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EFFECTS OF SOIL MANAGEMENT PRACTICES IN A FOREST

TREE NURSERY ON SOIL PROPERTIES AND ON

LOBLOLLY PINE SEEDLINGS

By

JACK T. MAY

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of Michigan
State University of Agriculture and Applied Science
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Department of Forestry

Year 1957

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Effects of Soil Management Practices in a Forest Tree Nursery on Soil Properties and on Loblolly Pine Seedlings

The effects of various soil treatments on germination of loblolly pine seed, development of seedlings, survival of out-planted seedlings, chemical content of seedlings, and soil characteristics were investigated during a three-year period. Treatments included different combinations of green manure crop and seedling rotations, methyl bromide applications, three levels of sawdust applications, and three levels of phosphorus and potassium applications.

Soil samples were analyzed to ascertain the effects of treatments on soil reaction, organic matter content, cation exchange capacity, available phosphorus, available potassium, exchangeable calcium and exchangeable magnesium. Seedling characteristics were evaluated by physical measurements and chemical analyses.

Methyl bromide treatments did not affect germination of seed or development of seedlings.

Sawdust applications reduced seedling shoot/root ratios, lowered the soil acidity, and increased the organic matter content and the cation exchange capacity of the soil. The soil organic matter content was reduced when sawdust and green manure crops were omitted. A green manure crop in a rotation increased the percentage of plantable seedlings and the survival of out-planted stock.

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The original level of available phosphorus was not maintained by the heaviest application of phosphorus, 450 pounds of P_2O_5 per acre. In an annual seedling rotation, 160 pounds of K_2O per acre maintained the level of available potassium at about 70 ppm of K.

Applications of mineral fertilizers immediately prior to sowing of seed did not affect germination of seed or mortality of seedlings. When phosphorus and potassium applications were omitted, the percentage of plantable seedlings was reduced. There was a direct relationship between the phosphorus and potassium content of the plant foliage and of the soil. Loblolly pine seedlings made a heavy drain on soil calcium and magnesium.

EFFECTS OF SOIL MANAGEMENT PRACTICES IN A FOREST TREE NURSERY ON SOIL PROPERTIES AND ON LOBLOLLY PINE SEEDLINGS

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CHAPTER I

INTRODUCTION

Loblolly pine (<u>Pinus taeda</u> L.) grows over a larger area and under a wider variety of conditions than any of the other southern pines (Lotti, 1956). Its range extends from southern New Jersey southwestward in a broadening crescent for a distance of nearly 1500 miles to Oklahoma and Texas. Loblolly pine is taking over many areas formerly dominated by longleaf pine (<u>Pinus palustris</u> Mill.) (Wahlenberg, 1946). It is one of the most valuable trees in the south, providing about one-half of the pine timber (Dorman and Sims, 1949).

Loblolly pine grows to a larger size faster than any of the other southern pines. During the first twenty years or so, slash pine (<u>Pinus elliottii</u> Engelm.) within its natural range may grow faster, but beyond that, and up to about 80 years, loblolly pine exceeds all other southern pines.

Loblolly pine is being extensively used for reforestation in the south. Of the 438,924,000 seedlings produced in 14 southern states in 1953-54, 36 per cent were loblolly pine (Myers, 1955). The proposed increase of state and private nurseries will expand seedling production in the southern region to nearly one and one-half billion seedlings by 1960. Because of its rapid growth, its adaptability to a variety of sites and its utility for numerous uses, loblolly pine should continue

to rank high in reforestation.

Artificial regeneration of forests has been a most important work for quite a long time in Europe. The technique and practice in the European nurseries has reached an amazing degree of perfection by continual improvement based on research and experience. Before 1939, of the two billion seedlings produced annually in Germany about 70 per cent were grown in privately owned forest tree nurseries (Pein, 1953). Many of these nurseries had been in the same family for over a hundred years. In contrast, of the 173 forest tree nurseries in the United States in 1954, 122 or 70 per cent were owned by public agencies. Forest tree seedling production in the United States started about the beginning of the twentieth century (Pettis, 1909; Bates and Pierce, 1913; Tillotson, 1917).

In general, survival and early growth of the planted trees have been fairly satisfactory when the nursery fertility level has been high and planting has been done properly. Mortality sometimes has been relatively high during the first year when precipitation in late winter or in spring was deficient, particularly on sites which are naturally dry (Stoeckeler and Limstrom, 1950). Wakeley (1935) reported that quality of planting stock affected not only the survival of southern pine seedlings, but also their rate of growth during the first several years. He devised a grading system based on such morphological characteristics as stem height, stem diameter, root length, and presence or absence of fascicled needles and winter buds. Wakeley stated that "The most conspicuous differences between grades result from differences

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in seedbed environment, in age, or in both. Low-grade seedlings result more often from overcrowding than from any other cause. Poor soil quality, abundance of weeds, and insufficiency of water are other important factors. The most clearcut results obtained by the Southern Forest Experiment Station in its planting experiments have been those bearing on the use of various grades of planting stock. These results have been abundantly confirmed by general experience practically throughout the southern pine region."

Later, Wakeley (1948) found that grades based on morphological characteristics were not a reliable index of a plant's capability for survival and growth. Wakeley states "Beginning in 1933-34, the planting of southern pines increased tremendously. At about the same time, discrepancies in the morphological grades began coming to light. One of the commonest was better survival of medium-sized or grade 2 plantable stock than of larger or grade 1 plantable stock". Wakeley found that, when seedlings of the same morphological grade were drawn from different nurseries and planted together on the same site, survival was consistently high for stock from some nurseries and consistently low for stock from other nurseries. There was a distinct tendency for one nursery to produce stock whose true grade was consistently above the average and for another nursery to produce stock whose true grade was consistently below the average, even when both nurseries received the same fertilizer and soil management treatments. Wakeley (1948) states "Evidently something about an individual nursery could, without showing in morphological grade, produce an internal chemical or

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physiological condition in the seedlings which greatly influenced their survival".

Wakeley (1948) found that fertilizer experiments in a single nursery substantiated the evidence that soil conditions influence physiological grades independently of morphological grades. Working with longleaf pine, he found that two fertilizer treatments significantly raised average morphological grade, but of these, one treatment significantly raised and the other significantly lowered physiological grade, as shown by subsequent survival.

The variability in morphological and physiological quality of stock is not surprising when the following factors are considered: (1) variability in seedling size and nutrient requirements, (2) variability in physical and chemical soil characteristics between nurseries and within nurseries, and (3) the scarcity of information regarding the fertilizer needs of a specific nursery or a specific species.

Huberman (1940a) found considerable variation in the mean dry weights of normal one-year-old nursery planting stock. The mean dry weights in grams per plant were: loblolly pine - 2.30, shortleaf pine - 2.89, slash pine - 3.97 and longleaf pine - 5.85. In general, the nutrient requirements are proportional to the yield of ash or dry weight. Thus the nutrient requirements for a longleaf pine seedling might be about 2.5 times that of a loblolly pine seedling.

Wilde (1938, 1946a) found that, in Wisconsin and adjoining states, the analysis of virgin soils under productive stands of various tree species gave the closest approach to the physiological optimum of growth conditions. Such data provided not only the amount of nutrients, but the constant ratio of various constituents, which is the chief prerequisite to balanced nutrition of seedlings. Youngberg and Austin (1954) found that Wilde's procedure was applicable to certain areas in the Pacific Northwest.

The low inherent fertility of the red and yellow podzolic soils in the southern pine region has been mentioned by several authors (Bennett, 1921; Bureau of Chemistry and Soils, 1938; Heyward and Barnette, 1934; Logan, 1916; and Wahlenberg, 1946). The soils are strongly leached, acid in reaction, and low in organic matter and plant nutrients. In much of the southern region, crop failures have so often followed the effort to grow truck crops on land which has just been cleared that there has developed a general opinion among truck growers that new ground is not suited to the growing of many crops the first year after clearing. Ware (1936), reporting on experiments at the Alabama Gulfcoast Substation, stated that "It was apparent long before maturity of the crops that those plots receiving no phosphorus would produce practically no crops, and that the almost complete absence of available phosphorus was one specific cause of crop failure on new ground even for crops to which phosphorus applications are not usually considered necessary. Where phosphorus was applied in adequate quantities for good production, crop yields however were still very low except where quantities of nitrogen were applied much in excess of amounts generally required on old ground". Ware found that the second year yields increased two to four-fold, even though no nitrogen was added. He attributes this increase to a release of nitrogen due to bacterial decomposition. May (1938) found the same response in a forest tree nursery. He reports that the poorest longleaf seedlings produced the second year of cultivation compares very favorably with the best stock produced the first year after clearing.

Very little information is available regarding the nutrient requirements of southern pine seedlings. The following comments expressed the sentiment of participants attending the first Southern Conference of Nursery and Planting Specialists (W. W. Ashe Nursery Conference", 1937). "Fertilizers: - not generally used in nurseries. A standard fertilizer cannot be recommended because of varying soil requirements. Each nursery must work out its own fertilizer requirements and study them continually. Better no fertilizer than the wrong fertilizer. Lime should be used sparingly, if at all, in conifer nurseries". In the thirties, most southern nurseries were using a 2-1 or a 1-1 rotation of forest trees and green manure crops. About 300 pounds of a complete fertilizer such as 4-8-4 or 6-10-7 was applied prior to the green manure crop. Wakeley (1935) stated that "very heavy applications of almost any fertilizer may cause injury or high mortality among young southern pine seedlings, particularly of the smaller-seeded species".

Cossitt (1937) recommended a 1-1 rotation rather than 2-1 rotation for the Stuart Nursery. He reported that the 2-1 rotation depleted the soil to such an extent that the class of stock was materially affected, resulting in an increased percentage of culls. He expected that the depleted condition would be corrected by a 1-1 rotation and two green manure crops per year.

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Nursery practice did not change materially during the period 1937 to 1949. In 1949, nurserymen were still applying from 200 to 400 pounds per acre of complete fertilizers and attempting to correct pronounced deficiencies by side dressing of any recommended fertilizer (Muller, 1949).

An additional factor that complicates the soil fertility problem is the fact that the same soil management practice is being used for all species. A species that produces twelve tons of oven-dry matter per acre each year receives the same fertilization as one that produces only six tons of oven-dry matter per acre. Nutrient requirements of individual species have been ignored.

Several investigations have been concerned with the effect of certain types of nursery management on the morphological characteristics of southern pine seedlings. Huberman (1940b), May (1933), and Scarbrough and Allen (1954) have shown that the largest and best seedlings are produced at low seedbed densities. Compost applications have resulted in increased root growth and stem growth (Muntz, 1944). Andrews (1941), Auten (1945), and Rosendahl and Korstian (1945) obtained variable responses for fertilizer ammendments. Westveld (1946) studied the response of slash pine to various nutrients in Norfolk soils in Florida. He was concerned primarily with branch and needle development and with root/shoot ratios. Maki and Henry (1951) found that root rot of pine seedlings could be controlled or partly alleviated by increasing the amounts of organic matter and fertilizers.

Numerous investigators in the field of Agronomy and Horticulture have recorded the effects of various soil management practices on soil

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fertility, and chemical composition of plants. Very few such studies have been reported, however, for forest seedling nurseries in the southern pine region.

An understanding of the effects of specific soil management practices on soil nutrients and mineral uptake by seedlings is essential if the nursery objective is the production of high-quality planting stock. In 1950, exploratory studies were initiated for the purpose of testing the effects of specific soil treatments on loblolly pine seedling development. In 1953, a study was initiated for the purpose of determining how specific soil management practices affect the chemical composition of the soil and the mineral content of one-year-old seedlings. The results of these investigations form the basis for this paper.

CHAPTER II

REVIEW OF LITERATURE

Basic Considerations

There is an abundance of literature on the general subjects of soil management, plant nutrition and crop yields. Rather complete reviews of literature are available on each phase of these subjects. Many of the results of general soils and plant investigations are applicable in the management of forest tree seedling nurseries. Only a few of the general contributions that have a direct bearing on the present investigations need be included with the contributions that are specifically associated with the subject at hand.

According to Wilde, *et al.* (1942) general investigations of fertilizer influence on tree growth were initiated about the middle of the nineteenth century. These early studies were concerned with the effects of fertilizers upon the growth of plantations and young forest stands. Nearly every tree species that is used extensively in reforestation has received some attention. Colby (1933) reviewed much of the literature on mineral nutrition in conifers from the work of Duhamel Du Monceau in 1775 to 1932. Colby included the recent work done by German scientists (Kübler, Bauer, Ramann, Gossner, Süchting, John, Dienes, Weidelt and Manshard) on seasonal absorption of nutrient salts from the soil by forest trees, both coniferous and dicotyledonous. Leyton (1948) discusses variations in mineral composition of foliage according to location on the tree, season of year, time of day, and age of tree. Rennie (1955), after investigating the uptake of nutrients by mature trees, concluded that a continuing nutrient removal in silvicultural cuttings would have an increasingly important long term effect on forest growth and the soil.

Leiningen (1931) found that many of the early investigations were unreliable because a number of important conditions were overlooked or misinterpreted. In many instances, highly productive forests were found on soils with a low content of plant nutrients. A number of misconceptions developed because the fact that trees are able to utilize nutrients from a tremendous volume of soil was overlooked. Wilde (1941) reports that some of the theories advanced discounted the importance of nutrients for growth of trees, particularly seedlings. These misconceptions were carried over so far that some European nursery managers suggested that starved seedlings raised on infertile soils were especially well suited to reforestation.

Many of the older Germany nurseries maintained soil fertility by using farmyard or stable manure plus some N, P, and K fertilizers. Benzian (1951) and Pein (1953) report that almost continuous crops have been grown for over 100 years. However, the importance of nursery soil fertilization has been fully recognized only during the past few decades (Wilde, 1946a).

A large number of conflicting reports from early and recent investigations have increased the complications involved in the problem of nursery soils fertilization. Wilde (1946a) partly attributed this confusion to a lack of general knowledge concerning soil chemistry and plant physiology.

It has been stated that the field trial represents the ultimate test to which any other proposed method of nutritional diagnosis must be submitted (Goodall and Gregory, 1947). But, as a diagnostic method, the field trial is subject to a number of disadvantages, namely (1) the results cannot be used during the year in which the trial is set up, (2) its results are subject to substantial errors and (3) it makes very heavy demands upon labor. Other diagnostic methods that have been widely used include sand or water cultures, soil analyses, and plant analyses. The value of these diagnostic measures have been widely tested by a number of investigators.

Goodall and Gregory (1947) discuss the merits of the following methods used for the diagnosis of fertilizer requirements of plants: field trials, pot culture methods, soil analysis, plant analysis, and observation of deficiency symptoms. They give the content of nutrients in plant material for a large number of species in relation to the incidence of deficiency or toxicity symptoms. They reviewed thoroughly the literature devoted to agricultural and horticultural crops.

Leyton (1948) reviewed the advances that have been made in the study of mineral nutrition of forest trees and discussed the applications of the work to forestry practice.

Effects of Nutrients on Development of Seedlings of Native Species

Pot cultures, soil analyses, plant analyses and deficiency symptoms have been used in the United States by a number of investigators working with forest seedlings.

A considerable number of investigations were made by graduate students who could investigate only a small segment of a problem or by field investigators who were limited by the lack of equipment and facilities. Anderson, C. E. (1933), Argetsinger (1941), Clifford (1929), Haman (1916) and Stoeckeler (1931) studied the effects of fertilizer on northern species. Felker (1938), Kapel (1939) and Sundling (1929) investigated the relationship between the soil reaction and seedling development. Andrews (1941), Forbes (1945), Lynch et al. (1943), McComb (1941), Rosendahl and Korstian (1945) Schopmeyer (1939), Voigt (1949), and Westveld (1946) investigated nutritional and physiological characteristics of loblolly pine or other species.

Clark (1916), Hansen (1923), Kopitke (1941), Larsen and Stump (1939), McIntyre and White (1930), Mitchell (1934, 1936, 1939), and Wilde (1938) have investigated the nutritional requirements of eastern white pine (Pinus strobus L.). Clark (1916) found that eastern white pine seedlings remove a large amount of nutrients from the soil each year. On the basis of chemical analyses of white pine seedlings, he concluded that a crop of seedlings removed 94.6 pounds of nitrogen, 31.8 pounds of phosphoric acid and 41.6 pounds of potassium per acre. Hansen (1923) found that seedlings grown without fertilizer treatments produced more dry weight than those receiving fertilizer treatments. He suggested that coniferous seedlings remove very little minerals from the soil.

Mitchell (1934, 1936, 1939) made exhaustive studies of nutrient requirements of eastern white pine and Scotch pine (Pinus sylvestris L.). Growing these species in sand cultures, he determined for the soil solu-

tions, the region of the minima, the working region, the region of tension, and the toxic region for nitrogen, phosphorus, potassium, and calcium. He found that seedling yield measured as total dry weight was almost directly proportional to nitrogen supply up to a concentration of 300 ppm. Greater concentrations of nitrogen caused a reduction in growth. Root/shoot ratio was affected adversely by increasing the nitrogen supply. The maximum root/shoot ratio was obtained with a nitrogen supply of 50 ppm in solution whereas the maximum yield was obtained at a concentration of about 300 ppm. Corsican pine (Pinus laricio Poir) grew to a much greater size than Scotch or eastern white pine in solutions of equal nitrogen supply and showed no signs of retarded growth in concentrations as high as 485 ppm of nitrogen.

Mitchell (1939) found that white pine seedling yield was almost directly proportional to phosphorus concentration up to about 200 ppm in solution. Greater supplies of phosphorus were toxic to even a greater extent than equivalent excess concentrations of nitrogen.

White pine seedling yield was almost linearly related to potassium concentrations up to about 100 ppm. The point of maximum yield was about 150 ppm. Increases in calcium supply up to about 100 ppm were accompanied by yield increments somewhat comparable in magnitude to those obtained with equivalent amounts of potassium. Between calcium concentrations of 100 to 350 ppm, there was but little change in seedling yield. At concentrations above 350 ppm seedling yield decreased as the calcium concentration increased. Mitchell's data indicate an optimum N-P_2O_5-K_2O ratio of approximately 2-4-1.

By analyzing the plant material, Mitchell obtained the internal concentration of nitrogen, phosphorus, potassium and calcium and then determined the relationship between the soil solution concentration and the seedling concentration of these elements. He also found that needle color could be correlated with nutrient content.

McIntyre and White (1930), working with a silt loam soil, found that only small additions of nitrogen (20 pounds per acre), but larger additions of phosphorus (80 pounds of P_2O_5) and potassium (50 pounds of K_2O), were needed to produce good quality planting stock of eastern white pine, pitch pine (Pinus rigida Mill.) and Norway spruce [Picea abies (L.) Karst.]. In some instances, the addition of calcium was necessary for best results.

Wilde et al. (1938, 1940, 1946a, 1955) have made exhaustive investigations of the fertility standards required for optimum production of forest tree seedlings of northern species in northern nurseries. Following the lead of Hilgard (1911), he used the results of analysis of virgin soils from sites highly productive for various species as a basis for interpreting needs of the species for nitrogen, phosphorus, potassium and calcium. He inferred that a virgin soil on a highly productive site should be capable of producing one crop of seedlings. However, since nursery stock is raised at a great density and no crop residue is left in the soil, the maintenance of a satisfactory fertility level in a nursery soil requires applications of fertilizer at rates higher than is common in farming practice. Wilde concluded that for Lake States nurseries an N-P_2O_5-K_2O ratio of 1-2-5 was optimum for production of conifers and that the annual nitrogen requirements ranged from 20 to 45 pounds per acre, P_2O_5 requirements from 40 to 100 pounds, and K_2O from 100 to 275 pounds. The optimum N-P_2O_5-K_2O ratio for hardwoods was 1-3-5 (Wilde and Patzer, 1940).

Youngberg and Austin (1954) found that an N-P_2O_5-K_2O ratio of 1-2-5 was optimum for Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco.] and its associates in some sections of the Pacific Northwest. They recommended a standard level of 40 pounds per acre of available N, 80 pounds of available P_2O_5, 200 pounds of available K_2O, 2000 pounds of calcium and 450 pounds of magnesium.

Wahlenberg (1930) found that on the soils in the Savenac Nursery in Montana, ponderosa pine (Pinus ponderosa Laws.) responded best to a complete fertilizer containing a relatively large amount of nitrogen, an intermediate amount of phosphorus, and a small amount of potassium. The results obtained by Wahlenberg do not agree with results obtained by other investigators. It is very probable that the levels of available and fixed nutrient content of the soil of the Savenac nursery are quite different from the soils in other regions.

Vaartaja (1954, 1955) studied the effects of soil amendments on growth of spruce in a Canadian nursery. He found that in a nitrogen deficient soil addition of peat, forest humus, fungicidal treatments and ammonium nitrate, alone or in various combinations, resulted in significant improvement in growth and colour of white spruce [Picea glauca (Moench) Voss]. Applications of ammonium sulphate had little effect on growth or colour.

The nutrient or fertilizer requirements of red pine (Pinus resinosa Ait.) and other northern species have been investigated by Bensend (1943), Chadwick (1937, 1946), Larsen and Stump (1939), Lunt (1938), McComb 1949), McComb and Kapel (1940, 1942), McIntyre and White (1930), Marth and Gardner (1937), Mitchell and Chandler (1939), Shirley and Meuli (1939), and Wilde and Patzer (1940).

Bensend (1943) observed the effect of nitrogen upon the growth and drought resistance of jack pine (Pinus banksiana Lamb.) seedlings that were grown in sand cultures and nursery soil. He found that the average seedling weight of jack pine was greatest at a nitrogen concentration of approximately 200 to 230 parts per million, and from this point on the curve dropped and leveled off. The same trend was obtained for stem weight and stem height. These trends were in agreement with those of Mitchell (1939), except that he found that the optimum nitrogen concentration for eastern white and Scotch pine was about 300 parts per million. The weight of roots increased up to 100 parts per million and further increase in nitrogen supply resulted in little change. The root/shoot ratio decreased with increase in available nitrogen until a supply of 100 parts per million was reached, after which there was little or no change.

Bensend found that jack pine seedlings grown under an optimum nitrogen supply, i.e. 200 to 250 ppm, were as drought resistant as seedlings grown in soil deficient in that element. Increase of nitrogen supply over the optimum resulted in a decrease in drought resistance.

Shirley and Meuli (1939) found that the top growth and drought resistance of two-year-old red pine seedlings could be reduced by an excess of nitrogen.

Larsen and Stump (1939) found that for most northern conifers nitrogen fertilizers stimulated top growth of seedlings and transplants while fertilizers containing phosphorus increased root development. In the nursery, complete fertilizers were more effective than fertilizers containing only one element. In contrast, in greenhouse tests addition of single elements frequently proved more effective.

Lunt (1938) grew red pine, eastern white pine, European larch (Larix decidua Mill.), Norway spruce, white spruce, and Scotch pine on a loamy sand soil. He made chemical analyses of some of the trees and from these analyses determined the N-P_2O_5-K_2O requirements for each species and for three ages of stock. He concluded that the annual N-P_2O_5-K_2O requirements of 1-0 red pine in pounds per acre were 41, 14, and 18; of 2-0 red pine, 154, 32, and 59; and of 2-1 red pine, 84, 23, and 41. The N-P_2O_5-K_2O ratios for these three classes of stock would be 3-1-1, 11-2-4 and 6-2-3, respectively. In general, he suggested for red pine and other conifers a ratio of 10-4-5. Of the species studied, Scotch pine made the heaviest demands on the soil and Norway spruce the least.

McComb and Kapel (1940) and McComb (1949) found that the response to fertilizers was governed in part by the type of soil and the species. On an acid, infertile, glacial clay exposed to erosion, black locust (Robinia pseudoacacia L.) and green ash [Fraxinus pennsylvanica var. lancelota (Borkh.) Sarg.] made little response to fertilization with nitrogen (140 pounds per acre), but made marked response to phosphorus alone (270 pounds per acre of P) at controlled pH values ranging from 4.3 to 7.7. Black locust that received phosphorus was 24 times and green ash 3 times as heavy as trees grown in untreated soil. On a graybrown podzolic soil and on a prairie soil, seedlings did not respond to nitrogen applications when the total nitrogen was in excess of about 2000 pounds per acre. Seedling response diminished as the residual soil nitrogen increased.

Marth and Gardner (1937) found that different species did not give a similar response to similar fertilizer treatments.

Hobbs (1944) grew four species of pine under starvation levels of nitrogen, potassium, and phosphorus. He found that the normal growth of seedlings was upset by nutritional unbalance. Hobbs reported that the coloration of needles was an indication of deficiency symptoms.

Day and Robbins (1950) grew red spruce (Picea rubens Sarg.) seedlings in sand culture and found that the colour of the needles was related to the content and concentration of the nutrient solutions. Wilde and Voigt (1948) used colour of leaf tissue as an indicator of nutrient deficiencies or adverse soil conditions.

McDermott and Fletcher (1955) found that growth and coloration of eastern redcedar (Juniperus virginiana L.) was not affected by variations in nutrient level. Fletcher and Ochrymowych (1955) report that, although optimum levels of most soil nutrients are now well established for most agricultural crops, relatively little is know about the nutrition requirements of most forest trees, particularly those species that grow on a wide variety of soil conditions.

The studies of Addoms (1937), Aldrich and Blake (1935), McIntyre and White (1930), and Mitchell (1934, 1939), indicate that seed weight exerts an important effect on the early cumulative dry weight of several species of pine. It is certain that the distribution of weights in an average sample of pine seeds include a range sufficient to account for large variations in the yield of one-year-old seedlings (Mitchell, 1939). The phosphorus, potassium, and calcium content of seed may be sufficiently high to provide the nutrient requirements for several months. The amount of food reserves in seeds of identical fresh weight varies not only with the seed source, but from year to year in the same sample (Youngberg, 1952). Variations in seed weight and nutrient content may account for some of the variations in seedling response due to different nutrients.

Southern conifers have been studied to only a limited extent, and all of the work has been done very recently. Many of the nursery investigations were concerned with the immediate effects of nitrogen, phosphorus, and potassium applications or other practices on general plant development. They did not include soil or plant analyses. Typical of this type investigation are the studies of Allen and Maki (1955), Andrews (1941), Auten (1945), Bryan (1954), Chapman (1941), Huberman (1940a, 1940b), Johansen (1955), Maki (1953), Maki and Henry (1951), May (1933), Rosendahl and Korstian (1945), Read (1934), Scarbrough and Allen (1954), Umland (1956), and Wakeley (1935, 1948, 1954).

Read (1934), in a lengthy discussion of nursery management, states, "That the forest tree nursery is probably the most important unit of the entire reforestation program." However, he omits any mention of soil fertility maintenance. Wakeley (1935) reports that in southern forest tree nurseries, largely because most of them have been laid out on a fairly good soil and have not been in existence long, the use of either soiling crops or fertilizer on a commercial scale has barely begun, and practically no systematic experiments with nursery fertilizers have been undertaken. May (1933) reported that fertility of an alluvial nursery soil was maintained with green manure crops. Huberman (1940a, 1940b) found that seedling development was correlated with seedling density and that dry weights of seedlings increased greatly in December.

Andrews (1941) found that on a sandy soil the most desirable loblolly pine planting stock was produced when both organic matter and concentrated fertilizer containing a high phosphorus content was added. Rosendahl and Korstian (1945) found that nitrogen applications to loblolly pine gave a positive response to tap-root length, shoot length, average length of needles, diameter of stem at root collar, mycorrhizal abundance, dry weight of roots and shoots, and percentage of plantable trees. Phosphorus and potassium applications did not produce any significant response on a Congaree silt loam, except on stem diameter. Auten (1945) found that soluble inorganic fertilizers applied at seeding time had a negative effect on seed germination and reduced seedling densities.

Pessin (1937) grew longleaf pine seedlings in water cultures and found that those seedlings that were supplied with all the essential mineral elements were the most vigorous and showed the best development. Especially poor vigor was shown by the seedlings grown in solutions lacking magnesium, iron, or potassium. Leaving either phosphorus or sulphur out of the nutrient solution produced the least effect on the seedlings. Pessin (1941) grew slash pine for nine months in washed sand which received no nutrient solution. The seedlings were then treated for eight months with nutrient solutions containing ten elements. The amounts of nitrogen, phosphorus, and potassium were varied. Seedling vigor was improved by increasing amounts of nitrogen. Changing phosphorus levels produced no significant effect on dry weight, while potassium in increasing amounts decreased the dry weights. The seedlings produced the longest roots when the nitrogen supply was smallest.

Addoms (1937) grew loblolly pine seedlings for eight months in a sand-peat mixture, then transferred them to a washed white quartz sand in unglazed pots. The composition of solutions were varied from time to time in an attempt to determine the optimum nutrient solution for growth. Even after selecting plants on the basis of uniformity, she found that great variations in the growth of individual plants occurred with the same nutrient solutions. She found, also, that loblolly pine seedlings are capable of utilizing nitrogen in either the nitrate or the ammonium form, the former more successfully in a highly acid solution, the latter more successfully in a more nearly neutral solution. She attributed differences in root development to differences in aeration.

