# Hardwood tree root systems

R.C. SCHULTZ and J.R. THOMPSON
Professor and Research Assistant
Department of Forestry, Iowa State University
Ames, Iowa 50011, U.S.A.

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**Abstract**

The mature tree root system provides infcrmation on the target root system that bareroot seedlings should have before they are field planted. This root system should consist of more than six permanent first-order lateral roots if the outplanted seedling is expected to survive and become a competitive grower. Nursery practices such as bed density control and under-cutting can produce more permanent first-order laterals on seedlings. Third year field results for red oak and black walnut plantations established by the Hardwood Nursery Cooperative support this model.

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Résumé

*Le systeme racinaire des feuillus nobles.*
*L'etude du systeme racinaire des feuillus nobles d'age mur constitue une information utile pour definir* le *systeme racinaire ideal que les plants* a *racines rues doivent posseder au moment de leur mise en terre. Le systeme racinaire devrait comporter plus de six racines laterales permanentes du premier ordre si l'on souhaite que les semis plantes survivent et deviennent competitifs. Les pratiques culturales en pepiniere, comme par exemple la rêgie de la densite du lit de germination et le cernage, peuventprovoquer l'apparition de racines laterales permanentes du premier ordre plus nombreuses sur les plants. Les resultats de trois annees sur le terrain dans des plantations de chene rouge et de noyer noir realisees par la* Hardwood Nursery Conference *confirment ce modele.*

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## Introduction

Nursery managers are constantly trying to improve the quality of seedlings they grow to assure better field survival and early growth. Because of the many uncontrolled factors involved in bare-root seedling production, it is imperative that nursery managers have a clear idea cf the target seedling that they are trying to produce. In the past the target seedling has been defined primarily by its above-ground characteristics with little attention paid to the root system. However, for a seedling to be successful in the field, it must have both a well developed root and a well developed shoot system. Little work has been done to quantify the roots necessary for seedling establishment because it is difficult to study undisturbed roots. This is unfortunate because it is the root system which is most heavily impacted by the cultural practices of bare-root production. In this paper we will define target seedlings by first describing the characteristics of a mature tree root system, and by summarizing the results of cultural practices that have been used by the Hardwood Nursery Cooperative to improve the root systems of three hardwood species.

## The Mature Hardwood Tree Root System

The major functions of a root system are to provide access to water and nutrients and to provide support anchorage for the tree. These functions are accomplished using limited photosynthates, by the spatial distribution of the roots, the longevity of the non-woody roots, root dormancy, and the presence of root hairs or mycorrhizae. The mature root system of individuals of many species can be divided into a central core of roots with a radius of about two meters. Within this core are found four to ten large laterals that radiate away from the base of the tree in all directions. These roots have large diameters near the base of the tree but that radius rapidly decreases to four or fewer centimeters close to the two meter distance from the base. It is within this two meter core that the most extensive grafting occurs and where most of the downward penetration of roots occurs.

Beyond the two meter central core the large first-order laterals decrease in size and primarily grow parallel to and within forty centimeters of the soil surface. Permanent second-order laterals are produced at intervals of twenty-five to one hundred centimeters along the first-order laterals. It is from these second-order roots that most of the non-woody roots are produced. Non-woody roots are usually less than one millimeter in diameter and vary in length from one centimeter to two meters in length. These roots lack any strong geotropic response and can be found growing in any direction. The non-woody roots branch often and fill the soil areas between the permanent wocdy roots. The large number of these non-woody roots produce an incredible number of root tips where much of the water and nutrient uptake occur. It has been conservatively estimated that a mature red oak tree has as many as 500 million root tips. Many of these tips are mycorrhizal (the symbiotic association of fungi and root tips). There are two major kinds of mycorrhizae (endo- and ectomycorrhizae) that can form, but within one tree species there usually is only one. The mycorrhizae are important for the tree because they greatly increase the absorbing surface area of the root system. For example, from 200 to 2,000 hyphae can radiate up to two meters from one mycorrhiza. Each hypha can have as many as 120 lateral hyphae. It has been estimated that the presence of mycorrhizae can increase the surface area of the root system by one hundred times.

The biomass of the root system accounts for fifteen to twenty-five percent of the total tree biomass. Mycorrhizae can add another eight percent to that figure. There is a massive turn-over within this biomass, primarily in the fine, non-woody portion. From thirty to eighty-five percent of the fine roots die annually. This turnover is a result of age and extensive grazing by soil organisms. The massive turn-over can be greater than the biomass of leaves that are shed each year from the stem. It has been estimated that the tree uses sixty to seventy percent of its annual carbon in fine root production.

In summary, the tree root system can be described as being extensive and radiating as much as one to two tree heights away from the base of the tree with the majority of the roots located in the upper forty centimeters. The four to ten large first-order lateral roots with their many second- and higher-order roots provide the sites for the non-woody roots. These roots support millions of tips that as a symbiotic association provide the large absorbing surface needed to provide water and nutrients to the rest of the plant. These root tips are short-lived and require a large amount of annual carbon to be dedicated for renewal. Understanding the dynamic nature of the root system will provide a better picture of a target bare-root hardwood seedling.

## Nursery Implications

The structure of the mature root system indicates that seedlings should also have a large support system of permanent first-order laterals from which the short-lived non-woody roots can grow. The larger the support system is, the more non-woody roots can be supported and the more efficient the seedling should be in acquiring water and nutrients. Thus seedlings shipped from the nursery should have a support system with a minimum number of permanent first-order lateral roots. Also, nursery cultural practices should be used to stimulate first-order lateral root production, and less emphasis should be placed on the number of fine or non-woody roots that are present on a seedling when it is shipped. Lifting, shipping, and handling in the field before planting will kill most of the fine non-woody roots which normally only live for one season.

As in nature, root systems respond to injury by producing new roots. This trait can be exploited by undercutting seedlings to produce more permanent first-order roots in the liftable depth of the seedling root system. Undercutting is the practice of drawing a sharp, and preferably reciprocating, blade horizontally through the soil at a given depth below the root collar at a time other than lifting. In addition, practices such as density control and proper nutrition and watering can be used to stimulate new root production. Attention should also be paid to the role of genetics in controlling root system characteristics of seedlings. The availability of improved hardwood seeds lags behind that of conifers though, so that, at least for the present, most of the improvement of seedling root systems should come from cultural practices.

