Forestry Research Review -- 1974
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ON THE COVER: Dr. M. M. Larson records data from oak seedlings
planted in crocks and placed in controlled temperature water
baths to maintain various soil temperatures.
Acorns of northern red oak, *Quercus rubra* L., require about 8 to 10 weeks of constant cold and moist conditions before much germination will occur. This cold requirement is commonly provided to nursery seeds by burying them in layers of sand below the frost line in the fall. This procedure is called stratification.

In studying this stratification process, it was found that application of a plant hormone, gibberellic acid (GA), to the acorns reduced the amount of chilling required for germination. It was also observed that seeds induced to germinate in this manner grew differently than the controls.

When GA was applied to the seeds either before or after stratification, stem growth was markedly increased. Initially, the roots emerged and grew more rapidly after the GA treatments. This trend became less apparent after about 1 week, when roots of the GA-treated seeds began to grow more slowly than the controls (Table 1). By this time, the development of the stem had begun. The stems of the GA-treated seeds grew more rapidly throughout the 18-week experimental period.

Figures 1 and 2 illustrate the effects of soaking stratified seeds in an increasing biochemical gradient of gibberellic acid. It is clear that as the amount of gibberellin applied was increased, stem growth increased at the expense of root growth.

If the level of GA applied was above 100 p.p.m., the stem became very slender and was subject to breakage. If the amount applied was less, stem growth was nearly normal. Seeds treated with 100 p.p.m. GA following stratification grew 25% taller than the controls and developed roots only 6% shorter.

<table>
<thead>
<tr>
<th>TABLE 1.—Length of Emerging Roots from Germinating Red Oak Seeds Soaked in Water (Control) or 500 p.p.m. Gibberellic Acid (GA).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root Length (cm.)</td>
</tr>
<tr>
<td>Days after Planting</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

*Significantly different from the control at the 1% level (t-test).
FIGS. 1 and 2.—Stem and root growth at 18 weeks of northern red oak seedlings from stratified acorns treated with a gibberellin inhibitor — 2-(chloroethyl) trimethyl-ammonium chloride (CCC), water, or gibberellic acid (GA). Means significantly different at 5% level within each dependent variable have different letters above the histograms.
It appears that treatment levels of GA could be judiciously selected to produce seedlings with an appropriate root/shoot ratio. For example, GA might be applied to prepare acorns for a planting site where moisture may be sufficient but competition for sunlight with native plants is a problem. Rapid initial root growth to provide water to the seedling would not, in this case, be as critical as the need for rapid stem elongation to enhance the plant's capacity to compete for sunlight. On a dry site, however, any treatments which would inhibit root growth should be avoided.
POSSIBLE METHODS FOR THE IMPROVEMENT
OF YELLOW-POPLAR SEED GERMINATION

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Department of Forestry

Yellow-poplar, *Liriodendron tulipifera* L., ranks with oak as one of Ohio's most important forest trees for hardwood lumber and veneer production. Although state nurseries in Ohio produce and ship more than 600,000 seedlings each year, demand often exceeds supply, and collection of adequate amounts of yellow-poplar seed is an annual problem. Although the tree is a prolific seed producer, often less than 10% of the seeds are capable of germinating. Techniques for increasing germination and survival of yellow-poplar would thus be of considerable interest to nurserymen.

Stratification requirements for germination of yellow-poplar can be partially replaced by applications of a plant hormone, gibberellic acid (GA). Studies indicate that stratification conditions which provide a constant cool (2°C) and moist environment for at least 10 to 15 weeks are required to achieve 3% germination of seed. In this laboratory test, GA doubled germination to 6% after only 4 to 5 weeks of stratification.

Another study was conducted at the State Nursery at Marietta, Ohio Department of Natural Resources, Department of Forests and Preserves. In this instance, percent survival of GA-treated or untreated seeds which had received 5 months of moist chilling in polyethylene bags at 2°C was compared with similar seeds which had received 5 months, 1-1/2 years, or 2-1/2 years of stratification in sand pits at the nursery. Figure 1 illustrates that soaking the seeds in GA doubled the percent survival attained with seeds pit-stratified for 1 year. It was also obvious that stratification in polyethylene bags at a constant 2°C for 5 months (treatment S) was more efficient than pit stratification for up to 2-1/2 years.

These results suggest the feasibility of soaking yellow-poplar seeds with GA at some time prior to germination, preferably at the onset of stratification. This simple procedure would likely insure the nurseryman that the seeds will receive adequate chilling for germination in 1 year and could more than double ultimate seedling production of yellow-poplar.

Cooperative research with the state nurseries in this area of increased production of yellow-poplar was enhanced by the recent addition of the OARDC Nursery. It is likely that other tree species yet to be tested will respond similarly to applications of growth hormones.
FIG. 1.--Effects of various methods of stratification on survival of yellow-poplar seedlings. Treatments consisted of pit stratification in sand for 5 months, 1-1/2, or 2-1/2 years, or holding seeds in plastic bags for 5 months at 2°C. without GA (S) or soaked in 250 p.p.m. GA prior to (G/S) or following chilling treatment (S/G). Histograms with dissimilar letters above were significantly different at the .05 level. Each mean based on three plot estimates.
EFFECTS OF TEMPERATURE ON EARLY GROWTH OF OAK SEEDLINGS

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Seedling establishment is a critical stage in the regeneration of a new stand of trees. Oak seedlings, whether starting from acorns or as outplanted nursery stock, must produce new roots in order to survive and grow. The new roots grow into the deeper soil layers which are less subject to moisture depletion by evaporation. At the same time, seedling roots must compete with established vegetation for water and mineral salts.

The OARDC Department of Forestry recently completed several studies to determine how variations in temperature and soil moisture influence the early growth of oak seedlings. Special attention was given to initial root growth as this is a key factor in seedling establishment. This article summarizes the results of the temperature studies. The following article summarizes the soil moisture studies.

In the field, the temperature effect on seedling growth is difficult to separate from the effects of light, wind, humidity, etc. Thus, oak seedlings were grown in greenhouses and growth chambers (Figures 1 and 2) where temperature and other environmental factors were closely controlled.

