ROOT GROWTH POTENTIAL AND WEED CONTROL EFFECTS
ON THE FIRST YEAR GROWTH OF PITCH X LOBLOLLY PINE
(Pinus rigida x P. taeda L.) AND LOBLOLLY PINE

by

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(ABSTRACT)

The study was initiated to determine the effects of RGP and three levels on weed control: no weed control (control), herbaceous weed control (Oust), and woody and herbaceous weed control (Oust-Garlon) on three pine seedlots: pitch x loblolly pine hybrid (PXL-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco loblolly pine (WCO-lob).

Lateral roots had the greatest response to the Oust treatment compared to all other seedling parts. All seedlot and treatment interactions were associated with lateral roots. After one growing season the Oust treatment resulted in a 148% increase in lateral root biomass compared to the control treatment. Shoot biomass in the Oust treatment increased by 70% compared to the control.

The ability to respond to weed control was related to RGP. Compared the loblolly pine seedlots the PXL-F2 had both significant higher RGP at planting and biomass accumulation in response to the Oust treatment. Compared to the loblolly pine seedlots the PXL-F2 lateral root biomass
and total tree biomass increased by 44% and 30%, respectively.

The addition of woody weed control to herbaceous weed control in the Oust-Garlon treatment did not result in significant increasing in loblolly pine seedling biomass compared to herbaceous weed control. Because of a tolerance sensitivity to Garlon 4™ the (PxL-F2) had 22% reduction in total tree biomass in the Oust-Garlon treatment compared to the Oust treatment. Therefore, the control of woody weeds in pitch x loblolly pine plantations will need to be accomplished using another herbicide.
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INTRODUCTION AND JUSTIFICATION

High survival and accelerated growth in southern pine plantations is a major goal of the forest industry in the southeast. Excellent environmental conditions and species, such as loblolly pine, have already made rapid growth a reality, but intensive management will be necessary to further increase growth and meet the future forest products needs of the United States. The planting of high quality seedlings and the reduction in competition for water, nutrients, and light by weed control will both help to increase seedling performance after outplanting.

Variation in conifer seedling quality has not always been explained using morphological characteristics such as height, root collar diameter, root/shoot ratio, and root length (Wakeley 1949, Burdett 1987). Root growth potential (RGP), a grading system based on the ability of a seedling to grow new roots has been developed as an alternative to traditional morphological grades. Variation in root growth potential (RGP), when measured under controlled conditions in a greenhouse, has related well to field performance (Feret and Kreh 1985, Burdett 1987).

The relationship between lab-RGP and field performance can be interpreted in a number of ways. Each
interpretation will imply a different method of improving seedling quality. Stone (1955) assumed that lab-RGP is correlated to RGP under field conditions (field RGP) and that seedling water stress is a major limiting factor for survival and early growth. If this is in fact true, better seedling quality can be achieved through efforts to increase RGP. Published evidence on a direct relationship between lab-RGP and field-RGP does not exist (Burdett 1987). Ritchie (1985) observed that lab-RGP is correlated with field performance because of its relationship to resistance to low temperature injury and other environmental stresses. If this is correct, improving the quality of planting stock could be directly achieved by improving stress resistance (Burdett 1987). Another rational to explain the correlation of lab-RGP and field performance is that RGP is an indicator of seedling vigor. RGP therefore is a indication of the whole plant’s physiological vigor (Ritchie 1985). If RGP is a measure of seedling vigor then quality could be improved directly by better handling and storage (Burdett 1987). Further study is needed to better understand the correlation between lab-RGP, root growth in the field, and field performance.

Dewald and Feret (1987) found that the number of
lateral roots on loblolly pine (*Pinus taeda* L.) seedlings was positively correlated to the seedlings RGP. The pitch x loblolly hybrid (*P. rigida* x *P. taeda*), which has been developed as a cold hardy alternative to loblolly pine, produces a root system with many fine lateral roots as compared to the loblolly pine. This may result in better survival and early growth than loblolly pine.

The cold storage of pine seedlings before planting is extensively used in the southern United States. The date of lifting and the duration of cold storage has been shown to greatly influence the RGP of pine species, but patterns vary with different species (Feret and Kreh 1985, Ritchie 1985). RGP of species respond differently to cold storage. If the pitch x loblolly hybrid is to be widely used in the Virginia Piedmont, the effects of cold storage on RGP must be known and understood.

The control of plant competition in newly planted pine plantations is also necessary to insure high rates of survival and growth. The control of only herbaceous competition during the first two years produced more dramatic seedling growth than the control of only woody competition (Miller et al. 1986, Tiarks and Haywood 1986). Woody and herbaceous weed control, when combined during the first two years, can produce large height and ground
line diameter (GLD) increases (Bacon and Zedaker 1987). The timing of herbaceous and woody weed control treatments has a significant effect on seedling growth (Bacon and Zedaker 1985). During the first two years, herbaceous weeds have been found to have a more negative effect on pine growth than woody competition. After three or four years the main competitor for light and space will be hardwood species and lololly pine responds well to woody weed control after the fourth year (Zutter et al. 1988). The combination of woody and herbaceous weed control has produced significantly larger two year old seedlings as compared to seedlings receiving herbaceous control only (Bacon and Zedaker 1987). Total weed control has no significant benefit over herbaceous weed control during the first two years (Miller et al. 1986). A timely application of an appropriate weed control will increase growth and therefore merits further study.

Little effort has been applied to the study of the effects of weed control on the growth of pine seedling roots. It has been assumed that greater shoot growth as a result of reduced competition may correspond to increased root growth. Actual responses in roots have not been quantified. The characteristics of total root mass, root depth, and horizontal elongation will affect the seedling
growth. A direct study of root growth as a result of weed control may have implications for the timing of herbaceous and woody weed control.

Different families of loblolly pine have shown different reactions to the control of competition. In a study of three loblolly pine families, growth was altered depending upon whether weed competition was controlled or not. Genotypes may respond differently to conditions of no competition for moisture and nutrients.
OBJECTIVES

High root growth potential at the time of planting and the proper timing of herbaceous and woody weed control are important to obtain high survival and rapid pine seedling growth. A comparison of the pitch x loblolly pine hybrid and loblolly pine root growth potential their response to different weed control timing was undertaken with an emphasis on:

1. Determining if the pitch x loblolly pine fine root system will cause higher RGP values in comparison to loblolly pine RGP.

2. Determining if there is a relationship between lab-RGP and field performance for the two species.

3. Comparing the root and shoot performance of the two species in response to no weed control, herbaceous weed control at planting, and both herbaceous and woody weed control in the first year.
LITERATURE REVIEW

Pitch Pine x Loblolly Pine Hybrid

Loblolly pine is the leading commercial timber species in the southeastern United States (Harlow et al. 1979). Its natural range extends north from Mississippi, Alabama, and Florida along the Atlantic coastal plain into Maryland and central Delaware from near sea level to 250 meters. Rapid growth and good form have resulted in loblolly pine being planted extensively within and beyond its natural range. When planted north or at higher elevations than its natural range, retarded growth is common. Low temperatures damage the crown and retard water absorption by the roots (Fowells 1965). Damage by snow and ice also limit loblolly productivity (Harlow et al. 1979).

The range of pitch pine extends from central Maine to northern Georgia and west to eastern Tennessee and Kentucky. The natural altitudinal distribution of pitch pine is from sea level to 900 meters. The existence of pitch pine in Maine demonstrates its ability to survive and grow in cold temperatures relative to loblolly pine. In New England it is generally a small tree because it commonly grows on poor soils. A multi-branched root system makes it extremely hardy on dry unproductive soils (Harlow et al. 1979).
Tree breeders began developing hybrids of pitch and loblolly pine in 1933 and since then the search has continued for a hybrid with the rapid growth and good form of loblolly pine plus the cold hardiness of pitch pine. Natural hybrids between pitch and loblolly pines have been observed and some of these display the desired traits of rapid growth, good form, and cold hardiness (Little et al. 1967).

In 1945 the Northeastern Forest Experiment Station planted hybrids produced from artificial crosses between pitch and loblolly. The hybrids produced were slow growing and poorly formed (Little and Somes 1951). The poor growth and form of these original crosses may have been the result of having used the wrong geographic sources and poor genotypes of parent trees (Little and Trew 1979).

During the 1950's South Korea undertook a hybridization program to improve pitch pine which is used for reforestation in Korea's higher elevations. The program has used pitch pine as the seed parent and loblolly pine as the pollen parent (Hyun, 1976). F1 seeds were produced by controlled pollination. Test plantations were established in different geographic areas with pitch pine used as the control. The results from these test
plantations indicated that the performance of the hybrid depends on the geographic location of the parent seed source. Within five years after planting the hybrids produced from the best seed source exhibited 24.4% greater growth compared to the hybrids from the poorest seed source (Hyun, 1976).