The Hardwood Nursery Cooperative, made up of the state forest nurseries in Illinois, Indiana, Iowa, Missouri, Ohio, and Wisconsin, has been testing ways of increasing the number of permanent first-order laterals on oak and walnut seedlings. It appears that roots must be a minimum of one millimeter in diameter and show lignification to be considered permanent lateral roots. These roots provide the sites for non-woody root initiation. Reducing bed density and using properly timed undercutting have been shown to increase the number of permanent first-order laterals on these seedlings.

Reducing bed density to 60 seedlings per square meter has been found to produce a large number of seedlings with a minimum of five to six permanent first-order laterals on red oak and seven to eight on black walnut. Increasing bed density above that level decreases root number faster than it reduces shoot size. Such seedlings with good shoots but deficient roots respond poorly in the field.

Undercutting provides another cultural practice that can increase first-order lateral root numbers. The rationale for undercutting can be found in nature. Naturally growing root systems are constantly injured as they grow through the soil. Replacement roots are rapidly produced because the wounded area acts as a carbon sink, attracting sugars from elsewhere in the plant. As a result, three to six wound roots develop rapidly at or just above the wound. The same type of roots are produced from the lifting wound after the seedling is field planted, and act as permanent roots produced from the taproot. By undercutting before lifting, these permanent roots can be produced to provide more sites for non-woody root production. There is an added advantage to undercutting oak and walnut. Both of these seedlings have the ability to grow radicles to depths of 45 to 60 cm, well below the 25 to 30 cm depth at which the seedlings are lifted. If the radicles are undercut at 15 to 20 cm, the new wound roots produced will remain with the seedling when it is lifted and will provide additional sites for non-woody root production. These roots have been observed after field planting and appear to function like laterals that initiate from the radicle above the undercutting wound.

Undercutting of red oak should take place after the second or third shoot flush has been completed on seventy or eighty percent of the seedlings in the bed. Ideally the undercutting should occur when the last formed leaves have expanded approximately three fourths their final size. It is at this point when large quantities of carbon start moving down into the root system. To be most effective this carbon should be captured in the newly forming wound roots rather than in the continually elongating taproot. For black walnut the undercutting should take place when the taproot at 15 cm is approximately 0.6 cm in diameter. In the central United States this occurs about the end of June to the middle of July. If the black walnut seedlings are growing too rapidly, multiple undercuts can be made without adversely reducing stem caliper.

It is critical that the undercut is made above the lifting depth. It is difficult to accurately control the depth of the blade because of uneven bed heights, different soil densities, etc. It is therefore recommended that undercutting be done at fifteen centimeters and that lifting be done at twenty-five to thirty centimeters.

Weather is another important consideration for successful undercutting. In June and July it is normally hot and often dry. It is therefore important to irrigate before and immediately after undercutting has been completed. It might be most beneficial to the plant if undercutting was done late in the afternoon so that rehydration of the seedling could take place overnight. If undercutting is done early in the morning the irrigated seedling still has to endure the hottest part of the day. Realistically, a compromise may have to be made if the employee work day is limited. It is not advisable to undercut when the temperature is above 32° C.

As mentioned at the outset, the members of the Hardwood Nursery Cooperative have developed these guidelines for producing red oak and black walnut that have enhanced numbers of permanent first-order lateral roots. It is probable that most of the same principals will hold for many of the hardwoods.