**Seedling Growth After Germination**

Freshly germinated seeds of both northern red oak (*Quercus rubra*) and white oak (*Q. Alba*) were planted in glass tubes filled with vermiculite. Root growth was observed

**FIG. 1.--**Oak seedlings planted in crocks and placed in controlled temperature water baths to maintain various soil temperatures.

**FIG. 2.--**Oak seedlings in a growth chamber. Acorns planted in glass tubes held in a light-proof box which opens for root measurements.
TABLE 1.--Average Growth of Northern Red Oak and White Oak Seedlings at Four Constant Temperatures.

<table>
<thead>
<tr>
<th>Temperature °F.</th>
<th>55°</th>
<th>65°</th>
<th>75°</th>
<th>85°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Oak at 20 Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taproot length (cm.)</td>
<td>14.4</td>
<td>26.4</td>
<td>30.0</td>
<td>28.2</td>
</tr>
<tr>
<td>Lateral roots (no.)</td>
<td>26</td>
<td>128</td>
<td>159</td>
<td>137</td>
</tr>
<tr>
<td>Height growth (cm.)</td>
<td>2.4</td>
<td>8.6</td>
<td>9.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Plant dry weight (g.)</td>
<td>0.16</td>
<td>0.42</td>
<td>0.70</td>
<td>0.59</td>
</tr>
<tr>
<td>White Oak at 28 Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taproot length (cm.)</td>
<td>20.7</td>
<td>30.0</td>
<td>32.6</td>
<td>30.0</td>
</tr>
<tr>
<td>Lateral roots (no.)</td>
<td>35</td>
<td>66</td>
<td>81</td>
<td>43</td>
</tr>
<tr>
<td>Height growth (cm.)</td>
<td>0.5</td>
<td>3.5</td>
<td>8.0</td>
<td>6.8</td>
</tr>
<tr>
<td>Plant dry weight (g.)</td>
<td>0.66</td>
<td>0.66</td>
<td>0.98</td>
<td>0.55</td>
</tr>
</tbody>
</table>

through the glass (Figure 2). Seedlings were subjected to four constant temperature treatments and 12 different day/night temperature regimes, the latter consisting of all combinations of the four constant temperatures.

Of the four constant temperature treatments, seedlings of both oak species grew best at 75°F. (Table 1). Growth was less at higher (85°F.) or lower (55° and 65°F.) temperatures.

Height growth of white oak was greatly reduced at the two coolest temperatures. This is probably a genetic adaptation, since white oak acorns germinate in the fall and any top growth would likely be winter killed. Red oak seeds germinate in the spring when seedling tops are less subject to freezing. Another conspicuous difference between the species was the greater number of lateral roots on red oak seedlings at the warmer temperatures (Table 1).

The seedlings from each of the 12 alternating day/night temperature regimes grew in direct relation to the amount of heat received during each 24-hour period. The day to night temperature differential, as such, had little effect. Hence, growth was related to the average daily temperature, whether or not the day/night temperature alternated or was held constant.

These results apply only to newly germinated seedlings. Other research has shown that after oak seedlings reach full leaf and the cotyledons drop off, growth is enhanced by warm days and cool night conditions which favor photosynthesis.

The temperature studies demonstrate the benefits of properly prepared seedbeds for oak regeneration. Removal of overstory trees speeds the warming of the soil by the sun. Elimination of overtopping herbaceous competition further increases the light and heat to seedlings, and therefore enhances seedling establishment.
Growth of 1-0 Nursery Stock

Oak seedlings are normally lifted from the seedbed in March or April. A lifting bar severs the taproots near the 8-inch depth and the seedlings are then pulled, baled, and shipped to the planting site. When outplanted, the trees must regenerate a new root system since few of the first-year lateral roots resume growth after planting.

Studies were conducted to find out how soil temperature influences root regeneration of freshly lifted stock. Soil temperatures were controlled by planting the trees in crocks which were then placed in controlled temperature water baths (Figure 1). Some of the seedlings were moved to different temperature baths each morning and evening to obtain alternating day and night soil temperatures.

Seedlings regenerated large new root systems after 30 days at the warmer soil temperatures (Figures 3 and 4). Seedlings in soil at 75° and 85° F. averaged 3.5 new roots totaling 32 to 37 cm. in length (Table 2).

Seedling growth was poor when soils were cool. With 55° F. soil, for example, seedlings averaged only 0.8 new roots, and shoot growth was only one-half of that of seedlings at warm soil temperatures (Table 2). The poor shoot growth in cool soil is surprising since the air temperature around all the trees averaged 75° F. (Figure 4). Dormant seedlings have abundant food reserves in roots, and the mobilization of these reserves is apparently temperature dependent.

Alternating the day to night soil temperature provided no growth advantage over constant temperatures for either roots or shoots. As with newly germinated seedlings described earlier, growth was related to the total daily soil heat. A close correlation ($r^2 = 0.88**$) was found between the dry weight of new growth (roots, stems, and leaves) and the daily soil heat sum.

A temperature pretreatment to stimulate root regeneration after planting was also tested. This consisted of placing roots in soil at 75° F. while tops were held in air at 36° F. The pretreatment period varied from 1 to 3 weeks.

The pretreatment was only moderately successful. Roots and shoots of seedlings pretreated 1 week tended to grow slightly better than untreated trees, but only at the warmer soil temperature. Longer pretreatment reduced growth.

<table>
<thead>
<tr>
<th>Soil Temperature °F.</th>
<th>55°</th>
<th>65°</th>
<th>75°</th>
<th>85°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root regeneration (no.)</td>
<td>0.8</td>
<td>2.3</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Total root length (cm.)</td>
<td>1.8</td>
<td>15.8</td>
<td>37.0</td>
<td>32.3</td>
</tr>
<tr>
<td>Length new shoots (cm.)</td>
<td>5.8</td>
<td>8.2</td>
<td>12.2</td>
<td>13.1</td>
</tr>
<tr>
<td>Leaf area (cm.$^2$)</td>
<td>128</td>
<td>212</td>
<td>310</td>
<td>302</td>
</tr>
</tbody>
</table>
FIG. 3.--Root regeneration of 1-0 northern red oak trees in soil at 75°F. Most new roots from near the cut end of the taproot.

