RESPONSE OF SLASH PINE

(*PINUS CARIBAEA* Morelet) TO VARIOUS NUTRIENTS

IN NORFOLK SOILS IN FLORIDA

By
Ruthford Henry Westveld

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INTRODUCTION

Slash pine has been used extensively for reforestation in the South, particularly in Florida. Of the 51,599,000 seedlings distributed from the nurseries of the Florida Forest Service since 1929, 98 percent were slash pine. The peak production in these nurseries of 8,310,000 slash pine seedlings in 1941 would reforest more than 12,000 acres with trees spaced 8' x 8'. Because of its rapid growth, its utility for numerous wood products and naval stores, its low susceptibility to serious diseases and insects, and its relatively high survival in plantations,

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1. There is some evidence that two species constitute what has been accepted as a single species known as slash pine (Forest Service 1944)[3]. Small (1933) took this point of view when he described a northern Florida species- slash pine (*Pinus plustris* Mill.), and a southern Florida species- Caribbean pine (*Pinus caribaea* Morelet), De Vall (1941), after investigating the problem, concluded that Small's nomenclature is correct. The study herein reported deals with what Small calls *Pinus palustris* and the Forest Service, U. S. Dept. Agr. calls *Pinus caribaea*.

2. Submitted in partial fulfillment of the requirements for the degree Doctor of Philosophy to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science.

3. Names and dates refer to "Literature Cited".

slash pine should continue to be a popular species in reforestation.

In general, survival and early growth of the planted trees have been satisfactory when planting has been done properly. However, 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. Wakeley (1935) reports that quality of planting stock affects not only survival of slash pine trees in plantations, but also their rate of growth during the first several years. Wakeley's observations on survival were corroborated by the author in 1941. Using Wakeley's three slash pine grades of planting stock, the author found at the end of the first growing season, the following percentage of survival: best-grade trees, 100; second-grade trees, 72; third-grade trees, 55. Wakeley aptly points out that poor soil quality is one of the factors that are responsible for the development of low-grade seedlings in the nursery, thus implying that through soil improvement, the quality of forest planting stock might be improved.

It is a well-known fact that some forest nurseries in the slash pine belt are situated on soils that are poor in nutrients and so low in colloids and organic matter that they have undesirable physical qualities. Even when a soil has good chemical, physical, and biological characteristics, the warm humid climate of the South makes the maintenance of soil fertility difficult. Consequently, an understanding of the nutrient requirements of slash pine, interpreted in terms of the soil and its management, is essential if the soil is not to be a conspicuous limiting factor in the production of high-quality planting stock. In 1941, an investigation of the literature and correspondence with the operators of state and federal nurseries which were producing slash pine revealed that practically no research had been done on the role of nutrition in the quality of slash pine seedlings produced in these nurseries. A study of this problem was immediately initiated. The results of this investigation from its inception to early in 1946 form the basis for this paper.

REVIEW OF LITERATURE

That proper nutrition has been recognized as an important factor in the production of high-quality forest planting stock is evident from the numerous studies of the use of fertilizers and other means of soil improvement that have been made in forest nurseries. Nearly every tree species that is used extensively in reforestation has received some attention. Eastern white pine (Pinus strobus L.), one of the first species to be used in reforestation in the United States, has been studied by several investigators (Kopitke, 1941; Larsen and Stump, 1939; McIntyre and White, 1930; Mitchell, 1934 and 1939; Wilde, 1938). The nutrient requirements of other northern conifers have received considerable attention also (Larsen and Stump, 1939; Lunt, 1938; McIntyre and White, 1930; Mitchell, 1934; Wilde, 1938).

On the other hand, the southern conifers have been studied only to a very limited extent, all of the work having been done very recently, due undoubtedly to the fact that reforestation in the South started much later than in the North.

That the nutrition of forest trees involves more than the determination of the amounts of the various plant nutrients needed to produce optimal growth is evident from the variety of studies that have been made. Studies of the nitrogen, phosphorous, and potassium requirements of nursery-grown trees have been the most popular. Other phases of tree nutrition that have come in for study are the following: (1) minor elements, (2) organic versus inorganic fertilizers, (3) the value of peat and other organic materials in maintaining organic matter in the soil, (4) the relation of mycorrhizae to nutrition, and (5) effect of pH of soil on nutrition.

Many of the studies of nutrient requirements have dealt with the three major elements, nitrogen, phosphorous, and potassium; but in recent years several specialized studies of individual elements have been made. Mitchell (1934) made exhaustive studies of the effect of nitrogen on eastern white and Scotch pine (Pinus sylvestris L.). Growing these species in sand cultures, he found that growth was best when they were supplied 300 p. p. m. of nitrogen. Greater amounts of nitrogen caused a reduction in seedling weight. Nitrogen content of the seedlings increased with nitrogen supply up to 200 p. p. m. Root-shoot ratio was affected adversely by increasing the nitrogen supply, and the highest ratio was produced below the nitrogen concentration that was optimal for growth alone. Since for planting purposes, a tree with a large root-shoot ratio is generally regarded as superior to one with a small root-shoot ratio, it might be inferred that nitrogen supply of less than 300 p. p. m. might produce a tree superior for planting. Since field tests with trees receiving different treatments are not reported, there is no evidence as to which trees proved best in field plantings. Mitchell's studies showed that for growth the optimal concentrations of other elements in p. p. m. were: phosphorous, 350; potassium, 150; calcium, 200. In applying the results of his pot-culture tests to the nursery, he found, by periodic tests and adjustment of the nutrient evironment to approximately the optimal internal concentrations of the trees, that better white pine planting stock could be grown in 2 years than by the usual methods employed in fertilization in average nurseries in 3 years.

Auten (1945) found that in using soluble inorganic nitrogenous fertilizers on shortleaf and pitch pine (Pinus echinata Mill. and Pinus rigida Mill.) in nurseries in the Central States damage to seedlings could be avoided if fertilization was postponed until at least 2 weeks after seedling emergence. When they were applied at seeding time, seedling density was reduced.