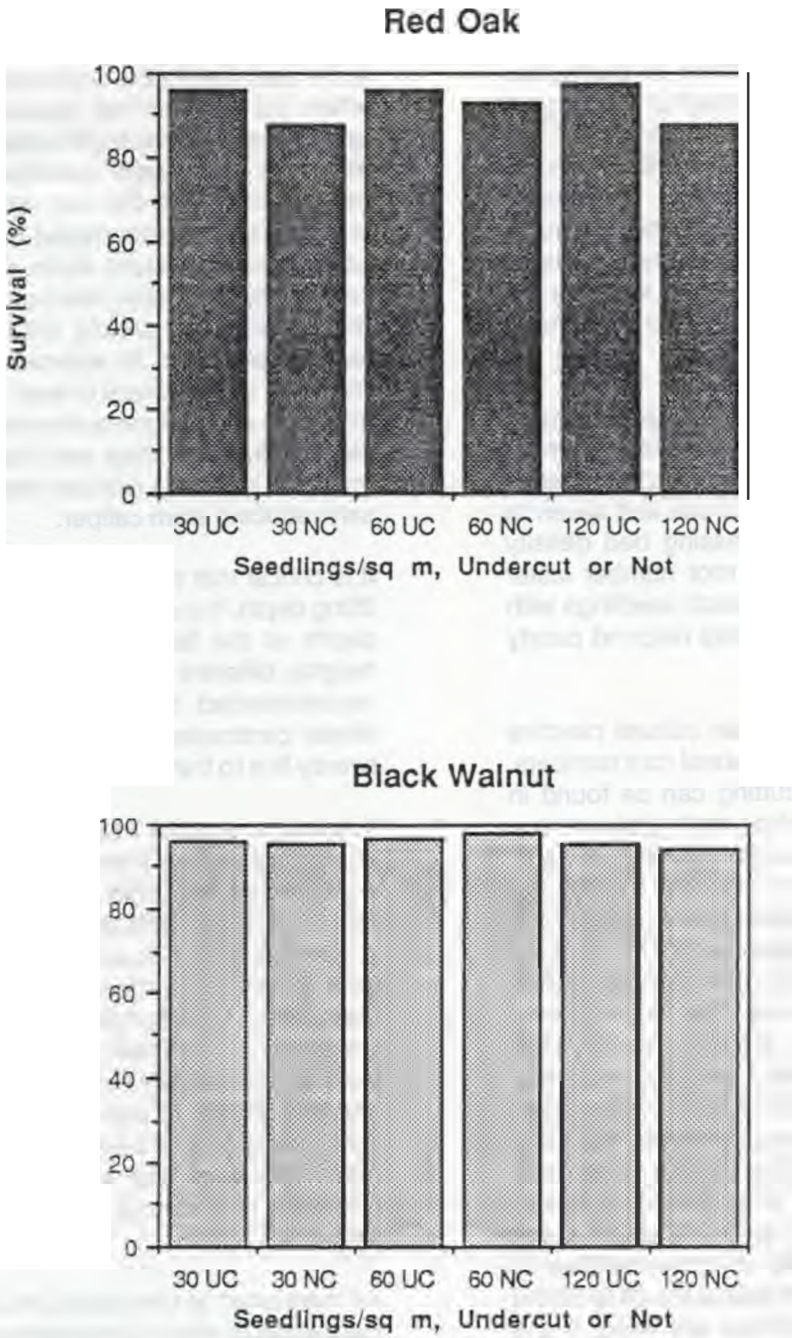



Figure 1. Survival after three growing seasons in the field of 1-0 bareroot red oak and black walnut seedlings grown at three different densities and undercut (UC) or not cut (NC).

## Materials and methods

Studies were established in each state, except Wisconsin, during the Spring of 1987, to test the effect of bed density and undercutting on the production of first-order roots. The study was laid out as a split-plot design with 4 to 6 blocks, depending on the nursery. Two or three blocks were established in each of two 145-m-long beds. Each block was divided in half to form whole plots that were either undercut or not undercut. Each whole plot was divided into three subplots to which three densities were randomly assigned. Densities cf 32 $m^{-2}$, 64 $m^{-2}$, and 128 $m^{-2}$ were used. These densities were established by thinning existing beds by laying templates over the bed and pulling or cutting excess seedlings from the plots. When two seedlings were very close to one another, the one to the left of the worker was always removed to minimize size bias. Half of the whole plots were undercut when the taproots at 15 cm depth were from 0.6 cm to 1.3 cm in diameter. The plots received the same fertilizer, weeding, and irrigation treatments as was customary for each nursery.

Seedlings at each nursery were lifted during the Spring of 1988, and 40 randomly selected seedlings from each subplot (160-240 seedlings per treatment) were measured. Height and root collar diameter were measured on each seedling. The number of permanent first-order lateral roots and the number of wound roots also were counted. To be counted the roots had to be one millimeter in diameter and lignified. Wound roots were identified as roots arising at or just above the wound created by the undercutting blade.

The lifted seedlings were field planted during the spring of 1988 in completely randomized designs. Each seedling has been mapped and measured each of the last three growing seasons. Seedling survival, height and diameter five centimeters above the ground have been measured at the end of each season. The growth data can be directly related to the root number of each seedling.

## Results and discussion

Because of limited space only the results from Illinois will be presented. The general responses in each of the other states were similar. The data after three growing seasons, for survival, total height, height increment, total diameter, and diameter increment are presented for each of the density and undercutting treatments, and as a function of the total number of roots for both red oak and black walnut.

Figure 1 shows survival data at the end of the third growing season. The data for red oak suggest that undercut (UC) seedlings had slightly better survival than than those that were not undercut (NC). The same trends do not exist for black walnut. The real key to survival can be seen in Figure 2. This figure clearly shows that seedlings with fewer than five roots had lower survival rates. The differences are greatest for the red oak. In comparing Figures 1 and 2 it becomes obvious that the density and undercutting treatments had indirect effects on survival through their effects on root numbers. Previously shown figures (SCHULTZ and THOMPSON, 1990) demonstrate that decreasing density and undercutting increase the number of seedlings with more lateral roots.

Figure 3 shows the differences in total height after the third growing season for the density and undercut treatments. It demonstrates that undercut seedlings were generally shorter than those that were not undercut. Density did not seem to influence total height after three growing seasons. If total height is reviewed in relation to the total number of roots per seedling, it becomes obvious, once again, that seedlings with fewer roots were shorter (Figure 4). For walnut there was a constant increase in height as root numbers increased to ten. Once a walnut seedling had ten roots it seemed to have reached its maximum height. For red oak total height continued to increase with increasing numbers of roots, with the greatest increase occurring between two and five roots.