Westveld (1946), using pot cultures and nursery soil, investigated the response of slash pine to various nutrients. He found that applications of nitrogen, nitrogen plus potassium plus 20 to 25 tons per acre of colloidal phosphates or peat plus nutrients produced a marked response in seedling growth. Combinations of two or more nutrients produced more favorable response than a single nutrient. Excess applications of nutrients, particularly nitrogen, depressed the growth of seedlings. The type of treatment had no significant effect on root/shoot ratio.

Maki and Henry (1951) found that root rot of southern pines was associated with low fertility. They believed that the addition of sawdust, ammonium nitrate at the rates of 300 to 600 pounds, 20 per cent superphosphate at the rate of 3,000 pounds, and 50 per cent muriate of potash at the rate of 240 pounds per acre would sustain a production of seedlings of satisfactory size and vigor.

Scarbrough and Allen (1954) grew longleaf pine seedlings on beds that had received the equivalent per acre of 4000 pounds of superphosphate, 300 pounds of muriate of potash and 10 tons of sawdust. Nitrogen was applied as a top dressing after seed germination. They found that seedlings from low density seedbeds grew larger and survived better than those from high density beds. Allen and Maki (1955) found that the green weight of longleaf pine seedlings and their ability to survive transplanting differ with the media in which they are raised. The mean green weight of seedlings with NPK applied was double that of those with nitrogen alone or with no fertilizer. Umland (1956) reported that with an application of 1000 pounds per acre of 10-22-12 fertilizer troughing developed toward the center of the seedbeds. With an application of 2000 pounds of 10-22-12 fertilizer, seedling heights were uniform throughout the bed. Bryan (1954) found that the colour and vigor of yellow, unthrifty loblolly pine seedlings could be improved by late season applications of nitrogen. If past fertilizing history of poor spots suggest that phosphorus or potassium is lacking, the elements may be applied simultaneously with nitrogen without harm to the stock.

Switzer and Nelson (1956) grew loblolly pine seedlings on a Kaufman sandy loam, alluvial phase. With three levels of nitrogen, two levels of P_2O_5 and two levels of potassium, only nitrogen treatments affected the dry weights of seedling tops and of the whole plant. They found that the phosphorus and potassium levels were adequate for a crop of pine seedlings. On the basis chemical analyses of the foliage and the soil, they concluded that a crop of one year old loblolly pine seedlings removes approximately 126 pounds of nitrogen, 20 pounds of phosphorus and 70 pounds of potassium per acre.

Wakeley (1954) gives an excellent review of the literature on the subject "Nursery Soil Management". He states, "Soil differences from nursery to nursery frequently make findings in one place inapplicable in another".

Soil Treatments in Nurseries in Great Britain

MacDonald (1953), reporting on developments in nursery practice in Great Britain, indicated that nursery fertility had been reduced to a critical level in the 1930's. An intensive research program was initiated about 1946. Holmes and Faulkner (1953) investigated the possibilities of improving fertility by partial sterilization of the soil by steaming or the application of formalin or other fumigants. Treatments of these types evidently modify fertility levels by modifying the population of soil micro-organisms. Many of the tests gave inconclusive results. Crowther (1950, 1951) reports that, in seedbed experiments in which composts and bulky organic manures were compared with artificial fertilizers, markedly poorer stands of seedlings were obtained in the compost-treated beds. He attributes these results to a drought effect in a particularly dry season. Soil acidification improved growth of seedlings at two nurseries. He found that on an acid sand soil (pH ca 4.0) top dressing with ammonium sulfate had a negative effect on height growth.

Some species gave a positive response to phosphorus in all four nurseries where experiments were done, while other species gave a negative response to soil treatments.

Rayner and Neilson-Jones (1946) made intensive investigations of problems associated with the growing of Scotch pine, Corsican pine, lodgepole pine (Pinus contorta Dougl.), and Maritime pine (Pinus pinaster Ait.) in Great Britain. They concluded that the development of unhealthy and semi-moribund plants was a starvation phenomenon and that deficiencies could not be corrected with inorganic fertilizers. They believed that in soils poor in inorganic nitrogen the nutrient requirements of the young trees are normally met by a proper mycorrhiza development. They reported that certain types of organic material in the soil contained substances actively injurious to root growth. Better aeration following deep ploughing reduced the toxic effect, but seedlings without mycorrhizae rooted poorly. They found that the toxic substances were of biological origin and that they operate directly by inhibiting fungal growth. Enduring effects brought about in the soil by the accumulation of undecomposed humus residues and by diversion of normal degradation changes into channels leading to the formation of by-products deleterious to vascular plants lead to the formation of an infertile soil.

Other investigations at English nurseries (Rothamsted Experiment Station Reports, 1952, 1953, 1954, 1955) have revealed that Sitka spruce [Picea sitchensis (Bong.) Carr] on acid nursery sites responded to nitrogen, phosphorus and potassium. Compost plus a complete fertilizer was not consistently superior to inorganic fertilizers alone. On the neutral or slightly acid soils of old nurseries, sitka spruce made very poor growth and did not respond to compost and fertilizers. The residues from seedbed mulches that contained considerable amounts of $CaCO_3$ in the form of limestone or shell fragments resulted in much poorer growth of one-year-old Sitka spruce than residues of covers free of $CaCO_3$. Calcareous seedbed mulches were used frequently before the autumn of 1947, when, on the recommendation of Rothamsted Experiment Station, they were banned in Forestry Commission nurseries. When a two year's grass ley was followed by two successive crops of one-year-old Sitka spruce, the second crop was much larger and more vigorous than the first crop. Formalin and chloropicrin treatments resulted in greatly increased growth and at the poor, long-established nurseries the crops resembled those grown in the very acid, newer nurseries. In 1954, a series of experiments in which different rates of phosphorus and potassium had been tested over several years were concluded. Plant response showed no signs of falling off even at the highest rates of phosphorus (6 g/sq. yd.) tested. A new series of experiments were designed to test higher rates of application.

Rayner (1947) studied the behavior of Corsican pine following different nursery treatments. She found that different types of soil conditions resulted in different types of root systems and different species of mycorrhizae. She reported that seedlings with normal root systems and adequate mycorrhizal vigor carried their constitutional vigor into the forest, and even to poor soils of non-forest type. Edwards and Holmes (1951) reported that phosphorus fertilizer placed beneath the drills was very successful in increasing the growth of Sitka spruce one year, but the same treatment in a previous year had given negligible results.

Effects of Nutrients on Soils and Seedling Growth in the Far Eastern Countries

Loblolly pine, slash pine, Maritime pine, and Monterey pine (*Pinus radiata* D. Don) have been planted in Australia and New Zealand, but unsuitability of soil and climate resulted in the failure of many of the plantations. A number of disorders including yellowing, spindle stands, resetting, and die-back developed on the poor, infertile sites. Several investigators have delved into the causes of the disorders or diseases and the possibility of developing remedial measures. Kessell and Stoate (1936, 1938) found that the sites producing healthy, vigorous trees had a significantly higher phosphorus and nitrogen content than the sites producing diseased trees. They did not find any significant difference in chemical composition of needles from healthy trees and diseased trees, except for potassium levels. Askew (1937) analysed the needles, stems and roots of Monterey pine seedlings. He found that needles were relatively rich in minerals, particularly nitrogen, and that mineral content was higher in stems than roots. As the tree aged, the calcium, phosphorus, sodium, chlorine, iron, and insoluble ash content decreased, while the nitrogen, magnesium and manganese content increased. He calculated that an acre of two-year-old Monterey pine seedlings absorbed the equivalent of 84 pounds of ground limestone, 84 pounds of sulphate of potash, 564 pounds of 44/46 per cent triple superphosphate, and 616 pounds of sulphate of ammonia. This amounts to 33 pounds of calcium, 123 pounds

of nitrogen, 254 pounds of P_2O_5 and 42 pounds of K_2O.

Young (1940a) observed that the phosphorus content of pine needles could be related to the phosphorus content of the soil when the soil was deficient in phosphorus. When the phosphorus level was sufficient for healthy growth, the phosphorus content of the foliage tended to remain constant.

Young (1948) investigated the response of loblolly pine and slash pine to phosphate manures. He applied different rates of superphosphate to loblolly and slash pine plantations. Stem diameter, stem height and stem volume were measured prior to the treatments in 1939 and again in 1946. Needles of each species were ashed and analyzed for SiO_2, sesquioxides, P_2O_5, CaO, MgO, Na, and K_2O. The mean ash content of needles was 2.94 per cent for slash and 3.63 per cent for loblolly. The P_2O_5, CaO and MgO content of slash pine needles was considerably below that of loblolly pine needles, whereas the K_2O content was about the same for the two species. Young found that growth response to phosphate fertilizer either alone or in combination with other nutrients was correlated with the original soil phosphate value and the amount of P_2O_5 added. He concluded that the nutrient requirements for loblolly and slash pine differ appreciably.

Kessell (1943) and Stoate (1950) believe that irregularities of growth which are not due to the attack of any known parasitic organism may be regarded as deficiency disease. Plantings in Australia were restricted to the poor soils, including the coastal sands. The fertility of some of the sands was estremely low, as indicated by total phosphate content of from less than one to around 20 ppm.

Phosphate and zinc have been used to correct a number of disorders in existing plantations and render possible the establishment of other plantations on poor, infertile soils hitherto considered unsuitable for afforestation with exotic conifers. No benefits occurred from the use of other recognized main plant nutrients, potash, nitrogen, or calcium, either singly or in the combinations tried.

Results from fertilizer studies in the nursery were in general agreement with results from plantation studies (Queensland Dept. Agr., 1951). Slash pine seedlings were grown under different levels of nitrogen, phosphorus and potash. A marked positive response was obtained with phosphate, whereas added nitrogen depressed growth. In the nursery, soil structure was improved by applying molasses to an area that had received heavy applications of sawdust for several years. Aggregation was increased 21 to 25 per cent.

Hearman (1938), Perry (1939), Smith (1943), and Young (1940a) have obtained results similar to those reported above.

Since 1932, seedling production in Japan has never fallen much below half a billion a year. In 1948, about 24,000 nurseries, ranging in size from 1/50 acre to about 8 acres, were well-distributed throughout Japan (Haibach, 1949). A tremendously increased planting program was in the planning stage. Within recent years, several Japanese investigators have studied the nutrient requirements for tree seedlings. Ono, Shibata, and Hoshino (1951) analyzed soil samples and found that the soils were deficient in nitrogen, phosphorus and potassium. They found that Japanese redwood or, Sugi, (Cryptomeria japonica) and Japanese cedar,

or Hinoki, (Chamaecyparis obtusa) gave a positive response to additions of nitrogen, phosphorus, potassium and calcium. They found that the sulphates of manganese, magnesium, zinc and boron and boric acid had little effect on seedling growth if the major nutrients were omitted.

Ando (1952) analyzed the Japanese redwood seedlings for nitrogen, phosphoric acid, potash, calcium and ash content. Contents expressed as a percentage of the dry weight at the end of one growing season were: Nitrogen 1.2 - 1.8 per cent, P_2O_5 0.3 - 6.4 per cent, K_2O 1.5 - 1.7 per cent, CaO 1.1 - 1.4 per cent and ash 6.0 - 6.5 per cent. For each nutrient the concentration was affected more by different stages of growth than by the amount of fertilizer applied. The concentration of nitrogen and calcium in the plant increased as concentrations in the soil solution increased. P_2O_5 and K_2O concentrations in plants were not influenced significantly by variations in fertilizer levels.

Ando and Hukasaku (1953) found that variations in nitrogen levels affected seedling development more than phosphorus or potassium. High levels of all three nutrients were toxic to Japanese redwood. When nitrogen was applied at rates of 0, 5, 10, 20, 40 and 60 grams per square meter, seedling growth increased with increasing nitrogen up to 20 grams, and then decreased. The maximum content of nitrogen in the seedling was found at 40 grams per square meter. It was 1.67 per cent for the whole plant, 1.83 per cent for the shoot, and 1.00 per cent for the roots. Relationships between weight and nitrogen content suggested that the optimum application was 20 grams per square meter. However, the percentage of nitrogen utilization was higher for the five gram application than for other rates.

Goor (1953) used pot culture tests to study the influence of nitrogen and phosphorus on the growth of Japanese larch (Larix leptolepis Murr.). He found an N/P antagonism in the Japanese larch. Nitrogen applications decreased phosphorus uptake and vice versa. The growth was optimum over a narrow N/P ratio and decreased rapidly on both sides of the optimum ratio. The lower the phosphorus content of the soil solution, the more rapidly growth decreased as the supply of nitrogen increased.

Sato and Muto (1951a) found that larch and spruce seedlings could be grown in incomplete nutrient solutions for short intervals and that the period of most efficient use of a nutrient was associated with the age and development of the seedling.

European Investigations

The early investigations on the mineral nutrient relations of forest trees were concerned primarily with the forest plantations and natural stands. Bauer (1912) found that every species of forest tree apparently has a different curve for mineral salt absorption throughout the year as well as a different curve for dry weight increase. Mineral absorption and dry weight increase may follow along the same path, but there is never a perfect correlation between the two. He observed that a tree may have different seasonal absorption curves for various ions.

During the past century nursery soil fertility was maintained with the use of animal manures and forest litter, supplemented by liming and some additions of mineral nutrients. Present nursery fertilization practices have been described by Aaltonen (1948), Hilf

(1949), Krussman (1954), Nicolaisen (1938), Olbrich (1948), Pein (1953), and Wittich (1950).

Becker-Dillingen (1937), Jessen (1938, 1939), Möller (1904), Schönnamsgruber (1955), have grown various species in nutrient solutions and have described the resulting growth patterns and deficiency symptoms. Jessen (1939) reported that applications of potash fertilizers increased the yield of dry matter and the potassium content of the seedlings.

Schönnamsgruber (1955) found a high correlation between the phosphorus content of leaves and that of the media, though the pattern was irregular at high concentrations. The addition of other nutrients, particularly magnesium, increased phosphorus uptake. He found that the phosphorus requirements were not the same for all species. Maximum dry matter was produced by poplars and elms when the phosphorus supply was high. Beech and birch produce maximum dry weights with only medium phosphorus supply. Black locust produced its maximum dry weight in cultures containing hardly any phosphorus. Süchting (1939, 1940), using a number of soil types, found that, in general, larch, pine, and spruce responded to all types of fertilizers. However, in some instances potash treatments reduced growth. The soils were deficient in nearly all nutrients. Mitscherlich (1955) proved that root and shoot growth of nursery seedlings could be increased with mineral nutrients and adequate water. He discounts an old opinion that nursery stock should be raised in a soil that is not superior to that in which the seedling will be planted.

Demortier and Fouarge (1938) observed that Scotch pine seedlings required much more nitrogen and phosphorus than potassium and that the seedlings utilized ammonium nitrogen more efficiently than nitrate nitrogen.

Grant (1952) described the Dunemann process, in which the seedbed consists of needle litter. Water is applied frequently. The seedlings develop very extensive fibrous root systems.

Nemec (1937, 1941) has studied the response of many species to fertilizers. He has observed the influence of supply on uptake of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, silica, iron and aluminum. The results of his studies reveal the complexity of the interrelationships involved. Nitrogen applications increased the uptake of silicic acid by seedlings and reduced the phosphorus uptake, particularly on soils low in phosphorus and high in silicic acid (Nemec, 1938a). Nitrates reduced and sulfate of ammonia increased the uptake of aluminum. Sulphate of ammonia increased the iron uptake by pine needles provided adequate phosphorus was present in the soil. Sulphate of ammonia produced a greater uptake of manganese than any other form of nitrogen, particularly on soils containing the lowest amounts of exchangeable calcium. The effects of $NaNO_3$, $Ca(NO_3)_2$, and $(NH_4)_2SO_4$ on one year transplants was investigated. He found that the effect on growth was determined largely by the degree of acidity and the nutrient supply. In general, $NaNO_3$ and $Ca(NO_3)_2$ were more effective on very acid soils and $(NH_4)_2SO_4$ was more effective on slightly acid to neutral soils.

Nemec (1937, 1938b, 1939a, 1938c) found that heavy applications of phosphorus tended to lower nitrogen uptake on soils that were rich in nitrogen. Seedling response was more favorable to basic slag than to superphosphate on soils that were well supplied with phosphorus and soluble nitrogen. Phosphate fertilization did not affect the potash uptake except on potassium deficient soils, but it did increase the uptake

of calcium. Phosphate fertilization increased growth of pine seedlings on strongly acid soils and on soils low in lime and potash provided potash was also applied. Purple discoloration of pine needles was found to be associated with a low phosphorus and calcium concentration in the soil. Generally, manuring acid soils with phosphorus resulted in a slight decrease in iron and aluminum absorption. However, he reports that the aluminum status affects iron absorption in a complicated manner.

Nemec (1939b) reported that pines are chlorophobes and recommended that chlorine free fertilizers should be used. Large applications of potassium chloride caused trees to die because of the flooding of needles and stems with chlorine ions. The effect on growth of potassium fertilization depended primarily on the potassium, phosphorus, and calcium supply in the soil. Manuring with potassium had a positive effect on growth only where the soil contained more than 100 mg. of P_2O_5 per Kg and about 150 mg. of CaO per 100 grams. Absorption of potassium by the needles depended, in general, on the potassium supply in the soil (Nemec, 1939c). On soils low in phosphorus, no material increase in potassium absorption by the needles resulted from increasing potassium fertilization, even on soils poorest in potassium. Absorption of phosphorus by needles decreased with decreasing phosphorus in the soil, in both potassium fertilized and non-potassium fertilized plots. The availability of phosphorus in the soil was influenced by the amount of exchangeable calcium. Even on soils low in potassium, the phosphorus content of needles was not increased by unbalanced potassium fertilizing if the calcium content of the soil was high.

Absorption of nitrogen by needles depended on the relative solubility of nitrogen in the soil. However, with a favorable phosphorus supply in the soil, fertilizing with potassium increased nitrogen absorption on soils with adequate nitrogen, particularly if the soil was deficient in potassium. On soils with a relatively low nitrogen content the nitrogen uptake of needles was reduced by unbalanced fertilizing with potash.

In general, absorption of calcium was dependent on the content of exchangeable calcium in the soil. Manuring with potassium fertilizers reduced the uptake of calcium by needles in the case of soils with a good potassium supply, but considerably increased uptake of calcium on soils poor in potassium. On soils with a low phosphorus and potassium content, fertilizing with potassium gave a closer K_2O:CaO ratio in the needles.

Absorption of magnesium by needles corresponded roughly to the content of exchangeable magnesium in the soil. On soils provided with adequate phosphorus but low in potassium, unbalanced potassium fertilization resulted in a slight increase in magnesium uptake by needles.

Liming of acid soils increased growth of spruce seedlings and raised the calcium content of the needles (Nemec, 1938a) except on soils rich in nutrients. Liming increased the nitrogen content and lowered the phosphorus content of needles.

Nemec (1941) reports that adequate fertilization of seedlings in the nursery guarantees favorable growth after planting.

Goncharov (1941), Jacob (1937) and Thun (1938) discuss the difficulties involved in arriving at optimal fertilizer ratios and conclude that there is no optimum N-P-K ratio that is applicable to all soils and all crops. Each soil and each crop will require individual treatment. Goncharov suggested that for hardwoods an N-P_2O_5-K_2O ratio of approximately 4-8-3 might be effective.

Soil Reaction and Tree Growth

Several investigators in recent years have studied the relationship between soil reaction and nutrient uptake and plant growth. Baker (1925) and Howell (1932) found that soil reaction had little effect on the seedling development of western yellow pine (Pinus ponderosa Laws). Within its natural range, the species was found on sites with pH ranges from about 4.5 to 9.0. Wherry (1922) reported that some eastern conifers such as longleaf pine preferred a very acid soil while other species such as loblolly pine and shortleaf pine preferred a slightly acid soil. Wide (1934) sets forth the optimum pH range for different species. He classified tree preference according to five pH ranges, 3.7 - 4.4, 4.5 - 5.4, 5.5 - 6.8, 6.9 - 7.2, 7.3 - 8.0. He reported that, in nursery practice, the reaction of the soil influenced not only the growth of seedlings but the rate and kind of fertilizer that should be applied. He found that the most desirable reaction of a nursery soil was between pH 5.0 and pH 6.0. Greenhouse experiments with northern conifers indicated that a difference of 1.5 pH between nursery and planting site was the maximum safe differential. Jacobi (1951) recommended optimum pH values for growing different hardwoods in the nursery. The overall range was 5.0 to 7.15. McComb and Karel (1942) grew black locust and green ash at four acidity levels (pH 4.3, 6.6, 6.9, and 7.7) and three fertility levels. They found that when phosphorus was deficient, growth increased up to pH 6.9 and decreased at pH 7.7. At a high fertility level best growth was obtained at pH 4.3. The good growth at a low pH was attributed to a relatively high base saturation and apparently adequate quantities of individually important bases.

Leyton (1952) investigated the effect of pH and form of nitrogen on growth of conifers. He found that a reaction between pH 4 and 5 resulted in optimum growth of root and shoot of Sitka spruce. Nitrate nitrogen stimulated root growth more than ammonia nitrogen, whereas stem growth was more responsive to ammonia nitrogen. Shibamoto, Takhara and Kawana (1950) found that the optimum pH for Japanese redwood and Japanese red pine seedling development varied according to the source of nitrogen. The optimum pH was higher when nitrate nitrogen was used than when ammonia nitrogen was used.

Stoeckeler (1949) reported that the acidity of Lake States nursery soils was increased by repeated applications of sulphuric acid and peat. Switzer and Nelson (1956) found that nitrogen treatments had a highly significant effect on soil pH. Soil acidity increased with increasing rates of nitrogen application.

Organic Matter and Nursery Soil Fertility

The nature and importance of organic matter in the soil has been thoroughly discussed by Baver (1948); Brauns (1952); Fraser (1955); Hopkins (1945); Jenny (1941); Joffe (1955); Lyon, Buckman, and Brady (1952); Lutz and Chandler (1946); Martin et al. (1955); Pieters (1927); Russell and Russell (1950); Russell et al. (1951); Waksman (1938, 1952); and Wilde (1946a).

Organic matter improves water holding capacity, aeration, cation exchange capacity, and structure of some soils (Baver, 1948). Morris and Collins (1951) and Joffe (1955) report that organic matter does not improve the structure of lateritic soils.

Soil fertility and productivity are closely associated with soil organic matter content. Organic matter, particularly humus, is a storehouse of important chemical elements essential for plant life, especially carbon and nitrogen, and, to less extent, calcium, phosphorus, potassium, magnesium, iron and possibly other minerals (Fraser, 1955).

The amounts of organic matter in virgin soils vary so widely that it is difficult to present representative figures. Mineral surface soil may contain from only a trace to 15 or 20 per cent of organic matter (Lyon, Buckman, and Brady, 1952). Normally a very marked change occurs when a virgin soil is placed under cultivation. A lower level of organic matter is gradually established as the soil seeks equilibrium or a minimum constant below which the organic level cannot be lowered no matter what system of soil management is followed (Joffe, 1955).

The addition of organic matter has a necessary role in any program of maintaining soil fertility in forest tree nurseries, particularly in the southern region of the United States. Nursery soils receive a maximum of abuse. A crop of one million seedlings per acre removes from five to fifteen tons of dry matter. No crop residues are left in the soil because even the root systems of seedlings are removed. Seedlings are lifted during the winter months when soil moisture is extremely high. Soil structure is unfavorably modified. However, a favorable soil structure must be maintained so that seedlings can be removed from the soil without injury to the root system (Wakeley, 1954). Intensive cultivation, high temperatures, abundant rainfall supplemented by artificial irrigation, and additions of commercial fertilizers promote biological activity and rapid decomposition of organic matter.

The decomposition of organic matter is a complex process. Adequate moisture, favorable temperature, abundant nutrients, and active micro-organisms are a requisite for decomposition of organic matter. Any variation in one of these factors will modify the rate and course of decomposition of organic matter. Allison (1955); Gamble, Edwinster and Orcutt (1951); Harmsen and Van Schreven (1955); Norman and Bartholomew (1943); Phillips, Weihe, and Smith (1930); Pinck, Allison, and Gaddy (1946); Turk (1942); Waksman and Hutchings (1936); Waksman and Tenny (1927); and White, Holben, and Jefferies (1949) have studied the influence of one or more factors on decomposition of organic matter. The general conclusion is that the accumulation of the lignins, which are more resistant to decomposition than other plant constituents, and the synthesis of microbial nitrogenous complexes account for the increase in soil humus by decomposition of natural organic materials.

The composition of plant material will influence the rate of decomposition and the accumulation of humus. Pieters (1927) and Broadbent and Bartholomew (1948) report that it is very difficult to increase organic matter in the soil by the use of green manure crops or highly carbonaceous residues. They reported that the rate of organic matter decomposition was inversely related to the quantity applied. Mixed types of organic matter frequently decompose more quickly than single types of materials (Waksman, 1952). Decomposition of stable humus can be accelerated by the addition of fresh material (Harmsen and Van Schreven, 1955).

The micro-organisms bringing about decomposition of plant and animal residues require considerable amounts of energy and nutrients as they grow and multiply. A nitrogen content of about 1.7 per cent is the minimum sufficient to supply the requirements of the micro-organisms for cell synthesis (Waksman, 1952). When organic materials have a carbon/nitrogen ratio greater than 20:1 only carbon dioxide is liberated during decomposition. All mineralized nitrogen is immediately bound in the protoplasm of the developing microbes. When large quantities of sawdust are added to the soil, nitrogen must be added in order to supply the requirements of micro-crganisms and to prevent a nitrogen deficiency in seedlings.

Bornebusch (1941), Brener and Wilde (1941), Holmes and Faulkner (1953), Karlsson (1945), Knight (1956), Maki and Henry (1951), Muntz (1944), Nemec (1939d), Pein (1953), Retan (1918), Wilde and Hull (1937), Wilde and Krumn (1946), Wilde and Wittenkamp (1939), and Wycoff (1956) have reported on the use and effects of organic matter in tree seedling nurseries. Although some conflicting results have been obtained, most investigators agree that the productivity of a permanent nursery is dependent upon a supply of organic matter that is used for the improvement of the physical condition of the soil, as a source of nitrogen and as a carrier of nutrients.

Within recent years, sawdust, wood chips or shavings, and other forms of wood waste have received considerable attention as a possible soil conditioner and source of organic matter. The possibility of using sawdust is of extreme importance to nurserymen in the southern region.

Peat, straw, manure, and other forms of organics are extremely scarce and expensive; whereas, sawdust is plentiful, accessible, and cheap. A complete review of the literature dealing with investigation of sawdust use is not within the scope of this paper.

Allison and Anderson (1951) reviewed the literature dealing with the use of sawdust and summerized the results. They report that very little information is available on the comparative values of artificial manures prepared from sawdust, straw, legumes, and other materials, but that there seems to be no reason to doubt that one material is as good as another if the content of fertilizer elements is the same. They emphasize the fact that nutrient content ratios vary for different species and that in some instances variations within a species, due to differences in soil nutrients, may be greater than the differences between species (Lunt, 1954; and Wilde, 1946).

Nursery Diseases and Soil Fertility

Chlorosis is probably the most common minor disease that affects coniferous seedlings (Korstian, Hartley, Watts, and Hahn, 1921). Although pathologists and physiologists classify chlorosis as a disease, it is a symptom of malnutrition. Wakeley (1954) defines chlorosis as a yellowing of part of all of the seedling foliage resulting from the breaking down or non-formation of the normal green pigment. He attributes chlorosis to an immense number of climatic influences and physical, chemical, and micro-biological peculiarities of the soil. In southern nurseries it has been associated with deficiences and excesses of nitrogen, deficiencies of iron or magnesium, excessive liming, and heavy applications of sawdust or compost. Wilde and Voigt (1952) report that chlorosis may be also caused by deficiences of other nutrients.

Damping-off is probably the most serious disease that is found in southern pine nurseries. Hartley and Pierce (1917) define damping-off as a term commonly used to describe the disease causing the death of very young seedlings due to parasitic fungi. Davis, Wright, and Hartley (1942), Wakeley (1954), and Wycoff (1952) attribute damping-off epidemics to a number of factors including (1) use of nitrogenous fertilizers prior to sowing; (2) presence of undecomposed organic matter in any form, particularly green manures; (3) high calcium content or high pH; and (4) high moisture content of the soil. Toumey and Korstian (1942) suggest that the most practical and least expensive method of controlling damping-off may be the attaining by cultural methods of conditions in seed beds inimical to the rapid development of damping-off fungi.

Root-rot of conifers has been frequently attributed to soil conditions. Eliason (1938) reports that repeated cropping with buckwheat on the sandy soil of a New York nursery has caused serious losses of red pine transplants due to root-rot. Root-rot of 1 and 2-year-old white spruce seedlings has been associated with excessive use of cover crops according to the New York Conservation Department (1951).

Levisohn (1951) reports that a serious haustorial infection is frequently encountered in run-down nurseries. Stone (1948) and Maki and Henry (1951) consider fertility depletion a primary cause of root-rot at the W. W. Ashe Nursery. Kessell and Stoate (1938), Hearman (1938), Neilson-Jones (1938), and Young (1940a) found that irregularities of growth or needle disorders were associated with nutrient deficiencies.