Bensend (1943) found the optimal nitrogen supply for growth of jack pine (Pinus banksiana Lamb.) to be 200 to 250 p. p. m. Weight of roots increased with increase in nitrogen supply up to 100 p. p. m., above which there was little change in root weight. Root-shoot ratio decreased with increase in available nitrogen until 100 p. p. m. was reached, above which there was little or no change. These relationships are not the same as for eastern white pine. Mitchell (1939) found that root weight increased with increase in available nitrogen supply up to 300 p. p. m. and that the maximum root-shoot ratio occurred with a nitrogen supply of 50 p. p. m. If a relatively large root-shoot ratio means superior-quality planting stock, these studies indicate that nitrogen should be used sparingly.

Bensend found that droughtresistance, although not improved, was not impaired by increased amounts of available nitrogen up to the optimum for growth (200 to 250 p. p. m.). When the nitrogen supply was raised above the optimum, drought resistance declined, however. Shirley and Meuli, (1939) using three levels of nitrogen (0, 245, and 490 p. p. m.) on 2-year-old red pine (Pinus resinosa Ait.), found that nitrogen reduced drought resistance; but they add that plants that receive no nitrogen are not necessarily the most satisfactory planting stock because the tops are too small to supply the food needed for rapid root penetration, a condition which is essential to survival on dry sites. Phosphorous without nitrogen increased drought resistance.

McComb and Kapel (1940) using an acid, infertile, glacial clay exposed by erosion, found that 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 phosphorous alone (270 pounds per acre of P) at controlled pH ranging from 4.3 to 7.7. Black locust that received phosphorous was twenty-four and green ash three times as heavy as trees grown in untreated soil.

Nemec's studies (1931, 1937) of phosphorous fertilization demonstrated that the response of both pine and spruce varied on different soil types. In his first bulletin on this subject he reports that spruce and pine make no response to phosphoric acid fertilization on soils containing more than 250 p. p. m. of P_2O_5 soluble in citric acid. In a later bulletin he reduces this minimum to 160 p. p. m. On soils deficient in phosphorous, additions of phosphorous stimulated growth only when the supply of assimilable calcium compounds was adequate. When calcium was inadequate and readily soluble iron compounds abundant, the effect of phosphoric acid fertilization was completely nullified. Especially on acid soils, Thomas meal was a more satisfactory source of phosphoric acid than superphosphate.

Certain aspects of potash fertilization have been studied by Wilde and Kopitke (1940). They found that the available potash retained in the soil varied with the base-exchange capacity of the soil, varying from an average of 70 pounds per acre in a soil with a base-exchange capacity of 3 m. e. to 260 pounds in a soil with an exchange capacity of 9 m. e.

Recommended rates of application of K_2O are based on these facts. On soils with a low base-exchange capacity where high levels of potassium are needed they suggest the possibility of increasing the soil exchange capacity through the application of peat or other materials of high base-exchange capacity and the use of catch crops, composts, or liquid fertilizers. Kopitke (1941) found that providing white apruce (Picea glauca(Moench) Voss), red pine, and eastern white pine seedlings with adequate potassium caused certain physiological changes in the plants which should decrease their susceptibility to frost injury.

Both Mitchell (1939) and Pessin (1937) have demonstrated that calcium is essential to satisfactory growth of the conifers they studied. Mitchell found that 200 p. p. m. was the optimal concentration of calcium for white pine. Chapman (1941) who grew shortleaf pine seedlings in quartz sand cultures containing 0, 249, 1245, 2490, and 3735 p. p. m. of water-soluble calcium found that concentrations of calcium above 249 p. p. m. affected seed germination and seedling survival adversely. Since the gap between 249 and 1245 p. p. m. is large, the exact concentration at which calcium is harmful cannot be interpreted from this study. In nurseries, the use of lime has not always been beneficial to conifers. Lunt (1938) produced better red pine seedlings without lime than with lime, and Auten (1945) found that the application of ground limestone reduced the seedling density. On the other hand, McIntyre and White (1930) were able to produce better white pine when the soil was limed than when it was not limed. The inconsistent effects of lime on coniferous seedlings are due to differences in soil reaction and buffering capacity, and indirectly, to the damping-off disease. (commonly caused by various species of Pythium, Fusarium, and Rhizoctonia)(Boyce, 1938). An increase in the pH of the soil often increases damage to seedlings by damping-off. In this case the calcium does not injure the seedling directly but, by increasing the pH of the soil, it increases damage from damping-off.

Minor elements have received little attention in tree nutrition studies. Auten (1945) reports no response by shortleaf and pitch pine to copper, manganese, zinc, and boron. Smith and Bayliss (1942) found that zinc is essential for healthy vigorous growth of Monterey pine (Pinus radiata D. Don). Seedlings of this species grown in water culture showed no zinc deficiency symptoms for about 2 months, but at the end of 6 months, the stems and needles of zinc-deficient trees were much shorter than those of trees receiving zinc.

Numerous investigators have carried on fertilizer experiments in nurseries with nitrogen, phosphorous, and potassium; but since the investigations generally did not include soil analyses, it is difficult to interpret from these studies the nutrient requrements of the species concerned. Typical of this type of investigation are the studies of Lunt (1938), Auten (1945), Wahlenberg (1930), McIntyre and White (1930), Andrews (1941), and Larsen and Stump (1939). Most of these studies demonstrate that the soils dealt with contain an available supply of one or more nutrients inadequate to produce the most satisfactory planting stock, and that by supplementing the supply of these nutrients, the trees are benefitted. Generally these studies do not show the actual total nutrient requirements. However, Lunt (1938) made chamical analyses of some of the trees he grew, and from these analyses concluded that the N-P_2O_5-K_2O requirements of 1-0[4] red pine in pounds per acre are 41, 14, and 18;

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4. The first digit refers to the number of years the tree grew in the

seed bed, the second digit refers to the number of years the tree grew in the transplant bed.

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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.