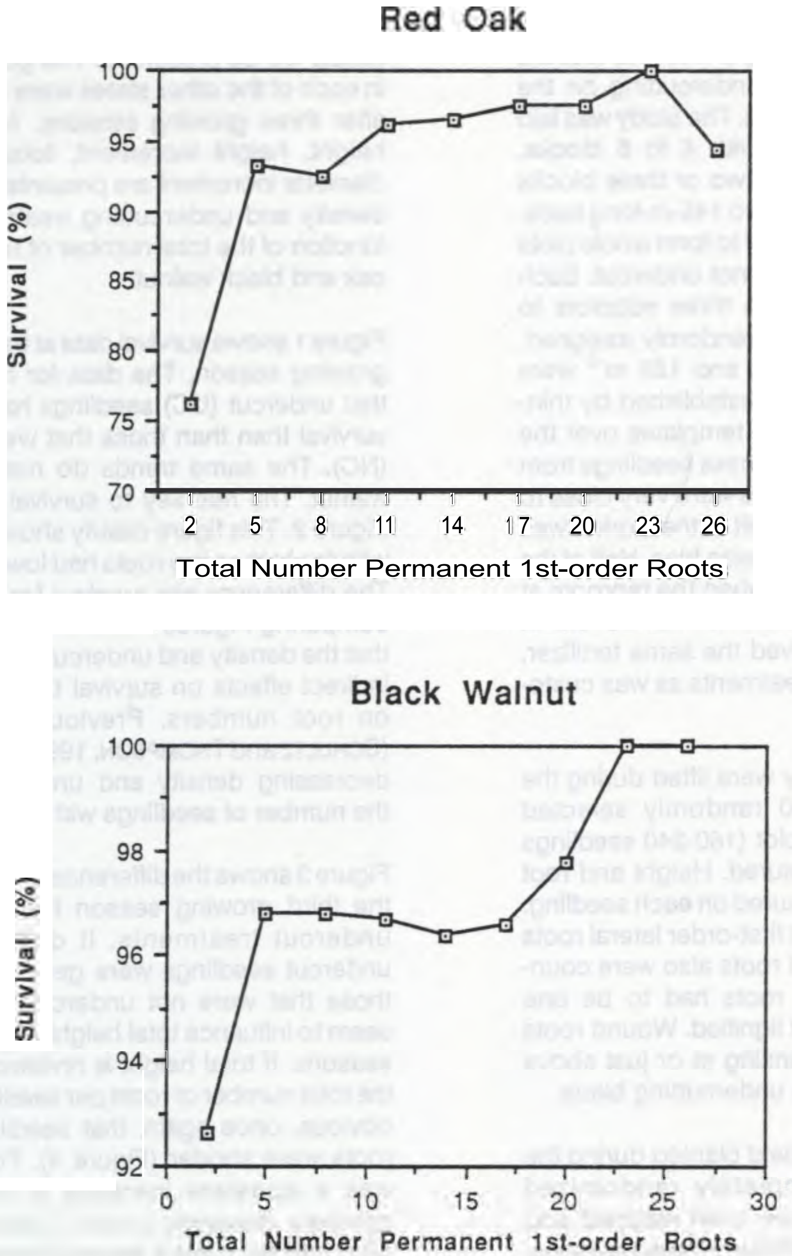
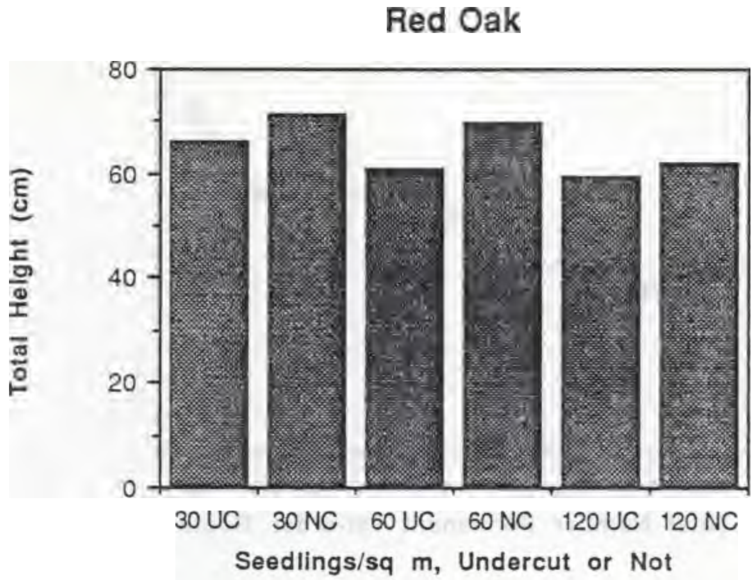



Figure 2. Survival of 1-0 bareroot red oak and black walnut seedlings, after three growing seasons in the field, compared to the total number of permanent first-order lateral roots on the seedlings when they were planted.



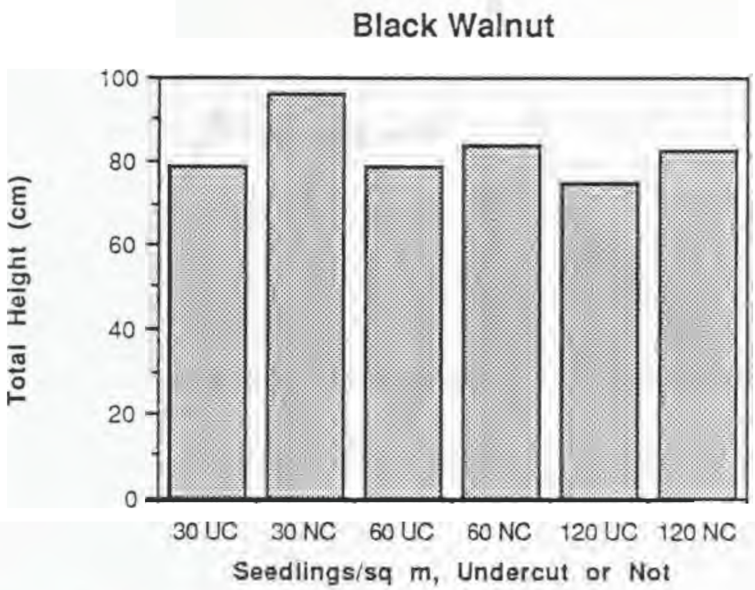
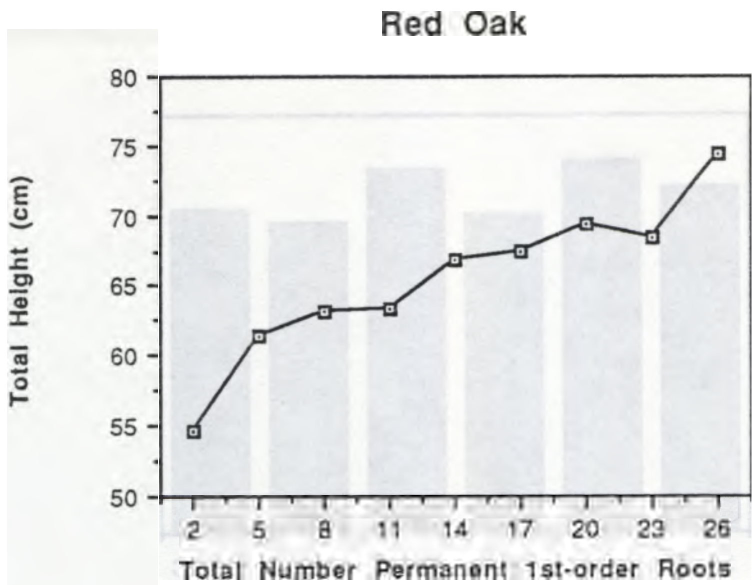




Figure 3. Total height after three growing seasons in the field of 1-0 bareroot red oak and black walnut seedlings grown at three different densities and undercut (UC) or not cut (NC).



