Hardwood Seedling Root Morphology and Nursery Practices

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Abstract

Root system morphology of seedlings is a major determinant of seedling success in the field. To identify the type of root system that is needed for seedlings the mature tree root system should be studied. Mature root system morphology suggests that trees need between 4-11 major lateral roots to survive and grow. A five-state cooperative has been studying the influence of nursery cultural practices on seedling root systems to provide another grading criterion for identifying target seedlings. The work of the cooperative suggests that successful red and white oak seedlings should have at least 5-6 first order lateral roots (FOLR) larger than 1 mm in diameter at the base (proximal to the taproot). Black walnut seedlings should have at least 7-8 FOLR. Controlling bed densities to an average of 64 seedlings/sq m will increase the proportion of seedlings produced with the requisite minimum number of roots. Undercutting can also be used to increase the number of FOLR on seedlings which may not be genetically disposed to do so. Although in the long run this may not be desirable, it is presently necessary due to insufficient quantities of improved seed for most hardwood species. Fourth-year field results support the hypothesis that hardwood seedlings with greater numbers of FOLR are more successful and competitive after outplanting.

Introduction

The goal of bare-root nursery managers is to produce high quality seedlings which can tolerate the lifting, handling, and planting processes, not only to survive but to grow competitively in the field. This goal is a challenging one to attain. No two nurseries are alike and within nursery variations in soils and microclimate may be as great as those between nurseries. Variability of annual weather and seed crops produces uncontrolled situations that may dramatically affect the quality of the crops. The aim of nursery cultural practices is to reduce some of this variability.

However, an even larger problem still seems to confront most of the industry. That is the problem of the target seedling. There are many standards used in the industry but most of these are not tied to long-term field performance but rather to the ease of handling in the nursery and in the field at planting time. Many of the standards are the same for a range of species because individual species have not been studied, and most consider only above-ground characteristics.

Seedling grading has been controversial because no scientifically based procedure has been developed for identifying which seedlings in a nursery will be the most competitive in the field (Kormanik 1989). Kormanik believes that this failure has

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led to the current practice of controlling seedling growth to produce beds of uniform-appearing individual seedlings regardless of their biological potential to perform after field planting. Seedling variation should be expressed in the nursery bed and grading procedures should be developed to identify target seedlings which will perform well in the field.

The target seedling is one with structural and physiological attributes which can be quantitatively tied to excellent field performance (Rose et al. 1990). In the past only height and diameter have been used as structural parameters to identify target seedlings. However, recent work with roots suggests that root system structure should also be included as one of the structural criteria (Kormanik 1986, 1988, 1989; Schultz 1989; Schultz and Thompson 1990, 1991). To develop a model for a successful seedling root system, the root system of mature trees should first be examined.

The Mature Hardwood Root System

Tree root and shoot systems exist in two very different environments. Normally a tree is fixed in one location for its entire life. Its shoot is exposed to the gaseous environment of the atmosphere. It is battered by strong winds mixed with rain, snow, or hail, scorched by the sun, or frozen by arctic air masses. The sun provides energy for photosynthesis but also delivers a large heat load that must be dissipated. The tree has evolved a rapidly growing stem that allows the plant to compete effectively for direct sunlight. This large stem requires large quantities of carbon to grow, and this carbon comes from the massive crown of branches and leaves that the stem supports. Such a large weight must be strongly anchored in the soil if the tree is to remain upright and competitive.

The root system grows in a very different environment. That environment is a porous medium containing approximately 45% solids, 5% organic matter, and 50% pore space by volume, half of which is ideally filled with air. The temperature extremes in the soil enivronment are not as great as in the atmosphere, nor do they change as rapidly. The soil is a harsh environment, however, for a succulent root tip required to work its way through pores that may be very small, filled completely with water instead of partially with air, and infested by a myriad of soil organisms constantly feeding on the carbon-rich primary root and its exudates. The response of root systems to this environment is a plastic one.

The root system provides water and nutrients to the shoot, which in part allows the return of the carbon-rich sugars needed for root growth. Roots, which are constantly stretched and contracted when the top sways in the wind, anchor the large, heavy top in the soil and keep it upright. Finally, the root system is the source of plant growth regulators, which move through the plant in very small quantities and act as signals for shoot and root activity. All of these major functions of tree root systems are accomplished using limited photosynthates by the spatial distribution of the roots, the longevity of non-woody roots, root dormancy, and the presence of mycorrhizae.

The root systems of many species respond similarily to a given soil environment. In deep, well-aerated soils most species will develop deeper root systems than in shallow soils. Because of similar responses 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, and beyond two meters a more diffuse zone of roots extending outward from the core. Within the central core 3-11 large laterals that radiate away from the base of the tree in all directions are usually present . These roots have large diameters near the base of the shoot, but their diameters rapidly decrease to four or less centimeters as the two-meter distance from the shoot is approached. It is within this two-meter core that the most extensive grafting occurs and where most of the downward penetration of roots occurs (Lyford 1980, Gilman 1990).

Outside the two-meter central core the large first-order laterals have decreased 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 responses and can be found growing in any direction. The non-woody roots branch often and fill the soil areas between the permanent woody 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 - 2,000 hyphae can radiate up to two meters from one mycorrhizae. Each hypha can have as many as 120 lateral hypha. In all, it has been estimated that the presence of mycorrhizae can increase the surface area of the root system up to 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 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 turn-over is a result of old age and extensive grazing by soil organisms. The massive turn-over of roots 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 for 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. Four to ten large first-order lateral roots with their many second- and higher-order roots provide the sites for growth of 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 the needs of a target bare-root hardwood seedling.

Nursery Implications

The structure of the mature root system suggests that seedlings should also have a large support system of first-order laterals roots (FOLR) from which the short-lived non-woody roots can grow. A small number of the FOLR on developing seedlings show rapid secondary thickening which is discernible very early in development and which form the structural root system for the seedling (Coutts 1987; Thompson and Schultz, unpublished).

The larger the support system is, the more non-woody roots can be supported and the more efficient the seedling should be in accessing water and nutrients. This hypothesis suggests that seedlings shipped from the nursery should have a support system with a minimum number of FOLR. It also suggests that nursery cultural practices should stimulate FOLR production and that 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 many of the 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 FOLR in the liftable depth of the seedling root system. This practice reallocates carbohydrate to root growth at the expense of shoot growth and can also be used to control height of seedlings. In addition, practices such as density control and proper nutrition and watering can be used to stimulate new root production and maintain seedlings at the proper size. Attention should also be paid to the role of genetics in controlling root system morphology of seedlings. However, the availability of improved hardwood seeds lags behind that of conifers and suggests that, at least for the present, most of the improvement of seedling root systems should come from cultural practices.

Finally, morphological characteristics of seedlings can be used as grading criteria if it is possible to identify a critical threshold for optimal performance (Duryea, 1985). Shoot morphology, especially height, has not consistently been related to field performance for bare-root hardwood seedlings in the central states. Using root grading as a morphological basis for grading has been proposed as an inexpensive means of identifying potentially successful seedlings before they are outplanted.