Mycorrhizae, Soil Fertility, and Tree Nutrition

The role of mycorrhizae on the growth of conifer seedlings has been explored by a number of investigators. Hatch (1937) reviewed the published data on early experiments dealing with mycorrhizae on conifers and continued investigations with pine. He concluded that mycorrhizae occurred normally only where there was a deficiency of one or more of a number of nutrient minerals. As a result of mycorrhizal formation on roots, trees growing in poor soils were able to obtain a more nearly adequate supply of mineral nutrients because of (1) the greater surface area of the infected short mycorrhizal root; (2) the greater abundance of the absorbing root ends due to the profuse branching of the mycorrhizal structure; (3) the delay in suberization of the cortex and endodermis of the infected short roots; and (4) the great extension of the fungal mycelium through the soil and the resultant increased surface for mineral absorption.

Miller (1938) found that shortleaf pine seedlings would not grow in old, depleted farm soils unless mycorrhizal fungi were present. Miller contended that organic matter should be built up in depleted soil to a point approaching natural forest conditions. Otherwise, the mycorrhizal fungi have nothing to grow on after removal of pine seedlings. McComb (1938) found that Virginia pine (*Pinus virginiana* Mill.) seedlings in a nursery on old agricultural land, in the absence of mycorrhizal fungi, ceased growth in the middle of the first growing season as a result of insufficient phosphorus nutrition. Seedlings with mycorrhizae absorbed phosphorus at a sufficient rate and developed in a normal manner.

Young (1940) working with slash pine in Australia, grew seedlings

in boxes in which the soils were inoculated with different species of fungi from healthy pine stands. After one season's growth, the mean height and mean dry weight of seedlings grown with the imported mycorrhizal fungi exceeded those of the controls. However, the increase in growth was not the same for all species of fungi employed.

Björkman (1940) found that the addition of nitrate nitrogen tended to decrease mycorrhizal development on the roots of pine and spruce seedlings, particularly when the rates of application were high. However, a high rate of nitrate nitrogen did not completely prevent the formation of mycorrhizae.

McComb and Griffith (1946) found that eastern white pine seedlings made satisfactory growth on an uninoculated soil that was fertilized heavily with phosphates. However, some mycorrhizae formed on the roots. Douglas-fir seedlings made a moderate growth response at high rates of phosphate, but mycorrhizae did not develop on the roots. They suggest that the stimulating effect of mycorrhizal fungi on conifer seedlings is due to heightened metabolism associated with the transfer of phosphorus and growth stimulators from fungi to seedlings. Stone (1949) obtained similar results with Monterrey pine. He analyzed needles for phosphorus content and concluded that the outstanding consequence of mycorrhizal infection was the uptake by seedlings of phosphorus that was previously unobtainable. He attributed much of the response by pines with mycorrhizal formation to improved phosphorus nutrition.

Neilson-Jones (1943) reports that under natural conditions the short roots of healthy plants are converted into mycorrhizae by association with certain specific fungi. He suggests that for some soils fertility was dependent more on the degree to which the soil permitted the development of an efficient root system than it does on the abundance of available bases. He further suggests that the excessive use of manures or fertilizers may disrupt the mycorrhizal relationship with the soil environment. Rayner and Neilson-Jones (1946) found evidence that the establishment and maintenance of correct mycorrhizal association in conifers is a requisite for normal and healthy growth on poor healthland soils.

Soil Fumigants, Soil Fertility, and Plant Nutrition

The problem of nursery stock production is being complicated by a rapidly increasing use of eradicants such as fungicides, insecticides and herbicides. Very little information regarding the effects of these substances on soil fertility and plant nutrition is available. Martin and Aldrich (1952) found that soil fumigation treatments with DD, chloropicrin, EDB, CS_2, and propylene oxide markedly affected the microbial population of the soil, but had little or no direct effect on soil aggregation. Martin and Ervin (1952) found that when a fumigant was applied to the soil insects and nematodes were readily killed and fungi, bacteria and related organisms were reduced in number. After fumigation the bacteria increased rapidly in number, but the fungi that became re-established represented fewer species than were originally present.

Hill (1955) used methyl bromide to control weeds, nematodes and root rot. Stunted, chlorotic seedlings developed in patches throughout the treated beds. He concluded that the fumigant immobilized some of the nutrients in the soil. Thiegs (1955) investigated the effects of methyl bromide and ethylene dibromide on nitrification. He found that methyl bromide retarded the nitrification of ammonium sulphate for a period of four to eight weeks, depending on soil conditions such as temperature, moisture, aeration, and soil reaction as well as the rate of application of the fumigant. The inhibition period for ethylene dibromide was only about two weeks or less. He was of the opinion that poor growth and possible injury to certain plants due to high levels of ammonia nitrogen were most likely to occur on acid soils that were low in nitrates.

Voigt (1955) studied effects of fungicides, herbicides and insecticides on the content of nutrient elements in tissue of Monterey pine seedlings. He found that the growth and nutrient accumulation by seedlings was inhibited by several eradicating agents. The extent of phytotoxicity varied with the biocide and the rate of application. The inhibitory effects of some of the eradicants were alleviated by applications of commercial fertilizers or organic matter. Wilde and Persidsky (1956) studied the effects of biocides on the development of ectotrophic mycorrhizae in Monterey pine seedlings. They found that the internal alterations of mycorrhizae under the influence of eradicants were characterized by irregularities in the shape of the fungal mantle, restricted penetration of mycelia, and reduced development of the Hartig net. They suggested that the external modifications of the short roots were the result of radical changes in the exudates of rhizospheric organisms. They observed that the effect of eradicants varied with the nature of the chemical compounds and their rate of application.

Effects of Soil Fertility on Morphological Characteristics of Seedlings

The effects on morphological characteristics of such factors as dates of sowing, irrigation, shading, type of mulch, density of seedlings, and root pruning in place have received considerable attention (Higgins 1928, Huberman 1940a, 1940b, Janouch 1927, May 1933, Wahlenburg 1929, Walsh 1954).

Wakeley (1935) used morphological characteristics such as stem height, stem diameter, root length, and state of bark, needle, and winter bud development as a criteria for the establishment of seedling grades. Later Wakeley (1954) reports that the inconsistent results obtained from morphological grades make it difficult to write specific recommendations for grading southern pine nursery seedlings.

Mitchell (1939) found that seedling dry weight, root/shoot ratio, bud formation, and needle color could be modified by variations in the external supply of nutrients. When nitrogen supply was excessively high in proportion to phosphorus, potassium and calcium supplies, shoot development was abnormal in relation to the root development. Individual increases in the supplies of phosphorus, potassium, and calcium resulted in increases in the ratio of root weight to shoot weight. He found that the growth response of eastern white pine seedlings to increase in the supply of nitrogen, potassium, and calcium was greater than to equal increments of phosphorus.

Rosendahl and Korstian (1945) studied the effects of fertilization of loblolly pine on root length, stem length, stem diameter, needle length, mycorrhizal abundance, and plant dry weight. They found that applications of nitrogen significantly affected each of these characteristics, whereas combinations of other nutrients generally did not result in

significant positive response.

Westveld (1946) found that variations in external nutrient supply resulted in variation in shoot growth, dry weight of stem and roots, and the number of branches per seedling.

McDermott and Fletcher (1955) found that eastern redcedar seedlings grown in pots did not respond to fertilizer treatments. In another study, Fletcher and Ochrymowych (1955) found the growth of eastern redcedar seedlings was markedly influenced by the amount of certain available mineral elements in the soil. Fastest growth in weight and length, most foliage and branches, most extensive root system, and healthiest appearance characterized seedlings grown on rich, calcareous soil with a high pH (ca 7.8), a high organic matter (6.0%) and soluble phosphorus content, and adequate to high amounts of potassium and magnesium. Poorest growth of eastern redcedar seedlings was associated with a low pH (ca 4.9), low organic matter content, (0.8 to 1.8%), and low amounts of calcium, potassium, and phosphorus. A high calcium content in the soil tended to promote an extensive root system and a vigorous stem with healthy foliage.

Björkman (1954) reports that on agricultural soils containing sufficient nutrients, Scotch pine and Norway spruce seedlings do not show any significant response to heavy fertilizer treatments. Heiberg and White (1951), Stone (1953), and Walker (1955) found that on potassium and magnesium deficient soils, fertilizer treatments resulted in a significant positive response for some species. Using chemical analyses of needle tissue, they found a strong correlation between increased growth and a high content of potassium in the tissue. Growth increase was also related to a greater amount of exchangeable potassium in the soil.

Sato (1954) found that fertilizer treatments could be used to modify such morphological characteristics of birch as stem height, root collar diameter, volume, and air dry weight. Increasing the amounts of K_2SO_4 in the soil solution increased the cellulose content of plants and improved the relationship between fibre length and breadth.

Maki (1950) reports that the development and vigor of longleaf pine seedlings can be modified by varying the supply of available nutrients in the soil.

Walker, Gessel, and Haddock (1955) grew western redcedar (Thuja plicata Donn) in culture solutions, sand cultures, and soil pot cultures. They found that oven dry weights of shoots and roots and shoot heights varied with variations in mineral composition of growth media.

Davis (1949) found that when loblolly pine seedlings were grown in a calcium deficient media the root tips were blunt and covered with a layer of dead, partially disintergrated cells. The needles were twisted, stiff, short, and the tips of many needles were dead.

Relationships Between Nutrient Availability and Physiological and Anatomical Characteristics of Seedlings

During recent years Bard (1945), Fletcher and Ochrymowych (1955), Lunt (1938), Mitchell (1939), Voigt (1955), Walker, Gessel, and Haddock (1955), and others have analysed seedling foliage for mineral content. Generally, mineral content of foliage increased as mineral content of the soil solution increased from a deficient to an optimum level. As the mineral content of the soil solution increased from optimum to a toxic or saturated level, the mineral content of foliage tended to remain constant or to decrease.

Young (1947) reported that mycorrhizae on loblolly pine roots were capable of supplying carbohydrates obtained from cellulose to the plants through the roots. This carbohydrate supply was suitable for pine nutrition and could, at least, supplement the carbohydrates supplied by photosynthetic activities.

Wilde and Voigt (1948b) found that the specific gravity of seedling stems was related to the mineral and moisture content of the growth media. Seedlings obtained from natural reproduction on cutover area with coarse, sandy soil showed considerably higher specific gravity of wood than seedlings produced on heavily fertilized nursery beds. They predict that weak and inelastic seedlings that have tissues of low specific gravity are liable to suffer especially severe injury by sleet, hail, and other adverse factors.

Wilde, Nalbandau, and Yu (1948) found that seedlings grown on a heavily fertilized soil have a significantly higher content of ash and protein and a significantly lower content of alcohol-benzene soluble substances than seedlings grown on a soil of low fertility. They suggest that the contents of ash and protein may serve as indicators of the balance of nursery-soil fertility and the desirable proportion of applied fertilizer salts.

Kopitke (1941) found that potash fertilization of white spruce, red pine, and eastern white pine promoted the accumulation of simple and invert sugars in the tissue of seedlings. It increased the content of total solids and raised the osmotic pressure and lowered the freezing point of the expressed sap. However, applications of K_2O in amounts higher than 300 pounds per acre reduced the content of soluble sugars in seedling tissue and arrested synthesis of proteins. He suggested frequent analysis of nursery soils and timely correction of potash deficiency as a prerequisite for production of frost resistant nursery stock.

Sato and Muto (1951b) found that for seedlings of several species native to Japan resistance to cold increased with increased amounts of potassium in the nutrient solution. Osmotic pressure of the sap was related directly to the concentration of potassium in the growth media.

Shirley and Meuli (1939) found that drought resistance of two-year-old red pine seedlings was dependent on a favorable balance of nutrients in the soil solution. Drought resistance decreased with increase in the nitrogen supply. When the nitrogen concentration was low, an increase in available phosphorus improved drought resistance of seedlings. Forest Service (1944) investigators reported that resistance to drought and field survival increased twenty per cent when a proper balance between nitrogen, phosphorus, and potassium had been maintained in the nursery beds during the growing season. Fertilization during the dormant season, prior to lifting, resulted in increased field survival and in increased resistance to drought. A high, unbalanced nitrogen concentration produced seedlings with a low resistance to drought.

Wilde and Voigt (1949) found that the absorption-transpiration quotient of seedlings could be controlled or modified by varying the fertility level of the growth media. The absorption-transpiration quotient was found to be correlated with the degree of succulence of seedlings and their vulnerability to drought and frost.

Wakeley (1954) suggests that fertilizer treatments of the nursery soil may greatly affect the physiological quality of southern pine nursery stock.

Davis (1949), working with loblolly pine, found that certain anatomical characteristics could be modified by varying the nutrient supply. Calcium deficient seedlings differed from those receiving 200 ppm of calcium in culture solutions in that production of primary tissues (cortex and pith) and secondary tissue (xylem) was reduced. The number and size of cells in leaf tissue were directly related to the calcium supply.

Effects of Nursery Practice on Field Survival of Planted Stock

The problem of satisfactorily classifying tree seedlings according to their capacities for survival and growth after planting has proved to be complex. The first seedling grades were developed in an attempt to judge these capacities by visible characteristics, including size. Several investigators have reported that survival of planted stock was correlated with nursery management practices.

Higgins (1928) reported that field survival of western yellow pine and jack pine seedlings in Nebraska was inversely proportional to the seedbed densities. Wahlenberg (1929, 1930) obtained similar results with ponderosa pine, western white pine (*Pinus monticola* Dougl.), and Engelmann spruce (*Picea engelmannii* Parry) from the Savenac Nursery in Montana. Scarbrough and Allen (1954) and Derr (1955) found that longleaf pine seedlings grown at low densities survived better than seedlings grown at high densities. Apparently, some investigators failed to realize that reduction in density made more nutrients available for the remaining plants.

Curtis (1955); Fowells (1953); Pomeroy, Green, and Burkett (1949); and Wakeley (1935) reported that large, thrifty nursery stock survived better than small, unthrifty stock.

Chapman (1948) reported that highest survival of shortleaf pine seedlings was obtained with seedlings having a low height/diameter ratio. He found that stem diameter was a more effective criterion of survival than stem height. Wilde and Voigt (1948) suggested that seedlings with stems of high specific gravity might survive better than seedlings with stems of low specific gravity.

Wilde, Wittenkapm, Stone, and Galloway (1940) and Wilde, Trenk, and Albert (1942) found that seedlings produced on highly fertile soils were better able to survive under adverse field conditions than those grown on soils of low fertility or with unbalanced fertility. Forest Service (1956) investigators found that field survival of slash pine seedlings was dependent upon the soil fertility level of the nursery seedbed.

Several investigators have modified a seedling's capacity for survival by changing the water absorption rate of roots or the transpiration rate of the foliage. A review of literature in this field is not included in this paper.

General Relationships Between Plant Nutrition and Soil Fertility

Opinions regarding the relative importance to plant growth of the physical and the chemical properties of soil have varied considerably during different periods in the development of soil science and plant science. This results from the existance of extreme variations in physical and chemical characteristics of soils, combined with wide variations in physical and chemical characteristics of soils, combined with wide variations in nutritive requirements of plants. Russell and Russell (1950), Shaw (1952), and Baver (1948) have discussed the physical properties of soils in relation to plant growth. Baver (1948) uses the term tilth to include all those soil conditions that determine the qualities of the soil as a suitable physical environment for plant growth. Adequate aeration, sufficient moisture, and ready infiltration of rainfall are functions of good tilth. However, a soil in good tilth is not necessarily a fertile soil. Liebig reported in 1840: "The crops on a field diminish or increase in exact proportion to the diminuation or increase of the mineral substances conveyed to it in manures." Russell and Russell (1950) have reviewed the basic relationships in plant nutrition as established by Boussingault, DeSaussure, Liebig, Lawes and Gilbert, and others. Mehlich and Drake (1955), Meyer and Anderson (1952), and Truog (1951) discuss the importance to plant growth of the essential nutritive elements and the desirable regulatory elements. Truog (1938) reports that, in the modern conception of soils and plant nutrition, the soil is a three-phase medium in which nutrients are held in various forms and degrees of availability.

The basic information concerning the relationships in plant nutrition and soil fertility are as applicable to forest nursery management as to production of agricultural crops. However, nursery managers and researchers frequently have not been acquainted with some of these fundamental relationships.

Soil Reaction

The reaction of the soil either affects the growth of agricultural plants and forest tree seedlings through the direct influence of H- and OH- ions and the balance of acidic and basic constituents; or it acts indirectly by affecting the physical condition of the soil, the availability of nutrients, the solubility and potency of toxic compounds, and the activity of beneficial and parasitic soil organisms. The reaction of a soil determines the species that can be grown and the kind of fertilizer that should be applied (Wilde, 1946a).

A low soil pH results, on the one hand, in a shortage of available calcium and sometimes phosphate, and on the other hand, in an excess of soluble aluminum, manganese, and perhaps other metallic ions. The relative importance of these factors depends on the composition of the soil and the susceptibility of the crop to a deficiency of calcium or phosphorus or an excess of aluminum or manganese.

In the humid southeastern United States, there is a persistent and unremitting inclination toward intensification of soil acidity as a result of (1) leaching of metallic cations, (2) removal of basic ions by plants, and (3) reaction of certain fertilizers (Bear, Prince, and Toth, 1952; Lyon, Buckman, and Brady, 1952; Peach, 1941; and Volk, 1956).

Russell and Russell (1950) report that the harmful effects of acidity can be corrected by use of calcium carbonate, which raises the pH level, or by the use of a neutral calcium salt such as calcium sulphate, that has no effect on the pH of the soil.

Cation Exchange

Undoubtedly the most important characteristic of colloidal clay is its capacity of cation exchange (Kelley, 1948). Organic matter in the soil possesses similar colloidal properties. Lyon, Buckman, and Brady (1952) report that each one per cent of silicate clay content has an exchange capacity of approximately 0.1 to 1.0 milli-equivalents per hundred grams of soil, whereas each one per cent of well humified organic matter in a mineral soil may have an exchange capacity in the neighborhood of 2.0 milli-equivalents per hundred grams of soil. The importance of exchange capacity to soil fertility and plant nutrition has been stressed by a number of workers (Lyon, Buckman, and Brady, 1952; Russell and Russell, 1950; Truog, 1951; Wilde, 1946a). In general, colloidal clay and organic colloids act as a storehouse, or bank, in which bases are preserved in a form available to plants, yet not easily removed by leaching. Wilde and Kopitke (1940) report that the amount of available potassium retained in the soil in spite of conditions favorable to leaching is directly dependent upon the level of the exchange capacity of the soil.

Mehlich and Coleman (1952) present a comprehensive review of the relationship between the types of soil colloids and the mineral nutrition of plants. They report that there is an important general relationship between exchangeable cations in the growth media and the content of calcium, magnesium, potassium, sodium, and other cations in the plant. The ionic environment of plant roots depends to a large extent on the amounts and proportions of various colloidal acids, bases, and salts in the soil. Geraldson (1956) found that, when other factors were constant, plant growth was a function of two nutritional variables, intensity and balance. Soil scientists and plant physiologists agree that the kind, amount, and rate of ion uptake by roots of plants is a complex phenomenon that may be modified by variations in the concentration and balance of one or more cations or anions.

Great variations exist in the chemical composition of soils due to the extent to which the main factors of soil formation come into play (Lawton, 1955). The degree of availability of the nutrient elements present may vary over a wide range. The scope of the field of literature devoted to the transformation of mineral elements from one degree of availability to another is too wide to cover adequately in this review.

Calcium

The relationships of calcium with soil reaction, soil structure, soil micro-organisms, nutrient availability and plant response have been reported by Bear (1942), Millar (1955), Russell and Russell (1950), and Thorne (1930). All investigators report that an adequate supply of lime (1) will maintain a soil reaction of approximately 6.0, (2) is beneficial in maintaining a favorable soil structure, (3) favors the more desirable soil organism, (4) affects favorably the availability and uptake of nutrient elements, and (5) promotes the growth of plants.

Nitrogen

Of the various plant nutrients, nitrogen probably has received the greatest amount of study, and for very good reasons. The quantity in the soil is small, while the amount withdrawn annually by crops is comparatively large. At times soil nitrogen is lost through volatilization; at other times it is dissolved in the soil solution and lost in drainage; and at other times it is held in a state of unavailability to higher plants. Its effects on plants usually are very marked and rapid. It tends primarily to encourage above-ground, succulent vegetative growth and to impart to the foliage a deep green color. Nitrogen is a nutrient regulator in that it governs to a considerable degree the utilization of phosphorus, potassium, and other elements. Insufficient quantities of nitrogen result in stunted growth, a restricted root system, and a chlorotic appearance of leaves. An excess of nitrogen will result in a harmful effect on certain crops. Bear (1942), Lyon, Buckman, and Brady (1952), Lutz and Chandler (1946), Millar (1955), Russell and Russell (1950), Thorne (1930), Waksman (1952), and others have reviewed thoroughly the nitrogen cycle and the relationship between soil nitrogen and organic matter. Because nearly all of the nitrogen in soils is generally associated with organic matter, only very small amounts are held in readily available form, as NH_4- or NO_3-. The remainder falls in the moderately available or slowly available category.

Harmsen and Van Schreven (1955) report that during microbial decomposition organic matter must contain 1.5 to 2.5 per cent nitrogen in order to guarantee good growth of microbes without absorption of nitrogen from the surrounding medium. When plant residues contain more than 1.5 to 2.5 per cent nitrogen, some will be liberated as ammonia, the actual amount depending on the original concentration of nitrogen in the residue. Waksman (1952) reports that the decomposition of straw and other plant material having a high carbon/nitrogen ratio can be hastened by the addition of available nitrogen and phosphorus in the form of inorganic salts. Allison (1956) found that in the decomposition of organic matter, 2 to 3 per cent of the total nitrogen is released annually, supplying 20 to 50 pounds of available nitrogen per acre on poor soils and up to 100 pounds per acre on good soils. Harmsen and Van Schreven (1955) report that the liberation of mineral nitrogen is much faster in a calcareous clay soil than in an acid sandy soil, since a slightly alkaline reaction seems to be optimal for nitrification.

The problem of nitrogen control is two-fold: (1) maintenance of an adequate supply in the soil and (2) the regulation of the turnover in such a way as to assure a ready availability at such times as needed to meet crop demands (Lyon, Buckman, and Brady, 1952). Since soils under any given climate tend to assume a normal or equilibrium nitrogen content under the cropping and manuring systems in use, any attempt to raise the nitrogen content to a point materially higher than this normal will be attended by unnecessarily high losses. Allison (1955) reports that crops commonly recover only 40 to 75 per cent of the nitrogen that is added.

Demortier and Fouarge (1938), Nemec (1938a), Vaartaja (1954), and Wilde (1946a) report that seedlings on coniferous species have the ability to use both ammonia nitrogen and nitrate nitrogen. Definite preferences during varying stages of growth have not been conclusively determined. The effect on growth of different forms of nitrogen depends largely on the degree of soil acidity and the supply of other nutrients.

Lewis (1938a, 1938b) and Tisdale (1952) reported on the utilization of different forms of nitrogen fertilizers by different crops. In general, they found that if other factors were not limiting, there were no significant differences between the effects of the various nitrogen fertilizers.

When the lime status of soil was maintained at an adequate level, inorganic nitrogen gave as good results as organic fertilizers supplying the same amount of nitrogen.

Several factors must be considered when nitrogen fertilizers are applied. Nitrate materials, such as nitrate of soda, calcium nitrate, and calcium cyanamide, generally tend to raise the pH of the soil. Compounds that supply the ammonium form of nitrogen, either directly or as a result of hydrolysis, will ultimately increase soil acidity (Collings, 1950). Puri and Asghar (1938) found that the amount of ammonia reacting with the soil was a function of pH values. Ammonia nitrogen is most highly available to plants at pH 6.0 to 6.5, whereas the nitrate nitrogen in sodium nitrate is most readily available at pH 4.0 to 4.5. Engels (1939) found that when nitrogen concentration was increased materially, it was necessary to increase phosphorus and potassium applications. He suggested that the best general fertilizer ratio for N-P_2O_5-K_2O, when the nutrient content of the soil was unknown, was 1:2:2.

Phosphorus

The function of phosphorus in the physiological activities of plants has been described very ably by Arnon (1953). He gives a comprehensive review of literature on the subject.

Many articles have appeared that discuss the soil-plant relationships in the nutrition of phosphorus. Colwell (1944), Dean and Fried (1953), Hutton and Robertson (1953), and Welch, Hall, and Nelson (1949) report that when the soil phosphorus supply is a limiting factor in plant growth increments of phosphate fertilizer added to the soil will result in increased yield of dry matter and fruit or seed. The rate of phosphorus absorption reaches its maximum earlier in the growth cycle than does the growth rate. Altering the phosphorus supply of a soil influences the rate and amount of phosphorus absorbed and the phosphorus content (percentage) of crops. Dean and Fried (1953) report that an increase in the soil phosphorus supply may result in increasing, decreasing, or leaving unchanged, the percentage of phosphorus in the plant, depending on the phosphorus level in the original soil. Hutton and Robertson (1953) grew corn on a virgin Red Bay fine sandy loam that had 6 pounds per acre of available phosphorus. After three years of cropping, the available phosphorus dropped to 1 pound per acre on untreated plots and increased to 30 pounds per acre on plots that received phosphorus fertilization. Colwell (1944) and Welch, Hall, and Nelson (1949) found that on phosphorus deficient soils soybeans responded to applications of phosphorus. The magnitude of yield increase was related to the level of available phosphorus in the soil. Dean and Fried (1953) report that under conditions where an increase in soil phosphorus results in no growth changes in a plant, an increase in supply usually is accompanied by an increase in the total phosphorus uptake by the plant and in the percentage of phosphorus in the plant tissue.

The total phosphorus content of Coastal Plain soils in the south Atlantic and Gulf States is extremely low in comparison with that in other regions of the United States. Available phosphorus may range from 1 to 15 per cent of the total phosphorus (Parker, 1953). Analyses of nursery soils reveal that levels of available phosphorus range from a trace on virgin soils to more than 100 parts per million on areas formerly devoted to farm crops (May and Gilmore, 1955). Since crops seldom use more than 15 to 20 per cent of the phosphorus applied in fertilizer, it usually requires large applications to produce maximum yields (Pierre, 1938). Applications of excess phosphorus year after year result in the accumulation of both available and fixed phosphorus in the soil.

Soils of the south Atlantic and Gulf States are acid in reaction, high in sesquioxides, and extremely variable in texture. Many articles have appeared on the retention and fixation of phosphorus in these soils. Coleman (1944a, 1944b) found that some soils have a higher capacity for phosphate fixation than others. Some of the better agricultural or nursery soils such as Orangeburg, Ruston, and Red Bay belong to the group with high fixation capabilities. Ensminger (1952) studied the fixation of phosphorus in a fine sandy loam in south Alabama. He found that 103 pounds of P_2O_5 per acre per year were accumulated from a 200 pound annual application of P_2O_5. However, little or no accumulation was was reported when the rate of application was low. Dean (1941) reports that a 5-fold or greater increase in amount of total phosphorus has been obtained as a result of intensive use of phosphate fertilizers. At the Rothamsted Experiment Station, the content of P_2O_5 on some plots increased from 0.44 per cent in 1881 to 2.80 per cent in 1944.

Kurtz (1953) reports that the fixation of phosphate ions to sesquioxides increased as the pH was decreased. Struthers and Sieling (1950) found that citrate and certain other organic materials inhibited the precipitation or fixation of soluble phosphate in the pH zone of 4.0 to 6.0. Later, Dalton, Russell, and Sieling (1952) found that the decomposition of organic products was highly effective in increasing the availability of fixed soil phosphate for some crops.

Black and Goring (1953) present a comprehensive review of recent literature on organic phosphorus in soils. They report that the amounts of organic phosphorus in soils are correlated positively with the amounts of organic carbon and nitrogen. The organic matter of mineral soils contains carbon, nitrogen, and phosphorus roughly in the ratio 110:9:1 by weight. Organic phosphorus is considered to be rather stable. However, the rate of organic phosphorus mineralization may vary appreciably during the year because of the continual changes of microbial activity in response to variations in soil conditions.

Phosphorus is not as soluble in water as nitrogen and potassium, and it generally is subject to only slight loss by leaching. Ensminger (1952), and Scarseth and Chandler (1938) found that losses of phosphorus by erosion could account for up to 63 per cent of the P_2O_5 applied during a long period. Losses were attributed to the removal of organic matter and clay fractions in drainage. Neller, et al.(1951) determined the content of phosphorus in a limed and unlimed Leon fine sand with an initial pH value of 4.5. They found that when superphosphate was applied to the surface 1 to 2 inches, the phosphorus was almost completely leached out of the unlimed soil in one year. An application of one ton per acre of lime reduced leaching of phosphorus by about 40 per cent and two tons reduced the loss by 80 per cent. They report that the pH value is a good indicator of leachability of fertilizer phosphorus in fine sandy soils, but it is not a reliable indicator in loamy sand, sandy loams, and loams.

Page (1953) working with Norfolk sand, found that liming tended to decrease the amount of NH_4F- soluble phosphorus and total phosphorus in the surface soil, to increase these forms in the subsoil, and to increase the acid-soluble phosphorus in both the surface and the subsoil.