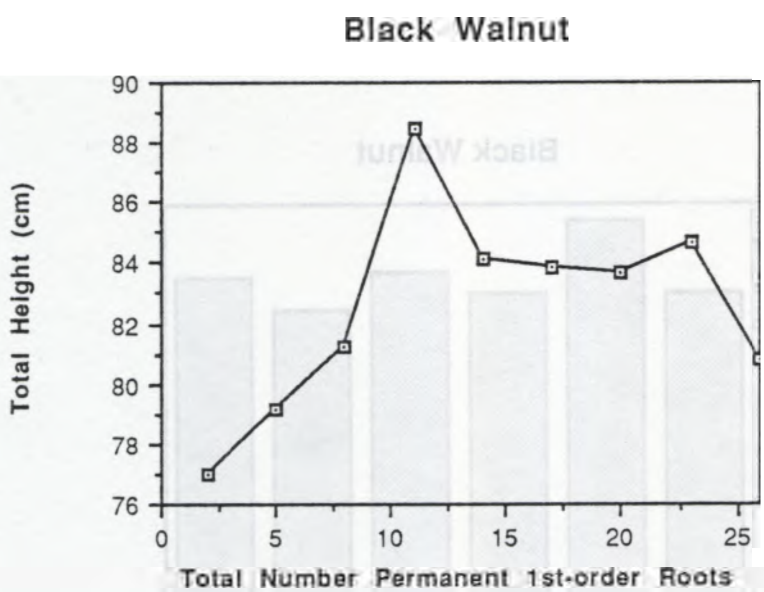




Figure 4. Total height of 1-0 bareroot red oak and black walnut seedlings, after three growing seasons in the field, compared to the total number of permanent first-order lateral roots on the seedlings when they were planted.

Figures 5 and 6 present height increments over the past three growing seasons. In all cases the undercut seedlings have shown a greater height growth increment than those that were not undercut. The difference is especially pronounced for black walnut. For both species seedlings with ten or more roots showed greater incremental growth in height over the three year period. With each additional permanent first-order lateral root at the time of planting the height growth increment continued to rise.

These height increment results have strong implications for nursery managers and tree planters. It is often suggested that larger seedlings are needed for good field survival and growth. However, planters don't like to plant the large seedlings. This study suggests that shorter seedlings can be effectively used as long as they have large numbers of lateral roots. Comparing figures 2 and 4 it is probable that within the next growing season or two, the shorter seedlings with the larger numbers of roots will overtake the initially taller seedlings that had fewer roots at planting time.

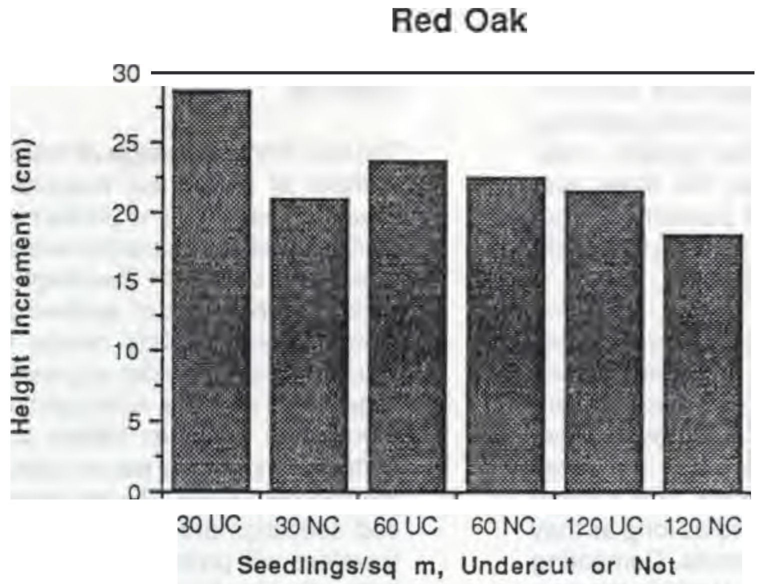
Figures 7 and 8 show the effect of density, undercutting, and number of roots on the diameter of the seedlings at the end of the third growing season. Although the differences are not great, the undercut seedlings have a larger diameter than those that were not undercut. The differences are most pronounced at the highest density. Figure 7 clearly shows that as the number of roots increases the diameter of the seedlings at the end of the third growing season also increases. The slope of the curves for both the oak and walnut increase constantly with increasing root numbers.

Figures 9 and 10 demonstrate the changes in diameter increment over the three growing seasons. In all cases there is a clear advantage of the undercut seedlings over those that were not undercut. The increase in diameter can be tied to increased numbers of roots in the red oak, but not in the black walnut. For the red oak the increase in diameter over the three growing seasons is very dramatic as the number of roots per seedling increases. For black walnut there seems to be little difference in the effect of root number on diameter growth because other factors could be responsible. The undercut seedlings were smaller and therefore had a higher root/shoot balance, which could explain the increased diameter growth for undercut seedlings.

The take-home message of these data is that the number of permanent first-order roots that a seedling has when it is planted in the field has a significant effect on performance during the first three years of growth. Seedlings with more roots generally show better survival and height and diameter growth. This means that it is these seedlings that are most aggressive in becoming established on a site. Although the seedlings with more roots are often initially shorter, they are better balanced and put on rapid growth during the first three years. The shorter but better balanced seedlings are actually easier to plant and therefore will probably be better planted. With better planting they will also grow faster.

The effect of nursery cultural practices is clear. As density increases, the seedlings become smaller both in height and diameter. If seedlings are undercut they are also generally smaller than their non-cut counterparts. However, the undercut seedlings have a significantly larger number of permanent first-order lateral roots. The larger number of roots, along with the smaller height and diameter, produce a better balanced seedling that is capable of faster growth and better survival in the field during the first three years that they have been measured.