Roots which are cut and extracted from their normal environment are exposed to harsh conditions. As a result, lateral roots less than one millimeter in diameter are usually lost. This loss produces an imbalance in shoot/root ratios and reduces the chance for successful field establishment and competitive growth of seedlings. If sufficient large FOLR are not present, the seedlings will not survive, or if they survive, will not grow competitively when field planted. Only FOLR greater than one millimeter in diameter generally survive lifting and outplanting procedures. Recent work (Kormanik and Ruehle 1987, Kormanik 1986, Kormanik and Muse

1986, Perry 1982, Ruehle and Kormanik 1986, Schultz and Thompson 1987, 1989, Schultz 1988) suggests that there is a critical number of first-order laterals needed to ensure survival and growth of seedlings when planted in the field. Forest nurseries in five central states (IA, IL, IN, MO, and OH) established a cooperative to improve cultural control of hardwood seedling quality. This paper will summarize work started five years ago by the cooperative and suggest standards for improving root and shoot characteristics of red oak (*Quercus rubra)*, white oak (*Quercus alba*), and black walnut (*Juglans nigra*) through bed density control and undercutting. (Additional cooperative work has been done with seed-source control, seedling performance in tree shelters, and the fate of fertilizers used for seedling production). White oak will not be discussed in detail. The cooperative used a minimum diameter at the root base proximal to the taproot to define FOLR which would persist through the nursery handling and outplanting process. A large number of field excavations over the past five years indicates that these roots persist in the field.

Bed density and undercutting were identified as two cultural treatments that could directly increase the number of permanent roots. Both shoots and roots of seedlings respond to the space in which they grow. As bed density increases, roots seem to be more restricted than shoots. Good-looking shoots can be produced from deficient root systems in the nursery because "ideal" conditions of moisture and nutrition are easily supplied. However, seedlings with good shoots but deficient roots respond poorly in the field.

Work of the cooperative has determined that reducing bed density to 64 seedlings per square meter is necessary to produce a large proportion of seedlings with a minimum of five to six FOLR on red oak and seven to eight FOLR on black walnut. Prior to reducing densities to the recommended level only 8-20% of the red oak seedlings had six or more FOLR and only 48-56% of the black walnut had eight or more FOLR. Growing seedlings at the recommended bed density increased the proportion of seedlings with the target root numbers to approximately 60% for those not undercut and approximately 80% for those that were undercut for both the red oak and walnut.

The cooperative has also looked at physically manipulating roots in the bed during the growing season. Undercutting is the practice of drawing a blade horizontally through the soil at a given depth below the root collar, at a time other than lifting. The term <u>root pruning</u> has also been used to identify this practice. However, root pruning is better defined as the practice of clipping off excess lengths of roots after the seedling has been lifted from the nursery bed.

The rationale for undercutting can be found in nature. Naturally growing root systems are constantly being injured as they hit rocks in the soil or are subjected to predation by soil organisms. Replacement roots are rapidly produced because the wounded area is a carbon sink attracting sugars from elsewhere in the plant. Consequently, 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 remain as persistent FOLR produced from the taproot (Thompson, 1991).

Undercutting also makes sense in the nursery setting because seedlings such as oak and walnut can produce radicles growing 18-24 inches deep during the first growing season. These seedlings are normally lifted at 10-12 inches, thus cutting off a significant portion of the radicle. If these radicles were cut at six to eight inches and new wound roots were produced, the lifted seedlings would have more potential sites for higher-order root regeneration. Such seedlings would be more competitive in the field. Because undercutting usually stops height growth in favor of root growth, undercut seedlings also have a better shoot/root ratio which can improve their growth in the field.

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 at the end of the leaf linear phase or right at the begining of the lag phase. 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 in height, multiple undercuts can be made without severely reducing stem caliper.

For undercutting to produce the desired effects 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 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.

Because most nurseries cannot presently control the genetic component for many of the hardwood species, undercutting can make seedlings which would naturally produce fewer FOLR more competitive in the field. By stimulating additional root development in the nursery bed the seedlings, which may be shorter than they would have been without undercutting, have more sites for higher order roots to develop. These seedlings will have a better chance for survival and within a few years will catch up and outgrow seedlings which were not undercut.

Methods

In the spring of 1987 studies were established to test the effects of bed density control and undercutting on development of FOLR with diameters greater than 1mm in diameter. Red oak and black walnut seedlings germinating in nursery beds in the spring of 1987 were thinned to $32/m^2$, $64/m^2$, and $112/m^2$ (3, 6, and 12 per ft^2), and undercut or not undercut. Seedlings were undercut when the taproots, at a 15-cm depth, were 0.6 cm to 1.3 cm in diameter. Six replications of each treatment were distributed over a number of nursery beds and received the same fertilizer, weed control, and irrigation treatments as was customary for each nursery.

Two hundred forty seedlings of each treatment were lifted, graded, and field-planted in each state in the spring of 1988. Grading involved measurement of height and diameter, and counting the number of FOLR (> 1 mm diameter and lignified) and the number of wound roots on each seedling (roots arising at or just above the wound created by the undercutting blade). Seedlings were field planted in a completely randomized design. Seedling survival, height, and diameter (5 cm above the ground) have been measured at the end of each growing season. Only the data for the Illinois planting will be presented in this paper. Similar results have been found in the other states.

Results and Discussion

Grading data indicated seedlings grown at the lowest density ($32/m^2$) that were undercut developed greater numbers of FOLR than seedlings from other treatment combinations (Tables 1 and 2). Undercutting increased the number of

Table 1. Responses of Illinois red oak seedlings to bed density and undercutting

Density/ undercutting	Height (cm)	Diam. (mm)	FOLR > 1 mm 1st order	Wound	Tot.
$32/m^2$					
undercut	38.9	7.8	13.4	6.1	19.5
not undercut	53.1	9.9	10.8	-	10.8
$64/m^2$					
undercut	37.8	7.4	10.6	5.8	16.4
not undercut	48.5	8.4	8.8	-	8.8
$112/m^2$					
undercut	38.6	6.9	8.7	6.2	14.9
not undercut	46.0	7.6	6.6	-	6.6

Table 2. Responses of Illinois walnut seedlings to bed density and undercutting

Density/ undercutting	Height (cm)	Diam. (mm)	FOLR > 1 mm 1st order	Wound	Tot.
$32/m^2$					
undercut	58.2	10.2	14.4	4.0	18.4
not undercut	88.9	11.7	10.7	-	10.7
$64/m^2$					
undercut	60.7	9.1	10.6	3.5	14.1
not undercut	78.5	10.2	7.5	-	7.5
$112/m^2$					
undercut	59.2	9.1	8.6	3.2	11.8
not undercut	77.0	9.9	6.6	-	6.6

roots by about 6 for oak seedlings and 3.5 for walnut seedlings grown at any density. This resulted from the formation of 2 to 6 wound roots, as well as from the increased diameter of lateral roots already present above the wound. As bed density increased, fewer FOLR were produced in both undercut and not undercut treatments. For both red oak and black walnut, limiting seedling density to about 64 seedlings/m^2 may be necessary to produce seedlings with adequate numbers of FOLR to ensure survival and competitive early growth after outplanting.

Survival of red oak and black walnut seedlings was influenced both by nursery cultural treatments and by the number of FOLR a seedling had when it was planted in the field. It is very apparent for red oak that reducing bed density to 64 seedlings/sq m and undercutting both had a positive influence on survival (Figure 1A). The lowest survival was for seedlings that were not undercut and were grown at the highest density. Undercutting seedlings at the highest density increased their survival so that it was equivalent to that of the best treatment combinations. Both undercutting and bed density reduction increased the number of FOLR which increased survival (Figure 1B). There is a major drop in survival of seedlings which had less than 5-6 FOLR.