FIG. 4.--Growth of red oak seedlings after 30 days at four soil temperatures.

These studies with 1-0 stock clearly show that root regeneration and height growth is directly related to the soil temperature, at least during the first weeks after planting. Cultural treatments which increase soil temperature will aid seedling establishment.

At Wooster, the average maximum soil temperature at the 2-inch depth reaches only 80°F in late July. Since the study trees grew comparatively well at a constant 85°F, most planting areas probably do not attain excessive soil temperatures for growth. However, very high temperatures at the soil surface often injure seedling stems at the ground line.
EFFECTS OF SOIL MOISTURE ON EARLY GROWTH OF OAK SEEDLINGS

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Department of Forestry

Tree seedlings must often endure periods of high soil water stress. The amount of water in soils can be reduced to levels which cause high stresses in several ways. Most of the water in the upper soil layers is lost through evaporation or removed by competing plants. Drought periods, poor infiltration of water into heavy soils, or poor water retention by sandy soils may limit soil water supplies. When soil water deficits reach critical levels, seedling growth is reduced or stopped altogether.

The objectives of the studies were: 1) to find a suitable method to experimentally control the soil water stress to tree seedlings, 2) to observe how various soil water stress conditions alter the initial root and shoot development of newly germinated oak seedlings, and 3) to determine how soil stresses affect the vital process of root regeneration and early growth of 1-0 red oak nursery stock.

Control of Soil Water Stress

The close control of soil water stress to plants is difficult to achieve. The soil water nearest the roots is absorbed first. Since water moves slowly in unsaturated soils, the soil next to the root becomes drier than soil farther away, especially when the rate of water absorption by the plant is high. Measurement of the water tensions at the root-soil boundary is very difficult.

These problems were largely overcome by subjecting the oak seedlings to artificial drought conditions which could be controlled. Seedlings were planted in a vermiculite soil medium and saturated with nutrient solutions containing various amounts of polyethylene glycol (PEG). The PEG, an inert material, lowered the osmotic potential of the soil solutions, thereby inducing an osmotic water stress to the seedling roots.

Several PEG solutions were used. These provided osmotic water stress conditions from -1/3 bars to -8 bars osmotic potential (1 bar is a unit of measure approximately equal to 1 atmosphere pressure, the negative sign indicates an osmotic potential value). Seedlings were watered several times each day to maintain nearly constant water stress conditions.

For reference, the water stress to plants in loam soil at field capacity is about -1/3 bars potential, and the water stress when leaves permanently wilt is about -15 bars potential. Thus, the stresses used in these studies are frequently encountered in the field.

Growth of Newly Germinated Seedlings

Seeds of northern red oak (Quercus rubra) and white oak (Q. alba) were germinated in a flat and the seedlings planted in vermiculite-filled glass cylinders when the taproots were about 1 inch long. The glass tubes were held in a lightproof box located in a growth chamber maintained at 75°F. constant temperature. (See Figure 2 of preceding article.)
TABLE 1.--Average Growth of Oak Seedlings After 36 Days at Various Water Stress Conditions.

<table>
<thead>
<tr>
<th></th>
<th>Water Stress Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oak Species</td>
</tr>
<tr>
<td>Lateral roots (no.)</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>White</td>
</tr>
<tr>
<td>Seedling dry wt. (g.)</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>White</td>
</tr>
</tbody>
</table>

FIG. 1.--Effects of low, moderate, and high soil water stress on initial shoot and root growth of oak seedlings after 6 weeks.
The PEG solutions used were -1/3, -4, and -8 bars osmotic potential, representing low, moderate, and high water stress conditions, respectively.

Both oak species grew well at low water stress condition (Figure 1, Table 1). Seedling taproots elongated almost 2 feet in only 36 days, which demonstrates the enormous potential of oak seedlings to develop deeply penetrating taproots. High water stress (-8 bars) greatly reduced all aspects of seedling growth, even though this stress condition is far less severe than the theoretical wilting point of -15 bars.

Red oak seedlings formed three times more lateral roots than white oak seedlings when water stress was low. The red oaks began stem elongation when taproots were 4 to 6 cm. long, whereas the white oaks delayed the start of stem growth until taproots had elongated 18 to 22 cm. At high stress, white oak seedlings formed the most laterals and had the longest taproots.

These results indicate that white oak seedlings endure drought conditions better than red oak and may explain, at least in part, the presence of white oaks on relatively dry sites.

**Growth of 1-0 Nursery Stock**

This section summarizes results of studies which determined how soil water stress conditions affect the vital process of root regeneration and early growth of red oak nursery stock. Trees were planted in vermiculite-filled pots and watered with PEG solutions of various osmotic potentials to simulate soil stress conditions. Growth was measured at 6 weeks.

The trees grew well at the low (-1/3 bar) water stress condition, as expected (Figure 2). At -4 bars (moderate stress), all aspects of growth decreased, and at -6 bars, shoot growth was severely reduced and root initiation was totally suppressed.

When seedlings were allowed to regenerate new roots at low stress and then transferred to -6 bar condition, the roots continued to grow at slow rates for several weeks. These results suggest that a growing root can continue to elongate in soil too dry for initiation of new roots.

The water stress treatments also affected seedling growth and development in other ways. As the soil stress condition increased, the number and size of leaves decreased. At low stress, time to bud break averaged only 6 days, compared to 32 days for trees at the greatest stress (-6 bars). New shoots emerged from the terminal bud cluster at low stress, but at greater stress conditions new shoots originated lower on the stem and the uppermost stem buds died (Figure 3). Seedlings planted in the field exhibit similar symptoms when subjected to severe drought periods.

These studies demonstrated the necessity of moist conditions for rapid establishment of planted oak trees. Root regeneration is particularly sensitive to even moderate soil stress conditions. Thus, areas selected for planting must be free from heavy plant competition and dry sites should be planted with more drought-tolerant species.
(Increasing Water Stress →)

FIG. 2.--Average number and length of new roots per tree after 6 weeks at various soil water stress conditions.