The data suggest that seedlings of red oak with fewer than five or six permanent first-order laterals should not be planted, regardless of their initial size. For black walnut, seven or eight roots probably are the minimum number needed for a successful seedling. In both species the more initial roots above the threshold level, the better the seedlings will survive and grow. Anything that can be done culturally in the nursery to improve root number will pay off in the long run. Field observations indicate that the growth differences seen between seedlings will be amplified over the next few years. We expect that undercut seedlings with the larger numbers cf lateral roots will be superior with respect to all parameters measured, and will continue to out perform those with fewer roots.



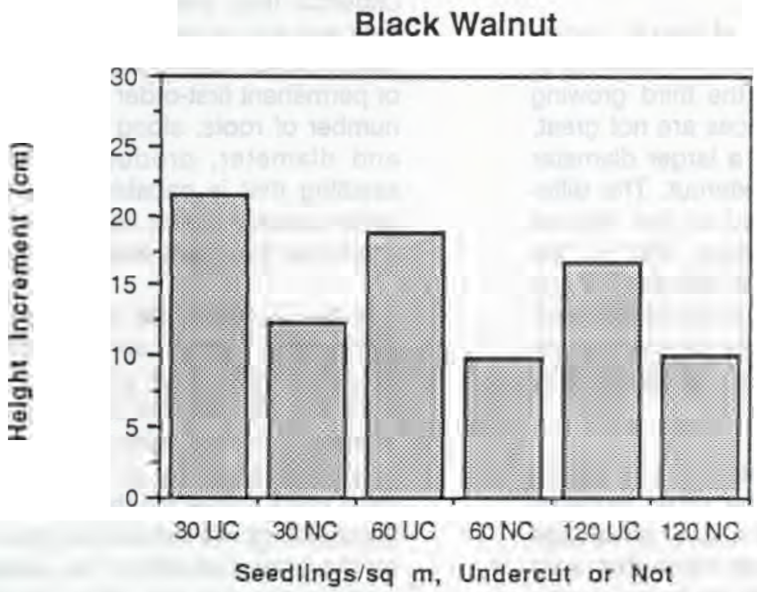




Figure 5. Height increment after three growing seasons in the field of 1-0 bareroot red oak and black walnut seedlings grown at three different densities and undercut (UC) or not cut (NC).

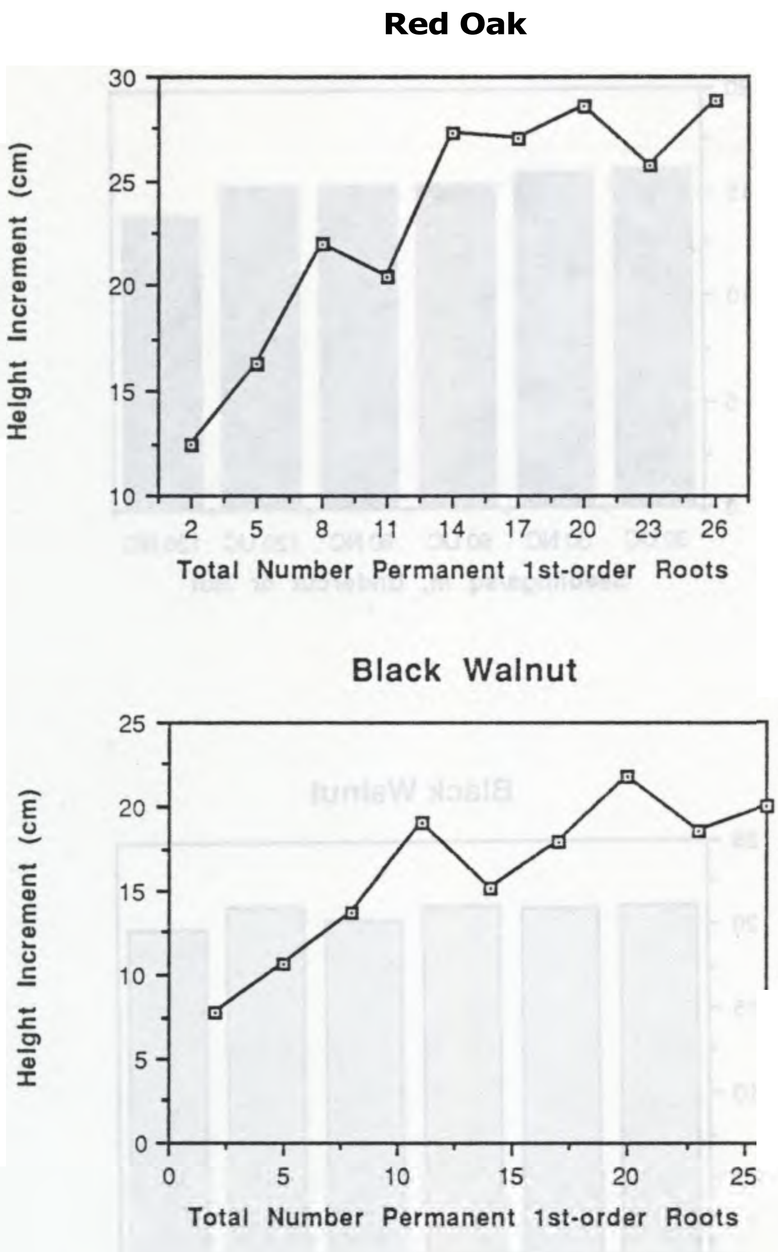
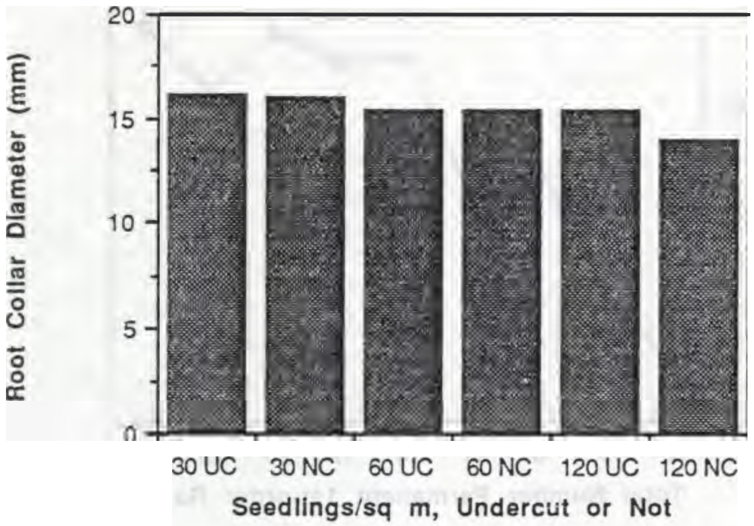
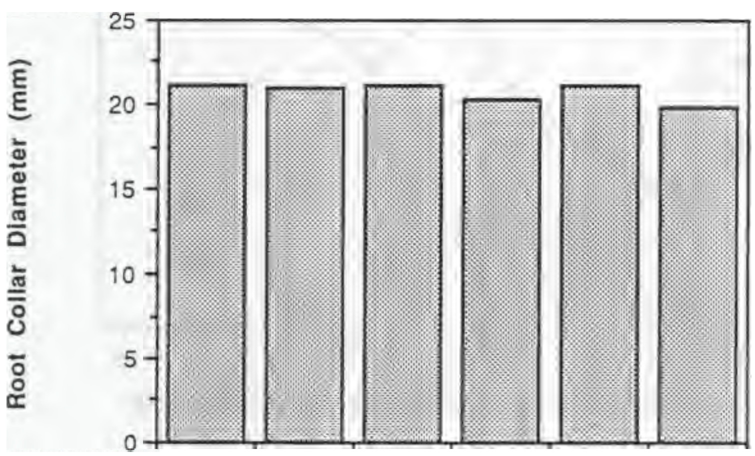