The Korean program has produced and planted P. rigida x taeda F2 hybrid seed. The F2 trees when compared to the F1 trees appear to be less cold hardy causing slightly slower growth in the colder areas of Korea (Hyun, 1976).

In the 1960's, the Westvaco Corporation and the Northeastern Forest Experiment Station began developing a winter-hardy, fast growing pitch x loblolly pine hybrid to plant on Westvaco lands in West Virginia, Virginia, and western Maryland. Phenotypically superior pitch pines were selected from Virginia north to New York. Phenotypically superior loblolly pines were selected in Maryland and Delaware. The attributes of superior growth and form were used in the selection process. Scion material was collected from the branch tips of the selected trees and grafted onto pitch and loblolly pine seedlings. In 1964 the grafted seedlings were transplanted to establish an orchard in New Lisbon, N.J. Controlled breeding was conducted to insure that all
pollinations were between the clones of the two species.

Progeny trials of the F1 hybrids were established between 1971 and 1977. The program involved 29 test plantations located in nine states from Kentucky to Massachusetts. All the test plantations are located outside the natural range of loblolly pine and have a wide range of soil, climate, and elevation. The plantations included plots of both pitch and loblolly pine to serve as controls. In general, the results depend upon the differences in soil type and climate of the various plantations. Little and Trew (1979) found that the survival of the best hybrid families was high. Loblolly pine survival was affected by climate and soil. The closer loblolly was planted to its natural range the better its survival. Some of the hybrid families have equaled loblolly pine in growth depending upon the climate and soil type of the plantation. Little and Trew (1979) found that relative growth and the most desirable hybrids for specific areas varied with geographic locations of the planting sites. Pitch pine controls were generally the shortest trees in the test plantings.

The different hybrid families vary greatly in form. The progeny do not all have the straightness and branching desired, yet most hybrids have a better form than pitch
pine. Some families have better form than their parent
trees (Little and Trew 1979).

The hybrid root systems greatly exceed the root
systems of either parent in length and branchiness. The
extensive root systems may be favorable for growth on
strip mines and other areas with depleted soils (Little
and Trew 1979).

Root Growth Potential

In 1949 Wakeley stressed that the traditional seedling
morphological grades of root collar diameter, root to
shoot ratio, and stem height were poor indicators of
seedling survival and growth. He recognized the need to
establish a grading system based on physiological
qualities (Wakeley 1949). The survival and growth of tree
seedlings require a physiological preparedness to produce
new roots and establish direct contact with the soil
(Smith 1985). Stone and his colleagues realized the
importance of a tree's ability to rapidly produce new
roots after being outplanted. This realization led to the
development of the root growth potential (RGP) test at
Berkeley in the 1950's (Stone 1955).

RGP has been defined as "the ability of a seedling to
initiate and/or elongate roots when held in an environment which is conducive to root growth" (Ritchie 1985). High RGP is an important quality in that it enables the finite root system of the seedling to extend itself and better utilize soil moisture and nutrients beyond its immediate surroundings. Without this ability to produce new roots, water stress and death will result (Ritchie 1985).

Thirty percent of the one billion loblolly pine seedlings planted annually in the south die as a result of: 1) poor quality planting stock; 2) improper handling and planting; 3) unfavorable site conditions (Ransanen 1980, Venator 1981). RGP is a direct measure of the quality of planting stock and is fixed when the seedlings are moved from storage. The degree to which RGP is expressed depends upon the two factors mentioned above the quality of handling and planting, and the condition of the planting site (Ritchie and Dunlap 1980).

Transplanted conifer seedlings generally have lower water potentials than established transplants (Sands 1984). Root extension is a requirement for the return to normal water relations in transplanted seedlings (Burdett 1987). Thus RGP will determine the ability of newly transplanted seedlings to avoid moisture stress. On very wet sites, survival is possible for seedlings with very
low RGP values. On very dry sites survival is impossible for all trees, including trees with very high RGP values. RGP, therefore, does not predict survival but survival potential. A higher RGP indicates a greater probability of seedling survival (Burdett 1987).

RGP is affected by bud dormancy (Ritchie and Dunlap 1980). After shoot elongation, over-wintering buds are formed and dormancy begins. Dormancy is initiated by shorter photoperiods and deepens with decreasing temperature. True dormancy is reached when a return of favorable growing conditions will not result in a resumption of growth without proper chilling.

Growth can proceed when buds have been exposed to chilling temperatures for a certain number of hours. Generally RGP increases with the accumulation of chilling hours and peaks after the chilling requirement has been fulfilled. RGP decreases after the chilling requirement has been fulfilled (Ritchie and Dunlap 1980).

Root growth potential is strongly linked to the time of year that lifting occurs. A seedling should be completely dormant before lifting and storage. Cold storage can then increase the seedling RGP. Seedlings, lifted and stored before true dormancy has been reached or after quiescence has begun, may experience a decrease in
RGP (Ritchie and Dunlap 1980).

Two methods of measuring RGP are currently in use. The test developed by Stone (1955) requires the removal of all white growing tips from the seedling and pruning of the roots to a specific length. The seedlings are then potted and held in an environment ideal for root growth for 28 to 30 days. An alternative method described by DeWald et al. (1984) uses hydroponics. In both systems it is essential to maintain a controlled environment. Changes in photoperiod, air temperature, potting medium, and other variables will introduce variance in RGP measurements (Burdett 1987). DeWald and Feret (1987) found, that even though the hydroponic system resulted in a fewer number of new roots and less total length of root growth, comparable relative RGP results are obtained using the soil system.

**Herbicides and Plantation Establishment**

The excellent growing conditions for pines in the southeast which allows the production of quality forest products also allows the growth of numerous woody and herbaceous weed species. These unwanted species compete with the planted seedlings for water, light, space, and nutrients. The control of these weeds greatly increases loblolly pine growth (Knowe et al. 1985).

On newly planted pine plantations, woody weeds,
herbaceous weeds, and pine seedlings all compete and interact. The control of the unwanted vegetation and the release of the pines can be achieved by using one of three general techniques: 1) control of woody vegetation only; 2) control of herbaceous vegetation only; 3) control of both woody and herbaceous vegetation. The feasibility or effectiveness of a particular technique depends on the cost of eradication and the amount of desirable growth obtained (Clason 1978). For any particular site, the effectiveness of the three different strategies will vary depending upon the amount of and type of competition present, the site factors including soil type, soil moisture, and available nutrients, and the type and timing of treatments (Miller et al. 1986, Nelson et al. 1981).

Herbicides were first used by the forest industry to control hardwood competition. The use of (2,4,5-trichlorophenoxy)acetic acid (2,4,5-T) for this purpose began in the 1940's. The high efficacy of this phenoxy herbicide stimulated its widespread use. From the 1940's through the 1960's the use of herbicides for interspecific competition control in forestry was primarily aimed at woody plants. As early as 1954, Huckepakler (1954) found poisoning with herbicides was a more effective method of controlling hardwoods than
girdling. The ban on 2,4,5-T for forest uses in 1979 forced the development of other chemicals including hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione), picloram (4-amino-3,5,6-trichloro-2-pyridine-carboxylic acid), glyphosate (N-(phosphonomethyl)glycine), and triclopyr ([3,5,6-trichloro-2-pyridinyl]oxy] acetic acid).

Arborescent weed control on a newly planted pine plantation can greatly increase pine growth. Annual woody plant control of a loblolly pine plantation can yield a 49% increase in volume at the age of six as compared to untreated plots (Cain and Mann 1980). Clason (1978) found that the removal of hardwood vegetation in a seven year old loblolly pine stand significantly increased pine growth.

The use of chemicals to control herbaceous vegetation is a relatively new silvicultural tool. Fitzgerald et al. (1973) found that herbaceous weed control on intensively prepared sites allowed rapid initial growth and crown closure. Numerous recent studies have verified Fitzgerald’s findings (Bacon and Zedaker 1987, Tiarks and Haywood 1986, Zutter et al. 1986, and Miller et al. 1986). Hexazinone, sulfometuron (2-[[[4,6-dimethyl-2-purimidinyl] amino]carbonyl]amino)sulfonyl]benzoic acid),
glyphosate, and other herbicides are commonly used for herbaceous plant control.