FIG. 3.--Red oak seedling grown at a moderately high soil stress condition. The stem is dead and a new shoot has sprouted from the base.
ROOT INITIATION INDUCED BY ROOT PRUNING IN NORTHERN RED OAK

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Department of Forestry

The artificial reforestation of hardwoods is a costly process, yet there are at least four instances when planting of hardwoods can be justified: 1) to control the genetic characteristics of the trees in the new stand, 2) to modify the species composition of the new stand, 3) to maintain a preplanned stocking density (trees/acre), and 4) to prepare for possible future intensification of hardwood silviculture.

Artificial regeneration of oak species is particularly difficult. Seed production is extremely variable between years. Collection of seed is expensive and seeds usually deteriorate when stored for more than 1 year. Direct seeding often fails due to loss of acorns to rodents. Outplanting of seedlings requires thorough site preparation, which is expensive.

Successful outplanting of northern red oak (Quercus rubra L.) is dependent on a seedling height growth rate greater than that of surrounding vegetation. Northern red oaks have a moderately well developed taproot so that nursery lifting, which involves running a steel blade under the seedling 8 inches (20 cm.) below the soil surface, removes the lower portion of the taproot. Few, if any, lateral roots are present on the pruned taproot of lifted seedlings. Prompt root regeneration (i.e., the initiation and growth of new lateral roots after planting) is required to provide the seedling with water and nutrients necessary for rapid height growth, and thus for survival.

Root pruning is necessary, not only for efficient lifting of nursery grown seedlings, but also for obtaining a root system short enough for efficient handling and field planting. It has been known for some time that root pruning stimulates new lateral roots to form near the cut end of the root (Figure 1). Partial root pruning is also a common practice in preparing nursery grown saplings to be balled and burlaped prior to transplanting.

As early as the 1880’s, it was suggested that the buds or young leaves provided a stimulus for the rooting of stem cuttings. In 1935, the synthetic plant hormone indoleacetic acid (IAA), which also occurs naturally in plants, was shown to stimulate root initiation in cuttings.

Few studies have been made of the control of lateral root initiation. In 1970, a program was started at the OARDC to study the nature of the biochemical stimuli involved in lateral root initiation following root pruning in northern red oak.

One part of the program was to test the effects of IAA and triiodobenzoic acid (TIBA), an inhibitor of IAA transport within the plant, on root initiation following root pruning. The trees were pruned, placed in an aerated solution containing IAA or TIBA for 24 hours, and then transferred to a nutrient solution for 30 days. This work showed that synthetic IAA stimulates root initiation in northern red oak and that TIBA, which prevents the transport of naturally occurring IAA, inhibits root initiation (Table 1).
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Concentration (p.p.m.)</th>
<th>Total No. New Lateral Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIBA</td>
<td>17.500</td>
<td>0.0</td>
</tr>
<tr>
<td>TIBA</td>
<td>0.175</td>
<td>2.4</td>
</tr>
<tr>
<td>TIBA</td>
<td>0.017</td>
<td>6.0</td>
</tr>
<tr>
<td>IAA</td>
<td>0.100</td>
<td>8.0</td>
</tr>
<tr>
<td>IAA</td>
<td>0.500</td>
<td>5.4</td>
</tr>
<tr>
<td>IAA</td>
<td>1.000</td>
<td>6.5</td>
</tr>
<tr>
<td>IAA</td>
<td>10.000</td>
<td>8.2</td>
</tr>
<tr>
<td>IAA</td>
<td>50.000</td>
<td>4.3</td>
</tr>
<tr>
<td>IAA</td>
<td>100.000</td>
<td>36.3</td>
</tr>
<tr>
<td>IAA</td>
<td>200.000</td>
<td>113.8</td>
</tr>
<tr>
<td>Control (H₂O)</td>
<td></td>
<td>4.6</td>
</tr>
</tbody>
</table>

FIG. 1.—(A) Root regeneration on a northern red oak seedling after root pruning. Note the position of the new roots near the cut end of the taproot. (B) Root initials near the cut end of the taproot before they have elongated enough to break through the root epidermis.
The amount of IAA in the pruned oak taproot was measured between the time of pruning and the time of root initiation. The results of this study (Figure 2) indicate a very pronounced increase in IAA levels within the root just after pruning and a few days prior to the time when new roots emerge through the epidermis of the taproot. This increased IAA level could be at the time of the first cell divisions, leading to formation of lateral roots.

At present, attempts are being made to characterize the root both anatomically and biochemically to identify any correlations between changes in biochemical environment and changes in the tissue which signal the beginning of root initiation. In addition to IAA, the levels of other hormones (cytokinins), which have the property of promoting cell division at very low concentrations and inhibiting cell division at higher levels, are being measured.

Other investigators have shown that undifferentiated callus tissue cultured from a portion of a soybean cotyledon will form roots when the IAA/cytokinin ratio is high, will shoot when this ratio is low, or will remain as callus at an intermediate ratio. Cytokinins are produced in root tips. It is thus possible that when oak roots are pruned the natural source of cytokinins is removed, decreasing their concentration in the root while increasing the IAA level. This could be a key factor in root initiation as shown by the tissue culture experiments. Further work is necessary to test this hypothesis and to clarify the relationships involved.

When the natural system controlling root initiation is understood, practical treatments to insure rapid root initiation on outplanted tree seedlings can be recommended.

![Graph showing changes in IAA content](image)

**FIG. 2.**—Changes in indoleacetic acid (IAA) level in the taproot of northern red oak seedlings following root pruning. Upper segment is from root collar down 10 cm. and lower segment is from 10 cm. down to the point of root pruning at 20 cm.
Although fertilization is a common practice in agriculture, it has not been used extensively in the production of most forest crops. The relatively low value of many wood products and the long period of time during which costs must be compounded are often considered prohibitive for many intensive cultural practices such as fertilization. In addition, it has often been assumed that nutrient requirements of forest species are relatively low and fertility of forest sites is adequate for tree growth.

In the production of Christmas trees, however, length of rotation and value of product are favorable for use of intensive cultural practices, including fertilization. Inherent soil fertility is often inadequate on many old-field sites on which Christmas trees are planted, particularly for the more exacting species such as the firs, spruces, and Douglas-fir. Lack of adequate information on optimum levels of nutrients for soils or plant tissue has been a major limitation in the past to the development of efficient and effective fertilization programs for Christmas tree plantation management. As a consequence, fertilization has often been done with little or no knowledge of the type and amount of fertilizer actually needed or the probable response to that fertilizer.