Truog (1953) reports that the liming of acid soils to a pH near the neutral point will increase the availability of both native phosphorus and that applied as a soluble fertilizer. Liming of acid soils to near the neutral point will reduce solubility and availability of some of the minor nutrient elements. However, a high state of general fertility can be maintained by addition of such minor elements as may be needed.

Utilization of phosphorus by roots of plants is determined by the degree of availability (Carter, 1951). On a Tifton sandy loam with a moderately high level of available phosphorus, peanut plants obtained most of their phosphorus from the soil, only a relatively small amount from fertilizer. On a Norfolk sandy loam with a low level of available phosphorus the plants secured most of their phosphorus from the applied fertilizer.

Potassium

Unlike calcium, nitrogen, and phosphorus, potassium does not enter into permanent organic combinations in plants. It apparently exists only as a constituent of soluble inorganic and organic salts and bases. Although potassium is an indispensable element and cannot completely be replaced even by chemically similar elements, its exact role in plants is obscure (Meyer and Anderson, 1952). Potassium appears necessary for the normal maintenance of the following processes: (1) carbohydrate

accumulation, (2) nitrate absorption, (3) nitrate reduction and protein synthesis, (4) cell division, (5) formation of organic acids and oils, (6) disease resistance, (7) frost resistance, (8) turgor control, and (9) photosynthesis. Lawton and Cook (1954) and Rohde (1937) have published embracive reviews of available information that deals with the role of potassium in plant growth. Potassium deficiency symptoms for many plants have been described by Lawton and Cook (1954) and others.

The range of total potassium contents of soils is enormous. In the southeastern United States the soils have been thoroughly leached and are relatively low in available potassium. Yet, in one southeastern state, Marbut (1935) reported that the K_2O content of the surface layer of a Durham sandy loam was 5.15 per cent, while that of a Tifton fine sandy loam was only a trace.

Potassium in its simpler chemical compounds is one of the most readily soluble elements; but in the soil-plant system compounds of potassium exist with extreme differences of solubility and mobility. Potassium in the soil occurs in compounds ranging from the easily soluble salts through stages of decreasing solubility to the essential constituents of certain primary minerals from which it is released only in destruction by slow weathering of the crystal structures.

From investigations of potassium availability in several Indiana soils Rouse and Bertramson (1950) concluded that the potassium supplying power of the soil was related to both the exchangeable and the non-exchangeable or slowly available form of potassium. Legg and Beacher (1951) use the term potassium supplying power to designate the capacity of the soil to supply potassium to growing plants from both the exchangeable and the moderately available forms. In an examination of eight red-yellow podsolic soils in Alabama, Pearson (1950, 1952) concluded that these highly weathered and leached soils have a low rate of conversion of non-exchangeable potassium to forms available to plants. Montmorillonitic soils released fixed potassium more readily than did kaolinitic soils. He also found a highly significant direct relationship between the original exchangeable potassium content of the soil and the total amount of potassium absorbed by plants.

When the available potassium supply is adequate, the removal rate by crops is high, often 3-4 times that of phosphorus and equal to that of nitrogen. If large quantities are present, plants tend to take up soluble potassium far in excess of their needs. This luxury consumption of potassium apparently does not increase crop yields to any extent. The opinion of Seay, Attoe, and Truog (1949) that there is a definite relationship between the potassium content of a plant and that of the medium on which it was grown has been verified by numerous investigations. However, Legg and Beacher (1952) are of the opinion that significant crop responses may not be obtained by additional potassium application to soils with a potassium supplying the power of 250 ppm and a base exchange capacity above 5 milli-equivalents per 100 grams of soil.

Hester and Skelton (1934) have shown that the efficiency of potassium utilization by vegetable crops varied with soil types. A Bladen sandy loam showed a much higher power for fixing potassium than

either Norfolk fine sand or a Portsmouth loamy fine sand. The calculated percentages of utilization of available potassium were 38.5 from the Bladen sandy loam, 82.8 from the Portsmouth loamy fine sand, and 84.8 from the Norfolk fine sand. More potassium was fixed in the heavier soil. Cooper, Schreiner, and Brown (1938) suggest that at least 75 per cent of the plant needs should be in the form of readily available phosphorus.

Frequently, the degree of saturation of the cation exchange complex by K is small, yet the availability of the exchangeable K is relatively large. In an examination of the response of alfalfa on New Jersey soils, Bear, Prince, and Malcolm (1945) concluded that optimum growing conditions existed when the exchange complex was made up of 65 per cent calcium, 10 per cent magnesium, 5 per cent potassium, and 20 per cent hydrogen. The calcium: magnesium: potassium ratio was 13.5:2:1. Plant growth was not affected substantially by considerable deviation from these ratios provided the percentage saturation of an individual cation or the sum of the metal cations was not limiting. Hester (1938) reports that soil containing a high calcium content will require more potash for adequate potassium fertilization than a soil with a low calcium content.

In a comparison of the response of a number of crops on a deep phase Norfolk sandy loam to potassium and magnesium additions, Page and Paden (1951) observed the following effects. Applications of potassium (a) increased the percentage of potassium in plants, (b) decreased or had no effect on the calcium and magnesium content of the plant, and (c) did not affect phosphorus and sodium content. Applications of magnesium (a) increased the percentage of magnesium in plants, (b) decreased or had no effect on calcium, and (c) did not affect phosphorus, potassium, or sodium.

Maki (1950) reported that high potassium level in soils resulted in more vigorous longleaf pine seedlings and higher survival of planted stock than did low potassium levels. Wilde (1946a) claimed that applications of feldspar and other primary minerals improved the growth of seedlings but failed to produce stock large enough to satisfy nursery standards. He suggested the supplementary use of readily soluble nutrients.

Magnesium and its Relation to Other Minerals

Magnesium, the only mineral constituent of the chlorophyll molecule, may be essential to photosynthesis.

Meyer and Anderson (1952) report that magnesium may also act in a regulatory or catalytic capacity in the process of plant growth.

The light soils of the Atlantic and Gulf Coastal Plain are generally deficient in magnesium. Magnesium-deficiency diseases of potatoes, tobacco, and cotton have been found on the Sandy Coastal Plain soils (McMurthrey and Robinson, 1938). Schreiner, Merz, and Brown (1938) conclude that deficiency of magnesium in all probability has affected crop production more widely than that of any other secondary plant nutrient. The widespread occurrence of magnesium deficiency in some Coastal Plain soils has been due to (1) the initial low level of magnesium in virgin soils, (2) the use of commercial fertilizers made from materials containing very little magnesium, (3) increased soil acidity, resulting from the heavier use of acid forming salts that facilitated the leaching of magnesium from the soil, and (4) losses resulting from crop removal and erosion (Lyon, Buckman, and Brady, 1952).

According to Johnson and Wear (1956), applications of magnesium to old fields in south Alabama resulted in significant increases in yields of potatoes. Increases in yield were much higher on light textured soils than on heavy textured soils. Prince, Zimmerman, and Bear (1947), working with 20 New Jersey soils, did not obtain any correlation between total magnesium content and crop producing powers.

The existance of an important general relationship between exchangeable cations in the soil and plant content of calcium, magnesium, potassium, and sodium has been established by a number of investigators (Camp, 1947; Cooper, Paden, and Garman, 1947; Page and Paden, 1951; Prince, Zimmerman, and Bear, 1947; Van Itallie, 1948; Zimmerman, 1947).

Prince, Zimmerman, and Bear (1947) grew alfalfa on soils treated with different levels of magnesium. The response to additions of magnesium was governed in part by the ratio of magnesium to other cations in the exchange complex, particularly calcium and sodium. The most significant single factor that influenced the uptake of magnesium by alfalfa plants was the quantity of available potassium. As the supply of available potassium decreased the magnesium uptake increased.

Van Itallie (1948) found it possible to cause magnesium deficiency in spite of a normal supply of magnesium in the soil by large additions of potassium and sodium. When the ratio of soil calcium to magnesium was about 8.5:1, he found about equal amounts of the two cations in the plant. When the calcium/magnesium ratio was about equal, he found more than three times as much magnesium as calcium in the plant. According to Zimmerman

(1947), absorption of magnesium by plants usually bears a straight line relationship to exchangeable magnesium/potassium ratios in the soil.

Soil Structure

The mainenance of favorable structure in cultivated soils is just as important to the nursery manager as is the maintenance of a balanced nutrient supply. Baver (1948), Shaw (1952), and Russell and Russell (1950) have discussed the relationships between the physical properties of the soil and plant growth. Martin, et al. (1955) concluded that the ideal soil from the physical point of view is one in which the smaller mechanical fractions, sand, silt, and clay, are bound together in water stable aggregates, forming a granular or crumb structure.

According to Page (1951) only when a favorable soil structure exists can the greatest advantage be gained by the liberal use of fertilizers. Van Daren and Klingebeil (1951) report that when adequate nutrient fertility levels are maintained water and air become the limiting factors affecting plant growth and yields.

In a preceeding section, it was reported that in nursery operations seedlings have to be lifted when the soils are wet. A loose, friable condition must be maintained in order that roots can be removed from the soil without damage. In sands or loamy sands, the single grains should be combined into stable aggregates. In heavier soils, the large clods should be broken down into favorably sized aggregates.

Clay and organic substances, plus iron, aluminum and silicon oxides, and hydrated oxides, play an important part in stabilizing aggregates. A general discussion of these factors are beyond the province of this review. However, they must be given full consideration in any soil management plan.

Conclusions from the Literature

1. The nutritional requirements of most tree species have not been determined. For the few species that have been investigated conflicting results frequently have been obtained.

2. In a majority of the investigations the results of treatments have been measured on the basis of their effects on morphological characteristics.

3. The diversities in soils within any one region have either not been recognized or accepted. The general assumption has been that for all soils the same response will be obtained from similar treatments.

4. The immediate and residual effects of additions of mineral fertilizers and organic substances used in connection with the production of southern pine seedlings have not been determined.

5. Chemical analyses of soils and foliage have been used in only a few of the studies on southern pine seedlings. Frequently, the studies were for only one year. Variations between years may be greater than the variations within a year.

6. Specific morphological characteristics of seedlings can be developed with rather widely varying proportions of mineral elements in the soil. Variations in the proportions of mineral elements in the soil can result in a change of physiological characteristics of seedlings without a corresponding change in morphological features.

7. Additions of fertilizer and organic materials that will result in favorable responses in one soil type may result in negative responses in another soil type.

CHAPTER III

LOCATION AND DESCRIPTION OF EXPERIMENTAL AREA

Auburn Nursery

The Auburn nursery is located approximately 7 miles southeast of the town of Auburn, in Lee County. It is in the transition zone between the Upper Coastal Plain region and the Piedmont region of Alabama, at a latitude of 32 degrees and 34 minutes north and a longitude of 80 degrees and 25 minutes west.

The nursery, consisting of 25 acres, is on a gentle east slope. The soils are Faceville sandy loam and Magnolia sandy loam. The area has been in crop or pasture for approximately 100 years. The cropping and fertilizing history prior to 1949 is not available, but it is known that lime had been applied at periodic intervals. At the time of purchase in 1949 the west portion was in alfalfa and the east portion in corn. The pH values of four samples taken in September 1949, were 6.0, 6.5, 7.0, and 8.0. The average pH[1] value of nine topsoil samples taken in February 1953, was 5.92, with a high of 6.2 and a low of 5.85. The average pH of the subsoil was 5.2.

Well water used for irrigation tested as follows:

Total solids in solution	85 ppm

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[1]pH is the negative exponent of the hydrogen ion concentration and is not subject to mathematical average. When pH values are within a narrow range, mathematical averages are often used.

Loss on ignition (includes chemically combined CO_2 and organic matter)	50 ppm
Chlorine	Trace
pH	6.0

Approximately one acre of the Faceville sandy loam was designated as an experimental area. Mechanical analysis according to the method of Bouyoucos (1936) indicated particle size class distributions as shown in Table 1.

TABLE 1.--Particle size class distribution of the Faceville soil type

Horizon	Depth	Sand	Silt	Clay	Textural Classification
	Inches	Per cent	Per cent	Per cent	
Topsoil	0-10	74	16	10	sandy loam
Subsoil	10-20	59	22	19	sandy loam

Alfalfa was turned under in January, 1950, and the first nursery seedbeds were prepared in March, 1950. Seedling crops have been grown on part of the experimental area annually since 1950.

North Auburn Experimental Area

The North Auburn experimental area used for out-plantings is located three miles north of Auburn on the gently rolling sandy loams of the Piedmont uplands and terraces. The planting site is a Cecil sandy loam, eroded phase, which has a moderately stiff, red sandy clay or clay subsoil that is exposed in spots.

Autauga County Experimental Area

The Autauga County experimental area used for out-planting is located nine miles northwest of Prattville in the sand hill section of the Upper Coastal Plain region. The planting site is a Lakeland (Norfolk) fine sand, deep phase. The original forest vegetation, consisting of longleaf pine and various species of scrub oak (Quercus marilandica Muenchh., Q. stellata Wangenh. and Q. falcata Michx.), was removed many years ago. The planting site was once in cultivation, but later was allowed to revert to grass and scattered trees. Broomsedge (Andropogon spp.) predominated.

Climate

The climate can be characterized as generally hot and moist, but it definitely has continental properties. The average number of frost-free days at Auburn is 237 (Hocker, 1955). Temperatures are mostly hot in summer and cool in winter. There are intermittent warm days during the winter months. The annual precipitation is generally high and moderately well distributed, but extreme variations in annual rainfall have occurred within the past few years. There is a tendency toward heavier precipitation in the winter and summer months and decidely lighter rainfall in the spring and fall. Precipitation and temperature data for Auburn are presented in the appendix.

CHAPTER IV

EXPLORATORY STUDIES

Comparison of Stock Produced by Different Nurseries

Loblolly pine seed collected in the vicinity of Auburn in the fall of 1949 were sown in nurseries in Alabama, Mississippi, Arkansas, and Texas in the spring of 1950. In February and March, 1951, seedlings from each nursery were out-planted at the North Auburn experimental area. Seedlings from all nurseries were graded and planted according to the same specifications.

Nitrogen, potassium and phosphorus content of needles and of nursery soil samples were determined with the Spurway Simplex Soil-Testing Kit (Spurway and Lawton, 1949; Cook and Millar, 1949). Values were expressed in terms of high, medium, and low mineral levels. Nitrogen content of needles was very low. Phosphorus and potassium content ranged from medium to high. Nitrogen, phosphorus and potassium content of soils were low.

Average survival for the five lots of seedlings was 60.6 per cent, with a range of 35 to 78 per cent.

The results supported Wakeley's (1948) findings that different nurseries or the same nursery may produce seedlings that are alike morphologically but have different capacities for survival.

Methyl-Bromide Study-1950

Dieter and Coulter (1949) reported that methyl bromide had effectively controlled nematodes, fungi, weeds and grasses. Maki and Henry (1951) found that methyl bromide was very effective in controlling root rot at the W. W. Ashe Nursery. Cossitt (1950) reported that methyl bromide depressed growth and development of southern pine seedlings.

In order to test the effectiveness and toxicity of methyl bromide, the fumigant was applied to seed beds three weeks prior to sowing of slash pine seed. Rates of application were 1, 2, and 4 pounds of methyl bromide per 100 square feet.

More plants and more plantable seedlings were produced on the non-treated plots than on the treated plots. Production decreased as the rate of application increased. The data were not analyzed statistically to determine if differences were significant.

Almost complete weed control was obtained for a year with all methyl bromide treatments. However, the 1 pound rate was apparently as effective as the 2 and 4 pound rates in the control of nut grass and other grasses or weeds.

Sawdust Study-1951

Sawdust was applied to an area that had been in loblolly pine in 1950. Rates of application were the equivalent of 10 and 20 tons of oven-dried sawdust per acre. Mineral fertilizers were applied at the following rates per acre: Nitrogen - 100 pounds; P_2O_5 - 250 pounds; and K_2O - 125 pounds. Sawdust and fertilizers were mixed into the top 6 inches of the soil using a Seaman-tiller. Additional nitrogen was applied as a top dressing during the growing season to all plots.

Mean seedling density was lower in plots that received the 20 ton application, but the seedlings were larger and more vigorous. Root and stem development were exceptionally good for both treatments.

Study of Mineral Fertilizer and Sawdust Treatments-1952

Six different levels of mineral fertilization, including a zero level, were tested in combination with three levels of sawdust application and two levels of methyl bromide treatment.

Fertilizers and sawdust were mixed with the soil with a disc plow and a tiller.

Measurements included seedling density, percentage of plantable seedlings, stem length, stem diameter, root length, and bud development.

Variation between seedlings within a sub-plot was extremely high, apparently due to an uneven mixture of sawdust and fertilizers with the soil.

In the statistical analysis, the only significant differences were between the fertilized and the non-fertilized plots. There were no significant differences from the effects of methyl bromide, sawdust, or fertilizer treatments. Seedlings on the non-fertilized plots were small in size and were very poorly developed. Only on plots that received methyl bromide did most of the seedlings develop fascicled needles.

At the suggestion of Doctor George W. Snedecor, visiting Professor of Biometry at Alabama Polytechnic Institute, the 1952 study was discontinued, and a new experiment was designed for an adjacent area.

CHAPTER V

PROCEDURE-MAIN EXPERIMENT

Experimental Design

The exploratory studies indicated that sawdust and mineral fertilizers could be applied immediately prior to sowing of loblolly pine seed without adverse effect and that seedlings could be produced successfully for three consecutive years on the same area. However, the individual and combined effects on the soil of applications of sawdust, applications of mineral fertilizer, and production of seedlings were not determined. Therefore, in 1953, an experiment was designed to test the effect of applications of sawdust and mineral fertilizers on plant growth and certain soil characteristics. Rotations were introduced as another variable. Chemical treatment with methyl bromide constituted a fourth variable.

The experiment was put on an area that had been in seedling production for three years and had received a uniform treatment.

The experimental design was a randomized block, split plot structure with rotations and chemical treatments applied to main plots and with treatments of fertilizer and sawdust superimposed in sub-plots (Cochran and Cox, 1950). Each of the six blocks or replications contained six rotation - methyl bromide combinations, upon which were superimposed nine fertilizer-sawdust treatments.

Treatments

Rotations

1. Annual seedling production.
2. One year in a green manure crop alternating with two years of seedlings.
3. One year in a green manure crop alternating with one year of seedlings.

Legumes (soybeans or cow peas) were used for a green manure crop. Seed were sown in April, following the application of sawdust and fertilizers. The crop was cut and partially turned under before the seed matured in the fall. The remaining material was turned under prior to seed bed preparation in the following spring.

Chemical Treatments

1. No methyl bromide.
2. Methyl bromide.

Methyl bromide was applied at the rate of one pound per 100 square feet.

Fertilizer Treatments

1. 150 pounds P_2O_5 per acre and 80 pounds of K_2O per acre.
2. 300 pounds P_2O_5 per acre and 160 pounds of K_2O per acre.
3. 450 pounds P_2O_5 per acre and 240 pounds of K_2O per acre.

For the annual seedling rotation applications of P_2O_5 and K_2O were made each year. For the green manure crop-seedling rotations, additions of P_2O_5 and K_2O were made only in the years the green manure crop was planted.

An initial application of 100 pounds of nitrogen per acre was made annually prior to establishment of the seedling or the green manure crop. Additional nitrogen was applied as needed in order to produce seedlings of plantable size.

Basic fertilizer materials were concentrated superphosphate, muriate of potash, and ammonium nitrate.

Sawdust Treatments

1. No sawdust.
2. 15 tons of pine sawdust per acre, oven-dry-weight basis.
3. 30 tons of pine sawdust per acre, oven-dry-weight basis.

Plot Size, Designation and Arrangement

Each main plot is 4 feet wide by 72 feet long and is assigned a number to designate its position in the block and the rotation-chemical treatment (Figure 1).

The dfsignation for each of the six main plots is as follows:

R1 Reg. - Annual seedling production, no methyl bromide.

R2 Reg. - Green manure crop alternating with two years of seedlings, no methyl bromide.

R3 Reg. - Green manure crop alternating with one year of seedlings, no methyl bromide.

R1 Mod. - Annual seedling production and methyl bromide.

R2 Mod. - Green manure crop alternating with two years of seedlings with methyl bromide soil treatment prior to seedling crop.

	Block I	Block II	Block III
FS	3 9 1 7 4 8 2 6 5 R 2 Reg	5 3 4 1 8 6 9 2 7 R 1 Reg	2 4 3 1 5 7 6 8 9 R 1 Mod
FS	9 4 6 7 3 2 5 8 1 R 3 Reg	3 8 6 2 5 4 9 1 7 R 1 Mod	2 7 6 3 9 1 8 4 5 R 2 Reg
FS	8 3 2 7 5 1 9 6 4 R 2 Mod	1 5 3 4 9 2 8 7 6 R 3 Reg	2 7 6 3 8 5 4 9 1 R 3 Reg
FS	6 9 1 4 8 5 7 2 3 R 3 Mod	1 3 8 5 6 7 4 9 2 R 2 Reg	5 9 1 8 3 6 2 4 7 R 1 Reg
FS	3 9 2 7 5 1 4 8 6 R 1 Reg	2 6 3 9 4 5 1 7 8 R 3 Mod	6 7 2 1 8 5 9 3 4 R 2 Mod
FS	8 6 9 5 1 4 3 7 2 R 1 Mod	7 3 5 2 9 8 1 4 6 R 2 Mod	5 9 7 3 4 6 2 8 1 R 3 Mod

	Block IV	Block V	Block VI
FS	6 5 8 4 9 7 1 3 2 R 1 Reg	7 9 2 1 5 3 4 6 8 R 3 Mod	5 6 8 4 2 3 7 1 9 R 1 Mod
FS	8 6 5 3 7 9 1 4 2 R 2 Reg	2 6 7 3 9 4 1 8 5 R 3 Reg	7 1 9 8 3 6 4 5 2 R 2 Mod
FS	9 1 3 5 7 2 4 6 8 R 2 Mod	4 3 2 1 9 5 7 6 8 R 1 Reg	5 2 6 8 4 1 7 9 3 R 1 Reg
FS	1 5 2 8 9 4 7 3 6 R 3 Mod	6 2 5 4 1 7 8 3 9 R 2 Reg	6 9 5 7 4 8 2 3 1 R 3 Mod
FS	2 7 1 4 8 5 9 3 6 R 1 Mod	6 2 5 8 4 9 3 1 7 R 1 Mod	4 1 6 9 8 5 2 7 3 R 2 Reg
FS	6 1 2 4 7 9 3 8 5 R 3 Reg	2 3 5 7 8 9 6 4 1 R 2 Mod	6 1 4 3 7 5 2 8 9 R 3 Reg

Legend

FS - Fertilizer Sawdust Treatments
R - Rotations
Mod. - Modified Series (Methyl Bromide)
Reg. - Regular Series (No Methyl Bromide)

Fig. 1.--Plot arrangement and designation.

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FS-1

FS-2

FS-3

FS-4

FS-5;

FS-6;

FS-7;

FS-8;

FS-9;

R3 Mod. - Green manure crop alternating with one year of seedling with methyl bromide soil treatment prior to seedling crop.

Each main plot is divided into 9 sub-plots 4 feet wide by 8 feet long. Each sub-plot is assigned a number to indicate its position in the main plot and the fertilizer-sawdust treatment. The designation for each of the nine sub-plots is as follows:

FS-1: 150 pounds of P_2O_5 per acre, 80 pounds of K_2O per acre, no sawdust.

FS-2: 300 pounds of P_2O_5 per acre, 160 pounds of K_2O per acre, no sawdust.

FS-3: 450 pounds of P_2O_5 per acre, 240 pounds of K_2O per acre, no sawdust.

FS-4: 150 pounds of P_2O_5 per acre, 80 pounds of K_2O per acre, 15 tons of sawdust per acre.

FS-5: 300 pounds of P_2O_5 per acre, 160 pounds of K_2O per acre, 15 tons of sawdust per acre.

FS-6: 450 pounds of P_2O_5 per acre, 240 pounds of K_2O per acre, 15 tons of sawdust per acre.

FS-7: 150 pounds of P_2O_5 per acre, 80 pounds of K_2O per acre, 30 tons of sawdust per acre.

FS-8: 300 pounds of P_2O_5 per acre, 160 pounds of K_2O per acre, 30 tons of sawdust per acre.

FS-9: 450 pounds of P_2O_5 per acre, 240 pounds of K_2O per acre, 30 tons of sawdust per acre.

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Discussion of Treatments

The experiment was designed to cover a six year period so that the longest rotation could be completed twice. This report covers a three year period, i.e. from 1953 through 1955. Rotations for the three year period were:

	1953	1954	1955
Rotation 1	Seedlings	Seedlings	Seedlings
Rotation 2	Green Manure Crop	Seedlings	Seedlings
Rotation 3	Green Manure Crop	Seedlings	Green Manure Crop

In the discussion symbols for seedlings and green manure crops will be S and GMC, respectively.

Methyl bromide treatments were included as a protection against damping-off losses. Losses did not materialize, and methyl bromide had little effect on soil nutrient availability or on plant development. Therefore, this treatment was discontinued after the second year. In the discussion plots that did not receive methyl bromide treatment are designated as the "Regular" series. Plots that did receive methyl bromide treatments are designated as the "Modified" series. The abbreviations "Reg" and "Mod" refer to the Regular series and the Modified series respectively.

The rates for phosphorus and potassium were selected in an arbitrary manner. Data provided by Huberman (1940a) and Stone (1948) indicated that a crop of loblolly pine seedlings would remove about 37 pounds of P_2O_5, 62 pounds of K_2O and 142 pounds of nitrogen each year. Assuming a recovery rate of 20 per cent for phosphorus, 60 per cent for potassium and 50 per cent for nitrogen, fertilizer requirements would be 185 pounds P_2O_5, 102 pounds K_2O and 284 pounds of nitrogen.

The review of literature indicated that previous studies started with low rates of application of phosphorus and potassium. For this study, the writer decided to bracket the calculated requirements in two treatments and use a much higher rate for the third treatment.

The 1952 exploratory study showed that nitrogen was essential for growth of pine seedlings, but that the working range of nitrogen availability was quite wide. Since the levels of ammonia nitrogen and nitrate nitrogen in the soil are changing continuously and loblolly pine seedlings may use either form, the writer decided to make a single application of ammonium nitrate prior to each crop and then apply additional nitrogen as needed to produce seedlings of plantable size.

The experiment was designed so that treatments could be modified or eliminated during the course of the study. Results of two years study showed that the selected fertilizer levels were adequate to produce a crop of seedlings and possibly maintain the level of soil fertility. Therefore, the range of fertilization levels was expanded by modification of treatments on half of the plots after the second year, before the 1955 crop was planted.

Reduced fertilizer treatments were applied to the plots that had received methyl bromide treatments. Original and new rates of application are as follows:

Original Rate - Regular Series	New Rate - Modified Series
150 pounds P_2O_5 and 80 pounds K_2O per acre.	No P_2O_5 and no K_2O per acre.
300 pounds P_2O_5 and 160 pounds K_2O per acre.	75 pounds P_2O_5 and 40 pounds K_2O per acre.
450 pounds P_2O_5 and 240 pounds K_2O per acre.	150 pounds P_2O_5 and 80 pounds K_2O per acre.

Some plots in the Modified series received the same treatment as some plots in the Regular series. However, plots that received like treatments in 1955 did not receive like treatments in 1953 or 1954. Consequently, the cumulative effects of first and second year treatments were sometimes quite different for the two series. Applications of P_2O_5 and K_2O fertilization are summarized in Table 2.

The number of fertilizer treatments increased from three in the original design to six after some treatments were reduced. In the discussion, fertilizer treatment Number 1 represents the lowest rate of application and consecutive numbers represent progressively higher rates of annual application.

Boundaries of each sub-plot were re-established from a permanent marker prior to treatments. Alleys between seed beds were plowed out with a middle buster. After sawdust and fertilizers were applied to each sub-plot, the material and soil were mixed by spading. Methyl bromide was applied under polyethylene covers about 5 to 10 days prior to sowing.