Wilde (1938) used the analysis of virgin soils from highly productive sites for various species as a basis for interpreting their needs for nitrogen, phosphorous, potassium, and calcium. He found that the $N-P_2O_5-K_2O$ ratio of several conifers in the Lake States was approximately the same for all species- 1-2-5. The N requirements ranged from 20 to 45 pounds; P_2O_5 requirements, from 40 to 100 pounds; and K_2O requirements, from 100 to 275 pounds per acre. The ratio from hardwoods was 1-3-5. It is noteworthy that Wilde's method of determining nutrient requirements shows the highest need is for potassium, while Lunt's method shows the highest need is for nitrogen. Mitchell's data (1939) when expressed as a $N-P_2O_5-K_2O$ ratio gives approximately a 2-4-1 ratio, which shows that the highest requirement is for phosphorous. Since both Mitchell and Wilde worked with white pine, the differences in nutrient requirements which they secured must be attributed to the methods used to make the determination.

Wahlenberg (1930) found that on the soils in the Savenac Nursery, ponderosa pine (Pinus ponderosa Laws.) was benefitted most by a complete fertilizer containing a small amount of potassium, a relatively large amount of nitrogen, and an intermediate amount of phosphorous.

McIntyre and White (1930), in nursery experiments on Hagerstown silt loam and DeKalb silt loam, found that only small additions (20 pounds per acre) of nitrogen but larger additions of phosphorous (80 pounds of P_2O_5) and potassium (50 pounds of K_2O) were needed to produce good-quality planting stock of white pine, pitch pine, and Norway spruce (Pica abies (L.) Karst.). In some instances the addition of calcium was necessary to get the best results.

On a sandy soil in North Carolina- 90 to 95 percent total sand- Andrews (1941) found that loblolly pine (Pinus taeda L.) seedlings produced the largest root-shoot ratios when 40, 80, and 40 pounds per acre of N, P_2O_5, and K_2O, respectively, were applied about 4 weeks after germination.

Larsen and Stump (1939) report on the response of white pine, Douglas fir (Pseudotsuga taxifolia (Poin.) Britton), Norway spruce, red pine, white spruce, and jack pine to numerous fertilizers, both organic and inorganic. In general, nitrogen fertilizers stimulated top growth of seedlings and transplants while fertilizers containing phosphorous increased root development. In the nursery, fertilizers containing nitrogen, phosphorous, and potassium were more effective than fertilizers containing only one of these elements. In greenhouse tests, single elements frequently proved more effective.

Several investigators in recent years have studied the response of forest tree seedlings to various nutrients either in quartz sand or soil cultures under greenhouse conditions. Some of these studies were supplemented by work in nurseries. Addoms (1937), in her study of loblolly pine, found that after selecting plants on the basis of uniformity, great variations in the growth of individual plants occurred, and concludes that starting with plants grown from seed of uniform size would be better technique. Mitchell (1939) found it necessary to take seed weight into account in order to interpret the results of his nutrition studies correctly.

Addoms attributed the yellowing of the leaves of the trees to a deficiency of nitrogen (nutrient solutions containing 136 and 156 p. p. m. were used). Pessin (1937) grew the most vigorous and well-developed longleaf pine (Pinus palustris Mill.) seedlings when sand cultures were supplied with calcium, nitrogen, potassium, phosphorous, magnesium, sulphur, and iron. Leaving either phosphorous or sulphur out of the nutrient solution produced the least effect on the seedlings. Lack of magnesium, potassium, or iron produced conspicuous abnormalities very early in the experiment. Pessin (1941) grew slash pines in washed sand which received no nutrient solution for the first 9 months, after which they were treated for 8 months with nutrient solutions containing ten elements in which the amounts of nitrogen, phosphorous, and potassium were varied. Maximum dry weights were produced in cultures that contained 213 p. p. m. of nitrogen, Phosphorous produced no significant effect on dry weight, while potassium in increasing amounts decreased the dry weight. Seedling vigor was improved by increasing amounts of nitrogen. The supply of phosphorous and potassium did not show any such relationship. The trees produced the longest roots when the nitrogen supply was smallest. Whether the response of the trees would have been the same if they had received nutrient solutions from the start may be open to question.

The relative merit of organic and inorganic fertilizers has been studied by several of the investigators mentioned previously. In the studies reported by Larsen and Stump (1939), most of the organic fertilizers seemed to be as effective as inorganic fertilizers but there were two exceptions. Red pine failed to respond to dried blood alone and 1-0 eastern white pine did not respond to steamed bone meal alone. Andrews (1941) reports that on the sandy soil with which he dealt, the best loblolly pine stock is produced when both organic material and concentrated inorganic fertilizer containing a high percentage of phosphorous is used. Wahlenberg (1930) was able to produce nearly as good ponderosa pine planting stock by fertilizing with a mixture of superphosphate, bone meal, tankage, and guano as by fertilizing with an inorganic fertilizer containing nitrogen, phosphorous, and potassium. On the other hand, Lunt (1938) found organic fertilizers superior to inorganic fertilizers in growing red pine seedlings in nurseries on sand, loamy sand, and sandy loam. He, as well as Auten (1945), give warning of the danger of injury to seedlings when inorganic fertilizers are used on relatively sandy soils. Mitchell (1939) prefers high-analysis inorganic fertilizers to organic or low-analysis inorganic fertilizers and was able to use the former without injury in nursery beds by making light applications. Wilde (1937) has found that there is less danger of injury to seedlings by inorganic fertilizers when they are applied as liquid humate fertilizers- a mixture of the inorganic materials with water and forest duff. Apparently the exceptional response of weak seedlings to this type of fertilizer is due in part to vitamin and hormone substances in the duff. Such fertilizers are too expensive, however, for general use.

Peat has been found effective for forest-nursery use not only as a source of nutrients (particularly nitrogen) but also to increase the base-exchange capacity of the soil, and to change soil reaction. Wilde and Hull (1937) were able, by using an inorganic fertilizer plus peat, to produce red pine seedlings that were nearly twice as heavy as those fertilized with inorganic fertilizer alone. Auten (1945) found that peat was the best source of organic matter in studies of shortleaf and pitch pine.

It increased both the density and height of both species, but results were not entirely consistent.