Major objectives of the comprehensive Christmas tree research program at the OARDC include developing standards for soil and foliar diagnosis of nutrient requirements of Christmas tree species, and developing recommendations for fertilization of Christmas tree plantations based on these standards. This work has centered on three major areas of study: 1) determination of critical elemental levels below which trees show reduced growth and/or symptoms of nutrient deficiencies, 2) study of response of different tree species and varieties to additions of fertilizers, and 3) study of possible variations in nutrient requirements of different seed sources or provenances of the same tree species.

Field evaluations of commercial Christmas tree plantations are being used as the primary technique to determine critical elemental levels needed for good growth and foliage characteristics of different species. Plantings growing on a wide variety of sites are selected for sampling. Growth, vigor, and foliage characteristics of trees on each plot are measured or rated. Paired soil and foliage samples are then collected and chemically analyzed to determine their respective nutrient contents. In addition, complete site information is taken, including soil descriptions and topographic data. Statistical comparisons are then made of growth, vigor, and foliage characteristics in relation to all of the factors measured on each plot.

Initially, these comparisons are used to indicate if critical level nutrient standards can be developed for each species growing on all types of sites, or whether separate standards will be needed for each species growing on more homogeneous areas. Subsequent statistical analyses are used to consider tree performance in relation to foliar and soil levels of plant nutrients, particularly nitrogen, phosphorous, potassium, calcium, and magnesium. From these, it is hoped that standards can be developed by using either soil or foliar diagnosis to indicate whether specific elements are deficient, low, sufficient, high, or in excess.
To date, evaluations in these field studies have concentrated on four species: Douglas-fir (Pseudotsuga menziesii), Fraser fir (Abies fraseri), balsam fir (Abies balsamea), and Colorado or blue spruce (Picea pungens). More than 400 plots at 15 sites in 11 Ohio counties have been sampled (Figure 1). It is anticipated that future samplings will be expanded to include: Norway spruce (Picea abies), white spruce (Picea glauca), white pine (Pinus strobus), and Scotch pine (Pinus sylvestris).

A second series of studies is aimed at evaluating the response of Christmas tree species growing on diverse sites to specific applications of fertilizer materials. The first plots

FIG. 1.--General locations of sites used in field evaluations of commercial Christmas tree plantations (numerals) and field fertilization studies (letters).
TABLE 1.--General Characteristics of Sites Used in Field Fertilization

<table>
<thead>
<tr>
<th>Area Letter and County</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wayne</td>
<td>Coshocton</td>
<td>Ashtabula</td>
<td>Ashland</td>
<td>Athens</td>
</tr>
<tr>
<td>Soil Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>silt loam</td>
<td>sandy loam</td>
<td>loamy sand</td>
<td>loam</td>
<td>silty clay</td>
</tr>
<tr>
<td>Drainage Class</td>
<td>well</td>
<td>well</td>
<td>well</td>
<td>well</td>
<td>poor</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
<td>6.2</td>
<td>5.1</td>
<td>5.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Total Nitrogen, %</td>
<td>0.12</td>
<td>0.09</td>
<td>0.11</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>Phosphorus, Lb./Acre</td>
<td>50</td>
<td>150</td>
<td>110</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Potassium, Lb./Acre</td>
<td>300</td>
<td>175</td>
<td>140</td>
<td>225</td>
<td>230</td>
</tr>
<tr>
<td>Calcium, Lb./Acre</td>
<td>2500</td>
<td>1500</td>
<td>750</td>
<td>900</td>
<td>6500</td>
</tr>
<tr>
<td>Magnesium, Lb./Acre</td>
<td>550</td>
<td>375</td>
<td>100</td>
<td>125</td>
<td>550</td>
</tr>
</tbody>
</table>

were planted in 1971 and 1972 at five locations (Figure 1, Table 1) using six species: Douglas-fir, Fraser fir, white spruce, Norway spruce, white pine, and Scotch pine. The major objective was to determine response of the different species to additions of nitrogen fertilizer at rates of 0 to 225 lb. per acre. However, areas were also limed to increase the pH to a minimum of approximately 6.0, and phosphorous and potassium were added to bring levels up to a minimum of 30 and 200 lb. per acre, respectively. In addition, one plot in each series received no weed control (weeds on all others were chemically controlled) in order to compare effects of competition on growth and tree nutrition. Initial fertilizations of these plots were made in the spring of 1973.

Results in the fall of 1973 were variable but a few general trends seem to be apparent. Most conclusive were the effects of weed control. Nearly all species on all sites showed some increases in nutrient content in the foliage where chemical weed control was used. Increases in foliar levels of nitrogen with additions of fertilizer varied, but appeared to be highest on sites where total nitrogen in the soil was near or below 0.10%. Samplings to be taken in 1974 and succeeding years should provide more conclusive results than the first-year data obtained in 1973.

Two additional plots were planted in Coshocton County in 1973 (Figure 1, Location B) to evaluate effects of nitrogen application methods (surface vs. disked-in) and nitrogen form (quick release urea vs. slow release sulfur-coated urea) on establishment and growth of five species (Douglas-fir, Fraser fir, blue spruce, white pine, and Scotch pine). Nitrogen fertilizers were applied just prior to or just after planting at rates of 0 to 225 lb. per acre. Results at the end of 1973 showed definite decreases in survival of seedlings as fertilization rate increased. Although there is some possibility that this was caused by increased weed competition, it appears more likely that the decreased survival resulted from too high levels of soluble fertilizer near the roots of the newly planted seedlings.
FIG. 2.--Growth of seed sources of Scotch pine from Scotland, northeastern France, and Spain at nutrient levels ranging from low to very high.
A third series of studies aimed at determining the response of Christmas tree species to fertilizer additions involves evaluating possible beneficial effects to near-marketable sized trees. Two stands of Douglas-fir, each approximately 10 years old, were fertilized (primarily with nitrogen, but also with lime, phosphorous, and potassium as noted earlier). The first of these was fertilized in the spring of 1972 (Figure 1, Location F). Definite increases in foliar levels of nitrogen were noted in samplings made in the fall of 1972 and 1973. Visual appearance of trees also improved. The second of these areas was fertilized in the spring of 1974 (Figure 1, Location G).