For black walnut, results were less dramatic (Figures 2A and 2B). However, both density reduction and undercutting again increase FOLR, and the greater the number of FOLR the higher the survival percentage.

On the average, both undercut oak and walnut seedlings were smaller than seedlings which were not undercut, both at the time of grading and after four years in the field (Figures 3A and 4A). This was not unexpected, since the source-sink response for carbohydrates favors the root system immediately following undercutting. By the end of the fourth year the differences in height between undercut and not undercut seedlings was not significant.

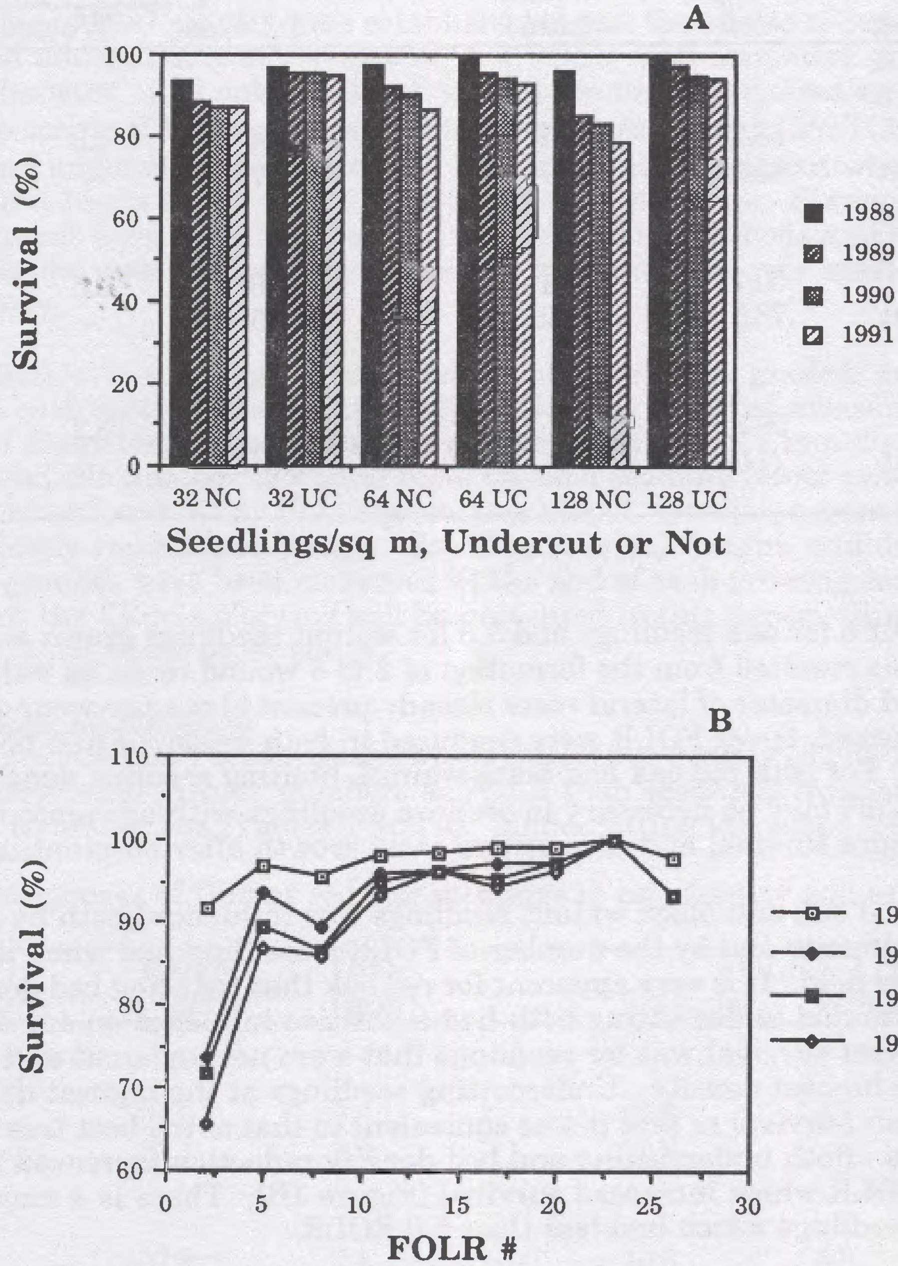


Figure 1. Survival of red oak seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Survival was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