Very limited study has been made of the timing of the application of fertilizers. Proper timing seems to be of greatest importance in the application of readily soluble forms of nitrogen. When applied too soon, seedlings may be injured (Auten, 1945) or little benefit is realized from the fertilizer because it leaches from the soil before the seedling can use it effectively (Andrews, 1941). Similar results occur when readily soluble forms of potassium are used (Wilde and Kopitke, 1940). This is especially true on soils of low base-exchange capacity.

The role of mycorrhizae in tree nutrition has been studied rather extensively in the past 10 years. No attempt is made here to review the extensive literature on this subject, but rather to call attention to the fact that nitrogen or phosphorous absorption by tree seedlings may be inadequate in the absence of mycorrhizae (McComb, 1943; Melin, 1925; Mitchell, Finn and Rosendahl, 1939).

Comprehensive study of the effect of pH of the cultures has not been made, but some limited work on the subject has been done in connection with other studies previously referred to. Chapman's study of shortleaf pine (1941) revealed that differences in pH between 3.7 and 4.82 had no noticeable effect on seedling behavior but that at pH of 6.23, seedling growth rate was slow and mortality high. Auten (1945) reports that shortleaf and pitch pine made more response in height growth to various forms of phosphorous fertilizer at pH 4.0 and 6.0 than at pH 8.0. Addoms (1937) found that the optimal pH for loblolly pine varied with different sources of nitrogen. When calcium nitrate was used, a pH of 3.8 to 5.0 resulted in the best development of loblolly pine seedlings; but when ammonium sulphate was used, a pH of 6.0 produced the best development. McComb and Kapel (1940) secured tremendous response in height growth of green ash and black locust to phosphorous fertilizers on a glacial clay in Iowa at pH levels ranging from 4.3 to 7.7 but the best response was at pH of 4.3. In contrast Nemec (1931, 1937) got little response of spruce and pine to phosphorous fertilization in soils with low pH (3.19 to 5.0).

The object of all nutrition and fertilizer studies on forest trees is to determine the role of proper nutrition in the production of high-quality planting stock. Various features have been used as indices of quality. The most common characteristics that have been used are height, dry weight, and root-shoot ratio. Trees with the greatest height and weight and with the largest root-shoot ratio have been regarded as the best trees for planting. These features have been supplemented in some cases by observations or records on foliage density and color, side branches, general vigor, needle length, or drought resistance. Only recently has the behavior of different grades of planting stock in field plantings been studied. In general, trees that had been classified as high-quality planting stock survived better and made faster growth than trees that had been classified as lower-quality stock (Lunt, 1938; Wilde, Wittenkamp, Stone and Galloway, 1940).

SCOPE OF EXPERIMENTAL WORK

The study as conceived in 1941 was to be comprehensive in scope. It was to consist of three phases: (1) greenhouse experiments, (2) nursery experiments, and (3) field-plantation experiments. The results of the first two only are included in this report since insufficient research has been done on the third to warrant its inclusion. The greenhouse experiments were to include a large number of treatments involving not only various combinations of nitrogen, phosphorous, and potassium but different quantities and modes of application as well. Anticipating that an improvement in the physical condition of the soil might be necessary to secure optimal effects from the nutrients, treatments that might throw some light on this problem were included. The most promising treatments then were to be tested in the nursery. The nursery-grown trees were to be planted in forest plantations where studies of mortality and growth would make possible a practical interpretation of the value of the different nursery treatments. As a supplement to the last phase, plans were made to study the effects of the application of nutrients to field planted trees on so-called low-quality sites.

Soon after the work was initiated problems developing from the war disrupted the systematic sequence of handling the work, and the nursery and field phases had to be curtailed greatly. Exploratory greenhouse work was done in 1941-42, and comprehensive greenhouse experiments were carried on in 1943-44 and 1944-45. Nursery experiments were initiated each year from 1942 to 1945, inclusive, but owing to various difficulties caused by the war, only the 1942 and 1945 experiments received sufficient attention to yield enough data to form the basis for statistical analyses.

The trees from the 1942 and 1945 nursery experiments were used to establish field plantations for studying the survival and growth of trees receiving different nursery treatments.

The greenhouse experiments were conducted on the campus of the University of Florida in a greenhouse made available through the cooperation of the Soils Department. The nursery experiments were carried out in the Austin Cary Forest Nursery operated by the School of Forestry of the

University. The nursery is approximately 10 miles northeast of Gainesville.

GREENHOUSE EXPERIMENTS

Experimental Methods

Seed Selection and Germination

Since other workers (Aldrich-Blake, 1930; Champion, 1933; Korstian, 1927; McComb, 1943; Mitchell, 1939) have demonstrated that the characteristics of the parent tree and seed weight influence the behavior and growth of tree seedlings, an effort was made to control these variables as much as possible in order to minimize their influence. It was not always practicable to use seed from a single tree, although this was done in the 1943-44 experiment. A representative sample from each lot of seed was weighed and the number of seeds in it counted in order to determine the average seed weight. Seed weight-classes were established, the range in each weight class being 3.0 mg. When only one weight-class was used, its mean weight was the mean weight of the entire lot of seed. When more than one weight-class of seed was used, the additional weight-classes were those nearest the weight-class having the mean weight of the entire lot of seed.

After the seed was segregated into weight-classes, it was spread in thin layers in moist acid peat moss and refrigerated at 40°F. for approximately one month[5]. Upon the removal from the refrigerator, the seed was

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5. Such treatment of slash pine seed is always desirable in experimental work because germination of treated seed begins sooner and is completed in a much shorter time than in untreated seed (Barton, 1928). When slash pine seed that has recently matured is used, stratification and refrigeration are essential because germination is generally very erratic and may extend

over a period of more than 2 months. The shorter the germination period, the smaller the average deviation in seedling age will be.

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sown promptly in germinating flats that contained the same soil as that used in the greenhouse pots. Three to 4 weeks after the start of germination, the seedlings were transferred to the pots, ten seedlings being planted in each.