Greenhouse studies constitute the third major area of concentration in the study of Christmas tree fertilization. To date, these studies have concentrated on possible differences in nutrient requirements of different seed sources or provenances of Scotch pine and Douglas-fir. Seedlings of different seed sources are grown from seed in cultures having the same proportions of the essential plant nutrients but with different total concentrations (from very low to very high). In the first of these studies, 10 different provenances of Scotch pine were grown at 11 nutrient levels for 8 months. Results indicated there were pronounced differences in nutrient requirements of seedlings grown from seed of different portions of the Scotch pine range (Figure 2).

Although field studies will have to be conducted before drawing final conclusions from these studies, results indicate that varying rates of fertilization should be used in nursery beds for different seed sources of Scotch pine in order to promote the most desirable shoot and root growth of the different provenances. Similar studies are currently underway with five seed sources of Douglas-fir, and initial results indicate there may also be decided variations in levels of nutrient requirements for this species. This could be of considerable importance, since fertility requirements of Douglas-fir are generally considered to be much higher than for Scotch pine. If final results show there are large differences in fertility requirements of various seed sources of Douglas-fir, field studies will be initiated to determine fertilization rates needed for different provenances growing under nursery and field plantation conditions.
Lignin is the substance in wood cells which gives wood its characteristic strength and hardness. It is also the source of large amounts of waste in the pulp and paper industry. Lignin, which forms a bond between wood cells (or fibers, as they are called in the paper industry), must be dissolved with chemicals and heat to produce pulp for papermaking. Most woods contain about 30% lignin by weight, which is reduced to 1 to 5% in the pulping process. Thus, for every ton (dry weight) of pulpwood processed, about 500 lb. of lignin are removed.

If cellulose is the most abundant organic chemical on earth, lignin is a close second. Cellulose has many uses; lignin has few. Some lignin is burned as fuel in the pulp mills; however, the energy required to recover it from the dilute solution after pulping is very nearly equal to its own heat energy value. Much lignin is dumped into waterways where it is degraded by microorganisms at a high oxygen cost.

At OARDC, research is underway to determine some of the basic aspects of lignin formation in wood and other plant cells. Environmental factors, which may influence the amount of lignin formed in wood, are also being investigated. There are indications from studies of cereal crops that the amount of lignin in cells might be affected by mineral nutrients in the soil, especially calcium and phosphorus.

In a preliminary study, slash pine seedlings were grown in nutrient solutions containing various combinations of high, medium, and low concentrations of calcium and phosphorus. Slash pine is a southern species not native to Ohio, but was chosen because it grows rapidly and does not require stratification for germination. The seedlings were harvested after 10 weeks of growth in the solutions, and the lignin content of their stems was determined. Low levels of both calcium and phosphorus produced seedlings with the highest lignin content. Conversely, high levels of calcium and phosphorus produced the lowest lignin contents (Figure 1).

Apparently it is not necessary to have both phosphorus and calcium at high levels to produce a low lignin content in the seedlings. When calcium was high, lignin content was low, even at a low phosphorus level. High phosphorus and low calcium also produced low lignin. These results are similar to findings with wheat stems by other workers.

As Figure 1 shows, the highest average lignin content was about 38% and the lowest was about 31%, for a difference of 7%. A lowering of lignin content by 7% would lower the extracted lignin from pulpwood by about 100 lb. per ton.

The next step will be to estimate lignin content in wood formed by large trees growing under various levels of calcium and phosphorous fertilizer. This experiment indicates that applications of limestone and phosphate may lower the lignin content in wood. If these findings hold up in field studies, an economic analysis will be made of fertilizer costs and benefits in terms of decreased pulping costs and waste treatment.
FIG. 1.—Relationship of lignin content of slash pine stems to calcium (Ca) and phosphorus (P) levels in the nutrient medium. The seedlings were grown from seed on vermiculite saturated with Hoagland's solution which contains all essential nutrients. The medium level of Ca and P was the normal amount in half-strength Hoagland's solution, 103 p.p.m. Ca and 16 p.p.m. P. The high level was three times normal and the low level was one-third normal. All nine combinations of Ca and P levels were tested. At the end of 10 weeks, the seedlings were harvested and the lignin content in the stems was determined.
Spruce gall aphids are not true aphids and cannot be controlled with conventional aphicides. The eastern spruce gall aphid, *Adelges abietis* (L.), infests Norway and white spruce, causing circular, spiny galls at the base of new twigs. This adelgid does not have an alternate host, and consequently it can continue to cause galling each year on the same tree.

Other spruce gall aphids, including the Cooley spruce gall aphid, *A. cooleyi* (Gillette), form galls on spruce only after migrants from a secondary host (Douglas-fir in this case) reach spruce. There will be no galling (pineapple-like swellings on the ends of new twigs) on Colorado blue spruce if they are completely isolated from the source of migrants (Douglas-fir).

Growers often ask how much separation between Douglas-fir and spruce is required to prevent *A. cooleyi* migrants from reaching spruce. Although a definite answer cannot be given to this question, live migrants have been trapped 3 miles from the nearest Douglas-fir. This indicates that it is almost impossible for a grower to produce clean Colorado blue spruce without using insecticides if he or a neighbor is growing Douglas-fir. Some growers plant these two conifers either side by side or in adjacent blocks. This can be done successfully only if a good chemical control program is followed.

During the past several years, the Woody Ornamentals Laboratory, Department of Entomology, OARDC, has been developing new insecticides and techniques to improve control practices for spruce gall aphids. Some of this work has culminated in new recommendations; other studies have either been unsuccessful or are not yet perfected enough to be cleared by the Environmental Protection Agency.

**Experimental Approach**

Many Christmas trees in Ohio are planted on hilly, uneven ground bordered by deciduous hardwoods. Access roads to these blocks of trees are usually not adequate to permit movement of heavy equipment among the trees when the ground is wet (early spring and late fall). Since these are the times when spruce gall aphids are exposed and vulnerable to pesticides, control measures were attempted for both eastern spruce gall aphid and Cooley spruce gall aphid, employing aerial application. Lindane and Sevin were sprayed on individual blocks of spruce and Douglas-fir, utilizing 1 lb. of actual insecticide in 3 to 18 gallons of water or diesel fuel per acre. The high gallonage was used to improve coverage, although it was known that more than 3 gallons of finished spray per acre, applied by helicopter, was not economical.

