bottom.

The elm seedlings in Figure 5 were grown for 43 days in a bottomless, sleeve container (like a milk carton) compared to the newly designed Rootmaker, and then was transplanted into 3-gallon containers for 10 days then removed for inspection. With air pruning on the bottom only, the roots grew downward and into the least well-aerated part of the larger container. With the Rootmaker, roots grew in all directions including downward. It also became clear that the more the root system was forced to branch, the better the top growth AND the greater the stem diameter development and taper. Even with the new Rootmaker containers that improved the root system, timing remains an important factor. Seedlings left in these containers beyond the optimum, would become crowded and run out of space causing an increase in height and ultimately staking would again be required.

Staking can be eliminated only if all of the factors contributing to stem and root development are acknowledged and monitored closely. The Problem: The more lower limbs are pruned, the greater the vertical growth; the more you stake, the more the vertical growth; the more nitrogen you apply, the more the vertical growth; the more the plants are crowded, the more the vertical growth; and the more the roots are restricted, the more the vertical growth. The Solution: Plant seeds in Rootmaker containers that stimulate secondary root production at the sides as well as the bottom of the containers, maintain proper spacing for top development, transplant timely to avoid root restrictions, leave the lower limbs on as long as is practical, grow the plants out of door where wind can cause flexing, use modest levels of nitrogen in proportion to other nutrients and you can throw the stakes away and save a huge amount on labor while developing trees with both superior tops and roots. Remember, it is not how many seeds you plant or plants you grow, but how many you sell, that is important.

Figure 5. Root development of elm seedlings following transplanting from a milk carton/bottomless plastic sleeve container (left) vs. the Rootmaker container, which air-prunes on the sides as well as the bottom (right). Note the absence of horizontal support roots with the plastic sleeve compared to the root development in all directions from the Rootmaker.

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