Preparation of Soil Pots

The soil, which is described elsewhere, was air dried and thoroughly mixed. Then it was put through a $\frac{1}{4}$-inch screen to remove roots and other foreign material, and finally through a 2 mm. screen. Nineteen kilograms of soil were placed in each pot. This amount brought the soil to within approximately 1 inch of the top of the pot. When colloidal phosphate[6]

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6. Colloidal phosphate is a mixture of very fine rock phosphate and clay which is washed from the phosphate rock after it has been mined. It is generally regarded as a waste product of the mining of rock phosphate, but in recent years, colloidal phosphate has been sold under various trade names as a fertilizer.

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or peat moss was used as the sole or part treatment, this material was mixed thoroughly in the upper 4 inches of soil, which, to secure proper mixing, was removed from the jar. Nitrogen, phosphorous, potassium, and other chemical nutrients were applied in solution later, except phosphorous and calcium, which in the 1944-45 experiment, were mixed in the upper 4 inches of soil. Water was added to the soil in the jars a day in advance of planting the trees. To each pot, 2700 ml. of distilled water were added to give the soil a moisture content of slightly over 14 percent.

Transplanting and Subsequent Care of Trees

In order to secure uniform distribution of the trees in each pot, the available area per tree was calculated, and by trial and error a design for the arrangement of the ten trees was developed which placed six trees in an outer circumference, three in an interior circumference, and one in the center of the pot. This design was outlined on a piece of cardboard with a cross section identical to that of the inside of a pot, and holes approximately $\frac{1}{4}$-inch in diameter were punched in the cardboard at the ten designated points. This cardboard was placed on the surface of the soil, and a lead pencil pushed into the soil at each hole to a depth of about 3 inches. When a tree, because of lateral root development, required an opening wider that $\frac{1}{4}$-inch, the size of the opening was increased by a rotating motion of the pencil in the original hole.

At the time of transplanting to the pots, the majority of the seedlings had a 2- to 3-inch tap root, and some had developed one to four lateral roots from 1/8- to 1/4-inch long. The seedlings were washed out of the soil by a stream of water in order to minimize the danger of breaking the very delicate tap root. Every effort was made to plant each seedling in the pot at the same depth that it occupied in the germinating flat, and to bring all roots into intimate contact with the soil by ample compression of the soil in closing the hole.

The pots were watered with distilled water often enough to keep the soil moisture above 10 percent. The time interval between the application of water varied with the age of the trees and with temperature and atmospheric humidity. During the first month 450 ml. of water were applied once a week. Toward the end of the experiments, as much as 800 ml. of water had to be added to some pots every day or every second day.

As rates of growth showed marked difference after the first 6 weeks, it was evident that water loss, chiefly through transpiration, varied more or less in proportion to growth. To maintain the moisture content of the soil of all pots reasonably uniform, the pots were weighed about every 2 weeks and their moisture contents adjusted.[7] Average daily water loss

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7. Since the weight of the pots included the weight of the trees, which varied, it was not possible to maintain absolutely uniform moisture contents in all pots. The faster-growing trees were the heaviest and thus were contributing more to the total weight of the pot than slow-growing trees. In consequence the faster-growing trees were growing under conditions of lower soil moisture than the slow-growing trees.

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between weighings was computed to serve as a basis for the amount of water to be applied until another weighing was made. In other words, each pot received approximately the amount of water it was losing through evaporation and transpiration.

Design of Experiment

As stated previously, each pot contained ten trees. Each soil treatment was replicated four times. Within each of the four blocks, the pots were randomized. In order to neutralize the effects of any minor differences in the microclimate of the greenhouse, the pots were rotated from one block to another so that each pot occupied an equal period of time in each block. Furthermore, pots which were located on the exterior side of the bench during one period were moved to the interior side of the bench during the next period and vice versa. With this design, all data could be subjected to analyses of variance. Thus, a simple method of interpreting the extent of significant differences was provided (Baten, 1938; Snedecor, 1940).

Weather Records

During most of the 1943-44 greenhouse experiment, a record of temperature was kept on a thermograph. This was done also during the 1944-45 greenhouse experiment. During the latter experiment, three sets of black and white Livingston atmometers were installed to measure rate of evaporation (Livingston, 1935).

When it was apparent that marked differences in the growth and behavior of the seedlings in the 1943-44 and 1944-45 experiments existed and that climatic factors other than temperature might be contributing factors, length of day was computed from daily maps of the Weather Bureau.

The only control of greenhouse temperature that was put into effect was to close all windows late in the afternoon when outdoor-night temperatures were expected to fall below 60°F. and to turn on steam heat when outdoor-night temperatures were expected to fall below 35°F. With these controls, the greenhouse temperature rarely fell below 60°F. during the 1943-44 experiments, and rarely below 55°F. during the 1944-45 experiments.

Observations and Measurements of Trees

After the seedlings were planted in the soil pots, the number of cotyledons and the height from the soil surface to the base of the cotyledons were recorded. This height measurement and all subsequent ones were measured to ± 1.0 mm. Height growth was measured at regular intervals- either 5 or 6 weeks- to coincide with the application of nutrients in those treatments that received split applications of nutrients, and just prior to harvesting the trees. Growth was measured from the base of the cotyledons to a point near the tip where the overlapping of the primary needles obscured the identity of the stem. These two points were chosen as termini for various reasons. Of greatest significance in choosing the base of the cotyledons as the lower terminus for growth measurements is the fact that growth prior to transplanting, which varied from 33 to 79 mm. in the 1943-44 experiment, and from 34 to 95 mm. in the 1944-45 experiment, is not included, thus eliminating variable growth which was inherent in the seed, and not a result of soil treatment. Furthermore, the base of the cotyledons is distinct and stationery, the latter characteristic being in contrast to the soil surfaee which varies because of slight soil washing. Any point chosen at or near the tip of a growing pine tree is not so well defined as the base of the cotyledons. The point at which the primary needles overlap and thereby obscure the identity of the stem is quite clear-cut and should represent resonably well the terminus of stem elongation.

Observation of number of side branches was made chiefly during the period of most active side-branch development. These observations were not made at regular intervals, but rather in accordance with the amount of change taking place. During the period of greatest activity, record was made of the first appearance of secondary needles and of the development of a terminal bud in those few instances where this occurred. The progress of the death of cotyledons was also recorded. When an abnormal color developed in a plant, note was made of this fact.