Collection of Soil Samples

Prior to treatments in 1953, a top soil sample was collected

Fertilizer Treatments[a]

Regular Series

TABLE 2.--Summary of P_2O_5 and K_2O fertilization for the period 1953-1955, inclusive (in pounds per acre)

Rotation Number	Year	Type of Crop	Fertilizer Treatments[a]					
			Modified Series			Regular Series		
			1	2	3	4	5	6
			P_2O_5 Fertilization					
1	1953	S	150	300	450	150	300	450
	1954	S	150	300	450	150	300	450
	1955	S	0	75	150	150	300	450
Total P_2O_5 Rotation 1			300	675	1050	450	900	1350
2	1953	GMC	150	300	450	150	300	450
	1954	S	0	0	0	0	0	0
	1955	S	0	0	0	0	0	0
Total P_2O_5 Rotation 2			150	300	450	150	300	450
3	1953	GMC	150	300	450	150	300	450
	1954	S	0	0	0	0	0	0
	1955	GMC	0	75	150	150	300	450
Total P_2O_5 Rotation 3			150	375	600	300	600	900
			K_2O Fertilization					
1	1953	S	80	160	240	80	160	240
	1954	S	80	160	240	80	160	240

Rotation	Year	Type of	Fertilizer Treatments[a]

TABLE 2.--(Continued)

Rotation Number	Year	Type of Crop	Fertilizer Treatments[a]					
			Modified Series			Regular Series		
			1	2	3	4	5	6
	1955	S	0	40	80	80	160	240
Total K_2O Rotation 1			160	360	560	240	480	720
2	1953	GMC	80	160	240	80	160	240
	1954	S	0	0	0	0	0	0
	1955	S	0	0	0	0	0	0
Total K_2O Rotation 2			80	160	240	80	160	240
3	1953	GMC	80	160	240	80	160	240
	1954	S	0	0	0	0	0	0
	1955	GMC	0	40	80	80	160	240
Total K_2O Rotation 3			80	200	320	160	320	480

[a]The Modified Series (fertilizer treatments 1, 2 and 3) and the Regular Series (fertilizer treatments 4, 5 and 6) received the same fertilization rates in 1953 and 1954.

from each main plot. A one pint composite sample of the top 9 inches[2] was obtained by taking one sub-sample from each sub-plot.

In January-February following lifting of seedlings, a soil sample was collected from each sub-plot. Similar samples were taken following the 1953, 1954, and 1955 seedling and green manure crops.

Laboratory Analysis of Soil Samples

1953 Samples

After they were air dry, the composite samples were rolled and screened through a 2 millimeter sieve. The material less than 2 millimeters in size was used for mechanical analysis and for chemical analysis. All analyses were made in duplicate.

Mechanical analysis was made according to the method of Bouyoucos (1936). Soil reaction was measured on a Coleman pH meter according to the general method of Piper (1950) and the specific directions of Russell (1950).

Soil organic matter was determined by the wet combustion method as outlined by Peach, Alexander, Dean, and Reed (1947). This method consists basically of oxidizing carbon in the soil with potassium dichromate and titrating the excess by reducing with ferrous sulfate. Percentage of carbon was converted to percentage of organic matter by the conventional 1.724 factor.

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[2]In the nursery, the soil is plowed and disked to a depth of 9 or 10 inches. It is standard procedure to sample the plow layer.

Total nitrogen in the soil was determined by the Kjeldahl method as given by the Association of Official Agricultural Chemists (1950).

Cation exchange capacity was determined by the method outlined by Russell (1950). Ten-gram samples were leached with 250 milliliters ammonium acetate. Excess ammonium acetate was removed with methyl alcohol. Ammonia on the exchange position was replaced with magnesium from magnesium oxide. Ammonia was distilled by a steam distillation apparatus.

Available phosphorus, available potassium, and exchangeable calcium were determined according to a procedure used by the Soil Testing Laboratory of the Alabama Extension Service. The extracting solution for phosphorous and potassium was a mixture of approximately 0.05 N HCL and 0.025 N H_2SO_4. For phosphorus determination an ammonium molydate-ammonium vandate mixture was added to a vial of extract and transmission per cent was read on a Cenco photometer. Potassium was determined with a Perkins Elmer flame photometer. Calcium was extracted with a solution of ammonium acetate and determined according to the same procedure used for potassium. All analyses in 1953, other than for phosphorus, calcium, and potassium were made in the Soils Laboratory of the Forestry Department, Alabama Polytechnic Institute.

1954, 1955, and 1956 Samples

Soil samples were oven dried at 105°C. to a constant weight, then rolled and screened through a 2 millimeter sieve.

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Soil reaction, organic matter content, and exchange capacity were determined as described above. For determinations of calcium, potassium, and magnesium, leachate solutions from the determination of exchange capacity were run on a Beckman Model DU flame photometer (Fieldes *et al.*, 1951).

Soil phosphorus was determined by means of a weak acid extraction according to the Truog (1930) method.

Determination of Germination and Seed Bed Survival

A stand density of approximately 35 seedlings per square foot was desired. The sowing rate was computed on the basis of seed viability, number of seed per pound, and predicted mortality during the growing season. Eight drills, spaced 6 inches apart, were sown lengthwise of the seed beds. Except for a control drill, seed were machine sown.

Although the rate of sowing by machine usually is uniform and accurate, some drills occasionally put out more seed than others. In order to eliminate any variation in number of seed for the control drill, seeds were counted and then sown by hand.

Germination counts were made in the segment of the drill in which the counted seed were sown. Counts were made at weekly intervals after the first seed had germinated. Dead seedlings were removed and the cause of death noted if it could be determined. Germination counts were continued for four weeks, or until germination practically ceased. Cumulative germination was computed for each sub-plot. Seedling mortality was followed by seedling counts made periodically until the end of the growing season.

During the second year, germination and survival counts were also made in a machine sown drill. Results for the counted seed and the machine drilled seed were so nearly alike that counting of seed was eliminated in the third year.

Measuring Morphological Features of Seedlings

At the time of lifting in December or January, seedlings from 1 or 2 drills were counted and classified as plantable or non-plantable (Wakeley, 1954). Group samples containing 25 or more seedlings were selected at random for measurements and testing. The number of seedlings in a sample was determined according to a procedure later described by Schultz (1955).

For the 1953 seedlings, the following measurements were obtained:

Stem length

Stem diameter at ground line

Root length

Green weight of shoot

Green weight of root

Oven dry weight of shoot

Oven dry weight of root

Volume of root

Volume of shoot

Presence or absence of terminal bud

Immediately after sampling, stem length and diameter and root length were measured. Soil was washed from the plants, and surface water was allowed to evaporate. Then the plants were cut at the ground line, and the tops and the roots were weighed. Volumes were determined by

measuring displacement of xylene by the samples in a graduate cylinder. Tops and roots were oven dried at 105°C to a constant moisture content and then reweighed.

Chemical Analysis of Samples

Sample seedlings from each sub-plot were oven dried at 105°C. In 1953, the whole plants were ground in a Wiley mill to go through a 1-millimeter screen and then stored in glass jars for subsequent chemical analysis. In 1954 and 1955, the plants were separated into three components, needles, stems, and roots; and each component was ground and analyzed separately.

An ash solution was prepared from 2 grams of each sample by the dry ashing procedure given by Piper (1950).

Calcium, potassium, and magnesium concentrations were determined by burning the ash solutions in a Beckman Model DH flame photometer and by comparing light intensities at specified wave lengths with intensities from standard solutions.

Phosphorus in the ash solutions was determined according to the method of the Association of Official Agricultural Chemists (1950).

Measuring Survival of Plants

For testing effects of nursery treatments on field survival, randomly selected seedlings from all sub-plots that received the same treatment were mixed to form a composite sample representing each treatment.

In January, 1954, four replicate plantings of seedlings from each treatment were established at the North Auburn experimental area.

Seedling heights were measured immediately after planting. Survival counts were made in May. Height and survival data were obtained in November.

Seedlings from the 1954 and 1955 crop were out-planted at the North Auburn experimental area and at the Autauga County experimental area in January 1955 and December 1955, respectively. Survival counts were made during the spring and fall following planting.

Statistical Analysis of Data

Data taken in 1953, 1954, 1955, and 1956 were subjected to analyses of variance (Snedecor, 1946) in order to determine the significance of the annual and cummulative changes following treatments. Many of the analyses produced significant first and second order interactions. Some of the significant interactions were due to treatment, others due to chance arrangements of the data.

As a result of the nature of the experiment and type of experimental design, some replications of treatments developed other than the standard block replication. For example, rotations two and three received similar treatments until 1955. Therefore, one would expect similar results for these two rotations in 1953 and 1954.

CHAPTER VI

EFFECTS OF TREATMENTS ON GERMINATION, MORTALITY AND NUMBERS OF PLANTABLE SEEDLINGS

Germination

Sowing dates for the three-year period were:

1953	April 28
1954	April 12
1955	April 4

Mean cumulative germination per cents for each year are presented in Table 3.

For 1953 and 1954, treatments did not affect germination of seed. In the analysis of the 1955 data, fertilizer treatments for the Regular series were highly significant. Germination was reduced on the plots that had received the heavy fertilizer applications for three consecutive years. It is possible that the cumulative effects of heavy fertilization might have resulted in an injury to the radicle, thereby preventing establishment of a seedling. Failure of germination or establishment due to a heavy concentration of mineral salts has been reported by Wakeley (1954) and others.

Seedling Mortality After Establishment

Seedling counts were repeated at intervals after germination until stem growth had ceased in late fall or early winter. Mortality for the growing season, expressed as a percentage of the cumulative

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germination was computed.

TABLE 3.--Cumulative seedbed germination of loblolly pine seed

Year and Treatment	Mean Germination	LSD[a]	CV[c]
	Per cent		
1953 All treatments	48.9	NS[b]	13.1
1954 All treatments	36.9	NS	15.9
1955 Modified series All treatments	65.8	NS	18.3
1955 Regular series		5.7	17.9
Fertilizer treatment 1	71.5		
Fertilizer treatment 2	69.5		
Fertilizer treatment 3	60.8		
1955 Combined Modified and Regular series	66.6		

[a]Least significant difference (5 per cent level). In this paper, the term "highly significant" refers to significance at the one per cent level. The term "significant" refers to significance at the 5 per cent level, but failing to attain the one per cent level.

[b]Non-significant.

[c]Coefficient of variation - per cent.

Mean mortality percentages by years were:

1953	11.3 per cent
1954	23.0 per cent
1955	9.0 per cent

In the statistical analysis, sawdust effects were highly significant in 1953. Other treatment effects were non-significant. Sawdust means for 1953 were:

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No sawdust	9.9 per cent mortality	
15 tons sawdust per acre	9.4 per cent mortality	
30 tons sawdust per acre	16.6 per cent mortality	
Least significant difference (5 per cent level)		3.5
Coefficient of variation - per cent		8.4

If the 30 tons of sawdust per acre were not mixed thoroughly with the soil, some mortality could be expected due to unfavorable moisture conditions. Since no significant effects were obtained by the 30 ton per acre application in 1954 and 1955, it can be assumed that the 1953 effects were due to improper application or to variations in sampling.

The factors causing mortality in 1953 and 1954 were not recorded. However, top damping-off and white grubs were major sources of loss. These losses were more or less evenly distributed over the area and were not influenced by treatments.

Percentage of Plantable Seedlings

1953

Treatments did not result in any significant differences in percentages of plantable seedlings. The mean percentage of plantable trees was 59.7. The coefficient of variation was 20.8 per cent.

1954

Seedlings from the control drill and seedlings from an equal area in another drill in each sub-plot were graded. The two sets of data were analyzed separately and then combined in one analysis. In the analysis of data, rotation effects were significant for the control drills and highly significant for the other drill. Differences due to sawdust and fertilizer were significant for the non-control drill.

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However, when data for the two drills were combined, rotation effects were highly significant and sawdust effects were significant (Table 4).

A green manure crop followed by seedlings resulted in a higher percentage of plantable trees than an annual seedling rotation. An increase in the rate of fertilization resulted in an increase in the percentage of plantable seedlings. An application of 450 pounds of P_2O_5 and 240 pounds of K_2O per acre was significantly superior to an application of 150 pounds of P_2O_5 and 80 pounds of K_2O per acre.

1955

Data for the Regular series and the Modified series were analyzed separately, and then combined in one analysis.

In the combined analysis, rotation by fertilizer interaction effects were almost significant. The mean percentage of plantable seedlings was 86.06. The coefficient of variation was 40.0 per cent.

There were no significant differences due to treatments for the Regular series.

For the Modified series, rotation and fertilizers created significant interaction effects, with fertilizers creating differences in the annual seedling rotation but not in the other rotations. Mean values for fertilizer treatments for Rotation 1, Modified series, were:

Fertilization in 1955	Plantable seedlings
1. None	83.78 per cent
2. 75 lbs. of P_2O_5 and 40 lbs. of K_2O per acre	87.89 per cent
3. 150 lbs. of P_2O_5 and 80 lbs. of K_2O per acre	87.28 per cent

Least significant difference for fertilizer means for the same rotation (5 per cent level) - 3.64

Treatments	Control Drill		Non-Control Drill		Combined Drills		LSD[a]
	Mean	Probability	Mean	Probability	Mean	Probability	

TABLE 4.--Percentage of seedlings plantable, 1954 crop

Treatments	Control Drill		Non-Control Drill		Combined Drills		LSD[a]
	Mean	Probability	Mean	Probability	Mean	Probability	
Rotations		<.05		<.005		<.01	3.32
1. S-S	76.23		74.08		75.15		
2. and 3. GMC-S	79.04		81.31		80.17		
Chemicals		>.50		<.10		<.10	NS[b]
1. No methyl bromide	77.75		77.22		77.49		
2. Methyl bromide	78.45		80.58		79.52		
Fertilizers[c]		<.10		<.05		<.05	1.45
1. 150 pounds P_2O_5 and 80 pounds K_2O per acre	77.49		77.10		77.30		
2. 300 pounds P_2O_5 and 160 pounds K_2O per acre	77.29		79.6		78.44		
3. 450 pounds P_2O_5 and 240 pounds K_2O per acre	79.55		80.0		79.76		
Sawdust[c]		>.50		<.05		>.10	
1. None	77.28		79.49		78.38		NS
2. 15 tons per acre	78.78		80.09		79.43		
3. 30 tons per acre	78.26		77.12		77.69		

Treatments	Control Drill	Non-Control Drill	Combined Drills	LSD[a]

TABLE 4.--(Continued)

Treatments	Control Drill		Non-Control Drill		Combined Drills		LSD[a]
	Mean	Probability	Mean	Probability	Mean	Probability	
Mean all treatments	78.10		78.90		78.5		
Coefficient of variation - per cent	10.5		11.3		9.0		

[a]Least significant difference (5 per cent level).

[b]Non-significant.

[c]Per seedling crop.

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Plantable seedlings were graded into Grades 1 and 2 (Wakeley, 1954) and percentages for each grade were computed. The mean percentage of Grade 1 seedlings was 13.0.

For the Regular series, treatments did not affect the percentages of Grade 1 seedlings.

Interaction effects of rotations with sawdust were highly significant for the Modified series. Percentages of Grade 1 seedlings for Rotation 1 and sawdust treatments in this series are presented in Table 5.

TABLE 5.--Grade 1 loblolly pine seedlings from the Modified series, 1955 crop (in per cent of total trees)

Sawdust Treatments	Rotations	
	1. S-S-S	2. GMC-S-S
1. None	13.78	15.28
2. 15 tons per acre per year for Rotation 1 and 15 tons in 1953 for Rotation 2	13.83	16.00
3. 30 tons per acre per year for Rotation 1 and 30 tons in 1953 for Rotation 2	6.72	23.33

Least significant difference for sawdust means for the same rotation (5 per cent level) - 4.82

Treatments of 30 tons of sawdust per acre produced significantly more Grade 1 seedlings under Rotation 2 than other treatments, and significantly less Grade 1 seedlings under Rotation 1 than other treatments.

Fertilizer effects were not significant. However, the smallest percentages of Grade 1 seedlings were produced on plots that received the lightest fertilizer applications.

Number of Seedlings and Number of Plantable Seedlings Per Square Foot

For the 1954 seedling crop, five analyses of covariance were made for five of the nine fertilizer-sawdust treatments. These treatment combinations were:

Fertilizer 1 - Sawdust 1
Fertilizer 1 - Sawdust 3
Fertilizer 2 - Sawdust 2
Fertilizer 3 - Sawdust 1
Fertilizer 3 - Sawdust 3

The covariance of Y, per cent of plantable trees, with X, number of seedlings per square foot, was computed for each of the above treatments. In some analyses there were no indications of a linear relationship between total number of plants and percentages of plantable trees.

A multiple regression was computed for each treatment with X_2, the second independent variable, equal to X_1^2. Another multiple regression was computed using the sums of the five regressions. The prediction equations for the six regressions are:

Fertilizer 1 - Sawdust 1	$Y = 85.4 - .1048X_1 - .0002733X^2$
Fertilizer 2 - Sawdust 3	$Y = 90.3 - .4426X_1 + .003112X^2$
Fertilizer 2 - Sawdust 2	$Y = 88.7 - .1056X_1 - .0005352X^2$
Fertilizer 3 - Sawdust 1	$Y = 105.7 - .6811X_1 + .003939X^2$
Fertilizer 3 - Sawdust 3	$Y = 72.6 - .4201X_1 - .004512X^2$
Total regression	$Y = 85.0 - .0605X_1 - .000652X^2$

None of the multiple regressions seemed to account for a large proportion of variability and they were of different shapes. However, there was close agreement among the computed number of plantable seedlings for stand densities up to 50 seedlings per square foot. Above this level, wide differences were obtained (Table 6).

TABLE 6.--Plantable seedlings for different densities (number per square foot)

Seedling Density	Fertilizer - Sawdust Treatments					
	F1-S1	F1-S3	F2-S2	F3-S1	F3-S3	All Treatments
0	0	0	0	0	0	0
10	8.3	8.3	8.6	9.4	7.9	8.4
20	16.2	15.5	16.7	17.0	16.4	16.3
30	23.4	22.5	24.1	23.7	24.5	23.4
40	30.1	29.9	30.7	30.6	30.9	30.4
50	36.0	38.6	36.4	38.5	34.8	36.2

For the existing fertility levels, it appears that there is no strong relationship between percentage of plantable seedlings and number of seedlings per square foot for densities below 50 seedlings per square foot.

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CHAPTER VII

EFFECTS OF TREATMENTS ON MORPHOLOGICAL CHARACTER OF PLANTS

Volume of Plant Material

Some volume measurements and shoot/root ratios for seedlings from the 1953 crop are presented in Table 7.

TABLE 7.--Mean volume of roots and shoots of loblolly pine seedlings, 1953 crop

Treatment	Volume		Shoot/Root Ratio
	Shoot	Roots	
	Cubic centimeters	Cubic centimeters	
No sawdust	91.1	35.8	2.61
15 tons sawdust per acre	74.7	33.3	2.23
30 tons sawdust per acre	74.1	34.3	2.17
Mean - all treatments	80.0	34.5	2.33
LSD[a]	11.1	NS[b]	0.19
Coefficient of variation - per cent	29.3	25.0	17.1

[a]Least significant difference (5 per cent level).

[b]Non-significant.

Sawdust treatment effects were highly significant for shoot volumes and for shoot/root ratio. Sawdust treatments may have effected shoot volume by reducing the amount of available nitrogen, thereby retarding shoot development. Root volumes were not affected by treatments. A more favorable shoot/root ratio was obtained as a result of sawdust treatments.

Length and Diameter of Seedlings

Data on stem length, stem diameter and root lengths were obtained for the 1953 seedlings. A summary of length and diameter measurements are presented in Table 8.

TABLE 8.--Length and diameter of loblolly pine seedlings, 1953 crop

Treatment	Stem Length[a]	Stem Diameter[a]	Stem Diameter Plantable Trees[b]	Root Length[a]
	Inches	Inches	Inches	Inches
No sawdust	6.68	.115	.1418	7.91
15 tons sawdust per acre	5.68	.104	.1400	7.83
30 tons sawdust per acre	5.85	.109	.1392	8.17
Mean all treatments	6.07	.109	.1403	7.97
LSD[c]	.40	NS[d]	NS[d]	NS[d]
Coefficient of variation - per cent	13.9	12.6	9.1	8.5

[a]Based on seedlings from the total population.

[b]Based on seedlings from the plantable population.

[c]Least significant difference (5 per cent level).

[d]Non-significant.

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Applications of sawdust resulted in a significant reduction of stem length and a slight but non-significant reduction in the diameters of plantable seedlings. It may be assumed that the level of available nitrogen was reduced by sawdust treatments resulting in a corresponding reduction of stem growth. Other treatment effects were non-significant.

Seedlings Developing Winter Buds

Treatments did not have a significant effect on the development of terminal buds. An average of 64.25 per cent of the plants from the total population developed buds. On the basis of plantable seedlings only, the percentage might be higher. Small or slender loblolly pine seedlings frequently do not form a bud during the first year in the seedbeds.

Shoot and Root Weights of 1953 Seedlings

Green weights and oven-dry weights for the 1953 seedlings are summarized in Table 9. The only highly significant differences were in the effects of different sawdust treatments on green and dry weights of stems. The analysis indicated that the sawdust and chemical interaction effects were significant for green weight of stems. For subplots that received methyl bromide, green weights decreased with increasing rates of sawdust application. The same pattern developed for oven-dry weights, but the differences were non-significant. The heaviest rates of fertilization produced greater green and dry weights than the lighter rates, but the differences were not significant.

The shoot/root ratios for oven-dry weights were computed. Only sawdust effects were significant (Table 9).

TABLE 9.--Mean weights and shoot/root ratio for loblolly pine seedlings, 1953 crop

Treatment	Weight of shoots		Weight of roots		Shoot/root ratio Oven-dry basis
	Green	Oven-dry	Green	Oven-dry	
	Grams	Grams	Grams	Grams	
Fertilizer					
1. 150 pounds P_2O_5 and 80 pounds K_2O per acre	2.57	0.95	0.96	0.41	-
2. 300 pounds P_2O_5 and 160 pounds K_2O per acre	2.57	0.94	0.97	0.40	-
3. 450 pounds P_2O_5 and 240 pounds K_2O per acre	2.84	1.03	1.04	0.42	-
Sawdust					
1. None	3.04	1.11	1.03	0.43	2.74
2. 15 tons per acre	2.59	0.93	1.00	0.39	2.40
3. 30 tons per acre	2.35	0.88	0.94	0.42	2.37
LSD[a]	0.40	0.14			0.16
Chemicals					
Methyl bromide	2.89	1.06	1.05	0.44	-
No methyl bromide	2.43	0.90	0.92	0.38	-
Mean all treatments	2.66	0.98	0.99	0.41	2.50
Coefficient of variation - per cent	31.5	30.7	26.8	29.9	14.7

[a]Least significant difference (5 per cent level).

Shoot and Root Weights of 1954 Seedlings

In 1954 and 1955, the only morphological measurements obtained were oven-dry shoot and root weights of plantable trees.

In 1954, treatments did not have any significant effects on the oven-dry weights of shoots or roots. However, the analysis indicated that the effects of chemical treatments on the shoot/root ratio were highly significant. Higher shoot/root ratios were obtained following the use of methyl bromide. A summary of treatment means for 1954 data is presented in Table 10.

Shoot and Root Weights of 1955 Seedlings

Weights of oven-dry shoots

Data for the Regular series and for the Modified series were analyzed separately and then combined in a single analysis. In the Regular series, the interaction of rotation with sawdust was highly significant. For the annual seedling rotation, the oven-dry weight of shoots decreased with increasing rates of sawdust. When a green manure crop appeared in the rotation, oven-dry weights of shoots increased with increasing rates of sawdust (Table 11).

In the Modified series, sawdust and rotation by sawdust interaction effects were highly significant. The pattern for the annual seedling rotation was similar to the annual seedling rotation in the Regular series, that is, oven-dry weights decreased with increasing rates of sawdust (Table 11).

Fertilizer treatment effects were not significant. However, when oven-dry weights of seedlings from the annual seedling rotation

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TABLE 10.--Mean oven-dry weights for plantable loblolly pine seedlings, 1954 crop

Treatment	Seedling Shoots	Seedling Roots	Shoot/Root Ratio
	Grams	Grams	
Chemicals			
No methyl bromide	1.534	0.638	2.439
Methyl bromide	1.632	0.623	2.617
LSD[a]	NS[b]	NS[b]	.113
Rotations			
1. S-S	1.561	0.636	2.477
2. and 3. GMC-S	1.595	0.628	2.553
Sawdust[c]			
1. None	1.584	0.629	2.551
2. 15 tons per acre	1.588	0.627	2.549
3. 30 tons per acre	1.578	0.636	2.484
Fertilizers[c]			
1. 150 pounds P_2O_5 and 80 pounds K_2O per acre	1.552	0.621	2.515
2. 300 pounds P_2O_5 and 160 pounds K_2O per acre	1.616	0.641	2.536
3. 450 pounds P_2O_5 and 240 pounds K_2O per acre	1.582	0.631	2.533
Mean all treatments	1.583	0.631	2.528
Coefficient of variation - per cent	24.2	25.4	12.5

[a]Least significant difference (5 per cent level).

[b]Non-significant.

[c]Rotation 2 did not receive sawdust, P_2O_5 or K_2O in 1954.

TABLE 11.--Mean weights of oven-dry shoots and roots of loblolly pine seedlings, 1955 crop (in grams)

Treatments	Modified Series Rotations 1.S-S-S	Modified Series Rotations 2.GMC-S-S[a]	Regular Series Rotations 1.S-S-S	Regular Series Rotations 2.GMC-S-S[a]
Shoots				
Sawdust[b]				
1. None	2.064	2.002	2.022	1.875
2. 15 tons per acre	1.602	1.854	1.869	1.959
3. 30 tons per acre	1.399	2.009	1.620	2.022
LSD[c] Two sawdust means for the same rotation	0.224		0.214	
Roots				
Sawdust[b]				
1. None	0.497	0.474	0.501	0.493
2. 15 tons per acre	.414	.424	.460	.504
3. 30 tons per acre	.398	.442	.455	.488
LSD[c] Two sawdust means for the same rotation	0.020		NS[d]	

[a]Rotation 2 did not receive P_2O_5 or K_2O fertilizer in 1954 and 1955.

[b]Sawdust was not applied to Rotation 2 in 1954 and 1955.

[c]Least significant difference (5 per cent level).

[d]Non-significant.

are plotted over total fertilizers, there is apparently a relationship between oven-dry weight and cumulative amount of fertilizer applied, with oven-dry weights increasing with increased fertilizer applications.

Weights of oven-dry roots

For the Modified series, sawdust treatment effects were highly significant. On the annual seedling rotation, the oven-dry weights of roots decreased with increasing rates of sawdust. This same relationship occurred for the Regular series, but the differences were not significant (Table 11). When a green manure crop appeared in the rotation, the same trend developed for the Modified series but not the Regular series.

Fertilizer treatment effects were not significant. However, when oven-dry weights of seedlings for the annual seedling rotation are plotted over total fertilizer, there is apparently a relationship between oven-dry weight and cumulative amount of fertilizer applied, with oven-dry weights increasing with increased fertilizer applications.

Shoot/root ratio

Shoot/root ratios for oven-dry weights were computed. This measurement is sometimes more reliable and more sensitive to treatments than weights of shoots or roots. For the Regular series, treatment effects were not significant.

For the Modified series, rotation and fertilizer effects were significant and the interaction effects of rotations with sawdust were highly significant. Mean shoot/root ratios are presented in Table 12.

TABLE 12.--Mean shoot/root ratios of oven-dried loblolly pine seedlings - Modified series, 1955 crop

Treatments	Rotations	
	1. S-S-S	2. GMC-S-S[a]
Sawdust		
1. None	4.232	4.260
2. 15 tons per acre	3.880	4.398
3. 30 tons per acre	3.465	4.639
Fertilizer		
1. None	3.575	4.384
2. 75 pounds P_2O_5 and 40 pounds K_2O per acre	3.918	4.349
3. 150 pounds P_2O_5 and 80 pounds K_2O per acre	4.084	4.564
LSD[b] between two sawdust or fertilizer means for the same rotation	0.364	0.364

[a]Rotation 2 did not receive sawdust, P_2O_5 or K_2O in 1954 and 1955.

[b]Least significant difference (5 per cent level).

Table 12 shows that for the annual seedling rotation, shoot/root ratios decreased with increasing rates of sawdust and increased with increasing rates of fertilizer. When a green manure crop was included in the rotation, the shoot/root ratio increased with increasing rates of sawdust. Fertilizer treatment effects were non-significant for Rotation 2.

Comparison of Mean Weights of Oven-Dry Plants

The trend for three consecutive years was toward heavier plants and higher shoot/root ratios (Table 13). Root weights remained fairly constant, while weights of shoots increased each year.

TABLE 13.--Mean weights of oven-dry loblolly pine seedlings and shoot/root ratios

Plant Component	Year		
	1953[a]	1954[b]	1955[b]
	Grams	Grams	Grams
Shoot	0.975	1.583	1.858
Roots	0.410	0.631	0.463
Entire Plant	1.185	2.234	2.321
Shoot/root ratio	2.378	2.509	4.013

[a]Plantable trees and culls.

[b]Only plantable trees.

CHAPTER VIII

EFFECTS OF TREATMENTS ON NURSERY SOILS

Soil Reaction

Mean pH values for different sampling dates are presented in Table 14.

TABLE 14.--Mean pH values of soil samples

Sampling Date	Mean pH Value	C.V.[a]
March 1953	6.36	12.0
January 1954	5.57	4.5
January 1955	5.45	3.3
January 1956	5.30	3.8

[a]Coefficient of variation - per cent.

Rotations 2 and 3 received the same treatments in 1953 and in 1954. The statistical analysis for the January 1954 data did not produce any significant differences. However, the annual seedling rotation and sawdust treatments indicated a possible downward trend in pH values (Table 15).

In the analysis of the January 1955 data, the interaction of sawdust with rotations was highly significant, as were differences due to sawdust treatments (Table 15). Rotation differences were significant.

The data revealed that sawdust treatments created differences in the annual seedling rotation but not in the other rotation.