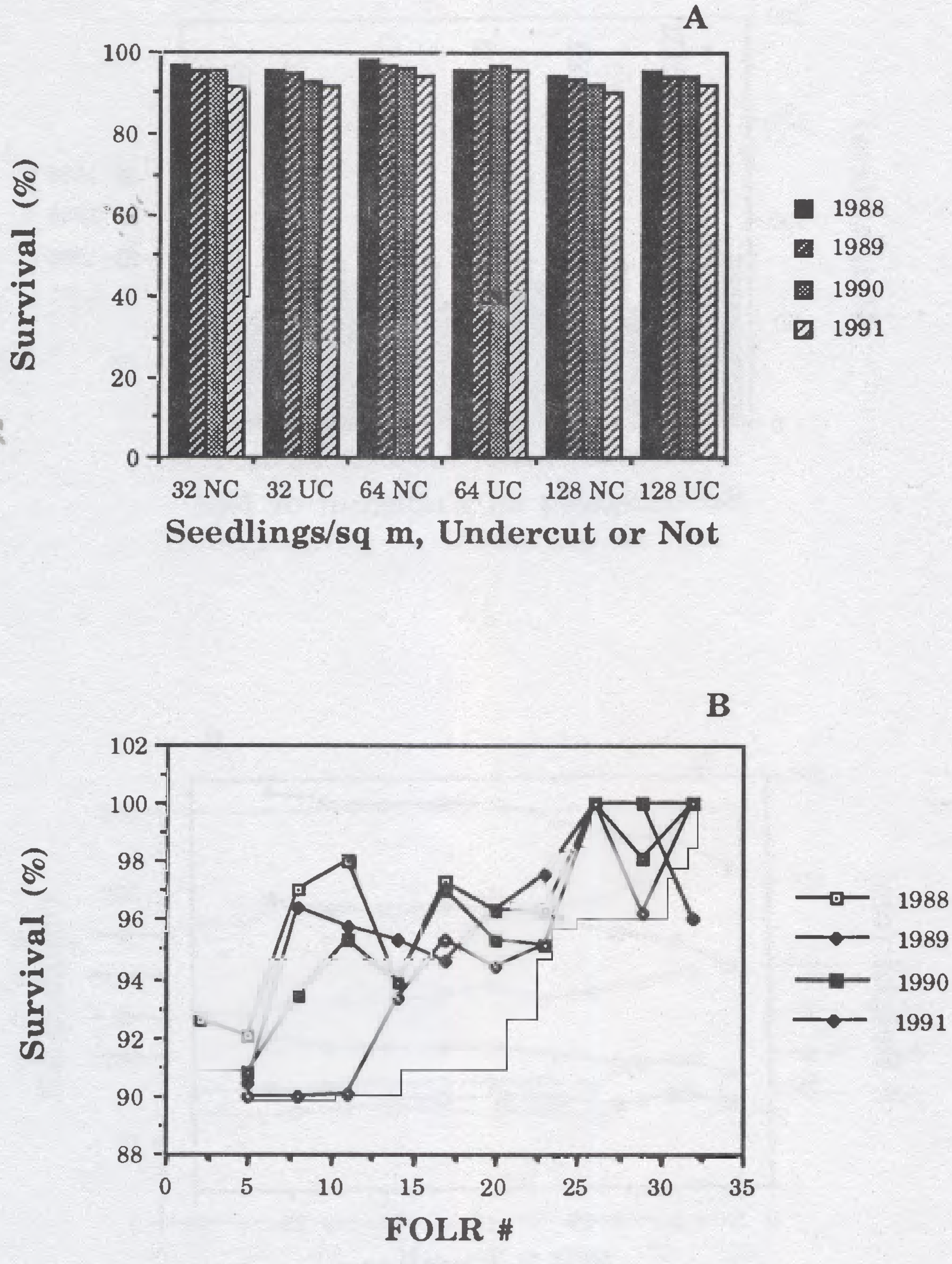


Figure 2. Survival of black walnut seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Survival was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

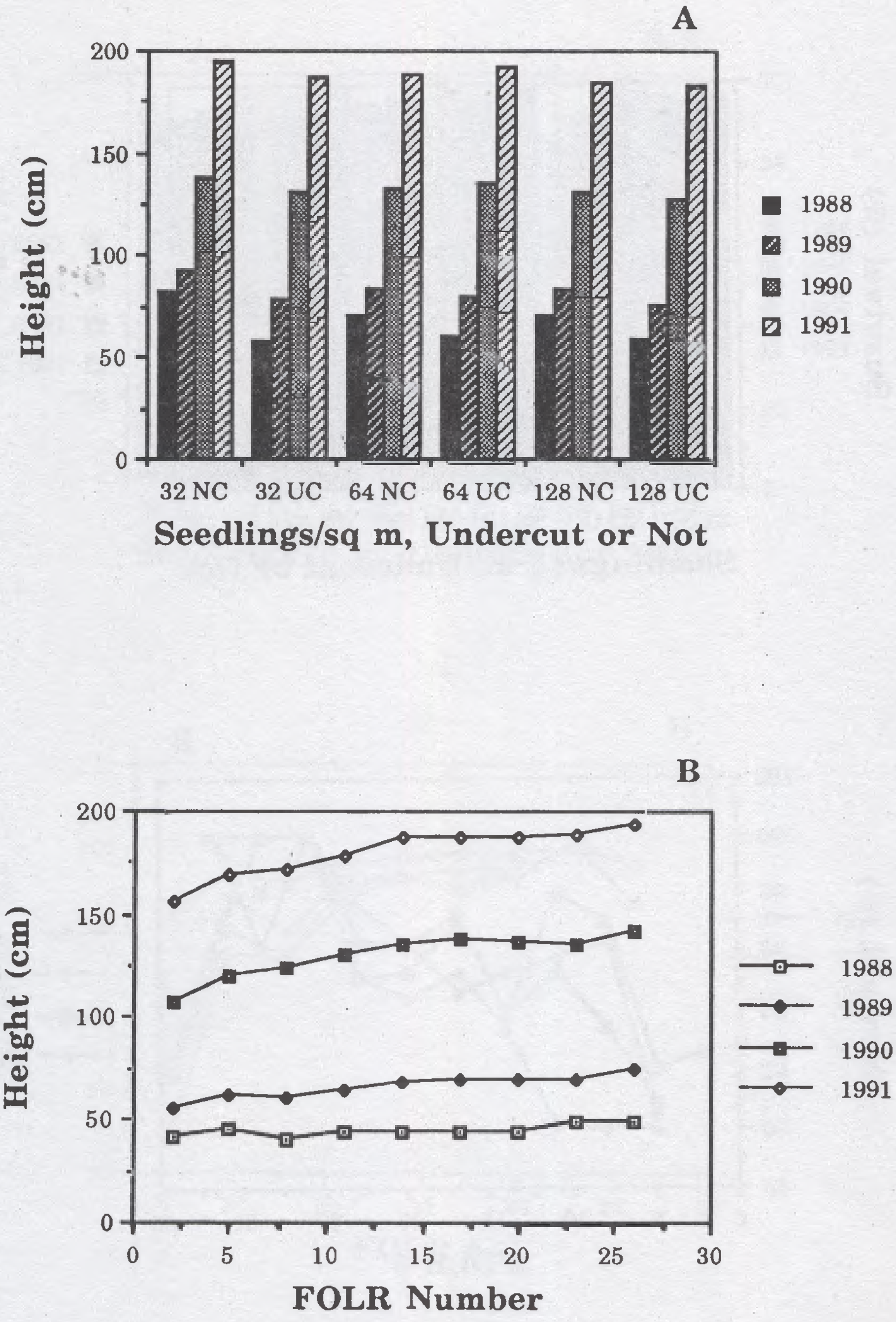


Figure 3. Total height of red oak seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Height was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