Just prior to harvesting the trees, a representative pot of trees from each treatment was photographed.

Harvesting of the trees was accomplished by running a stream of water from a garden hose into the soil, thus slowly washing the soil away from the roots. During the washing operation, the pot was placed on its side on a stand of convenient height, the top of which was made of 1/4-inch-mesh hardware cloth, supported by several strips of wood.

Quick disposition of the soil was accomplished in this manner. Extreme care in the operation was necessary to minimize root breakage and loss of small segments of the roots. Considerable water had to be run over the roots after they were extricated from the soil in order to wash off the more tightly adhering soil particles. This was especially true with those soils to which colloidal phosphate or peat moss had been added. Separation of the individual trees was difficult because the roots of the ten trees in each jar were badly entangled.

Representative trees (average height and branch development) were chosen from each treatment for photographing.

After the harvest, the diameter of the stem of each tree was measured with a micrometer to ± 0.01 mm. at 1/4 inch above the ground line which was assumed to be above any swelling of the stem. Each tree was then cut into two parts, shoot and root, and each portion placed in a properly labelled paper bag. The open packages were placed in a drying oven where they were left at a temperature of 65°C for approximately 72 hours. Each sample was then weighed to ± 0.01 gr.

A record was kept of the amount of water added to each pot, and of the weight of each pot at each weighing.

Physical and Chemical Characteristics of the Soil

The soil selected for the greenhouse studies is a Norfolk sand. It was taken from a ridge on the Austin Cary Forest which appears to have supported a longleaf pine type originally. Close cutting of the pine allowed the oaks to increase their representation, and now, turkey oak (*Quercus laevis* Walt.) and bluejack oak (*Quercus cinerea* Michx.) dominate the stand. Prior to 1937 the area burned more or less regularly each year, but since then fire has been kept out.

The soil was taken from the upper 6 to 8 inches, which includes all the A_1 horizon and 3 to 5 inches of the A_2 horizon. Henderson (1939) describes the A_1 horizon as gray to yellowish gray sand and the A_2 horizon as yellow sand. The soil was thoroughly mixed and allowed to air dry, after which it was screened through 1/4-inch hardware cloth to remove roots and other coarse plant parts. The air-dry, mixed soil was gray, yellow-tan in color.

Since colloidal phosphate, when mixed in varying quantities in the upper 4 inches of the soil, produced such significant effects on the growth and other characteristics of slash pine seedlings (see pp. 81-100 and 118-130) an effort was made to determine the physical and chemical effect of this material on the soil. When various analyses of the soil were made, similar analytical procedures were applied to soil to which had been added quantities of colloidal phosphate equal to the amounts used in the greenhouse experiments. It was soon apparent that measurable effects were not produced on the soil by colloidal phosphate when such small amounts as 0.5 and 1.0 ton per acre were applied. Most of the analyses on soil to which the colloidal phosphate was added were made, therefore, with mixtures containing 5 and 25 tons of phosphate per acre.

Mechanical Analysis

Mechanical analysis of the soil as well as the colloidal phosphate was made by the hydrometer method, employing the technic of Bouyoucos (1936). The results, which are based in each case on two samples, are presented in Table 1. Soil organic matter analysis, based on the method recently described by Schollenberger (1945) is shown also in this table. It is based on four samples:

Table 1. --Mechanical analysis of greenhouse soil samples and colloidal phosphate, and soil organic matter content of soil

Type of Sample	Sand	Silt & Clay	Soil organic matter
	Percent		
Soil	92	8	2.18 + 0.25*
Soil + 5 tons of colloidal phosphate	90	10	
Soil + 25 tons of colloidal phosphate	88	12	
Colloidal phosphate	13	87	

*Standard deviation.

The sandy character of the soil is evident in the data in the above table. In contrast the colloidal phosphate contains nearly as much silt- and clay-like material as the soil contains sand. Although an analysis of variance of the data on the three different soil samples does not reveal significant[8] effect of colloidal phosphate on the

8. The word "significant", when used in discussing experimental data, is used throughout the manscript in a statistical sense. Various degrees of significance can be recognized, but the two most commonly used are the 5 and 1 percent points. The former, which indicates that there are ninety-five chances in one hundred that the difference in means is not due to random sampling of a homogeneous population, is commonly spoken of as significant; the latter, which means that there are ninety-nine chances in one hundred that the difference in means is not due to random sampling of a homogeneous population, is referred to as very or highly significant.

soil, it is likely that a greater number of determinations by a more sensitive method might have shown a significant effect. This is more or less borne out by the moisture equivalent data (moisture holding capacity is related to particle size), and the fact that calculated values for amount of silt plus clay in the soil plus 5 tons of colloidal phosphate and in the soil plus 25 tons of colloidal phosphate are 8.63 and 11.16 percent respectively. In view of the impracticability of reading values on the hydrometer in units of less than one percent, the values from the analysis agree closely with the calculated values. Even with the addition of 25 tons of colloidal phosphate per acre to the upper 4 inches of soil, this material constitutes less than 4 percent of the total material in that soil zone.

Moisture Equivalent

Moisture equivalent of the soil samples and the colloidal phosphate was determined by the centrifuge method (Wright, 1939), the samples being left in the centrifuge for 15 minutes after a speed of 2200 revolutions per minute had been attained. Four samples were used in the determination of moisture equivalent of untreated and treated soils, and two samples were used for the colloidal phosphate.

	Moisture equivalent % moisture	Standard deviation
Soil	5.39	
Soil plus 5 tons colloidal phosphate	5.60	0.20
Soil plus 25 tons colloidal phosphate	7.23	
Colloidal phosphate	47.60	

A small increase in the moisture equivalent is produced when colloidal phosphate is added to the soil at a rate of 5 tons in the upper 4 inches, and a marked increase occurs when 25 tons is added. An analysis of variance reveals that the increase caused by 5 tons is not significant, but that the increase caused by 25 tons is very significant. The moisture equivalent of soil plus 25 tons of colloidal phosphate is also very significantly different from that of the soil plus 5 tons, a difference of 0.94 percent being significant at 1 percent.