None of the aerial application studies indicated that Cooley spruce gall aphid on sheared Douglas-fir can be effectively controlled by air. The aerial treatments were effective on spruce, a more open tree which permits better penetration of spray droplets.
Other work in Ohio, New York, Pennsylvania, and Washington has demonstrated that several of the carbamate insecticides, applied by ground equipment, are extremely effective against spruce gall aphids. In 1973, Sevin (carbaryl) was registered for this use. The recommendation is 1 lb. of actual insecticide (1-1/4 lb. of Sevin 80 S or 1 qt. of Sevimol 4) per 100 gal. of water. This spray should be applied in late fall or early spring (before bud break) by mist blower or hydraulic sprayer, using 100 gal. of finished spray per acre on small trees (up to 4 feet high) and 200 gal. per acre on larger trees. Complete coverage and proper timing are the keys to successful control of spruce gall aphids.

Five years ago, experimentation began with systemic insecticides, applied to the soil, to control spruce gall aphids. All experiments prior to 1973 failed. In 1973, five insecticides were applied on cultivated ground at the dripline of 6 to 8-foot Norway and white spruce on April 15. One of the insecticides prevented any new gall formation, another material radically reduced galling and killed all adelgids within the aborted galls which did develop, and a third material also looked promising.

Results from 1973 indicate that soil-applied systemic insecticides can be used to kill all gall aphids on spruce. Work is continuing in an effort to develop a new recommendation utilizing this approach for spruce planted in the landscape.

Summary

Aerial application of Sevin or lindane will control spruce gall aphids on spruce but not on Douglas-fir. Both insecticides can be used successfully on both conifers if applied by ground equipment in late fall or early spring.
SOIL-SITE QUALITY RELATIONSHIPS FOR YELLOW-POPLAR
AT TAR HOLLOW STATE FOREST

Larry C. Munn
Department of Forestry

Yellow-poplar (*Liriodendron tulipifera*) is an important component of Ohio's woodlands. This species, which had a standing volume in 1968 of 1,099.1 million board feet, is utilized extensively for its clear, easily worked wood and, to a lesser extent, for pulp. Yellow-poplar is very sensitive to soil nutrient and moisture levels and achieves its best development on cool, moist, nutrient-rich sites. In southeastern Ohio, it is commonly found growing on north and east facing slopes, or in sheltered coves.

Yellow-poplar, commonly called tuliptree, is a sub-climax species which requires a moist mineral seedbed and full sunlight for successful establishment. Under these conditions, it exhibits rapid height growth and will normally out-compete other species, forming a nearly pure, even-age stand. Tuliptree does not reproduce successfully under a closed canopy and generally requires a drastic disturbance of the existing forest vegetation, such as fire or clear cutting for establishment. The species reproduces well from stump sprouts following harvesting, which results in frequent appearance of trees with multiple trunks.

Because of its sensitivity to soil nutrient levels, there is considerable interest in its potential response to fertilization and other intensive cultural practices. It is highly desirable, in intensive forestry, to be able to accurately predict the volume of wood products which will be produced on a given site by a given tree species under a particular set of cultural practices. Productivity indicators for forest sites have been based on a wide range of site conditions, soil types, and tree species. As a result, they have not been consistently accurate when applied to an individual species and site.

An attempt is being made to develop a predictive model for yellow-poplar on a restricted range of sites. This study, which is being conducted at Tar Hollow State Forest and at the OARDC, is an attempt to develop a height-growth predictive model for tuliptree on sites mapped as Muskingum silt loam, G slope (25-70%). This particular soil mapping unit was chosen because of its widespread occurrence as a site supporting yellow-poplar in southeastern Ohio. Past studies have shown that the current system of soil mapping is not of immediate utility as an indicator of site quality, since wide variations in timber productivity have been found between sites occurring in similar mapping units. It is believed, however, that the present soil mapping system will provide a useful base for site quality evaluation if coupled with other readily measurable site factors such as effective soil depth, slope position, aspect, and available soil nutrients.

Approximately 40 plots, each encompassing at least five dominant or codominant crown class yellow-poplars, will be evaluated. Each plot tree is represented by a composite soil sample taken from 10 borings around the tree. Available nutrients in these 200 plus samples will be analyzed to correlate observed tree growth with soil fertility. Such soil tests have proven useful for evaluating productivity of agronomic crops, but application to forest situations has been limited by the general lack of data necessary to provide the correlations between soil nutrient levels and tree growth during the rotation period.
Easily measured indicators of soil fertility, such as pH and cation exchange capacity, will be determined, as well as the physical factors of slope position, soil depth, and aspect. The ages of plot trees have been determined by increment borings and the heights measured. Correlations between production at a given age and site quality will be determined.

Studies were conducted in the OARDC greenhouse facilities to determine possible factors which might limit yellow-poplar growth in the field. Emphasis so far has been directed towards soil pH, the effects of liming, and soil bulk density. Results indicate that increased bulk density of the subsoil and reduced thickness of the A horizon following soil erosion may limit growth of tuliptree on the Muskingum silt loam soil. Erosion is not usually a problem in well-managed forest soils; however, large areas of reforested land in southeastern Ohio eroded heavily following earlier clearing of the forest for crop production or pasture.

In one study, yellow-poplar seedlings were grown in cans of Muskingum subsoil material packed to various bulk densities (1.10 g./cc., 1.35 g./cc., and 1.60 g./cc.), and limed to four pH's—5.1 (unlimed), 5.5, 6.0, and 6.5. Analysis of the seedlings' root systems showed decreasing penetration and root length (length of the longest root) with increasing bulk density. Liming the soil from the original pH of 5.1 to 5.5 and 6.0 gave an increase in the length of the longest root, while liming to pH 6.5 seemed to be detrimental. An interaction between pH and bulk density was also observed in the case of root length.