TABLE 15.--Mean pH values, January 1954 and January 1955 soil samples

Sawdust Treatments	Rotations		Mean
	1. S-S	2. and 3. GMC-S[a]	
	January 1954		
1. None	5.45	5.64	5.61
2. 15 tons per acre	5.44	5.62	5.56
3. 30 tons per acre	5.49	5.55	5.53
	January 1955		
1. None	5.43	5.54	5.50
2. 15 tons per acre	5.29	5.51	5.44
3. 30 tons per acre	5.20	5.50	5.40
Mean	5.31	5.52	5.45

LSD[b] 1955 rotation means	0.211
LSD[b] 1955 sawdust means	0.049
LSD[b] 1955 two rotation means for the same level of sawdust	0.326
LSD[b] 1955 two sawdust means for the same rotation	0.084

[a]Rotation 2 and 3 did not receive sawdust treatments in 1954.

[b]Least significant difference (5 per cent level).

In the statistical analysis of January 1956 data, pH value for the Regular series and the Modified series were analyzed separately. Rotations, sawdust and interactions of rotations with sawdust affected pH values, but the effects were not the same for the two series (Table 16). For the Modified series, sawdust treatment effects were highly significant and the interactions of sawdust with rotations were significant. For the Regular series rotation effects were highly

TABLE 16.--Mean pH values for January 1956 soil samples

Treatment	Rotations							
	Modified Series				Regular Series			
	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[b]	Mean	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[b]	Mean
Sawdust								
1. None	5.322	5.317	5.528	5.389	5.134	5.278	5.528	5.289
2. 15 tons per acre	5.106	5.289	5.450	5.281	5.155	5.272	5.489	5.306
3. 30 tons per acre	5.033	5.344	5.461	5.280	5.028	5.188	5.517	5.244
Mean	5.154	5.317	5.480	5.317	5.107	5.230	5.511	5.283
LSD[c] sawdust means for Modified Series			0.076					
LSD[c] rotation means for Regular Series			0.196					

[a]Rotation 2 did not receive sawdust in 1954 or 1955.

[b]Rotation 3 did not receive sawdust in 1954.

[c]Least significant difference (5 per cent level).

significant.

Increases in rates of sawdust resulted in decreases in pH values. When a green manure crop was included in the rotation the pH level tended to remain constant with respect to the January 1954 pH.

By considering pH values for three sampling dates, another variable, time was introduced into the analysis. When the pH values for January 1954, January 1955 and January 1956 were combined in an analysis of variance, sawdust treatment effects were highly significant, and years and interaction effects of sawdust with rotations were significant. Rotation effects were not quite significant.

Bear, Prince and Toth (1952) found that removal of basic ions by plants tends to increase soil acidity. Bear (1942) reports that, upon oxidation, ammonium compounds tend to increase acidity. Total ammonium nitrate applications ranged from 700 to 1200 pounds per acre each year. Limestone, dolomite or other fertilizers containing calcium and magnesium were not included in the fertilization treatments. If calcium and magnesium levels are high and these elements are omitted in the fertilization program, pH levels may be expected to decrease until an equilibrium is reached. For many coastal plains soils, equilibrium values are within the range of pH 4.0 to pH 5.0.

Soil Organic Matter

The mean organic matter content for four sampling dates are presented in Table 17.

In the analysis of January 1954 data, only sawdust treatment effects were significant (Table 18).

TABLE 17.--Mean organic matter content of soil samples for different dates

Sampling Date	Organic Matter Content	C.V.[a]
	Per cent	Per cent
March 1953	2.16	38.4[b]
January 1954	1.99	13.3
January 1955	2.02	13.7
January 1956	2.04	13.4

[a]Coefficient of variation.

[b]Based on samples from 12 main plots.

The organic material of the 1953 green manure crop was not completely turned under prior to the January, 1954 sampling. Consequently very little of the green manure crop matter was included in the soil organic percentage. The data reveal a slight drop in organic matter content, in comparison with the organic matter content in March 1953 (Table 17).

In the analysis of January 1955 data, rotations, sawdust and interactions of rotations with sawdust were highly significant (Table 18). Increases in rates of sawdust resulted in increases in the organic matter content. Regardless of rotations, the organic matter content decreased on sub-plots that did not receive sawdust. For the annual seedling rotation, the highly significant difference might have been the result of a cumulative effect of sawdust treatments over a two year period.

TABLE 18.--Mean organic matter content of January 1954 and January 1955 soil samples (in per cent)

Treatment	Rotations		Mean
	1. S-S	2. and 3. GMC-S[a]	
	1954		
Sawdust			
1. None	1.888	2.007	1.968
2. 15 tons per acre	1.996	1.965	1.975
3. 30 tons per acre	1.981	2.034	2.017
	1955		
Sawdust			
1. None	1.703	1.719	1.714
2. 15 tons per acre	2.277	1.958	2.065
3. 30 tons per acre	2.565	2.149	2.288
Mean	2.182	1.942	2.022

LSD[b] 1954 - Sawdust means - 0.028
LSD[b] 1955 - Sawdust means - 0.074
LSD[b] 1955 - Rotation means - 0.119
LSD[b] 1955 - Two rotation means at the same level or at different levels of sawdust - 0.133

[a]Rotations 2 and 3 were alike in 1953 and 1954 and did not receive sawdust in 1954.

[b]Least significant difference (5 per cent level).

A green manure crop did not maintain an organic matter level equal to that of March 1953. A green manure crop plus 30 tons of sawdust per acre maintained the March 1953 level.

Data for the January 1956 samples were analyzed by series and then the data was combined in a single analysis. The relationships were consistent for each series and the combined data (Table 19).

Organic matter contents for the January 1956 data are summarized in Table 20.

The data for 1956 reveal that when sawdust is not applied in the annual seedling rotation, the organic matter content is reduced below the minimum level obtained in 1955 (1.690 versus 1.703). Increases in rates of sawdust resulted in increases in organic matter content. For maintaining soil organic matter content at or above the March 1953 level, annual applications of 15 tons of sawdust per acre without green manure crops were superior to 15 tons on alternate years or 30 tons every third year with green manure crops.

By considering organic matter content values for three sampling dates, another variable, time or years, was introduced into the analysis. Data for January 1954, January 1955 and January 1956 were combined in an analysis of variance. Probability levels are presented in Table 21.

Cation Exchange Capacity

Mean cation exchange values for different sampling dates are presented in Table 22.

TABLE 19.--Partial analysis of variance for organic matter contents for January 1956 data.

Source	D.F.	S.S.	M.S.	F.	Probability Level
Rotations - Regular Series	2	3.4567	1.7284	14.36	< .005
Rotations - Modified Series	2	3.5243	1.7621	11.76	< .005
Rotation - Regular and Modified Series	2	6.9016	3.4508	20.13	< .005
Sawdust in Regular Series	3	14.1161	7.0580	94.36	< .005
Sawdust in Modified Series	3	13.4833	6.7416	90.13	< .005
Sawdust x Rotation - Regular Series	4	3.5193	.8798	11.76	< .005
Sawdust x Rotation - Modified Series	4	2.0975	.5244	7.01	< .005

TABLE 20.--Mean organic matter contents for the January 1956 soil samples (in per cent)

Treatments	Rotations			Mean
	1. S-S-S	2. GMC-S-S[a]	3. GMC-S-GMC[b]	
Sawdust				
1. None	1.69	1.71	1.62	1.67
2. 15 tons per acre	2.26	1.89	2.07	2.07
3. 30 tons per acre	2.78	2.09	2.29	2.39
Mean	2.24	1.90	1.99	2.04
LSD[c] Sawdust means		0.116		
LSD[c] Rotation means		0.071		
LSD[c] Two sawdust means for the same rotation		.128		
LSD[c] Two rotation means at the same sawdust level		0.198		

[a]Rotation 2 did not receive sawdust in 1954 or 1955.

[b]Rotation 3 did not receive sawdust in 1954.

[c]Least significant difference (5 per cent level).

TABLE 21.--Probabilities of differences, as large as those found in the three year summary of organic matter content, being due to chance

Source of Difference	Probability Level	
	Regular Series	Modified Series
Rotations	< .025	< .005
Sawdust	< .005	< .005
Rotation x sawdust interaction	< .005	< .005
Years	< .30	< .05
Years x rotation interaction	< .05	< .005
Sawdust x years interaction	< .005	< .005
Sawdust x rotation x years interaction	< .005	< .005

TABLE 22.--Mean cation exchange values for different sampling dates

Sampling Date	Cation Exchange Capacity	C.V.[a]
	m.e. per 100 grams	
March 1953	3.66	20.1[b]
January 1954	3.95	9.9
January 1955	3.76	10.9
January 1956	4.12	9.2

[a]Coefficient of variation - per cent.

[b]Based on samples from 36 main plots.

In the statistical analyses, all significant differences were due to rotations, sawdust or the interaction of sawdust with rotations.

For the January 1954 data, rotations and sawdust treatments produced differences that were highly significant and the interaction effects of rotations with sawdust were significant (Table 23).

For the January 1955 data, differences due to sawdust treatments were highly significant. Rotation effects and the interaction effects of rotations and sawdust were significant at the 10 per cent level (Table 23).

The patterns established by the 1954 and 1955 data was substantiated by the 1956 data. Analyses were computed for each series and the data were combined in a single analysis. Rotation and sawdust treatment effects were highly significant. The interaction effects of sawdust with rotations were highly significant for the Regular series and significant for the Modified series (Table 23).

The data reveal that increases in the rates of sawdust applications resulted in increases in cation exchange capacity.

Green manure crops, without sawdust, resulted in significant increases in the level of cation exchange capacity values, but the levels decreased when seedling crops followed green manure crops.

Fertilizer effects were not significant but greater exchange capacity was found at the higher fertilizer rates than at the lower fertilizer rates.

In a previous section, it was reported that a combination of sawdust and a green manure crop increased the organic content of the

TABLE 23.--Mean cation exchange values (in milli-equivalents per 100 grams)

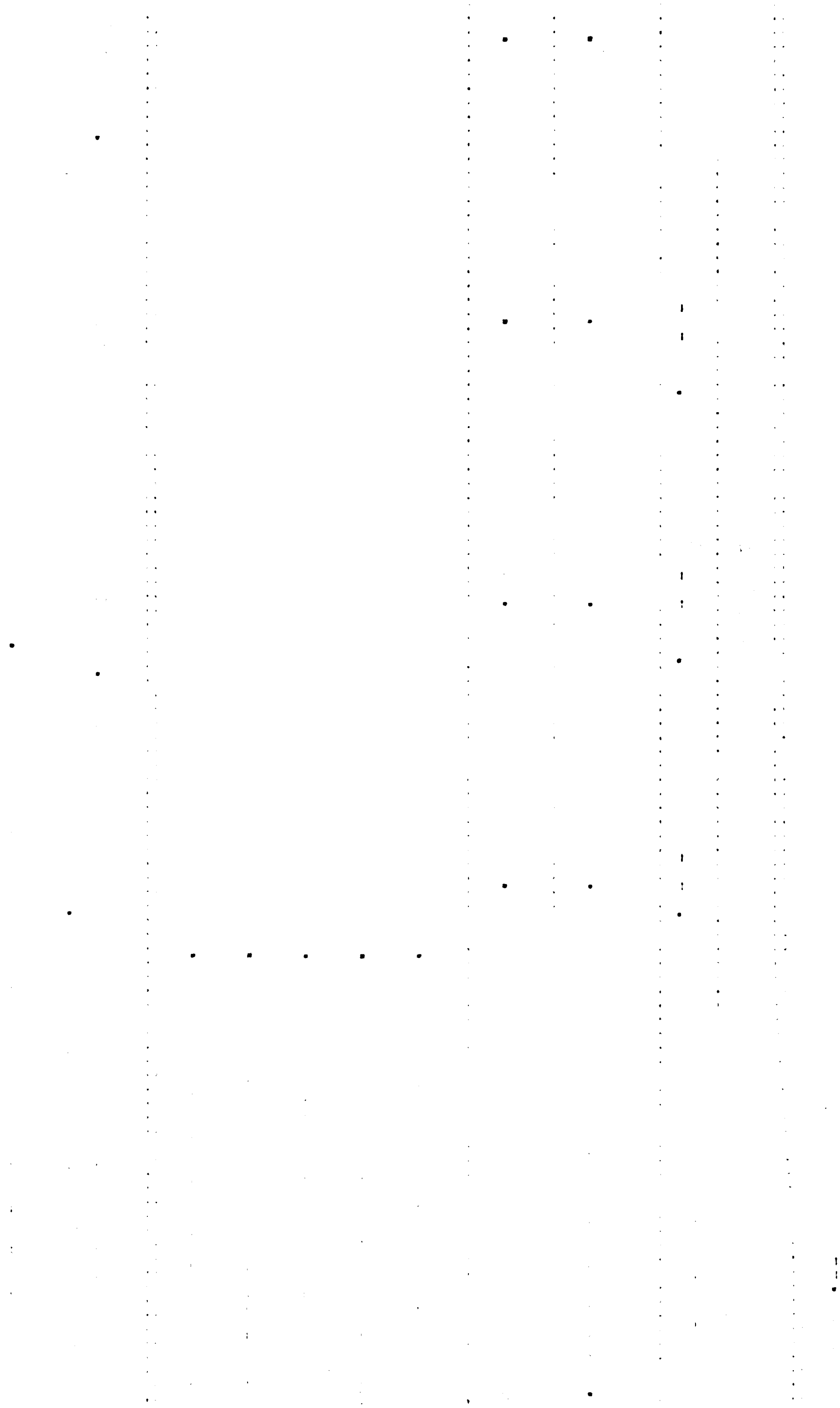
Sawdust Treatments	Rotations			Mean
	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[a]	
	January 1954 Samples			
1. None	3.61	3.90	4.02	3.84
2. 15 tons per acre	3.64	3.95	4.13	3.91
3. 30 tons per acre	3.68	4.28	4.31	4.09
Mean	3.65	4.04	4.15	3.95
	January 1955 Samples			
1. None	3.67	3.59	3.51	3.59
2. 15 tons per acre	3.85	3.68	3.73	3.75
3. 30 tons per acre	4.18	3.83	3.80	3.94
Mean	3.90	3.70	3.68	3.76
	January 1956 Samples			
1. None	3.81	3.80	3.76	3.79
2. 15 tons per acre	4.36	3.90	4.12	4.15

TABLE 23.--(Continued)

Sawdust Treatments	Rotations			Mean
	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[a]	
3. 30 tons per acre	4.78	4.16	4.29	4.41
Mean	4.32	3.95	4.08	4.12
LSD[b] 1954 rotation means	0.188			
LSD[b] 1954 sawdust means	0.103			
LSD[b] 1955 sawdust means	0.110			
LSD[b] 1956 rotation means	0.220			
LSD[b] 1956 sawdust means	0.143			

[a]Rotations 2 and 3 were alike in 1953 and 1954. Rotation 2 received sawdust in 1953. Rotation 3 received sawdust in 1953 and 1955.

[b]Least significant difference (5 per cent level).



soil. Baver (1930) stated that 30 to 60 per cent of the exchange complex of surface soils is due to organic matter. McGeorge (1931) found that the exchange capacity increased as organic matter or humus passed through various stages of decomposition; i.e., as the particle size decreased and the surface area increased. He found that a humus colloid has a seven times greater exchange capacity per unit of weight than a clay colloid.

Soil Nitrogen

Total nitrogen content of the March 1953 soil samples from the main plots averaged 0.0434 per cent. Because of the known close relationship between soil organic matter and total nitrogen and the fact that rates of nitrogen application were different each year, nitrogen determinations were omitted from the study.

Soil Phosphorus

The mean levels of available phosphorus for different sampling dates are presented in Table 24.

Analysis of variance for the January 1954 phosphorus data indicated highly significant differences due to fertilizers and significant differences due to chemicals, sawdust and interactions of sawdust with fertilizers (Table 25).

For the January 1955 phosphorus data, fertilizer treatment effects were highly significant and interaction effects of fertilizer with rotations were significant (Table 25). Increases in rates of P_2O_5 fertilization resulted in increases in the level of available phosphorus in the soil, but the amount of increase was greater for an annual

TABLE 24.--Mean content of available phosphorus in soil samples for different sampling dates

Sampling Date	Available Phosphorus	C.V.[a]
	Parts per million	Per cent
March 1953	131.1	32.65[b]
January 1954	100.0	15.9
January 1955	89.2	18.1
January 1956	62.1	19.5

[a]Coefficient of variation.

[b]Based on samples from 12 main plots.

TABLE 25.--Mean level of available phosphorus for January 1954 and January 1955 samples

Treatments	Year			
	1954	LSD[a]	1955	LSD[a]
	Parts per million		Parts per million	
Chemical		14.4		NS[b]
1. No methyl bromide	109.0		88.1	
2. Methyl bromide	91.2		90.2	
Sawdust		4.2		NS
1. None	103.1		90.7	
2. 15 tons per acre	100.1		88.1	
3. 30 tons per acre	97.0		88.7	
Fertilizers		4.2		13.4
1. 150 pounds P_2O_5 per acre	89.0		79.1	
2. 300 pounds P_2O_5 per acre	103.3		89.1	
3. 450 pounds P_2O_5 per acre	107.8		99.3	

[a]Least significant difference (5 per cent level).

[b]Non-significant.

seedling rotation than for a green manure crop-seedling rotation.

For the January 1956 phosphorus data, separate analyses were made for the Regular series and the Modified series. Fertilizer treatment effects were highly significant for each series. Rotation effects and interaction effects of rotations with fertilizers were significant for the Regular series (Table 26).

The data reveal that P_2O_5 treatments are more effective in maintaining the level of available phosphorus in an annual seedling rotation than in a rotation in which a green manure crop alternates with two years of seedlings.

A rotation in which a green manure crop alternates with one year of seedlings and the annual seedling rotation produced similar results (Table 26).

Sawdust treatment effects were not significant but the phosphorus content was lower for the 30 ton per acre application than for 15 tons per acre or for no sawdust.

In considering phosphorus values for a three year period, another variable, time, was added. Phosphorus values for three sets of data (January 1954, January 1955 and January 1956) were combined for each series. In the statistical analysis, years and fertilizer treatment effects were highly significant for each series. Sawdust effects and rotation by sawdust interaction effects were highly significant for the Modified series.

The available phosphorus in the January, 1956, samples should be equal to the available phosphorus present in March, 1953, plus the phosphorus added in 1953, 1954, and 1955, minus that used by the plant

TABLE 26.--Mean levels of available phosphorus for 1956 soil samples (in parts per million)

Fertilizer Treatments	Rotations			Mean
	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[b]	
Modified Series				
1. None	47.3	49.1	51.6	49.3
2. 75 pounds P_2O_5 per acre	65.3	57.7	60.6	61.3
3. 150 pounds P_2O_5 per acre	72.8	61.1	72.2	68.7
Mean	61.8	56.0	61.5	59.8
Regular Series				
4. 150 pounds P_2O_5 per acre	53.7	47.7	61.2	54.2
5. 300 pounds P_2O_5 per acre	67.8	58.7	71.6	66.0
6. 450 pounds P_2O_5 per acre	82.1	58.4	78.6	73.0
Mean	67.9	54.9	70.4	64.4
LSD[c] Modified Series sawdust means	4.9			
LSD[c] Regular Series sawdust means	4.3			
LSD[c] Regular Series rotation means	10.6			

[a]Rotation 2 received P_2O_5 treatments in 1953 only.

[b]Rotation 3 received P_2O_5 treatments in 1953 and 1955.

[c]Least significant difference (5 per cent level).

or fixed in unavailable form or lost through erosion. These values are summarized in Table 27.

The amounts of available P_2O_5 that were removed from the soil or fixed in unavailable form were plotted over total cumulative applications for the three year period (Figure 2). Data reveal that phosphorus utilization, fixation or loss through erosion increased with increased rates of application. The most efficient utilization of phosphorus was obtained with rotation 2.

It was unfortunate that reserve or total phosphorus determinations were not made each year. Ensminger (1950) found that levels of available phosphorus tended to reach equilibrium for a given rate of application, whereas unavailable phosphorus tended to increase. In a continuation of this study, an equilibrium should be obtained for each rate of application. Where phosphorus is omitted, the level of available phosphorus should approach zero. For these soils, the present rates of phosphorus application are not sufficient to maintain a constant level of available phosphorus.

Soil Potassium

Mean levels of available potassium for different sampling dates are presented in Table 28.

Available potassium levels are summarized in Table 29 for January 1954 soil samples.

In the analysis of variance, rotations, sawdust and fertilizer treatment effects were highly significant. Increases in rates of sawdust and K_2O fertilizer resulted in increases in available potassium. Interaction effects were not significant.

TABLE 27.--Summary of phosphorus application and utilization or fixation (in pounds per acre)

Fertilizer Levels	Fertilizer Treatments: Modified Series 1	2	3	Regular Series 4	5	6
Annual Seedling Rotation						
1. Mean P_2O_5 content prior to treatment[a]	602	602	602	602	602	602
2. P_2O_5 added during three year period	300	675	1050	450	900	1350
3. Mean P_2O_5 content at the end of third year	218	300	335	247	312	378
4. Loss or gain (1 + 2 - 3)	-684	-977	-1317	-805	-1190	-1574
5. P_2O_5 used by plants or fixed in soil per seedling crop	228	326	434	268	379	525
Green Manure Crop - Seedling - Seedling Rotation						
1. Mean P_2O_5 content prior to treatment[a]	602	602	602	602	602	602
2. P_2O_5 added during three year period	150	300	450	150	300	450
3. Mean P_2O_5 content at the end of third year	226	265	281	219	270	270
4. Loss or gain (1 + 2 - 3)	-526	-637	-771	-533	-632	-782
5. P_2O_5 used by plants or fixed in soil per seedling crop	263	318	386	267	316	391

TABLE 27.--(Continued)

Fertilizer Levels	Fertilizer Treatments					
	Modified Series			Regular Series		
	1	2	3	4	5	6
Green Manure Crop - Seedling - Green Manure Crop Rotation						
1. Mean P_2O_5 content prior to treatment[a]	602	602	602	602	602	602
2. P_2O_5 added during three year period	150	375	600	300	600	900
3. Mean P_2O_5 content at end of third year	237	279	332	281	329	362
4. Loss or gain (1 + 2 - 3)	-515	-698	-870	-621	873	1140
5. P_2O_5 used by plants or fixed in soil per seedling crop	-	-	-	-	-	-

[a]The mean content for 12 main plot samples was 602 ± 197 pounds per acre.

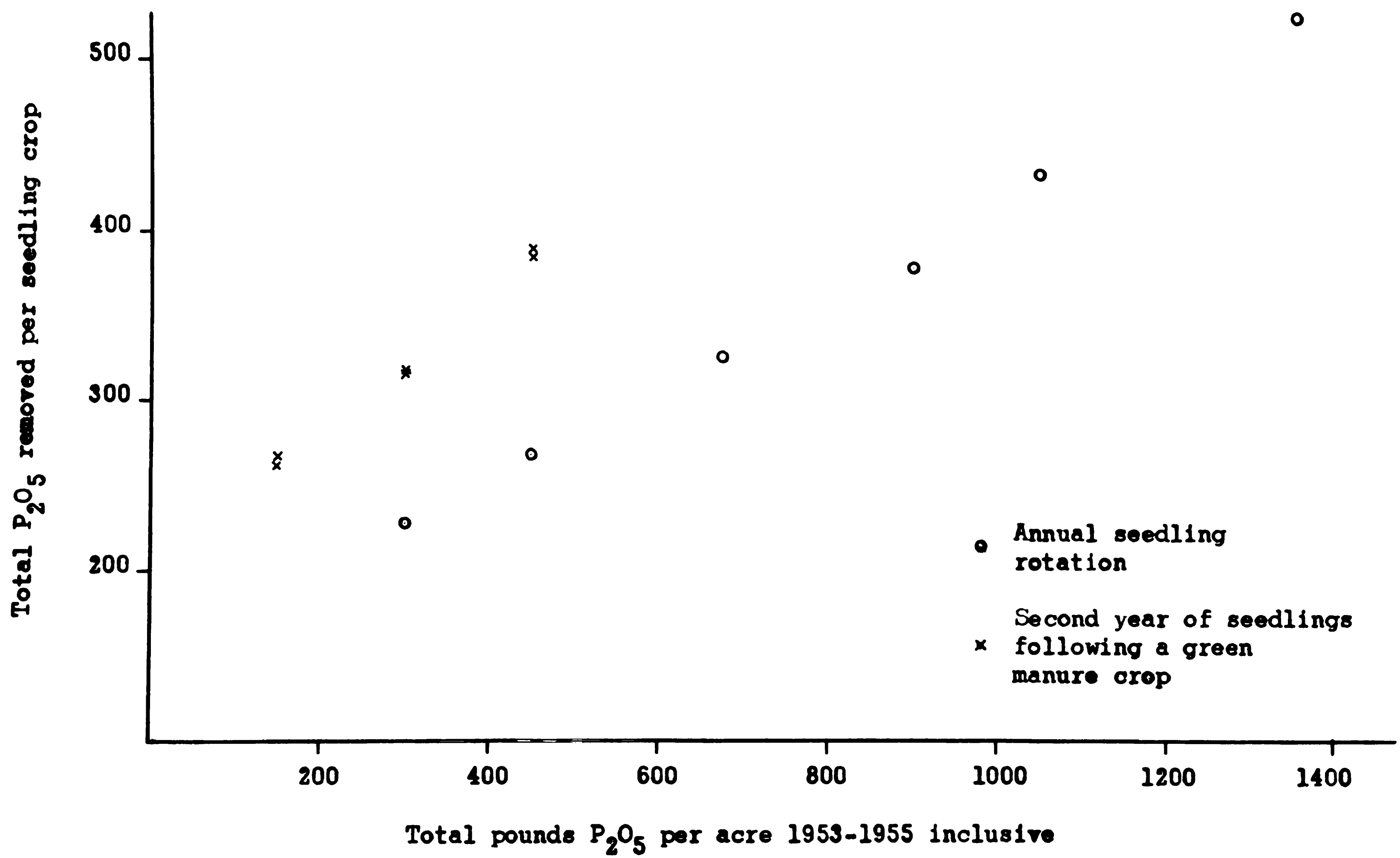


Fig. 2.-Total P_2O_5 in pounds per seedling crop, which was utilized, fixed in the soil or lost by erosion in relation to the total amount of P_2O_5 applied, 1953 to 1955 inclusive.

TABLE 28.--Mean contents of available potassium for different sampling dates

Sampling Date	Available Potassium	C.V.[a]
	Parts per million	Per cent
March 1953	52.9	24.6[b]
January 1954	95.1	14.0
January 1955	71.9	14.9
January 1956	78.7	14.7

[a]Coefficient of variation.

[b]Based on samples from 12 main plots.

The mean levels of available potassium were reduced during the 1954 growing season. Rotations 2 and 3 were in seedlings but they did not receive K_2O fertilization. Table 30 gives the mean levels of available potassium in the January 1955 samples.

The statistical analysis indicated highly significant differences due to sawdust, fertilizers and interactions of fertilizers with rotations. More potassium was available on sub-plots that received sawdust and K_2O fertilizer than on non-treated plots, with available potassium increasing with increasing rates of sawdust and K_2O fertilization. Fertilizers and rotations created highly significant interaction effects, with fertilizers creating differences in the annual seedling rotation but not in the other rotations. A fertilizer treatment of 240 pounds of K_2O per acre on the annual seedling rotation resulted in a level of available potassium almost equal to the mean level of the

TABLE 29.--Mean levels of available potassium in January 1954 soil samples (in parts per million)

Treatments	Sawdust Treatments			Mean
	1. None	2. 15 tons per acre	3. 30 tons per acre	
		Rotation 1 - Seedlings		
Fertilizers				
1. 80 pounds K_2O per acre	73.3	74.8	75.9	74.7
2. 160 pounds K_2O per acre	83.5	89.1	88.6	87.1
3. 240 pounds K_2O per acre	82.3	86.5	93.2	87.3
Mean	79.7	83.4	85.9	83.0
		Rotation 2 and 3 - Green Manure Crop[b]		
1. 80 pounds K_2O per acre	86.4	91.5	97.0	91.6
2. 160 pounds K_2O per acre	102.0	103.2	104.8	103.3
3. 240 pounds K_2O per acre	107.1	106.5	111.5	108.4
Mean	98.5	100.4	104.4	101.1
Mean, Rotations 1, 2 and 3	92.2	94.8	98.3	95.1

LSD[a] sawdust means	3.6
LSD[a] rotation means	8.3
LSD[a] two fertilizers means for same rotation	6.2
Coefficient of variation - per cent	14.0

[a]Least significant difference (5 per cent level).

[b]Data for rotations 2 and 3 is combined.

TABLE 30.--Available potassium in January 1955 soil samples (in parts per million)

Treatments	Rotations		Mean
	1. S-S	2. and 3. GMC-S[a]	
Sawdust			
1. None	73.6	66.9	69.1
2. 15 tons per acre	75.2	69.9	71.7
3. 30 tons per acre	78.9	73.0	75.0
Fertilizer			
1. 80 pounds K_2O per acre	61.7	67.5	65.6
2. 160 pounds K_2O per acre	76.1	70.7	72.5
3. 240 pounds K_2O per acre	89.9	71.4	77.6
Mean	75.9	69.9	71.9
LSD[b] Sawdust and fertilizer means	2.86		
LSD[b] Two fertilizer means for same rotation	5.60		

[a]Rotations 2 and 3 did not receive sawdust or fertilizer treatments in 1954. Combined data.