Figure 6. Height increment of 1-0 bareroot red oak and black walnut seedlings, after three growing seasons in the field, compared to the total number of permanent first-order lateral roots on the seedlings when they were planted.

**Red Oak**



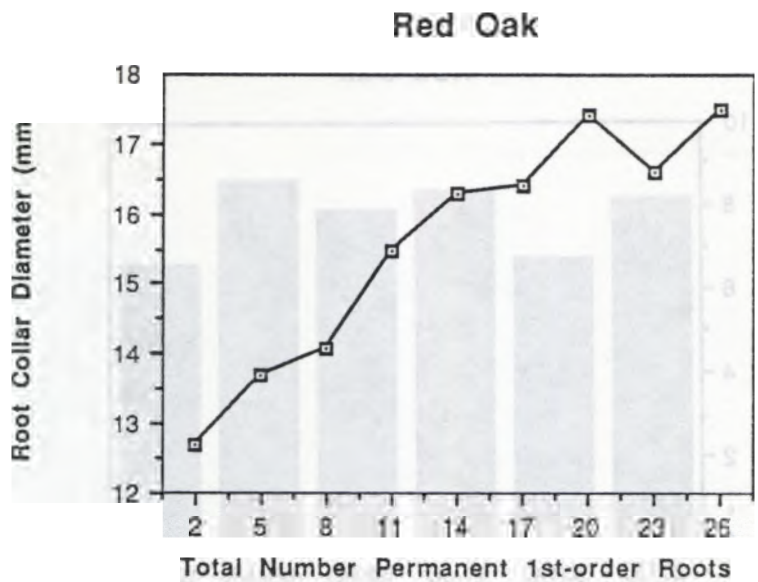

Black Walnut




3000 30 NC 6000 60 NC 12000 120 NC

Seedlings/sq m, Undercut or Not

Figure 7. Roct collar diameter after three growing seasons in the field of 1-0 bareroot red oak and black walnut seedlings grown at three different densities and undercut (UC) or not cut (NC).



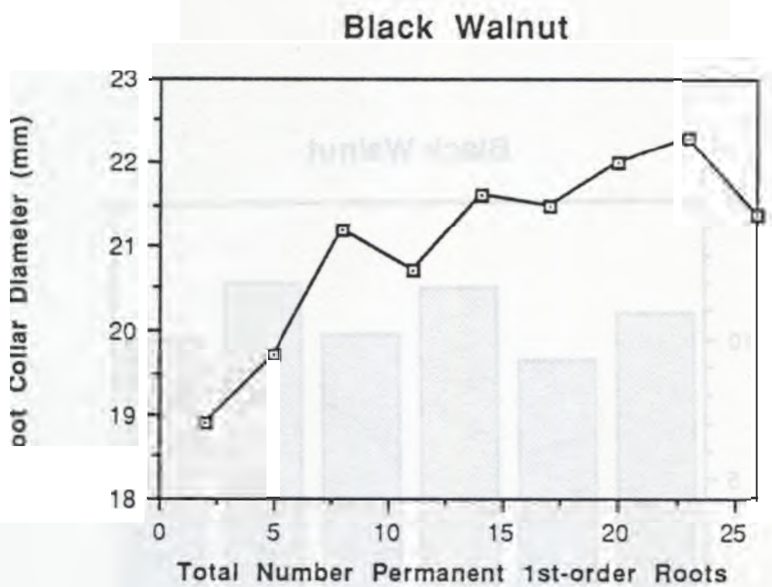




Figure 8. Root collar diameter of 1-0 bareroot red oak and black walnut seedlings, after three growing seasons in the field, compared to the total number of permanent first-order lateral roots on the seedlings when they were planted.