The response of pine to herbaceous weed control is often related to the dominance of weeds and the available moisture. Sites with high amounts of available water and normally low weed levels exhibit no treatment effects (Nelson et al. 1981). Sites with low levels of available water and high weed levels have a positive response to herbaceous weed control. In general, reduced moisture stress is a result of herbaceous weed control (Zutter et al. 1986). If moisture is not a limiting factor weed control does not increase pine growth. In a study established at 13 sites in the southern United States, Miller et al. (1986) found that, after two years, herbaceous weed control yielded ground line diameters significantly larger than controls at all 13 locations and heights that differed significantly in nine of the 13 sites. The timing of the herbicide application can alter seedling response. If weed populations are the low delaying herbaceous weed control until the second growing season can increase pine growth as compared to a first growing season herbaceous weed treatment (Bacon and Zedaker 1987).

The comparison of woody verse herbaceous plant control
on newly established loblolly pine plantations has been discussed in a number of articles (Bacon and Zedaker 1987, and Tiarks and Haywood 1986). Miller et al. (1986) found that herbaceous control yielded greater pine growth than woody control. After two growing seasons loblolly pine seedlings receiving herbaceous control had ground line diameters that were 85% larger than the control seedlings. The seedlings receiving woody control were only 26% larger than the controls. Tiarks and Haywood (1986) observed that herbaceous plant control increased pine survival from 78% to 89% at age four. In the same period, woody plant control did not influence survival.

The combination of herbaceous and woody weed control can have significant effects on the growth of young pines. Miller et al. (1986) in their region-wide study obtained trees that were 47% larger in ground line diameter (GLD) after two years of total weed control. Bacon and Zedaker (1987) found a 152% increase in volume in two year old pine plantations that had been treated with two thirds woody control plus herbaceous control. This was greater than the 127% volume increase obtained from total woody and herbaceous weed control. The benefit of both woody and herbaceous weed control is obvious.

The interaction between the two weed types and pine
seedlings is considerable and will determine the type, amount, and timing of the control needed for each site. In a southeastern region wide study, hardwood competition did not significantly reduce pine growth in the first year (Miller et al. 1986). During the second year herbaceous ground coverage increased on many sites treated for hardwood competition. During the same 2 year period herbaceous weed control produced ground line diameters significantly larger at 10 of 13 sites. With only herbaceous control, both pine and hardwoods would be equally released causing the acceleration of the race for canopy position. Within 3 to 4 years after planting only woody competition will affect the pine sunlight and aerial growing space (Miller et al. 1986). During that period, a well timed application of a chemical to control hardwood growth would increase the chance of pine becoming dominant in the canopy.

The value of genetic improvement and merits of weed control in the production of loblolly pine are accepted facts. The two practices when used in unison could increase productivity to an even greater extent than when either is used alone. Genetically improved families may react differently to competition control. Duba et al. (1984) found an interaction between individual loblolly
families and weed control. The expression of the genetic potential of 3 loblolly pine families depended on the presence or absence of competition and reflected changes in soil moisture. Family ranks, as indicated by GLD and height, were altered when a comparison was made between their response to weed control and no weed control.
MATERIALS AND METHODS

The effects of root growth potential and three levels of weed control on the survival and growth of three pine seedlots was studied.

Pine Seedlots

The seedlots used were as follows:

1. Pitch pine X loblolly pine F2 hybrid seedlings derived from wind pollinated F1 trees in the hybrid plantation at the Reynolds Homestead Agricultural Experiment Station (Critz, Va), referred to as PxL-F2;

2. Nursery grown loblolly pine seedlings from the Virginia Department of Forestry (Providence Forge, Va.), referred to as VDF-lob;

3. Genetically improved Piedmont source of loblolly pine seedlings from the Westvaco seed orchard (Summerville, N.C.), referred to as WCO-lob.

All planting stock was produced at the Virginia Department of Forestry's New Kent nursery (New Kent, Va.) using standard production methods.

Greenhouse RGP

In mid February 1988, three replications of 15 trees each were lifted by hand for each of the three seedlots. Replications consisted of seedlings randomly chosen from three different nursery beds. The seedlings were tested
for RGP immediately after being transported to the Reynolds Homestead Research Center. The remaining seedlings were divided into the nine replications needed for planting and placed in cold storage at 20°C. After 25 days the seedlings were removed from cold storage and RGP at the time of planting was tested for each of the nine replications of the three seedling types.

RGP tests were conducted in a greenhouse at the Reynolds Homestead Agricultural Experiment Station (Critz, Va.). RGP was tested using a system similar to the one developed by Stone (1955), which provides a simple and easy way to maintain an environment conducive to root growth (Ritchie, 1985). The seedlings were grown with a 16-hour photoperiod, supplemented with fluorescent lights, in a greenhouse maintained at 27°C during the day and above 15°C at night. Seedlings were planted in watertight trays (15/tray) containing Promix Bx™. After being watered to field capacity the trays were held in a water bath with a constant temperature of 20°C.

Before planting for RGP testing, the root systems were gently washed, pruned to 12cm. below the root collar, and any white root tips removed. Twenty-one days after planting the seedlings were carefully removed by hydraulic excavation and the following measurements were collected
for each seedling:
1. Total number of new short roots ( > 0.5 cm. and < 1.5 cm.);
2. Total number of new long roots ( > 1.5 cm.);
3. Total length of new long roots;
4. Dry weights (60°C) of the root system and shoot including needles;
5. Root collar diameter and shoot length;
6. Total projected area of lateral roots and tap root as determined using a Li Cor area meter. The lateral roots were separated from the taproot and both were run through the area meter separately.

Site Description and Outplanting

The field study was installed at two different sites on the Virginia Piedmont. One site was located on the Kennedy Farm in Dillwyn, Va.; another site was provided by Westvaco. Both sites were previously mixed pine hardwood stands. After harvest, each site was prepared by chopping and burning. Seedlings were outplanted as 1-0 stock on March 3, 1988. Seedlings were planted at 2 m x 3 m spacing with two rows of nursery-run loblolly pine planted between each weed control plot to act as a buffer strip.
Each plot was divided into the following non-contiguous 10 tree plots; PXL-F2, VDF-lob, and WCO-lob. In addition, two seedlings were planted 1 meter apart at five randomly selected plots of each non-contiguous 10 tree plot. These double-planted plots were later subsampled for root growth measurement.

**Weed Control Treatments**

Weed control consisted of the following treatments:

1. No weed control (control);
2. Herbaceous weed control at planting (Oust);
3. Herbaceous weed control at planting and woody weed control at planting (Oust-Garlon);

Both herbaceous and woody vegetation control were accomplished by herbicides. The herbicide treatments were applied by backpack sprayers. Sulfometuron, \(2-[[[(4,6\text{-dimethyl-2-pyrimidiny})\text{amino}][\text{carbon1}][\text{amino}][\text{sulfo nyl}][\text{benzoic acid}]\), [Oust \text{TM}] was applied in March 1987 at the rate of 0.30 kg ai/ha in a water carrier to provide herbaceous vegetation control. Hardwood stems were sprayed in September 1987 with a basal bark spray of a 5% solution (v/v) triclopyr, \([(3,5,6\text{-trichloro-2-pyridinyl}][\text{oxy}][\text{acetic acid}]\), [Garlon 4 \text{TM}] in diesel oil.
Field RGP

On March 8, 1988 five nursery run loblolly pine seedlings were planted at ten centimeter spacing in both the control and Oust treatments. The seedlings were dug on April 22, 1988 and field RGP was measured by the method used to evaluate greenhouse RGP.

Evaluation of Seedling Performance

Shoot and root performance were determined by measuring height, GLD, and shoot and root biomass in the fall 1988. Seedlings within each seedlot, weed control treatment, and block were randomly selected at each location with two surviving seedlings. The seedlings were carefully excavated using a spading fork. The roots and stems were then dried at 60°C for one week and weighed.

Evaluation of Weed Control

Percentage ground cover of herbaceous weeds was determined within a 1.0 x 1.5m area surrounding the seedling. Estimates of percentage tend to have a binomial distribution (Little and Hills 1978) therefore, an arcsine transformation was used to estimate ground cover. The following pretransformed classes were used (Little and Hills 1978):
<table>
<thead>
<tr>
<th>Percent Cover</th>
<th>Cover Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>65</td>
<td>6</td>
</tr>
<tr>
<td>79</td>
<td>7</td>
</tr>
<tr>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>97.5</td>
<td>9</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
</tr>
</tbody>
</table>

Crown volume index (CVI) of woody competition was determined within a 2 x 3 meter area surrounding the seedling. CVI was determined by measuring the height of the crown, the widest cross-section of the crown, and the width of the crown at a 90° angle from the widest cross-section of the crown. The three measurements were then multiplied together to calculate the CVI of an individual root stock. The CVI of the individual root stocks were then summed for all root stocks in the 2 x 3m area.