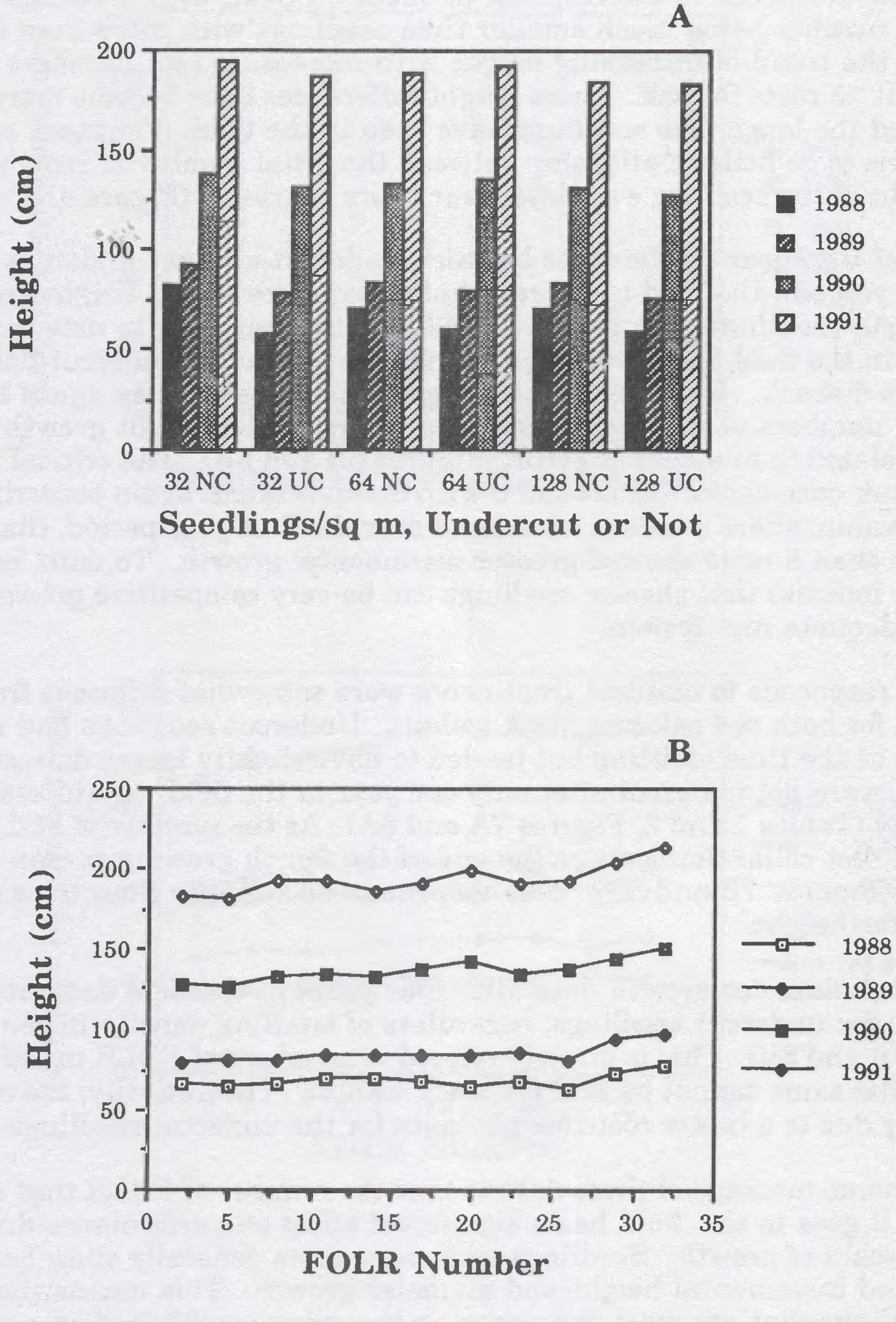


Figure 4. Total height of black walnut seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Height was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

Total height for oak seedlings after 4 years in the field was strongly related to initial numbers of permanent roots at the time of planting (Figures 3B). Once again, there is a break in the response at about 6 FOLR, with seedlings having less than that number being much smaller than seedlings with more than 6 FOLR. However, the trend of increasing height with increasing root numbers continues up to about 15 roots for oak. These height differences have become more pronounced the longer the seedlings have been in the field. For black walnut there seems to be little relationship between the intial number of roots and the total height of the seedling even after four years of growth (Figure 4B).

The lack of significant differences between undercut and not undercut seedlings after four years in the field is the result of faster incremental height growth for the undercut seedlings (Figures 5A and 6A). It is interesting to note that in the first year in the field black walnut seedlings that were not undercut had significant dieback. Incremental height growth responses may again be directly related to numbers of roots, since four-year incremental height growth was strongly related to numbers of FOLR (Figures 5B and 6B). The critical number of roots for oak once again lies around 6 with another break again occurring at 15. Even for walnut there seems to be a trend over the four year period, that seedlings with more than 8 roots showed greater incremental growth. To date, results of this study indicate that shorter seedlings can be very competitive growers if they have an adequate root system.

Diameter responses to cultural treatments were somewhat different from those for height for both red oak and black walnut. Undercut seedlings had smaller diameters at the time of lifting but tended to have slightly larger diameters than those that were not undercut after only one year in the field, regardless of nursery bed density (Tables 1 and 2, Figures 7A and 8A). As the number of FOLR increased, root collar diameter at the end of the fourth growing season also increased (Figures 7B and 8B). This response was stronger than the same response for height.

Incremental diameter growth data after four years in the field demonstrate an advantage for undercut seedlings, regardless of seedling density in the nursery (Figures 7B and 8B). This is directly related to numbers of FOLR in red oak, although the same cannot be said for black walnut. Theoretically, the advantage is probably due to a better root:shoot balance for the undercut seedlings.

The take-home message of these data is that the number of FOLR that a seedling has when it goes to the field has a significant effect on performance during the first four years of growth. Seedlings with more roots generally show better survival and incremental height and diameter growth. This means that it is these seedlings that are most aggressive in becoming established on a site. Although undercut seedlings with more roots may initially be shorter they are better balanced and put on rapid growth during the first four years. The smaller but better balanced seedlings are actually easier to plant and therefore will probably be better planted.

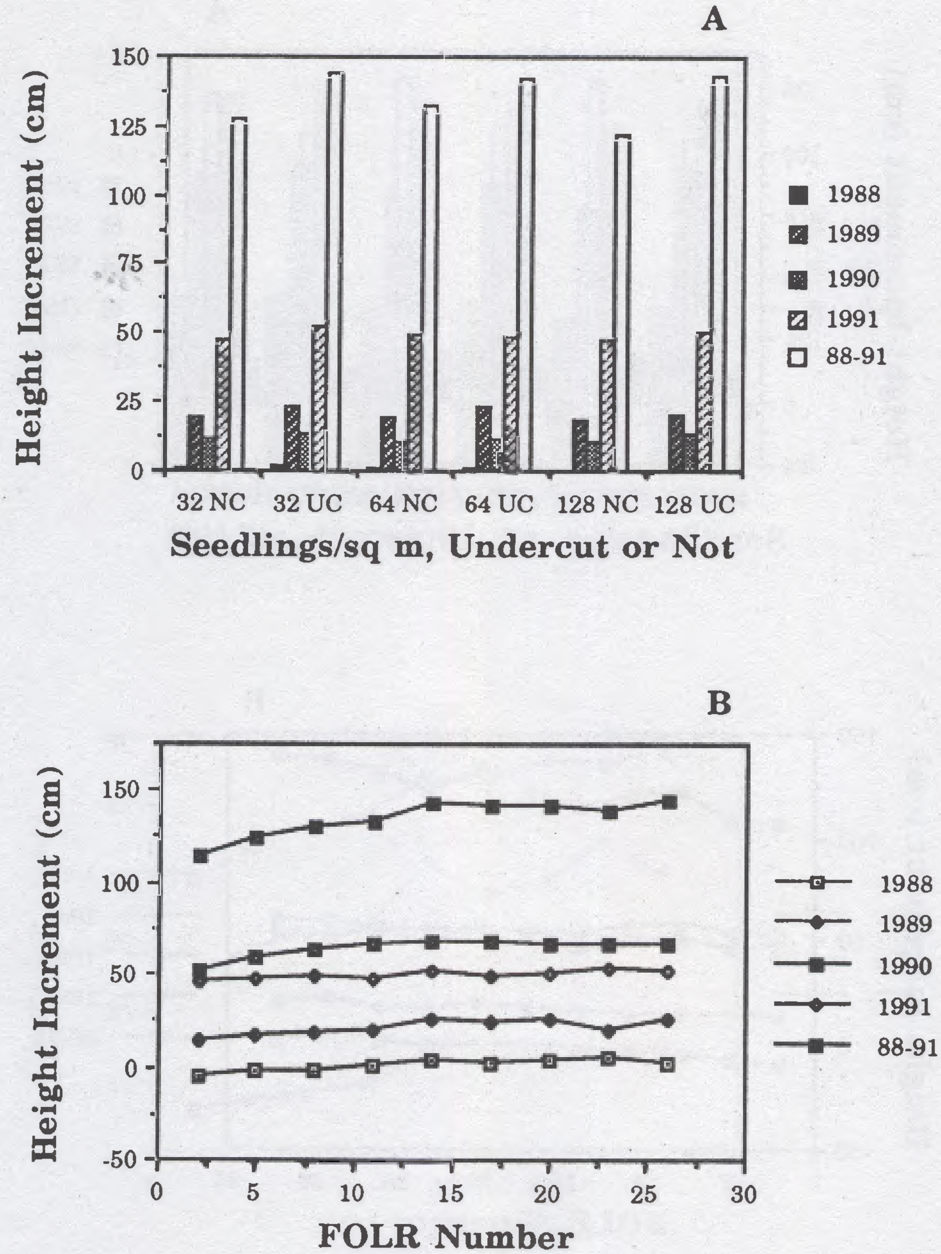
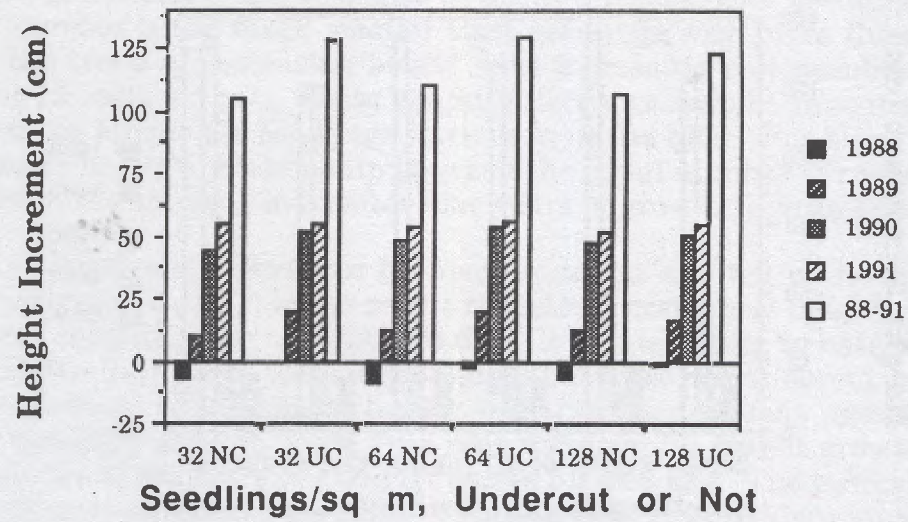