[b]Least significant difference (5 per cent level).

January 1954 samples (Tables 29 and 30).

In the statistical analysis of the January 1956 data, potassium values for the Regular series and the Modified series were analyzed separately. In each analysis, rotation, sawdust and fertilizer effects were highly significant and interaction effects of sawdust with rotation were significant. Potassium values for the January 1956 samples are presented in Table 31.

Data reveal that a wide range in levels of available potassium can be created by various treatments or combinations of treatments. For the annual seedling rotation, annual applications of fertilizer and sawdust have maintained a fairly constant level, based on levels of previous years (52.8 ppm in 1953, 92.2 ppm in 1954, 75.9 ppm in 1955, and 62.2 ppm in 1956).

When a green manure crop alternated with two years of seedlings, the potassium level decreased following each seedling crop (52.8 ppm in 1953, 94.8 ppm in 1954, 69.9 ppm in 1955 and 45.3 ppm in 1956).

A green manure crop alternating with one year of seedlings produced higher levels of available potassium than other rotations. Potassium levels increased following the green manure crop and decreased during the seedling crop (52.9 ppm in 1953, 98.3 ppm in 1954, 69.9 ppm in 1955 and 128.6 ppm in 1956).

By considering potassium values for three sampling dates, another variable, time, was introduced in the analysis. In the statistical analysis combining January 1954, January 1955, and January 1956 data, rotation, sawdust, fertilizer, year effects, interaction effects of rotations with years, and interaction effects of fertilizers by rotations

TABLE 31.--Available potassium levels for the January 1956 soil samples (in parts per million)

Treatment	Rotations					
	Regular Series			Modified Series		
	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[b]	1.S-S-S	2.GMC-S-S[a]	3.GMC-S-GMC[b]
Sawdust						
1. None	57.9	46.1	134.5	48.6	44.8	110.9
2. 15 tons per acre	67.8	44.4	144.2	53.9	42.5	123.2
3. 30 tons per acre	79.4	46.0	141.2	64.8	48.2	117.6
Fertilizers[c]						
4 or 1	55.1	42.8	133.8	51.7	42.8	112.9
5 or 2	71.4	45.9	140.8	52.9	46.9	118.8
6 or 3	78.6	47.8	145.3	62.7	45.7	119.9
Mean	68.4	45.5	139.9	55.8	45.1	117.2

LSD[d] Rotation means - regular series	18.7
LSD[d] Rotation means - modified series	6.4
LSD[d] Two sawdust or fertilizer means in regular series	8.8
LSD[d] Two sawdust or fertilizer means in modified series	7.2
C.V.[e] Regular series	15.5
C.V.[e] Modified series	14.7

[a]Rotation 2 did not receive sawdust or fertilizer applications in 1954 or 1955.

[b]Rotation 3 did not receive sawdust or fertilizer applications in 1954.

[c]Fertilizer treatments 4, 5, and 6 apply to the Regular Series and treatments 1, 2, and 3 to the Modified Series.

[d]Least significant difference (5 per cent level).

[e]Coefficient of variation - per cent.

by years were highly significant. The fertilizer with years interaction effects were highly significant for the Modified series. The interaction effects of fertilizers with rotation were significant for the Regular series.

Theoretically, the level of available potassium in the 1956 soil samples should equal the original potassium in the soil plus the added potassium minus the potassium that was used by the plant, fixed in the soil or lost through leaching. These values are summarized in Table 32. The average removal, fixation, or loss per seedling crop was computed for Rotations 1 and 2. The scatter diagram in Figure 3 indicates a linear relationship between the total K_2O applications and the amounts removed, fixed or lost per seedling crop. The amount of K_2O that is used, fixed or lost increases with the accumulated rates of K_2O fertilization.

Soil Calcium

No calcium was added to the sub-plots as a part of the fertilization program. The mean exchangeable calcium content of 12 main plot samples collected in March 1953 was 355 parts per million. The coefficient of variation was 27.0 per cent. Values for these samples were low in relation to mean values collected at later dates. The extraction method used for the March 1953 samples was different from the method used for the 1954, 1955, and 1956 samples.

Mean exchangeable calcium contents for the January 1954, January 1955 and January 1956 samples are presented in Table 33. In the statistical analysis, rotation effects were significant for the January 1954 samples. Sawdust effects were significant for the January 1955

TABLE 32.--Summary of potassium applications and removal, 1953 through 1955 inclusive (in pounds per acre)

Fertilizer Levels	Fertilizer Treatments					
	Modified Series			Regular Series		
	1	2	3	4	5	6
Annual Seedling Rotation						
1. Mean K_2O content prior to treatment[a]	127	127	127	127	127	127
2. K_2O added during three year period	160	360	560	240	480	720
3. Mean K_2O content at end of third year	124	127	150	132	171	189
4. Loss or gain (1 + 2 - 3)	-163	-360	-537	-235	-436	-658
5. K_2O used by plants, fixed in the soil, or loss by leaching per seedling crop	54	120	179	78	145	219
Green Manure Crop - Seedling - Seedling Rotation						
1. Mean K_2O content prior to treatment[a]	127	127	127	127	127	127
2. K_2O added during three year period	80	160	240	80	160	240
3. Mean K_2O content at end of third year	103	113	110	103	110	115
4. Loss or gain (1 + 2 - 3)	-104	-174	-257	-104	-177	-252
5. K_2O used by plants, fixed in the soil, or loss by leaching per seedling crop	52	87	128	52	88	126

TABLE 32.--(Continued)

Fertilizer Levels	Fertilizer Treatments					
	Modified Series			Regular Series		
	1	2	3	4	5	6
Green Manure Crop - Seedling - Green Manure Crop Rotation						
1. Mean K_2O content prior to treatment[a]	127	127	127	127	127	127
2. K_2O added during three year period	80	200	320	160	320	480
3. Mean K_2O content at end of third year	271	285	288	321	338	349
4. Loss or gain (1 + 2 - 3)	+64	-42	-159	+34	-109	-258
5. K_2O used by plants, fixed in the soil, or loss by leaching per seedling crop	-	-	-	-	-	-

[a]The mean K_2O content for 12 main plot samples was 127 pounds per acre.

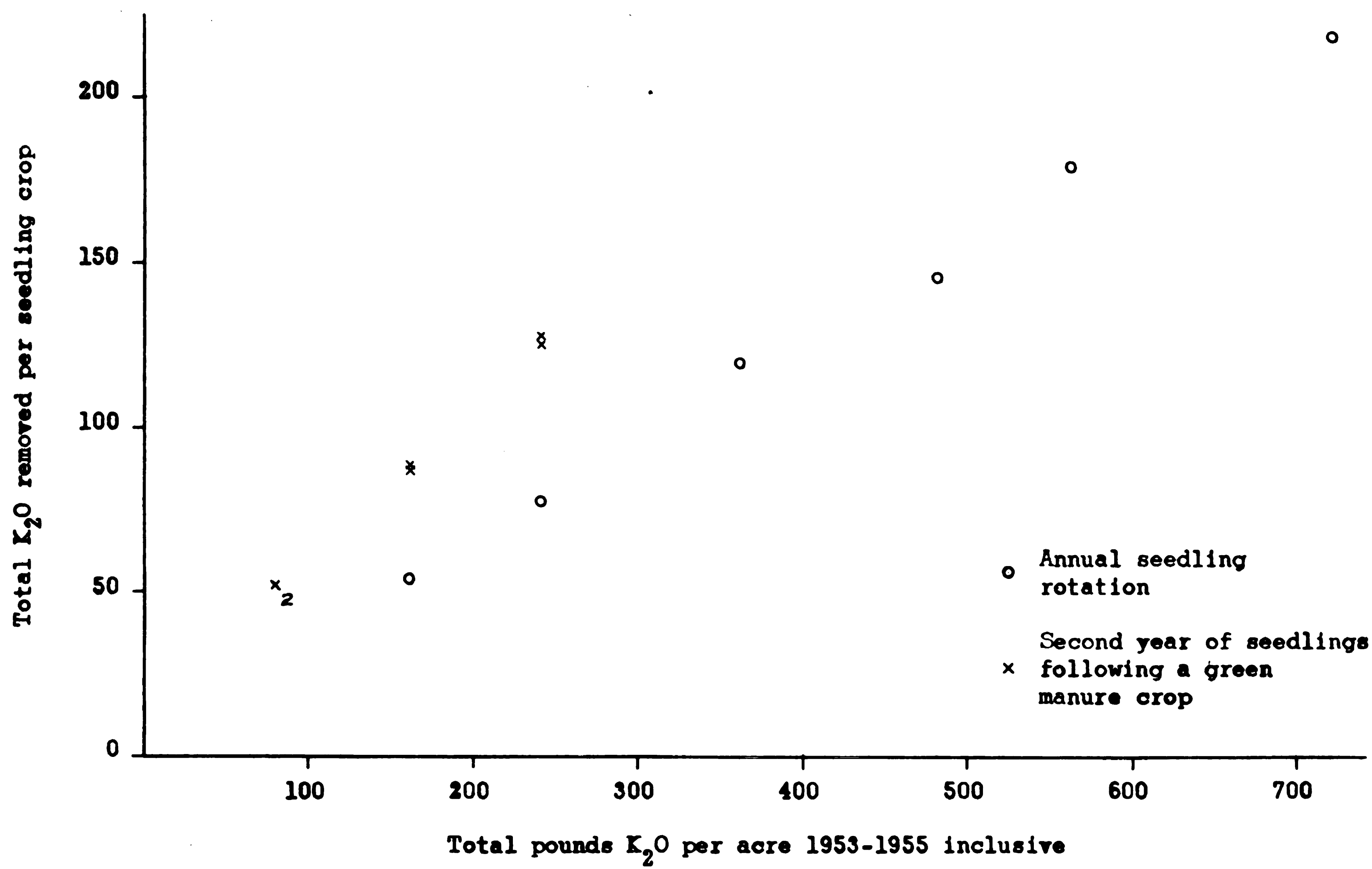


Fig. 3.-Total K_2O in pounds per seedling crop, which was utilized, fixed in the soil or lost by leaching in relation to the total amount of K_2O applied, 1953 to 1955 inclusive.

TABLE 33.--Exchangeable calcium content of soil samples (in parts per million)

Treatments	Date of Sampling			
	January 1954	January 1955	January 1956	
			Modified Series	Regular Series
Rotations				
1. S-S-S	480	506	438	414
2. GMC-S-S	560	539	394	410
3. GMC-S-GMC	588	556	470	487
2. and 3. GMC-S[a]	574	547	-	-
Sawdust[b]				
1. None	528	515	396	410
2. 15 tons per acre	546	533	434	438
3. 30 tons per acre	553	552	472	464
Mean	543	533	434	437
Coefficient of variation - per cent	14.5	16.4	19.7	16.1

LSD[c] 1954 rotation means	64
LSD[c] 1955 sawdust means	23
LSD[c] 1956 sawdust means Modified series	27
LSD[c] 1956 sawdust means Regular series	32

[a]Rotation 2 and 3 were alike in 1954 and 1955.

[b]Sawdust was applied annually to the annual seedling rotation and with the green manure crop on other rotations.

[c]Least significant difference (5 per cent level).

data and highly significant for the January 1956 data. Rotation effects for the 1955 and 1956 samples and sawdust effects for the 1954 samples were not quite significant.

By considering exchangeable calcium values for three sampling dates, another variable, years, was introduced into the analysis. When values for January 1954, January 1955, and January 1956 were combined in an analysis of variance, sawdust treatment effects were highly significant for the Regular and Modified series. For the Regular series, rotation effects and the interaction effects of sawdust with years were highly significant. Year effects and sawdust by rotation by year interaction effects were significant. For the Modified series, year effects were highly significant.

Data reveal that the effects of a green manure crop on exchangeable calcium is not consistent from one year to the next (Table 33). Exchangeable calcium increased on rotations 2 and 3 following a green manure crop in 1953. Exchangeable calcium decreased on rotation 3 following a green manure crop in 1955.

Exchangeable calcium decreased when seedling crops were in the rotation, except for the 1953 seedling crop on Rotation 1.

Levels of exchangeable calcium were consistently higher on plots that received sawdust treatments than on plots from which sawdust was withheld. It would seem therefore, that when calcium-containing fertilizers and sawdust were omitted, the levels of exchangeable calcium would decrease under a continuous cropping of seedlings or under a system of alternating seedlings with green manure crops.

Soil Magnesium

No magnesium was added to the seedbeds as a part of the fertilizer program. Determinations of exchangeable magnesium were not made for the March 1953 samples, but were made for the January 1954, January 1955, and January 1956 samples. Exchangeable magnesium values are presented in Table 34.

In the statistical analysis of the January 1954 data, rotation effects and the interaction effects of fertilizers with chemicals were highly significant. The level of exchangeable magnesium was significantly higher for the rotations containing a green manure crop than for the annual seedling rotation (Table 34). For the methyl bromide treatment, Modified series, increasing the rate of fertilization resulted in decreasing levels of exchangeable magnesium. When no methyl bromide was applied, the exchangeable magnesium content increased with increasing rates of fertilization. Sawdust treatment effects were not quite significant for the January 1954 samples.

In the statistical analysis of January 1955 data, sawdust effects and the interaction effects of sawdust with chemicals were highly significant. Rotation effects and sawdust by rotation by chemical interaction effects were significant. Exchangeable magnesium decreased in 1954, but the magnesium levels were higher for rotations that contained a green manure crop than for the annual seedling rotation. An increase in the rate of sawdust application produced an increase in the levels of exchangeable magnesium, with the rate of increase being greater on methyl bromide treated plots than on plots without methyl bromide treatments.

TABLE 34.--Exchangeable magnesium content of soil samples (in parts per million)

Treatments	Date of Sampling			
	January 1954	January 1955	January 1956	
			Modified Series	Regular Series
Rotations				
1. S-S-S	52.3	48.6	41.8	38.8
2. GMC-S-S	62.5	55.5	40.3	38.7
3. GMC-S-GMC	62.3	54.9	51.5	53.4
2. and 3. GMC-S[a]	62.4	55.2	-	-
Sawdust				
1. None[b]	56.5	48.2	37.7	39.6
2. 15 tons per acre	60.7	53.4	44.9	43.3
3. 30 tons per acre	59.8	57.4	50.9	48.0
Mean	59.0	53.0	44.5	43.6
Coefficient of variation-per cent	37.5	19.2	22.0	18.6

LSD[c] 1954 rotation means	5.9
LSD[c] 1955 rotation means	7.0
LSD[c] 1956 rotation means - Regular series	4.5
LSD[c] 1956 rotation means - Modified series	10.0
LSD[c] 1955 sawdust means	2.7
LSD[c] 1956 sawdust means - Regular series	3.7
LSD[c] 1956 sawdust means - Modified series	3.1

[a]Rotations 2 and 3 were alike in 1954 and 1955.

[b]Sawdust was applied annually to the annual seedling rotation and with green manure crops on other rotations.

[c]Least significant difference (5 per cent level).

In the statistical analysis of the January 1956 data, one analysis was made for the Regular series and another for the Modified series. Sawdust effects were highly significant for each series. Rotation effects were highly significant for the Regular series and significant for the Modified series. Sawdust treatments resulted in more exchangeable magnesium. The mean exchangeable magnesium content decreased during 1955, and the amount of the decrease was significantly greater for a seedling crop than for a green manure crop.

By considering magnesium values for three sampling dates, another variable, time, was introduced into the analysis. Exchangeable magnesium values for January 1954, January 1955, and January 1956 were combined for each series. Rotation and year effects were highly significant for each series. For the Regular series, sawdust effects were significant and the interaction effects of sawdust with years were highly significant. For the Modified series sawdust effects and the interaction effects of sawdust with years were highly significant.

Data reveal that the mean values for exchangeable magnesium decreased each year (Table 34). The rate of annual decrease was retarded by the use of sawdust or a green manure crop. It may be assumed that exchangeable magnesium will continue to decrease unless a magnesium-containing fertilizer is used.

CHAPTER IX

EFFECTS OF TREATMENTS ON CHEMICAL COMPOSITION OF PLANTS

Phosphorus in Plants

1953 - Entire Plant

For the 1953 seedling crop, the sample consisted of the whole plant. In the statistical analysis, differences in phosphorus contents of needles attributable to sawdust appeared to be highly significant. Other treatment effects were non-significant. Phosphorus means for sawdust treatments were:

Treatment	Phosphorus content
No sawdust	1425 ppm
15 tons per acre sawdust	1665 ppm
30 tons per acre sawdust	1527 ppm
Mean all treatments	1539 ppm
Least significant difference (5 per cent level)	135
Coefficient of variation - per cent	18.56

The apparent superiority of 15 tons sawdust per acre over no sawdust or 30 tons per acre cannot be satisfactorily explained. This difference may be due to chance.

1954 and 1955 Needles

In the statistical analysis, fertilizer treatment effects were significant for the 1954 data and highly significant for the 1955 data. Increases in rates of P_2O_5 fertilization resulted in increased phosphorus content of needles (Table 35).

Fertilizer treatments 2 and 3 in Rotation 1, Modified series, has received more P_2O_5 fertilization over a three year period than fertilizer treatment 6, Regular series (Table 2). Apparently some residual effects of P_2O_5 fertilization were carried over from one year to the next.

The inclusion of a green manure crop in a rotation did not have any significant effect on phosphorus content of needles.

1954 and 1955 Stems

In the statistical analysis, fertilizer treatment effects were significant for the 1954 data. Increases in rates of P_2O_5 fertilization resulted in increased phosphorus content of stems (Table 36).

Based on analysis of 1955 data, it appeared that treatments of the Modified series were not significant. Rotation and fertilizer treatment effects appeared to be highly significant, and sawdust and interaction effects of sawdust with rotation appeared to be significant for the Regular series (Table 36). However, when mean values of sub-plots were plotted, it was found that much of the variation was of a random nature rather than being due to treatments.

The data reveal that phosphorus content of stems is higher for an annual seedling rotation than for the second seedling crop following a green manure crop.

TABLE 35.--Phosphorus content of loblolly pine needles (in parts per million)

Treatments	Rotations		Mean
	1.S-S-S	2.GMC-S-S[a]	
1954 Seedlings			
Fertilizer			
1. 150 pounds P_2O_5 per acre	1451	1418	1429
2. 300 pounds P_2O_5 per acre	1492	1456	1468
3. 450 pounds P_2O_5 per acre	1511	1462	1478
Mean	1485	1445	1459
1955 Seedlings			
Fertilizer			
Modified Series			
1. No P_2O_5	1461	1492	1477
2. 75 pounds P_2O_5 per acre	1538	1513	1525
3. 150 pounds P_2O_5 per acre	1615	1560	1587
Regular Series			
4. 150 pounds P_2O_5 per acre	1452	1486	1468
5. 300 pounds P_2O_5 per acre	1557	1542	1549
6. 450 pounds P_2O_5 per acre	1650	1589	1620
Mean	1545	1530	1538

LSD[b] 1954 fertilizer means	36
LSD[b] 1955 fertilizer means in same rotation - Modified series	62
LSD[b] 1955 fertilizer means in same rotation - Regular series	86

[a]Rotations 2 and 3 were combined in the 1954 analysis. Rotation 2 did not receive P_2O_5 fertilization in 1954. Rotation 3 was not in seedlings in 1955.

[b]Least significant difference (5 per cent level).

TABLE 36.--Phosphorus content of loblolly pine stems (in parts per million)

Treatments	Rotations 1.S-S-S	Rotations 2.GMC-S-S[a]	Mean
1954 Seedlings			
Fertilizers			
1. 150 pounds P_2O_5 per acre	1674	1707	1696
2. 300 pounds P_2O_5 per acre	1634	1736	1702
3. 450 pounds P_2O_5 per acre	1804	1788	1793
Mean	1761	1744	1730
1955 Seedlings			
Fertilizers			
Modified Series			
1. No P_2O_5	1648	1460	1554
2. 75 pounds P_2O_5 per acre	1736	1525	1631
3. 150 pounds P_2O_5 per acre	1783	1515	1649
Mean	1722	1500	1611
Regular Series			
4. 150 pounds P_2O_5 per acre	1513	1329	1421
5. 300 pounds P_2O_5 per acre	1611	1435	1523
6. 450 pounds P_2O_5 per acre	1768	1437	1603
Mean	1631	1400	1516
Mean - Modified and Regular Series	1676	1450	1563

LSD[b] 1954 fertilizer means	46
LSD[b] 1955 rotation means - Regular series	162
LSD[b] 1955 rotation means for combined Modified and Regular series	142
LSD[b] 1955 fertilizer means for same rotation - Regular series	124
C.V.[c] 1954	9.7
C.V.[c] 1955	13.4

[a]Rotations 2 and 3 were combined in 1954. Rotation 3 did not receive P_2O_5 fertilization in 1954. Rotation 2 did not receive P_2O_5 fertilization in 1954 or 1955. Rotation 3 was not in seedlings in 1955.

[b]Least significant difference (5 per cent level).

[c]Coefficient of variation - per cent.

1954 and 1955 Roots

In the statistical analysis of 1954 data, fertilizer effects on phosphorus content of roots appeared highly significant and sawdust effects appeared significant. Increases in rates of P_2O_5 fertilization treatments resulted in increased phosphorus in roots (Table 37).

A similar pattern was revealed by the 1955 data. In a statistical analysis of data for the Regular series, rotation, sawdust, fertilizer and sawdust by rotation interaction effects appeared highly significant. The interaction effects of fertilizer with rotations appeared significant. In the Modified series, rotation effects appeared significant and the interaction effect of sawdust with rotations appeared highly significant. When mean values of sub-plots were plotted, it was found that much of the variation was of a random nature rather than being due to treatments. (Table 37)

Table 37 shows that annual seedling rotations with annual applications of P_2O_5 will result in a higher phosphorus content in roots than a rotation in which seedlings follow a green manure crop for one and two years without benefit of additional P_2O_5 fertilization.

In Rotation 1, 1944, and Regular series, Rotation 1, 1955, phosphorus content of roots increased with increasing rates of sawdust. These differences are likely due to chance rather than real differences between treatments.

Phosphorus Ratios Between Roots, Stems and Needles

In 1954, Rotation 1 had received two applications of P_2O_5, whereas Rotations 2 and 3 had received only 1 application. In 1955, the Regular

TABLE 37.--Phosphorus content of loblolly pine roots (in parts per million)

Treatments	Rotations		Mean
	1.S-S-S	2.GMC-S-S[a]	
	1954 Seedlings		
Fertilizer			
1. 150 pounds P_2O_5 per acre	1247	1243	1244
2. 300 pounds P_2O_5 per acre	1391	1228	1282
3. 400 pounds P_2O_5 per acre	1488	1307	1367
Mean	1375	1259	1298
	1955 Seedlings		
Fertilizer			
Modified Series			
1. No P_2O_5	1947	1489	1718
2. 75 pounds P_2O_5 per acre	2001	1579	1790
3. 150 pounds P_2O_5 per acre	1995	1557	1776
Mean	1981	1544	1762
Regular Series			
4. 150 pounds P_2O_5 per acre	1764	1443	1603
5. 300 pounds P_2O_5 per acre	1852	1485	1668
6. 450 pounds P_2O_5 per acre	2100	1476	1787
Mean	1905	1468	1686
Mean - Modified and Regular Series	1943	1505	1724

LSD[b] 1954 fertilizer means	56
LSD[b] 1955 rotation means - Modified series	432
LSD[b] 1955 rotation means - Regular series	389
LSD[b] 1955 fertilizer means for same rotation - Regular series	159

[a]Rotations 2 and 3 are combined in the 1954 analysis. They did not receive P_2O_5 fertilization treatments in 1954. Rotation 3 was not in seedlings in 1955.

[b]Least significant difference (5 per cent level).

series had received full fertilizer treatments and the Modified series had received reduced fertilizer applications. Table 38 gives the phosphorus content and ratios between plant components.

TABLE 38.--Phosphorus content of loblolly seedlings and the ratios between roots, stems and needles

Year and Treatment	Phosphorus Content			Phosphorus Ratio Roots/Stems/Needles
	Roots	Stems	Needles	
	Parts per million	Parts per million	Parts per million	
1954 Seedlings				
Rotation 1	1375	1704	1485	1.00:1.24:1.08
Rotation 2 and 3 (combined)	1259	1744	1445	1.00:1.38:1.15
1955 Seedlings				
Modified series	1762	1611	1530	1.00:0.91:0.87
Regular series	1686	1516	1546	1.00:0.90:0.92

Potassium in Plants

1953 - Entire Plants

For the 1953 seedling crop, the sample consisted of the whole plant. In the statistical analysis, there were apparently no differential effects of chemical or fertilizer treatments on the potassium content of the plant. Sawdust effects alone were highly significant. Sawdust means for 1953 data were:

Treatment	Potassium content
No sawdust	5535 ppm
15 tons per acre	5834 ppm

30 tons per acre	5075 ppm	
Mean for all data	5481 ppm	
Least significant difference (5 per cent level)		389
Coefficient of variation - per cent		15.0

Differences in potassium content between seedlings grown with no sawdust and with 15 tons of sawdust per acre were not significant. An application of 30 tons of sawdust per acre produced a significant reduction in either potassium uptake or potassium accumulation by the seedlings.

1954 Needles

Needles, stems and roots of seedlings from the 1954 and 1955 crops were analyzed separately. Potassium content of 1954 seedling needles are presented in Table 39.

TABLE 39.--Potassium content of loblolly pine needles - 1954 crop (in parts per million)

Treatments	Rotations		Mean
	1. S-S	2. and 3. GMC-S[a]	
Chemicals			
1. No methyl bromide	5318	4774	4955
2. Methyl bromide	4843	4411	4555
Sawdust			
1. None	5383	4586	4852
2. 15 tons per acre	5065	4600	4755
3. 30 tons per acre	4792	4593	4659
Mean	5080	4593	4755
LSD[b] Chemical and rotation means		396	
LSD[b] Two sawdust means for same rotation		354	

[a]Rotations 2 and 3 received the same treatments in 1953 and 1954. They were in a green manure crop in 1953 and in a seedling crop in 1954.

[b]Least significant difference (5 per cent level).

Chemical and rotation treatment effects and the interaction effects of sawdust with chemicals, sawdust with rotations and sawdust with fertilizers were significant. Methyl bromide treatments reduced the potassium content of needles. A green manure crop, preceeding seedlings in a rotation, resulted in a lower potassium level than an annual seedling rotation.

When methyl bromide was included in the treatments, potassium in needles decreased with increasing rates of sawdust. When methyl bromide was omitted, sawdust treatment effects were not significant.

For the annual seedling rotation, the potassium level decreased with increasing rates of sawdust. When a green manure crop was included in the rotation, sawdust treatments did not produce any significant differences.

1955 Needles

Data for 1955 needles were analyzed separately for the Regular series and the Modified series. Potassium content of needles are presented in Table 40. For the Regular series,rotation and fertilizer effects were highly significant and the interactions of fertilizers with rotations were significant. For the Modified series only fertilizer effects were significant.

Rotation 1, under annual cropping, has received annual applications of potassium fertilizer. The Modified series and the Regular series received like fertilizer treatments in 1953 and 1954, that is, treatment pairs 1 and 4, 2 and 5, and 3 and 6. Therefore, fertilizer treatments 2 and 3 in the Modified series had received more potassium

TABLE 40.--Potassium content of loblolly pine needles, 1955 crop (in parts per million)

Treatments	Rotations: 1. S-S-S	Rotations: 2. GMC-S-S[a]	Mean
Modified Series			
Fertilizer			
1. None	5227	5439	5333
2. 40 pounds K_2O per acre	5591	5477	5534
3. 80 pounds K_2O per acre	5872	5534	5703
Mean	5563	5484	5523
Regular Series			
Fertilizer[b]			
4. 80 pounds K_2O per acre	5585	5346	5465
5. 160 pounds K_2O per acre	6341	5578	5959
6. 240 pounds K_2O per acre	6532	5638	6085
Mean	6153	5520	5837
LSD[c] Fertilizer means - Modified series			253
LSD[c] Fertilizer means - Regular series			264
LSD[c] Two fertilizer means for same rotation - Modified series			358
LSD[c] Two fertilizer means for same rotation - Regular series			375
LSD[c] Two rotation means - Regular series			458
C.V.[d] Modified series			9.7
C.V.[d] Regular series			9.6

[a]Rotation 2 did not receive fertilizer treatments in 1954 or 1955.

[b]Fertilizer rate for rotation 1 and 2 in 1953 and for rotation 1 in 1954.

[c]Least significant difference (5 per cent level).

[d]Coefficient of variation - per cent.

over the three year period than treatment 4 in the Regular series. The values given in Table 40 indicate that some residual effects were carried over from year to year.

Annual applications of 160 and 240 pounds per acre of K_2O, with the annual seedling crop rotation, resulted in the highest concentration of potassium in needles.