**Statistical Analysis**

The following null hypotheses were tested:
1. There is no difference in the RGP at lift and RGP at planting of the PxL-F2, VDF-lob, or WCO-lob.
2. Cold storage has no effect on the RGP of the PxL-F2, VDF-lob, or WCO-lob.
3. There is no relationship between RGP and field shoot and root increment for PxL-F2, VDF-lob, or WCO-lob.
4. The shoot and root increment of the PxL-F2, VDF-lob, and WCO-lob are not affected by the three treatments: control, Oust, and Oust-Garlon.
5. PxL-F2, VDF-lob, and WCO-lob do not differ in their response to competition control.
6. There is no relationship between level of weed control and root increment for the PxL-F2, VDF-lob, or WCO-lob.

Hypothesis 1 was tested by analysis of variance (ANOVA) using a one factor, completely randomized block design. Replications were established in the nursery and maintained during the RGP tests. The following model was used:

\[ Y = \text{Mean} + B_{ks_i} + G_j + \text{Error} \]

**Where:**

- \( B_{ks_i} \) = Blocks where \( i = 1, 2, 3, \ldots, 9 \) (5 seedlings each),
- \( G_j \) = seedlots where \( j = 1, 2, 3 \)
Duncan's New Multiple Range Test was used for means separation in Ho 1.

Hypothesis 2 was tested by comparing the means of the three seedlots at lifting and planting.

Hypothesis 3 was tested by linear regression.

Hypotheses 4, and 5 were tested by analysis of variance (ANOVA) using a two factor randomized block design. The following model was used:

\[ Y = M + H_i + G_j + (H_i)(G_j) + Bks_k + \text{Error} \]

where:

- \( H_i \) = Herbicide treatment where \( i = 1,2,3 \).
- \( G_j \) = Genetic background where \( j = 1,2,3 \).
- \((H_i)(G_j)\) = Interaction between Genetic and Herbicide treatments.
- \( Bks_k \) = Blocks where \( k = 1,2,3,...9 \).

Duncan's New Multiple Range Test was used for means separation in Ho 4, and Ho 5.

Hypothesis 6 was tested by linear regression. The following model was used:

\[ Y = a + b(x_1) + b(x_2) \]

where

- \( Y \) = seedling biomass increment after one growing season;
- \( b(x_1) \) = percent herbaceous ground cover;
- \( b(x_2) \) = volume of crown area for woody weeds.
RESULTS AND DISCUSSION

Root Growth Potential

There were no significant differences among seedlots in RGP at the time of lifting (Table 1). The VDF-lob seedlot had an RGP 155% and 357% greater than the PxL-F2 and WCO-lob seedlots, respectively, but because of a large variance there was no statistically significant difference (P < 0.05) among seedlots (Table 1). The PxL-F2 had a significantly greater RGP at the time of planting compared to the loblolly pine seedlots with total number of new roots 82% and 153% greater than the VDF-lob and WCO-lob seedlots, respectively (Table 1). Total length of new roots of the PxL-F2 was 109% and 233% greater than the VDF-lob and WCO-lob seedlots, respectively.

After cold storage RGP increased by 967%, 473%, and 100% for the PxL-F2, WCO-lob, VDF-lob seedlots, respectively (Table 1). Cold storage of loblolly pine can result in increased or decreased RGP depending on time of lifting, conditions of storage, and seedlot (DeWald and Feret 1987). Increases in RGP after cold storage of 100% or 150% are not uncommon. The large increases in the RGP of the PxL-F2 and WCO-lob seedlots appear to be due to the
TABLE 1. Root growth potential (number of new roots) of the pitch x loblolly pine hybrid (PXL-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco loblolly pine (WCO-lob) at the time of lifting (February 15, 1988) and planting (March 7, 1988).

<table>
<thead>
<tr>
<th>Date</th>
<th>Seedlot</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PXL-F2</td>
<td>VDF-lob</td>
<td>WCO-lob</td>
<td>mean</td>
</tr>
<tr>
<td>Lifting</td>
<td>4.7a</td>
<td>10.2a</td>
<td>3.0a</td>
<td>5.9</td>
</tr>
<tr>
<td>Planting</td>
<td>37.8a</td>
<td>20.8b</td>
<td>15.0b</td>
<td>24.5</td>
</tr>
</tbody>
</table>

1) Values in a row followed by different letters are significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.
low RGP at lifting.

**Seedling Morphology**

At the time of planting total root area, total shoot biomass, and total shoot/lateral root biomass were significantly different among seedlots ($P < 0.05$) (Table 2). PxL-F2 total shoot biomass and total shoot/lateral root biomass ratio was 14% and 32% less than the mean. PxL-F2 total root area was 29% greater than the mean. Lateral root biomass, total root biomass, total seedling biomass, total shoot/total root biomass ratio, and root collar diameter, and were not significantly different ($P < 0.05$). The PxL-F2 lateral root biomass was not greater then the loblolly pine seedlots but its greater total root area was due to a finer root system compared to the loblolly pine seedlots. PxL-F2 had 16mm$^2$/gram of root compared to 9.1mm$^2$/gram of the loblolly pine seedlots.

RGP (total number of new roots) was found to be positively correlated to the morphological variables of total root area, lateral root biomass, and negatively correlated with total shoot/lateral root biomass ratio (Table 3). Root collar diameter and total shoot/total root biomass ratio were not correlated with RGP.

The capacity to produce new roots at the time of
TABLE 2. Morphological characteristics of the pitch x loblolly pine hybrid (PxL-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco loblolly pine (WCO-lob) at the time of planting, March 8, 1988.

<table>
<thead>
<tr>
<th>Seedlot</th>
<th>Biomass</th>
<th>Biomass Ratio</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral Total</td>
<td>Shoot Tree</td>
<td>Root</td>
</tr>
<tr>
<td>PxL-F2</td>
<td>.43a</td>
<td>0.9a</td>
<td>3.2b</td>
</tr>
<tr>
<td>VDF-lob</td>
<td>.33a</td>
<td>1.0a</td>
<td>4.2a</td>
</tr>
<tr>
<td>WCO-lob</td>
<td>.31a</td>
<td>1.1a</td>
<td>3.8ab</td>
</tr>
<tr>
<td>mean</td>
<td>.36</td>
<td>1.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

1) Values in a column followed by different letters are significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.
Table 3. The correlation of seedling morphological characteristics with root growth potential (number of new roots) across all seedlots \(n = 21\) at the time of planting (March 10, 1988).

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem</td>
<td>Lateral Total</td>
</tr>
<tr>
<td>Root</td>
<td>Root</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Stem</th>
<th>Lateral</th>
<th>Total</th>
<th>Shoot</th>
<th>Shoot/ Root</th>
<th>Total</th>
<th>Lateral</th>
<th>Area</th>
<th>Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>r value</td>
<td>-0.52</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.64</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>ns</td>
<td>0.01</td>
<td>ns</td>
<td>ns</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1

*ns = nonsignificant at the p < 0.05 level*
planting and the capacity to grow roots in the nursery are not independent. Therefore, it is not surprising that total root area and lateral root biomass were correlated to RGP. Through the production of many fine roots the PxL-F2 had a root area 50% greater than the average across all seedlots (Table 2). The greater root area resulted in a 109% and 233% greater RGP compare to the VDF-lob and WCO-lob, respectively.

The correlation of the total shoot/lateral root biomass ratio with RGP implies that the shoot/lateral root ratio may be a better indicator of seedling quality than the traditional shoot/root ratio. Lateral roots are the primary means of obtaining water, therefore the exclusion of the taproot results in a refined ratio that may better predict seedling survival after outplanting.

**Seedling Survival and Root Growth Potential**

Overall mortality in the study was very low 8 percent, and there was no difference among the three seedling types. The percent mortality of PxL-F2, VDF-lob, and WCO-lob was 7%, 9%, and 7%, respectively.

Survival of loblolly pine has been shown to be correlated with RGP (Feret and Kreh 1985, Larsen et al.)
1986). All three seedlots had sufficient RGP to survive after transplanting. The WCO-lob had a relatively low RGP but it was adequate for a high rate of survival. Feret and Kreh (1985) found that seedlings required a "minimum or threshold RGP" to survive. Twenty centimeters of total root elongation was found to be necessary for high survival rate. Root growth required for survival will depend on environmental conditions and site (Ritchie 1985). All three seedlots had greater than threshold RGP values for the study site and environmental conditions were good during the first growing season. As a result, survival was high for all seedlots.