It is noteworthy that the moisture equivalent of the soil with 5 and 25 tons per acre is 104 and 134 percent of that of the untreated soil and that the calculated percentage of silt plus clay for soil plus 5 tons and soil plus 25 tons is 108 and 139 percent of that of the original soil. In other words, the moisture equivalent is increased in almost the same proportion as the percentage of silt plus clay.

Large and Small Pores

Using the method described by Leamer and Shaw (1941), the percentage of large and small pores was determined for the greenhouse soil and for the greenhouse soil containing colloidal phosphate at rates of 5 and 25 tons per acre. The results of these determinations based on two samples of each, are shown in Table 2.

Table 2. --The percentage of small and large pores and total pores in greenhouse soil with and without colloidal phosphate

Type of sample	Small pores	Large pores	Total pores
Soil alone	41.5	15.5	57.0
Soil + 5 tons of colloidal phosphate	38.0	20.0	58.0
Soil + 25 tons of colloidal phosphate	39.5	17.5	57.0

The addition of colloidal phosphate to the soil did not change the total pore space, but it did alter the relative amounts of small and large pores. The percentage of small pores was reduced, and the percentage of large pores was increased by the addition of colloidal phosphate. An analysis of variance showed that the differences were not significant, however.

Other Physical Effects of Colloidal Phosphate on Soil

An examination of the surface of the oven-dried soil samples (diameter approximately 3 inches) used in the foregoing test showed evidence that the samples to which colloidal phosphate had been added had been altered physically. Cracks had developed on the surface indicating that the colloidal phosphate had caused some binding of soil particles, and as shrinkage occurred in drying, cleavage lines developed at some of the weaker points. The extent of cracking is shown in Table 3.

Table 3. --The extent of surface cracking in oven-dry soil containing different amounts of colloidal phosphate

Soil sample	Sample #1		Sample #2	
	Number of cracks	Size of cracks mm.	Number of cracks	Size of cracks mm.
Soil + 5 tons of colloidal phosphate	2	10 x 0.25	2	10 x 0.25
			1	5 x 0.25
Soil + 25 tons of colloidal phosphate	1	50 x 1.0	1	25 x 1.0
	2	4 x 0.5	1	10 x 1.0
			1	
Untreated soil	0	-	0	-

It is obvious that the amount of cracking of the soil is related to the amount of colloidal phosphate in the soil. The cracks in the soil sample containing 25 tons of colloidal phosphate were two to four times as wide, and the total length was approximately twice as long as in the soil sample containing 5 tons per acre. No cracks occurred in the untreated soil.

The soil containing variable amounts of colloidal phosphate was tested for plasticity. None of the samples became plastic. This is not surprising inasmuch as the soil containing 25 tons of colloidal phosphate per acre contains less than 15 percent clay, the minimum amount generally considered to be needed to cause plasticity.

The soil samples used for the plasticity tests were molded into balls approximately one inch in diameter and then allowed to air dry. After they were dry, pressure was applied to test the relative strength of the soil masses. The amount of force required to break them was more or less proportional to their colloidal phosphate content. Upon breaking the untreated soil separated into small aggregates while the soil containing 25 tons per acre of colloidal phosphate broke into relatively large aggregates.

Base-Exchange Capacity and Exchangeable Bases

Base-exchange capacity and exchangeable bases of the untreated soil and of the soil containing variable amounts of colloidal phosphate were determined by the method described by Schollenberger and Simon (1945). The results of these analyses are shown in Table 4.

Table 4. --The base-exchange capacity, exchangeable bases, and percent of base saturation of greenhouse soil with and without colloidal phosphate

Type of Soil sample	Total base exchange capacity	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Total exchangeable bases	Approximate percent saturation*
	Millequivalents per 100 grams					
Soil only	4.34	0.31	0.09	0.43	0.83	19.1
Soil + 0.5 ton colloidal phosphate	3.97	0.33	0.09	0.51	0.93	23.4
Soil + 1.0 ton colloidal phosphate	3.80	0.36	0.21	0.36	0.93	23.5
Soil + 5.0 tons colloidal phosphate	3.46	0.53	0.16	0.43	1.12	32.4
Soil + 25.0 tons colloidal phosphate	3.87	1.17	0.21	0.64	2.02	52.2
Standard deviation	0.21	0.03	0.05	0.08		

*Since bases other than Ca, Mg, and K were not determined, and possibly occurred in the soil in very small quantity, the percent of base saturation is probably slightly higher than that shown in the table.

The mean base exchange capacity for all soil samples is 3.89 m.e./100 gr. of soil. Although the individual samples varied somewhat, an analysis of variance revealed no significant difference between the various samples containing different amounts of colloidal phosphate.

Amount of exchangeable bases is very low as is also the percent of base saturation. The soils containing colloidal phosphate at rates 5 and 25 tons per acre contain appreciably more exchangeable calcium than the untreated soil and the soil with small amounts of colloidal phosphate. The differences between the former and latter soil samples are very significant.

There is also a very significant difference in the amount of calcium in the soil containing 5 tons of colloidal phosphate and the soil containing 25 tons of this material. Undoubtedly only a part of the calcium in the latter samples is exchangeable calcium, the remainder (the amount above that found in the soil alone) being calcium that went into solution from the colloidal phosphate when the soil was leached with ammonium acetate.

Although there are sifferences in the amount of exchangeable K and Mg in the various soil samples, none of the differences are significant. The greater amount in some of the soil samples containing colloidal phosphate was probably caused by small amounts of K and Mg from the colloidal phosphate going into solution in leaching the soil.

Available Phosphorous

Available phosphorous was determined on two different soil extracts, one secured by using sodium acetate (Morgan, 1935), and the other secured by using carbonic acid (McGeorge and Breazeale, 1931) as an extracting solution. The results of these determinations are shown in Table 5.