Figure 5. Annual and total height growth increment of red oak seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Height increment was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

A



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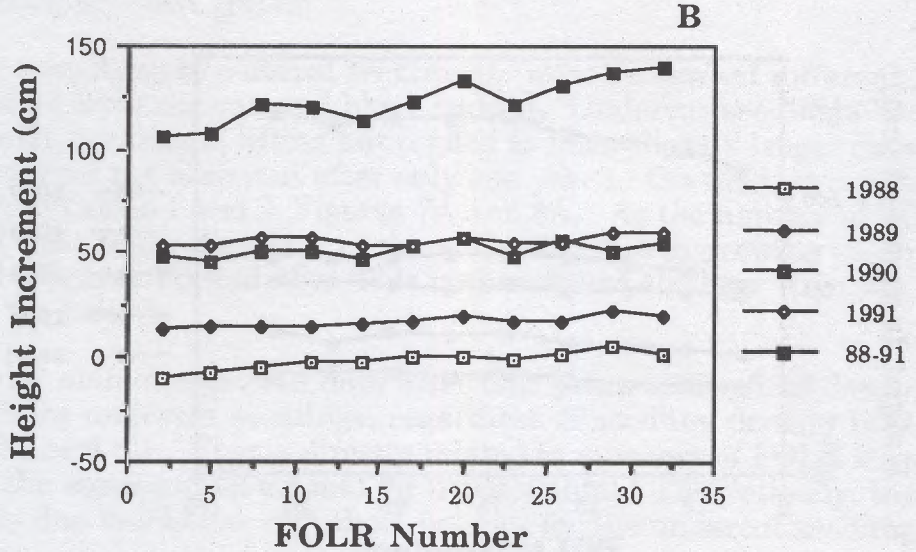


Figure 6. Annual and total height growth increment of black walnut seedlings at the end of each of four growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Height increment was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

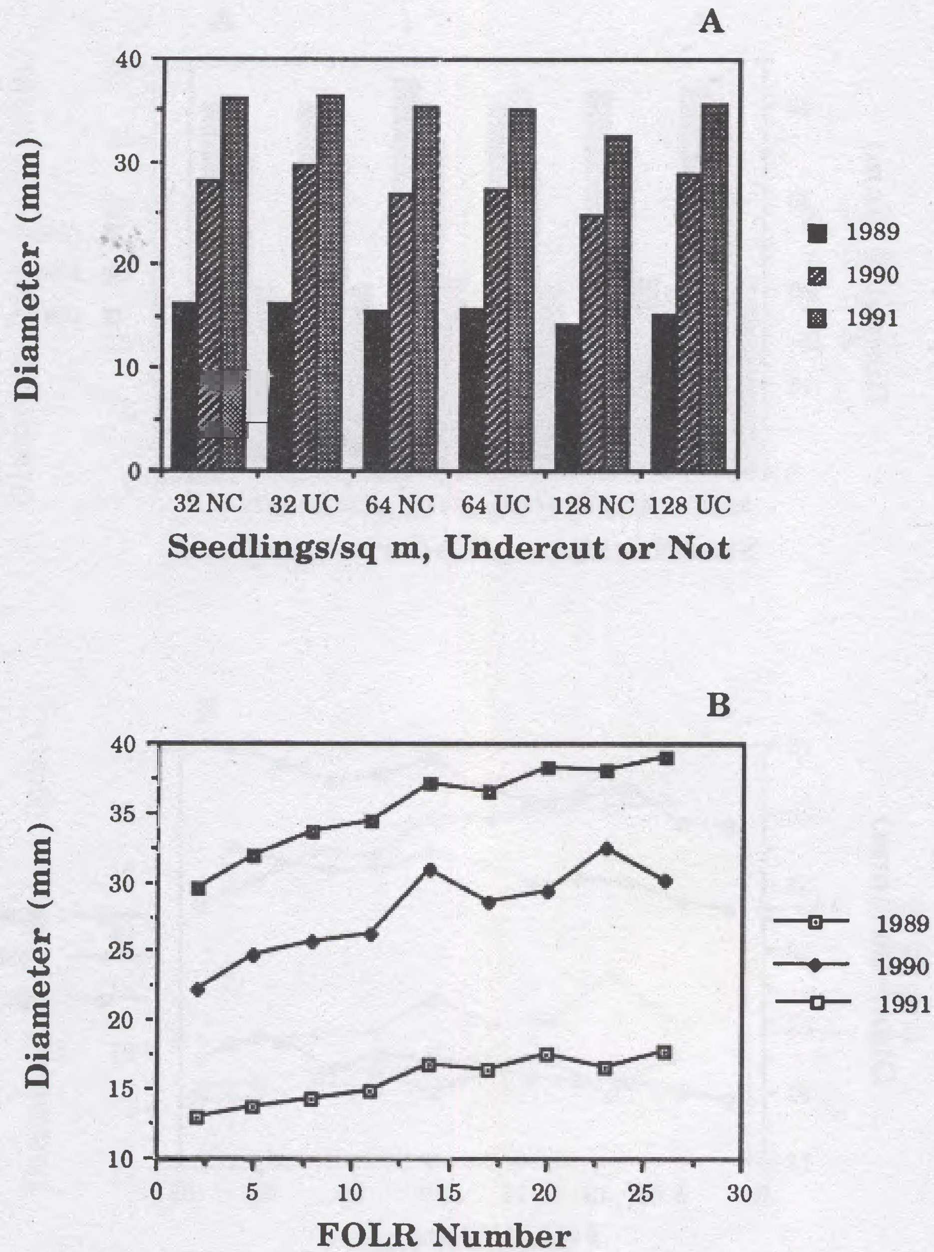
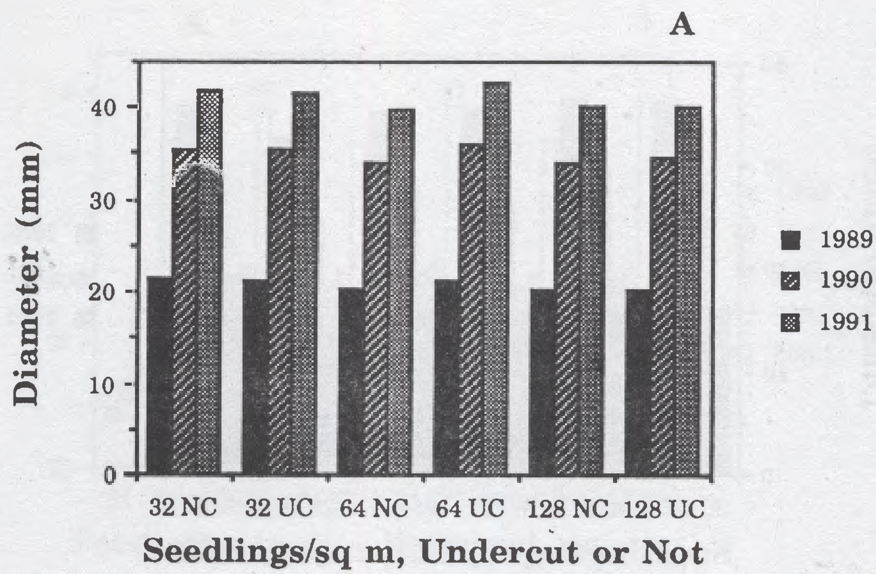