**Effectiveness of the Weed Control Treatments**

The Oust treatment significantly reduced the percentage of herbaceous ground cover to 26% of the control treatment (Table 4). The reduction in herbaceous weeds resulted in increases in both pine biomass and woody weed volume (Table 4). Other investigators have found increases in woody competition after herbaceous weed control (Bacon and Zedaker 1987). The removal of herbaceous weeds reduces competition for water and therefore results in the release both desirable and
TABLE 4. Effect of Oust and Oust-Garlon on herbaceous and woody weeds after one growing season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Herbaceous Weeds (percent cover)</th>
<th>Woody Weeds (volume M$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>53 a 1)</td>
<td>.30 a</td>
</tr>
<tr>
<td>Oust</td>
<td>14 b</td>
<td>.48 a</td>
</tr>
<tr>
<td>Oust-Garlon</td>
<td>9 c</td>
<td>.001 b</td>
</tr>
</tbody>
</table>

1) Values in a column with different letters were significantly different at the 0.05 level of probability using Duncan’s New Multiple Range Test.
undesirable trees.

The combination of herbaceous and woody weed control in the Oust-Garlon treatment reduced herbaceous ground cover to 9% of the control (Table 4). *Vaccinium* spp. which was included in the herbaceous weed category because of its herbaceous weed like growth habit was controlled by triclopyr ester. The control of *Vaccinium* resulted in the larger reduction of herbaceous ground cover in the Oust-Garlon treatment as compared to the Oust treatments. The Oust-Garlon treatment reduced the volume of woody weed competition by 99% when compared to the control (Table 4).

**Seedling Response to Weed Control Across All Seedlots**

Among treatments, the effects of weed control on the accumulation of seedling needle biomass, stem biomass, total shoot biomass, lateral root biomass, taproot biomass, and total root biomass, total tree biomass, and GLD increment were all significant (*P* < .01) when averaged across the three seedlots (Table 5). The biomass ratios of total shoot/total root, needle/lateral root, total shoot/lateral root, and total tree/needle were significantly different (*P* < 0.01) when averaged across all seedlots (Table 6). There was no difference in height
Table 5. Summary of ANOVA on the growth increment after one growing season of the pitch x loblolly pine, Virginia Department of Forestry loblolly pine, and Westvaco loblolly pine, factored with the weed control treatments: no weed control (control), herbaceous weed control (Oust), and woody and herbaceous weed control (Oust-Garlon).

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>Biomass</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Ground Line</th>
<th>Diameter</th>
<th>height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Needle</td>
<td>Stem</td>
<td>Total</td>
<td>Lateral</td>
<td>Taproot</td>
<td>Total</td>
<td>Total</td>
<td>Ground Line</td>
</tr>
<tr>
<td></td>
<td>Shoot</td>
<td>Root</td>
<td>Shoot</td>
<td>Root</td>
<td>Root</td>
<td>Shoot</td>
<td>Tree</td>
<td>Line</td>
</tr>
<tr>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>**</td>
<td>NS</td>
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<tr>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>*</td>
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<td>*</td>
<td>NS</td>
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<td>*</td>
<td>NS</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

1) WS = non significant
* = significant at the 0.05 level
** = significant at the 0.01 level
growth between the three treatments (Table 5).

Seedlot and Treatment Interactions

Lateral roots responded to weed control with a greater percentage biomass increase than other seedling part (Table 7). All significant interactions between seedlot and treatment were associated with lateral root development (Tables 5 and 6). There were interactions between seedlots and treatments for lateral root biomass, total root biomass, needle/lateral root biomass ratio, and total shoot/lateral root biomass ratio. Interactions between seedlots and treatments will be discussed below on a seedlot by treatment basis.

General Response to the Oust Treatment

Compared to the control treatment, the control of herbaceous weeds with the Oust treatment increased the biomass of all above ground seedling parts. Needle, stem, total shoot, and total tree biomass were enhanced by 59%, 70%, 64%, and 76%, respectively (Table 7). Lateral root and total root biomass were increased by 148% and 115%, respectively. The biomass ratios of needle/lateral root,
Table 6. Summary of ANOVA on the biomass ratios after one growing season of the pitch x loblolly pine, Virginia Department of Forestry loblolly pine, and Westvaco loblolly pine factored with the weed control treatments: no weed control (control), herbaceous (Oust), and woody and herbaceous weed control (Oust-Garlon).

<table>
<thead>
<tr>
<th></th>
<th>Needle/Lateral</th>
<th>Total Lateral</th>
<th>Total Shoot/Lateral</th>
<th>Total Tree/Needle</th>
<th>Total Root</th>
<th>Total Shoot/Needle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Treatment</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Seedlot</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedlot x</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) NS non significant
   * significant at the 0.05 level
   ** significant at the 0.01 level
TABLE 7. Effect of weed control treatments on seedling growth increment after one growing season across all seedlots (means); and within seedlots: pitch x loblolly pine hybrid (Pxl-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco seed orchard loblolly pine (WCO-lob).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seedlot</th>
<th>Needle</th>
<th>Stem</th>
<th>Total Shoot</th>
<th>Lateral Taproot</th>
<th>Total Root</th>
<th>Tree Height</th>
<th>Ground Line Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shoot</td>
<td>Root</td>
<td>Root</td>
<td>Tree</td>
<td>Line</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(grams)</td>
<td>(mm)</td>
<td>(cm)</td>
<td>(cm)</td>
<td>(cm)</td>
</tr>
<tr>
<td>Control</td>
<td>Pxl-F2</td>
<td>18.9 a</td>
<td>10.0 a</td>
<td>28.9 a</td>
<td>5.7 a</td>
<td>3.1 a</td>
<td>8.8 a</td>
<td>37.7 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>17.1 a</td>
<td>9.2 a</td>
<td>26.3 a</td>
<td>4.7 a</td>
<td>3.4 a</td>
<td>8.1 a</td>
<td>34.4 a</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>19.5 a</td>
<td>9.8 a</td>
<td>29.4 a</td>
<td>4.4 a</td>
<td>3.6 a</td>
<td>8.1 a</td>
<td>37.4 a</td>
</tr>
<tr>
<td>2)</td>
<td>mean</td>
<td>18.5 A</td>
<td>9.7 A</td>
<td>28.2 A</td>
<td>4.9 A</td>
<td>3.4 A</td>
<td>8.3 A</td>
<td>36.5 A</td>
</tr>
<tr>
<td>Oust</td>
<td>Pxl-F2</td>
<td>37.0 a</td>
<td>22.2 a</td>
<td>59.1 a</td>
<td>17.6 a</td>
<td>6.5 a</td>
<td>24.1 a</td>
<td>83.2 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>26.6 a</td>
<td>13.4 b</td>
<td>40.0 b</td>
<td>9.3 b</td>
<td>5.4 a</td>
<td>14.8 b</td>
<td>54.7 b</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>25.1 a</td>
<td>14.2 b</td>
<td>39.3 b</td>
<td>9.7 b</td>
<td>5.2 a</td>
<td>14.9 b</td>
<td>54.2 b</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>29.4 B</td>
<td>16.5 B</td>
<td>45.9 B</td>
<td>12.2 B</td>
<td>5.7 B</td>
<td>17.9 B</td>
<td>63.8 B</td>
</tr>
<tr>
<td>Oust-Garlon</td>
<td>Pxl-F2</td>
<td>27.9 a</td>
<td>16.4 a</td>
<td>44.2 a</td>
<td>16.0 a</td>
<td>4.7 a</td>
<td>20.6 a</td>
<td>64.9 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>32.0 b</td>
<td>18.5 a</td>
<td>50.0 a</td>
<td>11.4 b</td>
<td>6.8 a</td>
<td>18.2 b</td>
<td>68.3 a</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>24.7 a</td>
<td>16.1 a</td>
<td>40.8 b</td>
<td>8.4 b</td>
<td>5.9 a</td>
<td>14.3 b</td>
<td>55.0 a</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>28.2 B</td>
<td>16.8 B</td>
<td>45.0 B</td>
<td>11.9 B</td>
<td>5.8 B</td>
<td>17.7 B</td>
<td>62.7 B</td>
</tr>
</tbody>
</table>

1) Seedlot values, within the same treatment, in the same column with the same small case letter were not significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.

2) Treatment values in the same column with the same upper case letter were not significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.
total shoot/lateral root, and total shoot/total root were reduced by 36%, 34%, and 23% compared to the control. Compared to the control GLD was enhanced by 38% in the Oust treatment.