When means for three years are compared, it appears that factors other than rates of K_2O fertilization may affect uptake or accumulation of potassium by needles. Means by years were:

1953 seedlings (entire plant)	5481 ppm
1954 seedlings - needles only	4755 ppm
1955 seedlings - needles only	
Modified series	5523 ppm
Regular series	5837 ppm

1954 and 1955 Stems

In the analysis of 1954 data Rotations 2 and 3 were combined. Rotation effects were significant. The potassium content of stems was higher for a seedling crop that followed a green manure crop than for one that followed another seedling crop (Table 41).

The statistical analysis of data for the 1955 stems indicated that fertilizer effects on potassium content of stems were highly significant for the Modified series and significant for the Regular series. Fertilizer treatments 2 and 3, Modified series 1955, had received more K_2O fertilization over a three year period than treatment 4, Regular series. Apparently some residual effects of potassium fertilization were carried over from one year to the next.

Rotation 2 did not receive K_2O fertilization in 1954 or 1955. The potassium content of the stems decreased when a seedling crop

TABLE 41.--Potassium content of loblolly pine seedling stems (in parts per million)

Treatments	Rotations		Mean
	1. S-S-S	2. GMC-S-S[a]	
1954 Seedlings			
Fertilizer[b]			
1. 80 pounds K_2O per acre	6991	8193	7792
2. 160 pounds K_2O per acre	6922	8340	7867
3. 240 pounds K_2O per acre	7372	8392	8052
Mean	7095	8308	7903
1955 Seedlings			
Fertilizer[b]			
Modified Series[c]			
1. No K_2O	5227	5536	5381
2. 40 pounds K_2O per acre	5894	6163	6029
3. 80 pounds K_2O per acre	6188	6217	6202
Regular Series[c]			
4. 80 pounds K_2O per acre	5760	5387	5574
5. 160 pounds K_2O per acre	5878	5719	5798
6. 240 pounds K_2O per acre	6221	5853	6037
Mean - Modified and Regular Series	5861	5813	5837

LSD[d] 1954 rotation means	703
LSD[d] 1955 two fertilizer means for same rotation - Modified series	421
LSD[d] 1955 two fertilizer means for same rotation - Regular series	416

[a]Rotations 2 and 3 are combined for 1954. Rotation 3 was not in seedlings in 1955.

[b]Rotation 2 did not receive fertilizer treatments in 1954 or 1955.

[c]The two series received similar fertilizer treatments in 1953 and 1954.

[d]Least significant difference (5 per cent level).

followed a seedling crop without benefit of additional fertilization.

1954 and 1955 Roots

In 1954, there were no significant effects of treatments on potassium content of seedling roots. The range was 2925 ppm to 6275 ppm, with a mean of 4411 ppm. The coefficient of variation was 8.4 per cent. There was considerable variation within treatments. It is difficult to remove completely all soil particles from the roots. Therefore, determination of mineral content of whole roots are subject to considerable experimental error.

Fertilizer effects in 1955 were highly significant for each of the series. The interaction effects of fertilizers with rotations were significant for the Regular series. Mean potassium contents of roots according to fertilizer and rotation treatments are presented in Table 42.

Fertilizer treatments 2 and 3 in Rotation 1, Modified series, had received more K_2O fertilization over a three year period than treatment 4, Regular series. (Table 2) Apparently some residual effects of K_2O fertilization were carried over from one year to another.

There is no logical explanation for the pattern observed for fertilizer treatment 6, Rotation 2 (Table 42).

In general, data reveal that potassium content of roots increases with increasing rates of K_2O fertilization.

Potassium Ratios Between Roots, Stems and Needles

Table 43 gives the mean potassium levels for roots, stems and needles, and the R/S/N ratios.

TABLE 42.--Potassium content of loblolly pine seedling roots, 1955 crop (in parts per million)

Treatments	Rotations		Mean
	1. S-S-S	2. GMC-S-S[a]	
	Modified Series		
Fertilizer - 1955			
1. No K_2O	5235	5450	5343
2. 40 pounds K_2O per acre	5631	5621	5626
3. 80 pounds K_2O per acre	5984	5949	5967
	Regular Series		
Fertilizer - 1955[b]			
4. 80 pounds K_2O per acre	5601	5334	5467
5. 160 pounds K_2O per acre	6026	5714	5867
6. 240 pounds K_2O per acre	6257	5494	5876
Mean	5789	5593	5691
LSD[c] Fertilizer means for the same rotation - Modified series	326		
LSD[c] Fertilizer means for the same rotation - Regular series	301		

[a]Rotation 2 did not receive K_2O fertilization in 1954 or 1955.

[b]This was the fertilizer rate for rotation 1 and 2 in 1953 and for rotation 1 in 1954.

[c]Least significant difference (5 per cent level).

TABLE 43.--Potassium content of loblolly pine seedlings and ratios between roots, stems and needles

Year and Treatment	Phosphorus Content			Phosphorus Ratio
	Roots	Stems	Needles	Roots/Stems/Needles
	Parts per million	Parts per million	Parts per million	
1954 Seedlings				
Rotation 1	4125	7095	5080	1.00:1.72:1.23
Rotations 2 and 3	4554	8308	4593	1.00:1.82:1.01
All treatments	4411	7903	4755	1.00:1.79:1.08
1955 Seedlings				
Modified series	5645	5871	5524	1.00:1.03:0.98
Regular series	5737	5803	5837	1.00:1.02:1.02
All treatments	5691	5837	5680	1.00:1.03:1.00

Table 43 reveals that levels of potassium concentration in plants may vary from one year to another and that the ratios between roots, stems and needles may not be constant.

Calcium in Plants

Calcium was not included as a treatment. However, some of the treatments that were applied had significant effects on the calcium content of seedlings.

1953 Entire Plant

The only significant difference in calcium content of the entire seedling was due to sawdust treatments. Means for sawdust treatments were:

Treatment	Calcium content
No sawdust	1585 ppm
15 tons sawdust per acre	1586 ppm
30 tons sawdust per acre	1488 ppm
Mean - all treatments	1553 ppm
Least significant difference (5 per cent level)	83
Coefficient of variation - per cent	11.4

Sawdust applied at a rate of 30 tons per acre reduced calcium concentration in the plant.

1954 and 1955 Needles

In the statistical analysis of data on the 1954 seedlings, differences due to rotation and sawdust treatments were highly significant. A green manure crop in the rotation increased the concentration of calcium in needles (Table 44). It is possible that a green manure crop may be very effective in maintaining a high level of available calcium, perhaps by converting relatively unavailable calcium to a form that is readily taken up by pine seedlings. Calcium concentration in needles decreased as the rate of sawdust application increased.

For the 1955 data, rotation and sawdust effects were highly significant and rotation by sawdust interactions were significant for the Modified series. For the Regular series, all treatment effects were non-significant. Rotation, sawdust, and rotation by sawdust interaction effects barely missed significance. When mean values of sub-plots were plotted, it was found that much of the variation was due to chance rather than being due to treatments.

Calcium content of needles declined from 1954 to 1955 (Table 44).

TABLE 44.--Calcium content of loblolly pine seedlings, 1954 and 1955 crop (in parts per million)

Treatment	1954 Rotations			1955 Rotations					
				Modified Series			Regular Series		
	1. S-S	2.& 3. GMC-S[a]	Mean	1. S-S-S	2. GMC-S-S[b]	Mean	1. S-S-S	2. GMC-S-S[b]	Mean
Needles									
Sawdust									
1. None	1854	2385	2208	1241	1489	1365	1315	1564	1410
2. 15 tons per acre	1688	2426	2180	1124	1595	1359	1337	1633	1485
3. 30 tons per acre	1664	2174	2004	1106	1356	1231	1230	1561	1396
Mean	1735	2328	2131	1157	1480	1318	1294	1566	1430
Stems									
Sawdust									
1. None	1050	1269	1196	-	-	891	-	-	929
2. 15 tons per acre	965	1263	1164	-	-	881	-	-	969
3. 30 tons per acre	961	1200	1121	-	-	849	-	-	916
Mean	992	1244	1160	786	1092	874	855	1033	938
Roots									
All treatments	365	525	472	322	386	354	351	422	370

Needles	
LSD[c] 1954 rotation means	182
LSD[c] 1954 sawdust means	73
LSD[c] 1955 rotation means - Modified Series	208
LSD[c] 1955 sawdust means - Modified Series	91
Stems	
LSD[c] 1954 rotation means	65
LSD[c] 1954 sawdust means	33
LSD[c] 1955 rotation means - Modified Series	106
Roots	
LSD[c] 1954 rotation means	43
LSD[c] 1955 rotation means - Regular Series	58

[a]Rotations 2 and 3 were combined in 1954. They did not receive sawdust treatments in 1954.

[b]Rotation 2 did not receive sawdust treatments in 1955.

[c]Least significant difference (5 per cent level).

Although no covariance or regression was computed to measure the relationship of soil and plant calcium content, it is reasonable that such a relationship should exist and be positive in nature. The level of available calcium, expressed as calcium carbonate, decreased from 2665 pounds per acre in January 1955 to 2177 pounds per acre in January 1956.

1954 and 1955 Stems

The same treatments affected calcium content in stems as in needles. In the analysis of data for the 1954 seedlings, rotation and sawdust effects were highly significant. A green manure crop in the rotation increased the concentration of calcium in stems. Calcium content decreased as the rate of sawdust increased (Table 44).

In the statistical analysis of data for the 1955 seedlings, differences due to rotation effects were highly significant. The residual effect of the green manure crop extended over the second year of seedlings, with the green manure crop increasing the calcium content of stems.

1954 and 1955 Roots

Rotation effects on calcium content of roots were highly significant in 1954, and for the Regular series in 1955. A green manure crop in a rotation increased the calcium content of roots for two consecutive years following the green manure crop (Table 44).

Calcium Ratios Between Roots, Stems and Needles

Calcium concentration in roots, stems and needles decreased from

1954 to 1955. Means and ratios are:

Year	Calcium content and ratios				
	Roots		Stems		Needles
1954 means in ppm	472		1160		2131
Ratio	1.00	:	2.46	:	4.51
1955 means in ppm	370		906		1374
Ratio	1.00	:	2.45	:	3.71

Relationship Between the Level of Available Calcium in the Soil and Calcium Concentration in Plants

A decrease in the level of available calcium in the soil was associated with a decrease in the concentration in the plant. The levels of available calcium in soils and calcium content of plants are:

	Calcium content	
	1954	1955
Soil	533 ppm	435 ppm
Plant		
Roots	472 ppm	370 ppm
Stems	1160 ppm	906 ppm
Needles	2131 ppm	1374 ppm

Magnesium in Plants

Magnesium was not included as a treatment. However, some of the treatments that were applied had significant effects on the magnesium content of seedlings.

1953 - Entire Plant

Sawdust effects on magnesium content were highly significant. Means for sawdust treatments were:

Treatment	Magnesium content
No sawdust	1007 ppm
15 tons sawdust per acre	1036 ppm
30 tons sawdust per acre	939 ppm
Mean all treatments	992 ppm

Least significant difference (5 per cent level)	66
Coefficient of variation - per cent	14.1

Applications of 30 tons of sawdust per acre resulted in significantly lower magnesium concentrations than did no sawdust or 15 tons of sawdust per acre.

1954 Needles, Stems and Roots

The pattern of results was similar for roots, stems and needles, although the degree of significance was not the same for all variables. Sawdust treatment effects were significant for roots but not for stems or needles. Applications of 30 tons of sawdust per acre resulted in significantly lower magnesium concentrations in roots than did no sawdust or 15 tons of sawdust per acre (Table 45).

Chemical treatment effects were highly significant for roots, significant for needles, and nearly significant for stems. The magnesium content of roots, needles and stems was reduced when methyl bromide was applied to seedbeds prior to a seedling crop. Since methyl bromide treatments did not significantly affect the concentrations of phosphorus, potassium or calcium in plants, there is no logical reason why it should affect magnesium concentrations.

Differences due to rotation effects were highly significant for needles, stems and roots. Higher magnesium concentrations occurred on rotations that included a green manure crop than on the annual seedling rotation (Table 45).

1955 Needles, Stems and Roots

The Modified and Regular series were analyzed both separately and

TABLE 45.--Magnesium content of loblolly pine seedlings (in parts per million)

Treatment	Plant Component					
	Roots	LSD[a]	Stems	LSD[a]	Needles	LSD[a]
		1954 Seedlings				
Rotations		30		73		33
1. S-S	964		955		784	
2. and 3. GMC-S	1127		1163		891	
Chemicals		21		NS[c]		26
1. No methyl bromide	1140		1127		881	
2. Methyl bromide	1006		1060		830	
Sawdust[b]		18		NS[c]		NS[c]
1. None	1082		1094		862	
2. 15 tons per acre	1085		1095		859	
3. 30 tons per acre	1051		1093		846	
Mean all treatments	1073		1094		855	
Coefficient of variation-per cent	6.3		6.8		7.9	
		1955 Seedlings				
Rotations						
Modified Series		101		NS[c]		NS[c]
1. S-S-S	1117		916		1002	
2. GMC-S-S	1008		998		1048	
Regular Series		NS[c]		NS[c]		NS[c]
1. S-S-S	1148		930		1063	
2. GMC-S-S	1132		1062		1098	
Mean all treatments	1101		977		1053	
Coefficient of variation-per cent	12.5		12.8		12.4	

[a]Least significant difference (5 per cent level).

[b]One sawdust treatment was applied to each seedling crop.

[c]Non-significant.

in combination. Rotation effects on roots in the Modified series were significant. The magnesium content of roots was higher for the annual seedling rotation than for a rotation that included a green manure crop (Table 45). This variation was probably of a random nature rather than being due to treatment since the effects were opposite to those produced in 1954.

Magnesium Ratio Between Roots, Stems and Needles

Magnesium content did not vary appreciably between roots, stems and needles. Mean levels and ratios for 1954 and 1955 were:

Year	Magnesium content and ratios		
	Roots	Stems	Needles
1954 means in ppm	1073	1094	885
Ratio	1.00 :	1.02 :	0.82
1955 means in ppm	1101	977	1053
Ratio	1.00 :	0.89 :	0.96

Although the level of available magnesium in the soil decreased from 368 to 309 pounds per acre of magnesium carbonate between January 1955 and January 1956, there was no marked decrease in magnesium concentration of the plant.

CHAPTER X

FIELD SURVIVAL

1953 Seedlings

Nursery treatments had no significant effects on field survival and initial growth of 4320 seedlings that were out-planted on the North Auburn experimental area in February, 1954. Mean values for survival and height growth are presented in Table 46.

TABLE 46.--Mean survival and height increase for loblolly pine seedlings planted February 1954

Date of Measurement	Survival	C.V.[a]	Height Increase	C.V.[a]
	Per cent	Per cent	Feet	Per cent
May 1954	97.25	4.1	-	-
November 1954	77.19	12.6	0.51	23.6
October 1955	74.31	12.9	2.24	17.4

[a]Coefficient of variation.

Calendar year 1954 was very unfavorable for seedling survival. Rainfall recorded for the year was only 28.44 inches, 24.35 inches below average.

1954 Seedlings

Seedlings from the 1954 crop were out-planted in January, 1955.

A total of 5184 seedlings were planted on the North Auburn experimental area and 5076 seedlings were planted on the Autauga County experimental area. Height growth measurements were obtained for plants on the North Auburn experimental area. All dead seedlings were dug and carefully examined to determine the cause of death if possible.

On the North Auburn experimental area pales weevil attacked seedlings on an area that had been cleared recently of pine saplings. Mortality was rather heavy in one locality. On the Autauga County experimental area, white grub damage was rather heavy. The planting site occupied an abandoned field or pasture, and the grub population in the soil was rather heavy.

A small percentage of dead stock was found to be planted with U-roots. Survival of planted stock was not affected by nursery treatments. Mean survival for the two areas is presented in Table 47.

TABLE 47.--Survival of loblolly pine seedlings planted January 1955

Plantation	Mean Survival	Coefficient of Variation
	Per cent	Per cent
Actual survival		
North Auburn	93.00	6.95
Autaugaville	56.82	27.4
Adjusted survival[a]		
North Auburn	98.79	3.00
Autaugaville	93.93	9.8

[a]Excludes losses attributed to pales weevil, white grubs, and improper planting.

The statistical analysis indicated that rotation and chemical treatment effects on height growth were highly significant for the North Auburn planting. Mean value by treatments were:

Treatments	One-year height growth
No methyl bromide	0.687 feet
Methyl bromide	0.775 feet
Rotation 1 - S-S	0.688 feet
Rotations 2 and 3 - GMC-S	0.753 feet
Mean all treatments	0.731
Least significant difference (5 per cent level)	0.051
Coefficient of variation - per cent	15.5

Growth was not measured at the Autauga plantation.

1955 Seedlings

A total of 4,320 seedlings were out-planted at each location in 1955. Although the degree of significance differed for some treatments, the survival patterns were similar on the two sites. A summary is given in Table 48. Rotation effects on spring survival were statistically significant for the Modified series on the North Auburn experimental area and for the Regular series on the Autauga County experimental area. Series effects were highly significant at Autauga. For October survival, rotation effects were highly significant for both series at North Auburn and significant for the Regular series at Autauga. Data in Table 48 reveal clearly that, under the conditions of this study, a green manure crop in the rotation had a significant positive effect on survival of out-planted seedlings. The cause of this effect is not

TABLE 48.--Survival of out-planted loblolly pine, 1955 seedling crop (in per cent)

Treatment	North Auburn Experimental Area		Autauga County Experimental Area	
	Means	LSD[a]	Means	LSD[a]
May Survival				
Rotations				
Modified Series		2.28		NS[b]
1. S-S-S	95.28		81.14	
2. GMC-S-S	97.60		83.68	
Regular Series		NS[b]		4.04
1. S-S-S	95.20		86.39	
2. GMC-S-S	95.29		91.20	
Means - Modified and Regular Series	95.84		85.60	
Coefficient of variation - per cent	5.1		10.0	
October Survival				
Rotations				
Modified Series		3.08		NS[b]
1. S-S-S	87.22		76.72	
2. GMC-S-S	92.13		78.96	
Mean	89.68		77.84	
Regular Series		3.08		4.72
1. S-S-S	88.34		79.29	
2. GMC-S-S	92.04		88.05	
Means	90.19		83.67	
Means - Modified and Regular Series	89.93		80.76	
Coefficient of variation - per cent	7.2		12.6	

[a]Least significant difference (5 per cent level).

[b]Non-significant.

clearly understood. It was shown that a green manure crop tends to maintain or increase the amount of available calcium and magnesium in the soil. It is possible that the nutrient ratio within the plant was affected favorably by conditions that resulted from the green manure crop.

Although fertilizer effects were not significant, survival of seedlings from the Regular series was consistently higher than that of the Modified series. This difference was highly significant for planting on the dry sandy site on the Autauga County experimental area.

Finding a way to insure high field survival is the final objective in most phases of nursery research. In this study, nursery treatments did not significantly affect field survival of the 1953 seedlings. Rotation effects on seedlings were significant in 1954 and 1955. A continuation of the study should produce a wider range between treatment means, and the effects of treatments on survival should be more pronounced.

CHAPTER XI

SUMMARY AND CONCLUSION

Summary

The effects of various soil treatments on germination of loblolly pine seed, development of seedlings, survival of out-planted seedlings, chemical content of seedlings and on soil characteristics were investigated during a three-year period. Treatments included (1) three rotations that included different combinations of green manure crops and seedlings, (2) methyl bromide, (3) three levels of sawdust and (4) three levels of phosphorus and potassium.

Soil samples were collected before initial treatments were made and thereafter annually in January from each of the 324 sub-plots. All samples were subjected to chemical and physical analysis in the laboratory to ascertain the effects of the treatments on soil reaction, organic matter content, cation exchange capacity, available phosphorus, available potassium, exchangeable calcium and exchangeable magnesium.

Data on seed germination, seedling mortality in the seedbed and percentages of plantable seedlings was obtained during the growing season.

Representative samples of seedlings were selected at the time of lifting. Seedling characteristics were determined by measurements and chemical contents. Field survival was determined by out-planting of other seedlings.

Soil and plant data were statistically analyzed, using the analysis of variance technique.

Many of the results were positive in nature. In other instances, conflicting results were obtained from one year to another. The significant differences due to treatment effects increased when the range of fertilization was expanded in the third year.

Conclusions

From this study, it can be stated tentatively that loblolly pine seedlings can be grown annually on the same area for a period of several years provided sufficient quantities of nitrogen, phosphorus and potassium are applied.

Inclusion of a green manure crop in a rotation had some effects on the soil and seedlings. A leguminous green manure crop tended to maintain the pH level of the soil, whereas soil acidity was increased as a result of the annual seedling rotation. A green manure crop alternating with a crop of seedlings resulted in an increased level of available potassium. The level increased proportionately with the rate of potassium fertilization. When a green manure crop alternated with two consecutive seedling crops and potassium fertilizer was not applied to the second seedling crop, there was a marked decrease in the level of available potassium during the second year. Available magnesium in the soil was increased when a green manure crop was included in the rotation.

The potassium content of loblolly pine needles, the magnesium content of stems and needles, and the calcium content of roots, stems, and needles were higher for the rotation in which a green manure crop alternated with one year of seedlings than for other rotations.

The percentage of plantable seedlings and the field survival of out-planted stock was higher for seedlings from the rotations that included a green manure crop than for the annual seedling rotation.

Methyl bromide treatments did not affect germination of seed or survival and growth of seedlings. The effects of methyl bromide treatments on the availability of mineral nutrients was not consistent from one year to another.

Some soil properties were changed by the use of sawdust alone or by the interaction of sawdust and a green manure crop. Soil acidity increased with increasing rates of sawdust applied annually. Yet, the levels of available potassium, calcium and magnesium increased with increasing rates of sawdust.

Organic matter content was maintained at a nearly constant level by the annual application of fifteen tons of sawdust per acre, by fifteen tons of sawdust per acre in the rotation of a green manure crop with one year of seedlings, or by thirty tons of sawdust per acre in the rotation of a green manure crop with two years of seedlings. Organic matter content was increased by annual applications of thirty tons of sawdust per acre or by thirty tons of sawdust in the rotation of a green manure crop with one year of seedlings.

The exchange capacity of the soil increased with increasing rates of sawdust. An application of fifteen tons of sawdust per acre and a green manure crop alternating with one year of seedlings resulted in an increase approximately equal to that obtained with two consecutive applications of sawdust.

Applications of thirty tons of sawdust per acre did not affect germination of seed or mortality of seedlings. However, the percentages of Grade 1 seedlings were reduced by the application of thirty tons of sawdust per year in the annual seedling rotation, but increased when thirty ton applications of sawdust per acre were included with a green manure crop.

An annual application of sawdust resulted in reductions of shoot volume, stem length, stem diameter, and green and oven-dry shoot weights. Shoot/root ratios, based both on volume and on weight, were reduced with increasing rates of sawdust. When a rotation contained a green manure crop, applications of sawdust resulted in an increase in weights of oven-dry shoots.

Mineral fertilizers can be applied to the seedbed area before preparation of seedbeds. Annual applications of 300 pounds of P_2O_5, 160 pounds of K_2O, and 100 pounds of nitrogen per acre did not reduce germination of seed. However, residual effects of annual fertilization over a period of several years may affect germination of seed. After three annual applications of 450 pounds of P_2O_5 and 240 pounds of K_2O per acre, there was a reduction in germination.

Fertilizer treatments did not affect mortality of seedlings in the seedbeds.

There were no significant differences in the percentages of plantable seedlings for different fertilizer rates within the range of 150 pounds of P_2O_5 plus 80 pounds of K_2O and 450 pounds of P_2O_5 plus

240 pounds of K_2O per acre. When applications of P_2O_5 and K_2O were omitted the percentage of plantable seedlings was reduced, even though rates of nitrogen remain unchanged.

The original level of available phosphorus in the soil was not maintained by the heaviest rate of P_2O_5 fertilization, 450 pounds of P_2O_5 per acre. There was an annual decrease in the mean level of available phosphorus, and a correspondingly greater decrease with smaller rates of phosphorus fertilization.

A relatively stable level of available potassium was maintained when 160 pounds of K_2O were applied with each seedling crop. Decreasing rates of potassium fertilization resulted in decreasing levels of available potassium.

In an annual seedling rotation the phosphorus and potassium content of stems, needles, and roots increased with increasing rates of phosphorus and potassium fertilization.

Loblolly pine seedlings made a heavy demand on calcium and magnesium in the soil. For each seedling crop there was a decrease in the levels of exchangeable calcium and magnesium, but the rate of decrease was reduced when sawdust or green manure crops were included in the treatment.

It is expected that pronounced phosphorus, potassium, calcium, and magnesium deficiencies will develop in seedlings if these elements are not included in fertilizer or organic matter applications. It should be possible to find a relationship between visible deficiency symptoms and mineral levels in the plant tissue and in the soil solution.

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APPENDIX

TABLE 49.--Monthly and annual precipitation and temperature data for Auburn, Alabama[a]

Month	Precipitation					Temperature		
	30 year average	1953	1954	1955	1956	Average	Maximum	Minimum
	Inches	Inches	Inches	Inches	Inches	Degrees F.	Degrees F.	Degrees F.
January	4.94	5.11	.92	6.47	2.36	49.4	59.7	39.1
February	5.07	7.91	4.11	4.41	7.82	51.5	62.3	40.6
March	6.87	3.59	2.93	3.28	8.07	56.7	67.7	45.2
April	4.72	12.99	1.89	4.83	3.19	64.3	76.1	52.6
May	3.62	6.09	2.32	6.91	1.28	71.9	83.7	60.1
June	3.94	6.53	1.52	1.76	3.40	78.9	90.4	67.5
July	5.18	5.98	4.54	10.65	4.70	80.3	90.9	69.7
August	4.64	3.76	1.85	2.99	1.78	79.9	90.4	69.3
September	3.15	6.96	.75	.73	10.19	76.6	87.8	65.5
October	2.21	.93	.92	2.07	2.06	67.1	79.2	54.9
November	3.63	2.23	2.89	4.83	1.39	55.8	67.3	44.6
December	4.82	14.27	3.80	.82	7.29	49.8	60.0	39.5
Annual	52.79	76.35	28.44	49.75	53.53	65.2	76.3	54.1
Departure	-	+23.56	-24.35	-3.04	+0.74	-	-	-

[a]Hocker (1955) and Weather Bureau (1953, 1954, 1955, and 1956).

Fig. 4.-General view of nursery experimental area. Seedlings have been removed from some plots and from all the isolation zones between sub plots.

Fig. 5.-Close view of seedlings in an annual seedling rotation that received like treatments each year. Treatment consisted of 300 pounds P_2O_5, 160 pounds K_2O and 15 tons of sawdust per acre prior to each crop.

Fig. 6.-Close view of seedlings in an annual seedling rotation in which the rates of fertilization had been reduced after the second year. The two previous seedling crops had received 150 pounds P_2O_5, 80 pounds K_2O, and 30 tons of sawdust per acre with methyl bromide treatment. These seedlings had 30 tons of sawdust per acre but no P_2O_5, K_2O, or methyl bromide.

Fig. 7.-Close view of seedlings in a green manure crop - seedling rotation from which sawdust had been omitted. The treatment consisted of 150 pounds P_2O_5 and 80 pounds K_2O per acre, applied prior to the green manure crop.

Fig. 8.-Close view of seedlings in a green manure crop - seedling rotation that had received an application of 30 tons of sawdust per acre prior to the green manure crop. The plot also received 450 pounds of P_2O_5 and 240 pounds of K_2O per acre before sowing of the green manure crop.

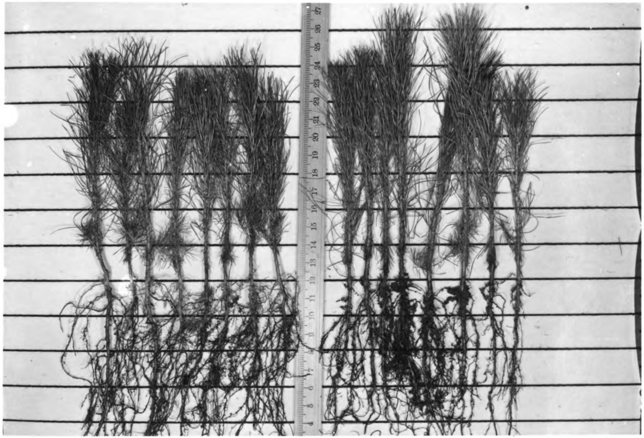

Fig. 9.-One-year-old loblolly pine seedlings from different rotations. Seedlings on left are from annual seedling rotation plots that had received 300 pounds P_2O_5, 160 pounds K_2O and 30 tons sawdust per acre each year. Seedlings on right are from the second seedling crop following a green manure crop. The above fertilizer and sawdust applications were made prior to the green manure crop.

Fig. 10.-One-year-old loblolly pine seedlings from annual seedling rotations that received different rates of fertilization. Seedlings on right are from plots that received 30 tons of sawdust per acre and no P_2O_5 or K_2O fertilizers in 1955. Seedlings on left are from plots that received neither sawdust, P_2O_5 nor K_2O treatments in 1955.