Figure 7. Root collar diameter of red oak seedlings at the end of each of three growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Diameter was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).



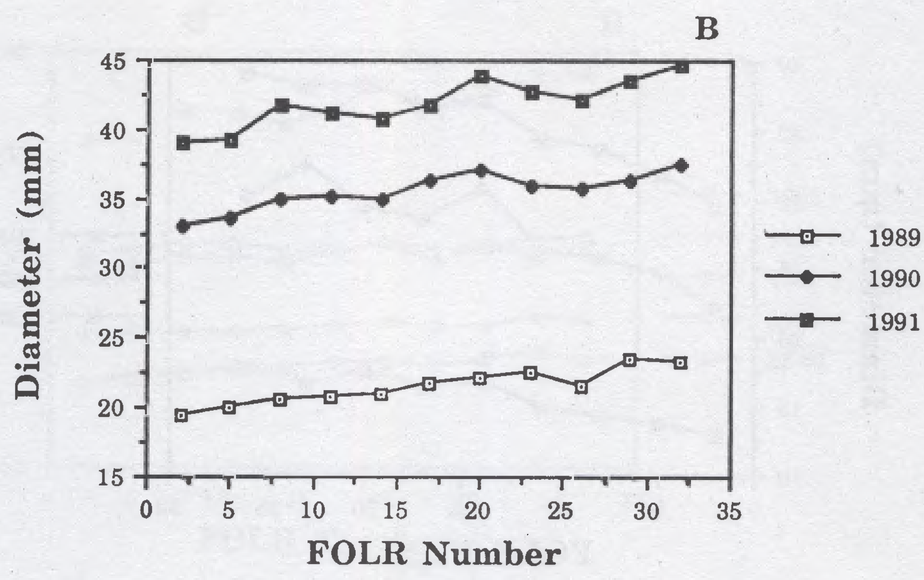


Figure 8. Root collar diameter of black walnut seedlings at the end of each of three growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Diameter was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

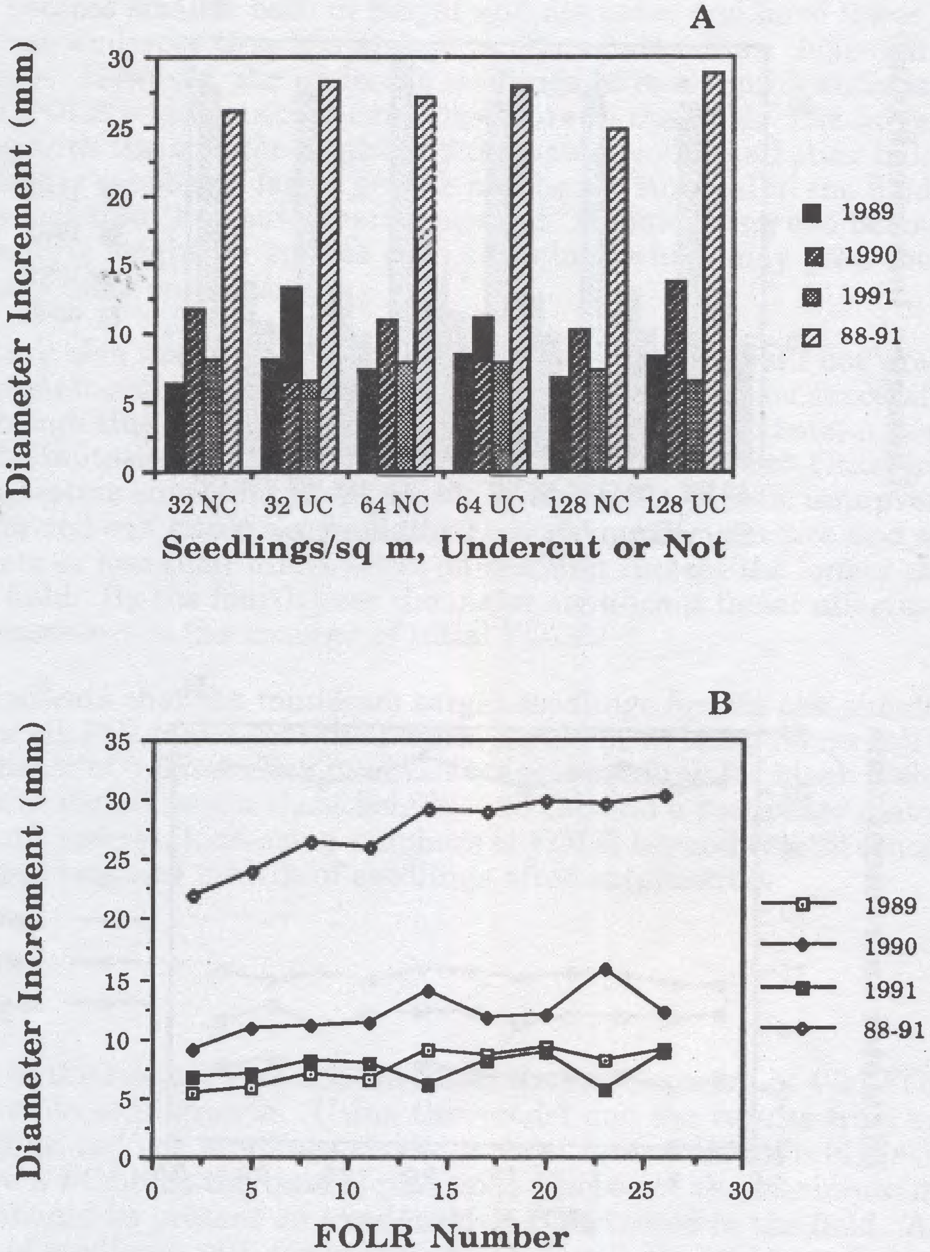
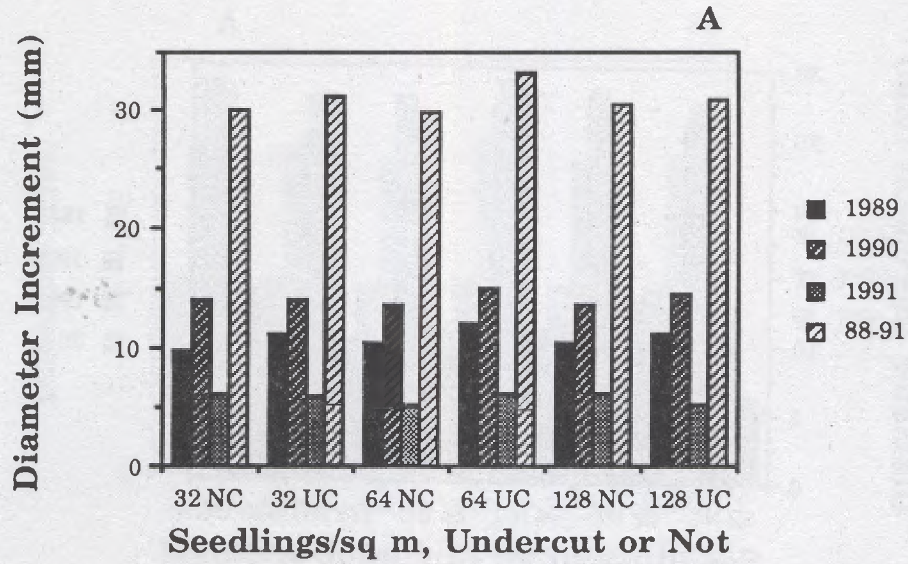