General Response to the Oust-Garlon Treatment

Compared to the control the Oust-Garlon treatment increased needle biomass, stem biomass, total shoot biomass, total tree biomass, and GLD, by 52%, 73%, 60%, 72%, and 38%, respectively (Table 7). Compared to the control lateral root and total root biomass were increased by 142% and 113%, respectively. The ratios of needle/lateral root biomass, total shoot/lateral root biomass, and total shoot/total root biomass were decreased by 35%, 30% and 23%, respectively (Table 8). There were no significant differences between the Oust and Oust-Garlon treatment for any seedling measures (Table 7).

Numerous authors have found that weed control during the first year stimulates pine growth (Bacon and Zedaker 1987, Knowe et al. 1985, Nelson et al. 1981, and Zutter et al. 1986). In the southeastern United States GLD generally increases in response to weed control during the first year (Miller et al. 1986). Height growth increases
TABLE 8. Effect of weed control treatments on seedling biomass ratios after one growing season across all seedlots (mean); and within treatments: pitch x loblolly pine hybrid (PXL-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco loblolly pine (WCO-lob).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seedlot</th>
<th>Needle/ Root Lateral Shoot/ Shoot/</th>
<th>Total Lateral</th>
<th>Total Tree/ Total Shoot/ Root</th>
<th>Root Needle Total Root</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lateral</td>
<td>Shoot Root</td>
<td>Lateral Needle</td>
<td>Total Root</td>
</tr>
<tr>
<td>Control</td>
<td>PXL-F2</td>
<td>3.6 a</td>
<td>5.3 a</td>
<td>2.0 a</td>
<td>3.0 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>4.1 a</td>
<td>6.2 a</td>
<td>2.3 a</td>
<td>2.8 a</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>6.0 b</td>
<td>9.0 b</td>
<td>1.9 a</td>
<td>3.3 a</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>4.5 A</td>
<td>6.8 A</td>
<td>2.1 A</td>
<td>3.1 A</td>
</tr>
<tr>
<td>Oust</td>
<td>PXL-F2</td>
<td>2.5 a</td>
<td>4.0 a</td>
<td>2.3 ab</td>
<td>2.3 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>3.3 a</td>
<td>5.0 a</td>
<td>2.2 a</td>
<td>2.5 a</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>2.9 a</td>
<td>4.6 a</td>
<td>2.9 a</td>
<td>2.5 a</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>2.9 b</td>
<td>4.5 b</td>
<td>2.2 A</td>
<td>2.4 B</td>
</tr>
<tr>
<td>Oust-Garlon</td>
<td>PXL-F2</td>
<td>2.1 a</td>
<td>3.4 a</td>
<td>2.4 a</td>
<td>1.9 a</td>
</tr>
<tr>
<td></td>
<td>VDF-lob</td>
<td>3.6 b</td>
<td>5.0 b</td>
<td>2.1 a</td>
<td>2.5 a</td>
</tr>
<tr>
<td></td>
<td>WCO-lob</td>
<td>3.5 b</td>
<td>6.0 b</td>
<td>3.5 a</td>
<td>2.8 a</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>2.9 b</td>
<td>4.8 b</td>
<td>2.3 A</td>
<td>2.4 B</td>
</tr>
</tbody>
</table>

1) Seedlot values, within the same treatment, in the same column with the same small case letter were not significantly different at the 0.05 level of probability using Duncan’s New Multiple Range Test.

2) Treatment values in the same column with the same upper case letter were not significantly different at the 0.05 level of probability using Duncan’s New Multiple Range Test.
vary depending on location and site (Miller et al. 1986). The nonsignificant difference in height among treatments are consistent with the results of other studies on the Virginia Piedmont (Bacon and Zedaker 1987, Miller et al. 1986). Bacon and Zedaker (1987) also found that the addition of woody weed control to herbaceous weed control in the first growing season may not increase seedling growth. This study confirms their findings.

**RGP vs. Seedling Response in the Control Treatment**

There was no relationship between RGP and seedling biomass increment within the control treatment. The lack of relationship between RGP and seedlot response in the control treatment implies that RGP does not measure a seedling's ability to compete with weeds as well as it measures a seedlings potential to respond in a more optimum environment. Ritchie (1985) stated that "RGP represents only a potential to grow roots. It follows that this potential may or may not be fully expressed when the seedling is outplanted."

The presence of weeds in the control treatment inhibited growth to the point that no significant differences in growth occurred among the three seedlots
(Table 7). If competition for water and nutrients alone reduced seedling growth, then higher RGP values would have resulted in greater seedling response even under stress due to competition. The pine-weed relationship may be more complicated than a simple competition for water, space, and nutrients.

The three species that were the major competitors with the pines in the control treatment were goldenrod (Solidago spp.), aster (Lactuca spp.) and pokeweed (Phytolacca americana). Goldenrod has been found to have allelopathic effects on sugar maple (Acer saccharum), (Fisher et al. 1978), black cherry (Prunus serotina), (Horsley 1976), black locust (Robinia pseudoacacia), (Larson and Schwarz 1980), and jack pine (Pinus banksiana) (Brown 1967). Lactata spp. has been found to have allelopathic effects on a number of crop plants (Rice 1964). It is quite possible these weed species may have had varying allelopathic effects on the three seedlots and thus confounded the relationship between RGP and seedling growth in the control treatment.

All seedlots had "minimum or threshold" (Feret and Kreh 1985) RGP that resulted in high survival in the control treatment, but the RGP required to allow survival may not be sufficient to allow rapid growth in periods of
competition and stress. Accelerated seedling growth under conditions of competition may require a second, higher, RGP threshold. All three seedlots may have been below the second threshold and therefore no difference in growth was possible because of competition for water, nutrients, and light.

**Control Treatment and Seedlot Response**

In the control treatment the only significant difference among seedlots was in the needle/lateral root biomass ratio (Table 8). The WCO-lob had a needle/lateral root biomass ratio that was 46% and 67% greater than the VDF-lob and Pxl-F2, respectively. After one growing season, the needle/lateral root ratio was the only morphological measure significantly correlated with RGP in the control treatment (Table 9). As RGP increased the ratio of needle/lateral root biomass decreased. Although seedlots with higher RGP did not produce significantly greater amounts of biomass, their smaller needle/lateral root ratio could have resulted in less water stress during periods of drought and competition for water.

Carlson (1986) found that the shoot/root ratio can influence the development of moisture stress in loblolly
Table 9. The correlation (r values) between root growth potential and seedling increment variables after one growing season for the treatments no weed control (Control), herbaceous weed control (Oust), and woody and herbaceous weed control (Oust-Garlon), n = 21.

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>Biomass</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Needle Shoot</td>
<td>Stem Shoot</td>
</tr>
<tr>
<td></td>
<td>(grams)</td>
<td>(gm/gm)</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------</td>
<td>------------</td>
</tr>
<tr>
<td>Control</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Oust</td>
<td>0.44</td>
<td>0.50</td>
</tr>
<tr>
<td>Oust-Garlon</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

1

ns = nonsignificant at the P < 0.05 level
pine seedlings. A comparison of transpiring surface with root surface is the best measure of absorption and transpiration capacity (Carlson 1986). An approximation of the water balance capacity is the shoot/root ratio (Carlson 1986). The shoot/root ratio affects the ability of a seedling to obtain and transpire water and therefore affects water balance. Larsen et al. (1986) reported that 80% of the variation in first-year survival of loblolly pine could be explained by a regression model including both shoot/root ratio and RGP. The relatively high WCO-lob seedlot needle/lateral root biomass ratio, which may be more accurate than the shoot/root ratio in measuring a seedling’s capacity to uptake and transpire water, may have resulted in greater water stress as compared to the other seedlots.

RGP and Seedling Growth in the Oust Treatment

Oust, a mitotic inhibitor, changes the physiological state of pine seedlings (DuPont). Compared to the control treatment the use of Oust reduced the field RGP of loblolly pine seedlings (Table 10) by 229%. However this reduction in field root growth during the first 45 days did not result in reduced first year growth in the Oust
Table 10. Effects of Oust (30 kg ai/h) on the root growth potential of field planted loblolly pine.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total Length of new roots (cm)</th>
<th>Total Number of new roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>13.3 a(^1)</td>
<td>11.2 a</td>
</tr>
<tr>
<td>Oust</td>
<td>4.3 b</td>
<td>3.4 b</td>
</tr>
</tbody>
</table>

\(^1\) Values in a column with different letters were significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.
treatment (Table 7).