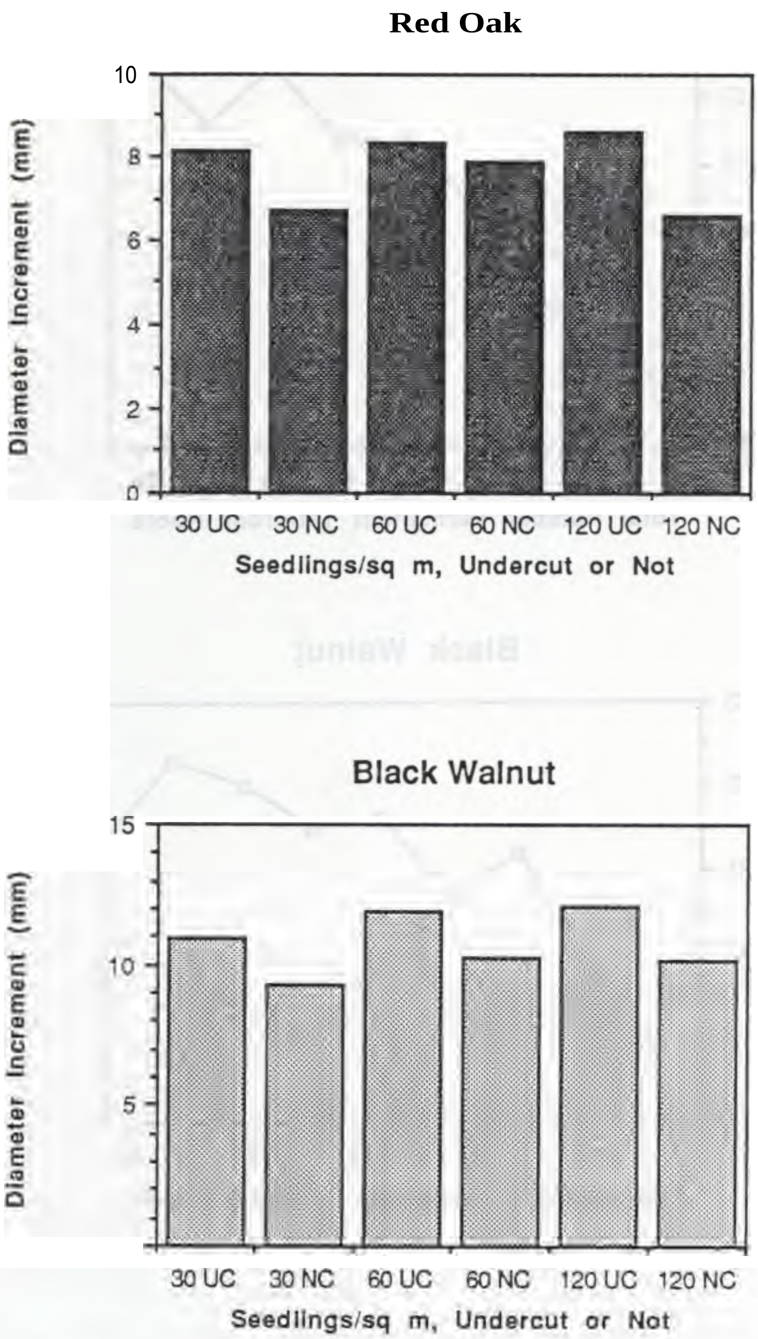
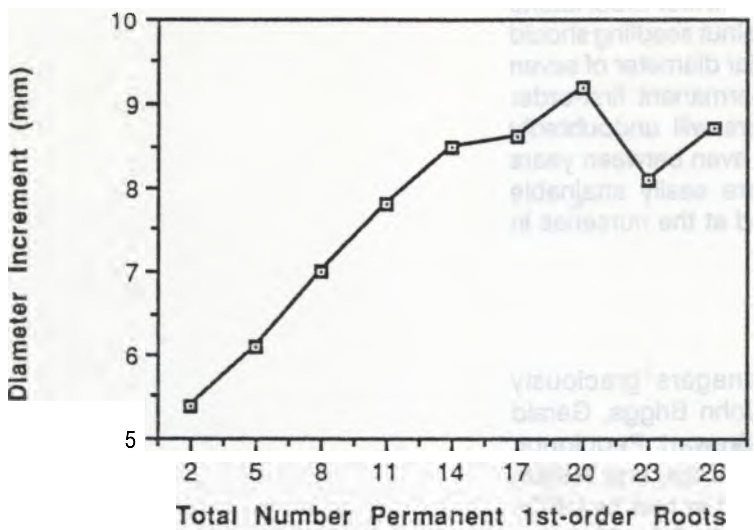



Figure 9. Diameter increment after three growing seasons in the field of 1-0 bareroot red oak and black walnut seedlings grown at three different densities and undercut (UC) or not cut (NC).

**Red Oak**




**Black Walnut**

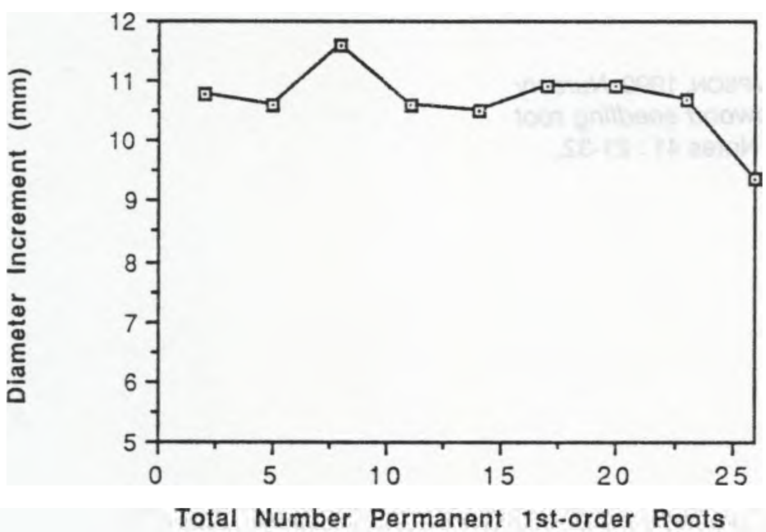



Figure 10. Diameter increment of 1-0 bareroot red oak and black walnut seedlings, after three growing seasons in the field, compared to the total number of permanent first-order lateral roots on the seedlings when they were planted.

The target 1-0 seedlings for red oak should be close 35 cm tall, with a root collar diameter of six mm, and six or more permanent first-order lateral roots. The target 1-0 black walnut seedling should be 45 cm tall, with a root collar diameter of seven mm, and seven or more permanent first-order lateral roots. These numbers will undoubtedly vary between nurseries and even between years but we believe that they are easily attainable under most conditions found at the nurseries in the central United States.

## Acknowledgements

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