Figure 9. Annual and total diameter growth increment of red oak seedlings at the end of each of three growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Diameter increment was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).



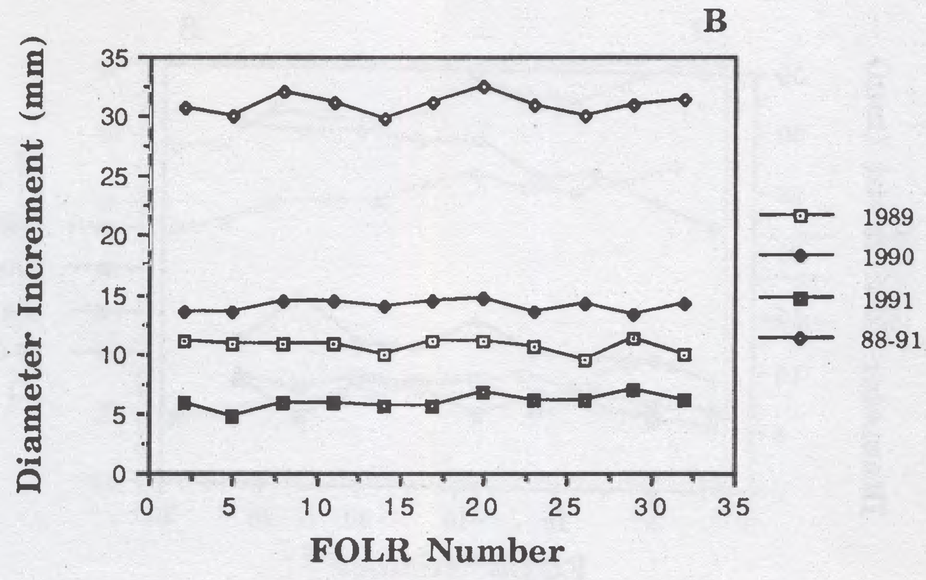


Figure 10. Annual and total diameter growth increment of black walnut seedlings at the end of each of three growing seasons in the field. Seedlings were grown at three densities and half were undercut in the nursery bed (A). Diameter increment was compared to the number of first order lateral roots (FOLR) greater than 1 mm at the base at the time of field planting (B).

The effect of nursery cultural practices is quite clear. As density increases the seedlings become smaller both in height and diameter and have fewer FOLR. If seedlings are undercut they are also generally smaller than their non-cut counterparts. However, the undercut seedlings have a significantly larger number of FOLR which make them competitive in the field. 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 four years that they have been measured. Undercutting can be used to control seedling height for species such as walnut which may grow too large to handle easily after one season.

Undercutting also may give seedlings which genetically would not produce as many large first-order roots the number of FOLR needed to be successful in the field. Although this is not the ideal scenario for culturing plants, it is useful given the present limitations of available improved hardwood seeds. Other studies done by the cooperative show that there is good potential for genetic improvement of root numbers for red oak and walnut. Both the undercutting practice and seed bed density seem to lose their direct effect on seedling success the longer the seedlings are in the field. By the fourth year the major significant factor affecting most growth parameters is the number of intial FOLR.

The data indicate that the minimum target seedlings for red oak should have at least five or six FOLR and that their shoot should be at least 38 cm tall with a root collar diameter of 0.6 cm. The minimum target seedling for black walnut should have seven or eight roots, a shoot height of 50 cm, and a root collar diameter of 0.8 cm. For both species, increasing numbers of FOLR beyond the threshold level improves survival and growth of seedlings after outplanting.

Summary

The model of the mature tree demonstrates that a minimum of 4-11 FOLR are needed for successful growth. Using this model and the results from extensive field plantings, red oak seedlings should have at least 6 FOLR and black walnut should have 8 FOLR at the time of planting. These are the minimum number of roots that should be present on a seedling that is planted in the field. A high proportion of seedlings with fewer than 6 FOLR will die, and very few will become members of the co-dominant or dominant canopy of the developing plantation. For hardwoods, it is the FOLR present at outplanting which are important in developing a successful root system, and not the number or mass of higher order roots. Most of these fine roots succumb to the handling processes involved in getting the seedling from the nursery into the planting hole.

The minimum red oak target seedling in the central states should also be 38 cm (15 in) in height and 0.64 cm (0.25 in) in diameter. The minimum black walnut target seedling should be 50 cm (20 in) in height and 0.8 cm (0.3 in) in diameter.

Increasing the proportion of seedlings meeting these minimum targets is possible using such cultural practices as bed density control (60/ m^2; 6/ft^2), proper fertilization and irrigation, and undercutting when practical. Undercutting should be done at the end of the second or third leaf linear phase for red oak or when the black walnut taproot at 15 cm is approximately 0.6 cm in diameter. Undercutting should be done at a depth (approximately 18 cm) well above the anticipated lifting depth and late in the afternoon or early in the morning. It should be followed by irrigation and should not be done when the actual air temperature is above 32° C.

With proper density control, undercutting, fertilization, and irrigation regimes at least 80-90% of the crop should meet the minimum target size.

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