Before the germination of weeds in early May the only effect of Oust on the pine seedlings was negative due to the reduction in RGP. This reduction in root growth occurred early in the season when root growth is normally slow because of cold soil temperatures. Seven weeks after Oust application soil temperatures had risen to a point that allowed weed emergence and the indirect positive effect of weed control began. The common temperature required for the germination of many Piedmont weed species is 15° to 20°C (Barton 1962, Gebben 1965). At 20°C the half-life of Oust is only 7 weeks and pine root growth would have increased due to the higher temperature. Increasing pine root growth in the Oust treatment was then probably a result of reduced competition, increased soil temperature, and the rapidly declining negative effects of Oust.

Despite the early reduction in root growth in the Oust treatment (Table 10), by November the Oust treated seedlings had a total root biomass 172% greater than the control treatment. Herbaceous weed competition did not germinate and become a factor in the control treatment until early May. After germination competition for water and nutrients increased as weed biomass increased. This
competition during the active growing season resulted in reduced seedling growth in the control treatment. Compared to the control, the end result of the Oust treatment was a 64% and 115% increase in shoot and root biomass, respectively (Table 7). The direct negative effects of Oust on pine root growth were therefore small in comparison to the negative effects of weed competition.

In the Oust treatment significant linear relationships were found between RGP (total number of new roots) and total tree ($R^2 = .26$), total shoot ($R^2 = .22$), total root ($R^2 = .32$), and lateral root biomass ($R^2 = .33$) after one growing season. There was no relationship between RGP and GLD or height (Table 11).

The Oust treatment compared to the control reduced herbaceous weed cover by 54% (Table 4) and therefore there was likely a reduction in competition for water and nutrients compared to the control (Knowe et al. 1985). Due to weed control greater root growth was possible for all seedlings, particularly seedlings with greater inherent RGP (Table 11). The greater growth of the seedlots with higher RGP may possibly be explained by a second RGP threshold. RGP of all seedlots was too low to allow growth differences among seedlots in the environment the control treatment. The reduced competition in the Oust
TABLE 11. Linear relationships between seedling biomass increment after one growing season and number of new roots (RGP) at the time of planting in the herbaceous weed control treatment (Oust treatment).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intercept</th>
<th>Slope (RGP)</th>
<th>R²</th>
<th>SE (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Stem Biomass (gm)</td>
<td>31.49</td>
<td>.52</td>
<td>.22</td>
<td>15.25</td>
</tr>
<tr>
<td>Total Tree Biomass (gm)</td>
<td>42.58</td>
<td>.77</td>
<td>.26</td>
<td>20.00</td>
</tr>
<tr>
<td>Total Root Biomass (gm)</td>
<td>11.09</td>
<td>.25</td>
<td>.32</td>
<td>5.50</td>
</tr>
<tr>
<td>Lateral Root Biomass (gm)</td>
<td>6.79</td>
<td>.20</td>
<td>.33</td>
<td>4.31</td>
</tr>
<tr>
<td>Ground Line Diameter (mm)</td>
<td>NS¹</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS = non significant
treatment resulted in an environment more conducive to seedling growth and RGP was more "fully expressed" (Ritchie 1985). In this environment the RGP of the VDF-lob and PxL-F2 was great enough to allow increased seedling growth.

Weed Control and Root Growth Potential vs. Seedling Growth Response

Significant linear relationships were found between the percentage herbaceous ground cover and seedling GLD, total seedling biomass, and total root biomass (Table 12). Including woody weed volume in the model did not significantly improve the relationship of seedling growth to herbaceous weed cover. Significant linear relationships were also found between percentage ground cover and the biomass ratio needle/lateral root (Table 13). The $R^2$ values for total seedling biomass and total root biomass were .43 and .52 respectively (Table 12). When RGP was included in the model $R^2$ values for total seedling biomass and total root biomass were improved to .51 and .60, respectively (Table 12). A greater ability to develop new roots (RGP) increases a seedlings growth in response to herbaceous weed control.
TABLE 12. Linear relationships between seedling growth increment after one growing season with percent herbaceous weed cover and number of new roots (RGP) across the control and Oust treatments, and across all seedlots.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intercept</th>
<th>Slope</th>
<th>RGP</th>
<th>R²</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLD (mm)</td>
<td>12.90</td>
<td>-0.08</td>
<td>--</td>
<td>.54</td>
<td>1.74</td>
</tr>
<tr>
<td>Total Tree Biomass (gm)</td>
<td>73.80</td>
<td>-0.71</td>
<td>--</td>
<td>.43</td>
<td>13.98</td>
</tr>
<tr>
<td>Total Root Biomass (gm)</td>
<td>20.58</td>
<td>-0.22</td>
<td>--</td>
<td>.52</td>
<td>5.05</td>
</tr>
</tbody>
</table>

**Herbaceous Weed Cover Only**

**Herbaceous Weed Cover and RGP**

| Total Tree Biomass (gm) | 61.43 | -0.71 | 0.46 | .51 | 17.88|
| Total Root Biomass (gm) | 16.85 | -0.22 | 0.14 | .60 | 4.66|
Table 13. Linear relationships of pitch x loblolly pine hybrid (Pxl-F2), Virginia Department of Forestry loblolly pine (VDF-lob), and Westvaco loblolly pine (WCO-lob) between seedlot needle/lateral root biomass ratio and herbaceous weed competition.

<table>
<thead>
<tr>
<th>Seedlot</th>
<th>Intercept</th>
<th>Slope</th>
<th>(R^2)</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Herbaceous Weed Cover (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>-----------</td>
<td>--------</td>
<td>---------</td>
<td>-----</td>
</tr>
<tr>
<td>Pxl-F2</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>VDF-lob</td>
<td>2.98 **</td>
<td>0.02 *</td>
<td>.34</td>
<td>0.81</td>
</tr>
<tr>
<td>WCO-lob</td>
<td>1.72</td>
<td>0.08</td>
<td>.86</td>
<td>0.72</td>
</tr>
<tr>
<td>All seedlots</td>
<td>2.41</td>
<td>0.04</td>
<td>.39</td>
<td>1.12</td>
</tr>
</tbody>
</table>

1) NS = non significant
* = significant at the .05 probability level
** = significant at the .01 probability level
As herbaceous weed competition decreased a relatively greater proportion of biomass production went into root growth as compared to shoot growth. Compared to the control, treatment with Oust resulted in increases of 64% and 115% for total shoot biomass and total root biomass, respectively (Table 7). This resulted in a 28% decrease in the shoot/root ratio for seedlings receiving herbaceous weed control. The needle/lateral root ratio decreased by 36% for seedlings in the Oust treatment (Table 8).

Nelson et al. (1981) and Zutter et al. (1986) both found that as weed biomass and percent ground cover increased, moisture stress in pine seedlings increased. It is a reasonable assumption that in the present study the weed control treatments effectively reduced the competition for water and therefore reduced water stress by the removal of competing vegetation. The reduction in competition for water and the larger root system would allow greater quantities of water to be available to the seedlings. The reduction in the needle/lateral root biomass ratio benefited the seedlings through a reduction in needle surface area compared to root surface area. This altered ratio may have resulted in more water absorbed by the roots and a reduction in water lost due to transpiration. Weed control therefore resulted in larger
seedlings that were better prepared to survive and grow in conditions of either adequate water supply or drought. Because of larger root systems the seedlings should also be better prepared to compete for limited water and nutrients in the advent of future herbaceous weed competition or drought.

**Pxl-F2 Response to the Oust Treatment**

The Pxl-F2 hybrid and the two loblolly pine seedlots combined had a significantly different relationship with percentage ground cover and total seedling and total root biomass (Figure 1). The intercepts and slopes were both significantly different ($P < 0.05$). The Pxl-F2 hybrid had a greater response to the Oust treatment compared to the two loblolly pine seedlots. Compared to the treatment average, Pxl-F2 stem biomass, total shoot biomass, lateral root biomass, total root biomass, and total tree biomass increased by 33%, 28%, 44%, 34%, and 30%, respectively (Table 7). As herbaceous ground cover decreased the Pxl-F2 responded with greater increases in both total tree biomass and total root biomass then the loblolly pine seedlots (Figure 1). The higher RGP values may have contributed to the greater response to weed control (Table
Figure 1. Linear relationships between total tree biomass (grams) and percent herbaceous weed cover of the pitch x loblolly pine (PxL-F2) and loblolly pine (VDF-lob and WCO-lob) after one growing season.

\[ Y = 97.16 - 1.09x \quad R^2 = .70 \]

SE = 17.17

\[ Y = 62.76 - .54x \quad R^2 = .37 \]

SE = 16.56
The Pxl-F2 had the highest RGP and therefore expressed the greatest growth response to herbaceous weed control.