Since 1.10 g./cc. is the natural bulk density of the A horizon and 1.60 g./cc. is the natural bulk density of the B horizon in Muskingum soil at Tar Hollow, these results suggest that seedling establishment would be enhanced by loosening the subsoil through subsurface tilling at the time of planting. The detrimentally high bulk density of the subsoil provides insight into why the thickness of the A horizon is such an important factor in site quality (in addition to nutrient supply). Interestingly, root weight was not significantly affected by either bulk density or pH, indicating that perhaps the morphology of the roots was altered rather than total dry matter production.

It is hoped that the present study will accomplish two objectives: 1) provide an accurate predictive model for site quality of the Muskingum soil for growth of yellow-poplar, and 2) give an indication of cultural practices which may be utilized to increase production on sites impoverished by mismanagement in the past.
RAINFALL INFILTRATION ON COAL MINE SOILS

John Vimmerstedt, Paul Sutton, and James Finney
Departments of Forestry and Agronomy

Infiltration is the word used to describe movement of precipitation into the soil. When rain falls on the soil surface, it either soaks in (infiltrates), runs off, evaporates into the air, or remains on the surface as puddles. On coal mine soils, there has been special interest in comparing the amount of rain entering the soil through infiltration and the amount running off the surface.

Clogging of stream channels with sediment from mined areas is a severe problem in southeastern Ohio. For example, highway crews spend a lot of time removing mud from roads and drainage ditches downslope from surface mines. Runoff water brings sediment from the spoil banks to the streams, roadside ditches, and fields and pastures on the lower slopes and in the bottoms. The search is on for effective ways of reducing erosion of mine soils.

The spray infiltrometer is a tool used in studying infiltration, runoff, and sediment loss (Figure 1). Water is pumped from storage tanks through a spray nozzle onto a 1/3,000-acre plot. Water running off the plot is collected by a suction system into a calibrated tank, where rate of runoff is recorded on a chart (Figure 2).

By controlling water pressure and nozzle height, the amount of rain applied is known. By measuring how much is running off, the amount of infiltration can be determined by subtraction. (Infiltration = Rainfall minus Runoff.) There is a shunt in the vacuum collection system, so small samples of the runoff water can be taken to measure its sediment content.

Using the spray infiltrometer, investigations have been conducted on the effects of subsoliling and mulching on infiltration and sediment yield from toxic acid mine soils. Subsoliling creates deep channels which allow rapid infiltration of water (Figure 3). Mulching protects the soil surface from the erosive force of raindrop impact. These treatments were tested in various combinations to see if sediment loss could be reduced and infiltration

FIG. 1.--Jim Finney and Paul Sutton operating the sprinkling infiltrometer on Unit 2 of the EORDC.
increased on a toxic acid mine soil on Unit 2 of the Eastern Ohio Resource Development Center near Caldwell.

The treatment combinations used were:

1. Mulching followed by disk ing.

2. No mulching, disk ing followed by subsoiling in one direction.

3. No mulching, disk ing followed by subsoiling in two mutually perpendicular directions.

4. Mulching, disk ing, subsoiling in one direction, followed by a second mulching.

5. Mulching, disk ing, subsoiling in two directions, followed by a second mulching.


FIG. 3.--Paul Sutton subsoiling a toxic acid mine soil at Unit 2, EORDC.
Moldy hay at 2.2 or 4.4 tons per acre was used as the mulch. Plots were subsoiled on 2-1/2 foot centers to a depth of 18 inches. Plots to be subsoiled were first mulched at the rate of 2.2 tons per acre. Following subsoiling, 2.2 tons of additional mulch were applied on the surface. Plots not subsoiled but mulched received 2.2 tons of mulch strewn on the surface and disked in with a heavy-duty disk.

In making the tests, artificial rain was applied for 1 hour at 4.5 inches per hour. This high rate of rainfall has the energy of raindrop impact similar to a summer thunderstorm. A second run was made on each plot, 1 day after the first run, to see how the treatment effects changed following a single rainstorm. Rainfall was also applied on two sets of plots in July and on two other sets in September to see if treatment effects changed during the summer.

Results

Soil Erosion. Results show that mulching is very effective in reducing erosion from these toxic acid mine spoils (Figure 4). Without mulching, subsoiling tended to increase sediment yield, probably because subsoiling loosened up the soil and made individual particles easier to detach.

Infiltration. Both mulching and subsoiling increased total infiltration during a 1-hour run (Figure 5). Subsoiling plus mulching increased infiltration by a factor of 10 more than the no subsoiling-no mulching treatment during the dry runs. Infiltration was consistently higher during the initial dry runs than during the wet runs the next day, but no difference was detected in infiltration between the plots receiving rain in July and those receiving rain in September.
Conclusions

Mulching, by itself, will greatly reduce sediment loss from acid, toxic mine soils.

Subsoiling alone, without addition of a protective mulch cover, is not a good practice because sediment yield increases, and the channels formed by subsoiling are rapidly sealed by soil particles.

Subsoiling combined with mulching will give rapid infiltration, thus reducing runoff. Where mine soil is apt to slip downhill, as on the outer edge of banks resulting from contour mining, rapid infiltration may not be a management goal. On the other hand, on the bench areas of contour-stripped mines, or in mines employing area stripping, subsoiling combined with mulching has considerable potential for reducing runoff.
Ohio's major soil types and climatic conditions are represented at the Research Center's 13 locations. Thus, Center scientists can make field tests under conditions similar to those encountered by Ohio farmers.

Research is conducted by 15 departments on more than 6500 acres at Center headquarters in Wooster, nine branches, Green Springs Crops Research Unit, Pomerene Forest Laboratory, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres
Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres
Green Springs Crops Research Unit, Green Springs, Sandusky County: 26 acres

Jackson Branch, Jackson, Jackson County: 344 acres
Mahoning County Farm, Canfield: 275 acres
Muck Crops Branch, Willard, Huron County: 15 acres
North Central Branch, Vickery, Erie County: 335 acres
Northwestern Branch, Hoytville, Wood County: 247 acres
Pomerene Forest, Laboratory, Keene Township, Coshocton County: 227 acres
Southeastern Branch, Carpenter, Meigs County: 330 acres
Southern Branch, Ripley, Brown County: 275 acres
Western Branch, South Charleston, Clark County: 428 acres