Another factor that may have contributed to the greater Pxl-F2 growth was the probability that the hybrid had an extended growing season compared to loblolly pine. When seedlings were excavated in mid November 1988, soil temperatures had cooled yet active root growth was observed on some seedlings. The genetics of the Pxl-F2 may have caused active root growth to begin earlier in the growing season and continued for a longer period of time in the fall than the loblolly pine seedlots. Prolonging growth during the period of limited herbaceous competition would result in a greater return for each unit of weed control. The ability of the Pxl-F2 to respond to the control of herbaceous weeds suggests it may be a more desirable species in the Virginia Piedmont as the use of herbaceous weed control in plantation establishment becomes more prevalent.

VDF-lob Response to the Oust Treatment

The VDF-lob seedlot responded to the Oust treatment with enhanced biomass accumulation (Table 7). The VDF-lob
needle, stem, total shoot, lateral root, total root, and total tree biomass were significantly greater (P < 0.05) than the control treatment. (Table 7). VDF-lob was the only seedlot that had no significant differences in any of the biomass ratios (Table 8), despite a 25% reduction in the needle/lateral root biomass ratio between the Oust and control treatments. A linear relationship was found between the needle/lateral root biomass ratio and percentage ground cover (Table 13). The relationship between the two variables indicates that the VDF-lob seedlot may improve its ability to obtain and use water as competition decreases.

**WCO-lob Response to the Oust Treatment**

WCO-lob response to the Oust treatment was root growth and biomass ratio adjustment. The WCO-lob seedlot was the only seedlot that did not have significant increases in needle, stem, total shoot, taproot, and total tree biomass as a result of herbaceous weed control; yet, lateral root biomass, and total root biomass were significantly different between the control and Oust treatments (P < 0.05) (Table 7). Compared to the control, the Oust treatment increased lateral root biomass, and total root
biomass 118%, and 84% respectively (Table 7). The increased root biomass between treatments resulted in reductions in the ratios of needle/lateral root biomass, and total stem/lateral root biomass by 52% and 49%, respectively (Table 8).

The WCO-lob overall response to the Oust treatment was the establishment of potentially better water relations. In the control treatment the WCO-lob needle/lateral root biomass ratio was significantly greater than the two other seedlots. Through the production of lateral roots the WCO-lob needle/lateral root biomass ratio was reduced to the point that it was not significantly different than the other seedlots in the Oust treatment (Table 8). The needle/lateral root biomass ratio of the WCO-lob was 31% greater than the control treatment average. The needle/lateral root ratio had a linear relationship with percentage ground cover for the WCO-lob (Tables 13). As ground cover decreased the WCO-lob responded with less needle biomass per lateral root biomass. The altered ratio resulted in a seedling that could obtain more water via a larger root system, transpire less water because of a relatively smaller needle biomass.
General Loblolly Pine Response to the Oust-Garlon Treatment

Neither loblolly pine seedlot responded to the addition of woody weed control (Table 7). These results reaffirm the findings of Bacon and Zedaker (1987). Pxl-F2

Response to the Oust-Garlon Treatment

The use of Garlon 4 to control woody weeds inhibited the growth of the Pxl-F2. Compared to the Oust treatment all biomass measures of Pxl-F2 in the Oust-Garlon treatment decreased (Table 7). Although the decreases were not significant the trend was apparent. Shoot growth and root growth were reduced by 25% and 14%, respectively. Total biomass was reduced to 78% of the Oust treatment. The loblolly pine seedlots had small nonsignificant increases in biomass between the Oust and Oust-Garlon treatments. The reduction in Pxl-F2 growth resulted in the Pxl-F2 being smaller then the VDF-lob in total seedling biomass. Because the Oust-Garlon treatment controlled Vaccinum, significantly greater reductions in herbaceous weed cover resulted when compared to both the control and Oust treatments (Table 4). Woody weeds were also
significantly reduced (Table 4). Because the hybrid responded favorably to herbaceous weed control in the Oust treatment, further reductions of herbaceous weeds in the Oust-Garlon treatment would be expected to result in greater growth as occurred in the two loblolly pine seedlots.

The 22% reduction in PxL-F2 growth can only be explained by a sensitivity to Garlon 4. The herbicide was applied as a direct spray to the hardwood stump sprouts yet reductions in both both Vaccinium cover and PXL-F2 biomass resulted. These reductions were likely the result of the volitilization and/or drift of Garlon 4.

No conclusions about effects of the combination of woody and herbaceous weed control on PxL-F2 growth during the first year can be made from this study because of the negative effects of Garlon 4 on the PxL-F2 seedlot. Future control of woody weeds in pitch x loblolly pine plantations may need to be achieved using a herbicide other then Garlon 4.

RGP vs. Seedling Growth in the Oust-Garlon Treatment

There was no relationship between RGP and seedling growth in the Oust-Garlon treatment. The lack of
correlation between RGP and seedling growth in the Oust-Garlon treatment was likely due to the damaging effect of Garlon 4 on the hybrid.

**Seedlot Ranking Between Treatments**

Seedlot ranks in biomass production, biomass ratios, and GLD were altered between the control and Oust treatment (Table 7). Duba et al. (1984) found similar results in their study of three loblolly pine genotypes and vegetation control. Three genotypes that did not differ significantly in GLD when grown without weed control responded to herbaceous weed control with increased and significantly different growth between genotypes (Duba et al. 1984). In this study there was no difference in total biomass among seedlots in the control treatment (Table 7). Herbaceous weed control resulted in significantly greater PxL-F2 biomass increment as compared to the loblolly pine seedlots (Table 7). The VDF-lob seedlot tended to respond to the addition of woody weed control with greater growth than the WCO-lob. Therefore the ability to rapidly grow in a weed free environment can not be equated to an ability to grow under conditions of competition.
CONCLUSIONS

Herbaceous Weed Control

The control of herbaceous weeds during the first growing season resulted in accelerated seedling growth. GLD increment, stem biomass, and root biomass increased in response to weed control. Lateral roots had the greatest response to weed control. All seedlot and treatment interactions were associated with lateral roots.

The large response of lateral roots to weed control caused a diminished needle/lateral root biomass ratio in favor of the lateral roots. The smaller ratios may better prepare seedlings to respond to periods of drought, and therefore may affect future survival and growth when herbaceous weed competition returns.

The ability to respond to weed control is related to RGP. As herbacecus ground cover decreases the ability to produce new lateral roots and exploit available water increases as RGP increases. Higher RGP values result in lower needle/lateral root biomass ratios and potentially better water relations.

The pitch x loblolly pine hybrid had a greater response to herbaceous weed control than the loblolly pine seedlots. This can be attributed to higher RGP values. The rapid growth of the hybrid after herbaceous weed
control and its cold hardiness should make it a viable alternative to loblolly pine on the Virginia Piedmont and similar areas.

The WCO-lob had the lowest RGP and the least response to herbaceous weed control. Only lateral and total root biomass were significantly increased in the Oust treatment. This resulted in a lower needle/lateral root biomass ratio compared to the control and therefore, potentially better water relations.

The VDF-lob seedlot responded to herbaceous weed control with biomass accumulation. The needle/lateral root biomass ratio decreased by 20% but was not statistically different between the control and Oust treatments.

Herbaceous and Woody Weed Control

First season control of woody weeds in combination with herbaceous weed control did not result in significantly greater increases in loblolly pine growth when compared to herbaceous weed control alone. Other investigators have obtained similar results on the Virginia Piedmont (Bacon and Zedaker 1986). Woody weed control may therefore be delayed until later in the
rotation.

The use of Garlon 4 to control woody weeds caused a 22% reduction in PxL-F2 total biomass compared to the Oust treatment. Due to the possible sensitivity to Garlon 4, the control of woody weeds in pitch x loblolly pine plantations will need to be accomplished using another herbicide.
LITERATURE CITED


VITA

Andrew D. Barnes, son of Lewis G. and Myra C. Barnes was born in Bradford, Pa. After obtaining an Associate Degree in Forest Technology at the Williamsport Area Community College in Williamsport, Pa. he lived and worked in Haiti. While in Haiti he worked in reforestation with the Baptist Haiti Mission and later the Pan American Development Foundation. He returned to the United States and has earned a B.S. in Forestry at the University of Maine and a M.S. in Forestry at Virginia Tech.

He is married to Donalda Smith Barnes, and has two children, Sarah and Michael.