Table 5. --Carbonic-acid soluble and sodium-acetate soluble phosphorous in various types of greenhouse soil samples

Type of soil sample	Carbonic-acid soluble P	Sodium acetate soluble P
	p. p. m.	
Untreated soil	5.0	8.0
Soil + 1 ton colloidal phosphate	5.5	8.5
Soil + 25 tons colloidal phosphate	25.0	-

According to Rogers and other (1939), the total phosphorous in virgin soil of the Norfolk series ranges from 0.01 to 0.05 percent in the surface soil and from 0.01 to 0.06 in the subsoil. Expressed as p. p. m., the range would be from 100 to 600. It is evident from the data in Table 5 that a relatively small proportion of the phosphorous is readily available. Taking the sodium-acetate-soluble phosphorous as a basis, the soil contains nearly enough available phosphorous to meet the annual requirements (approximately 16.7 pounds) of a crop of 1-year slash pine seedlings (see Appendix). Based on the carbonic-acid-soluble phosphorous, the soil may not meet these requirements. It is obvious that a one-ton application of colloidal phosphate does not remedy the situation. On the other hand, a 25-ton application increases greatly the supply of available phosphorous and thus gives insurance against an exhaustion of the supply. The colloidal phosphate can be an important source of available phosphorous in the soil, probably for several years.

Soil Reaction

The pH of the soil was determined electrometrically with a glass electrode at a soil-water ratio of 1:1 by weight (Reed, Fielding, and Cummings, 1945). Based on four samples, the pH of the soil is 5.18.
In order to determine the ability of the soil to release bases to the clay fraction, soil samples with and without colloidal phosphate were leached with 0.05N HCl, washed with distilled water and with alcohol, and allowed to stand at room temperature for 2 weeks. The pH of the samples was determined five times during the first week and at the end of the second week. The record of these determinations is presented in Table 6.

Table 6. --Change in pH and H-ion concentration of greenhouse soil with and without colloidal phosphate during a 2-week period following leaching with 0.05N HCl

Time after leaching-days	Soil	Soil + 5 tons colloidal phosphate	Soil + 25 tons colloidal phosphate	Soil	Soil + 5 tons colloidal phosphate	Soil + 25 tons colloidal phosphate
	pH			H-ion concentration x 10^{-5}		
0	3.44	3.58	4.00	36.3	26.0	10.8
1	3.70	3.93	4.22	20.0	15.0	6.1
3	3.81	3.99	4.42	15.0	10.0	3.8
4	3.81	3.99	4.42	15.0	10.0	3.8
6	4.00	4.14	4.59	10.2	7.2	2.6
14	4.14	4.39	4.80	7.3	4.1	1.6

Leaching with 0.05N HCl did not reduce the pH of the soil containing colloidal phosphate as much as that of the untreated soil. It is evident that the colloidal phosphate produced a definite buffering effect on the soil. The buffering effect is evident also in the smaller change in H-ion concentration in 2 weeks in the soils containing colloidal phosphate than in the untreated soil. This is especially true in the soil treatment at a rate of 25 tons per acre of colloidal phosphate. Change in H-ion concentration was much greater during the first week than during the second week. In other words, as the pH progressed toward the original pH of the soil, the change in H-ion concentration slowed down. This would indicate that available bases would be released to the colloidal complex very slowly as a result of minor changes in pH in the soil caused by the withdrawal of bases by growing plants.

1941-42 Experiment

The 1941-42 experiment was not controlled so effectively as later experiments and was very limited in scope owing to the development of unforeseen difficulties. It was useful for testing experimental procedure, and it furnished some sata for comparison with that from later experiments. Because of the limitations of this project, it is discussed only briefly.

The plan for this experiment differed as follows from that described earlier under "Experimental Methods":

1. The seedlings were nearly 2 months old (exactly 2 months from seeding time) when transplanted in the soil pots.
2. Six trees were planted in each pot.
3. Commercial fertilizers were mixed in the upper 4 inches of soil in advance of planting. Ammonium sulphate and sodium nitrate were used as sources of nitrogen in such proportions that they yielded equal quantities of nitrogen; superphosphate and muriate of potash were the sources of phosphorous and potassium, respectively.
4. Height of the seedlings was measured from the ground line to the tip of the longest needle.

Five different treatments were applied to the soil as follows:

1. No nutrients added (designated in the discussion which follows "check").
2. 20# N, 20# P_2O_5, and 20# K_2O per acre (designated as "20NPK").
3. 40# N, 40# P_2O_5, and 40# K_2O per acre (designated as "40NPK").
4. 60# N, 60# P_2O_5, and 60# K_2O per acre (designated as "60NPK").
5. 40# N, 40# P_2O_5, and 40# K_2O per acre plus 20# Fe, 20# Mn, 20# Cu, 10# Zn, and 2# B (designated as "NPK + minor elements").

Various features of the trees that were measured at the end of the experiment are shown in Table 7.

Table 7. --The mean height, weight, root-shoot ratio, and number of branches of slash pine seedlings grown in different cultures for 128 days (total age of trees- 178 days)

Treatment	Height mm.	Dry weight grams	Root-shoot ratio	Branches number
Check	225.4	1.39	0.45	1.71
20NPK	243.8	1.55	0.45	1.54
40NPK	240.8	1.68	0.43	3.00
80NPK	253.0	1.81	0.46	4.00
NPK + minor elements	207.3	1.39	0.56	2.25
Standard deviation	0.1	0.18	0.04	0.56
Difference between treatment means to be significant at 5 percent				1.72
F value treatment	1.56	0.98	1.97	3.29*

*Significant at 5 percent.

The addition of nutrients to the soil affected the growth of the seedlings, but only the effect on number of branches per tree was significant. The lack of significant difference between the trees from the various treatments, at least in height and weight, probably was due to the lack of uniformity in the age of the seedlings caused by irregular germination. As the amount of nitrogen, phosphorous, and potassium added to the soil was increased height and dry weight of the seedlings increased, the height of the 40NPK treatment excepted. There is no trend in the root-shoot ratios. The analysis of variance of the number of branches per tree reveals that significant differences exist between the treatments. Since a difference of 1.72 branches in the means of any two treatments is significant at 5 percent, an examination of the values in Table 7 shows that the 80NPK treatment was significantly superior to the check, 20NPK, and the NPK + minor elements treatments. Except for the inconsistency of the 20NPK treatment, as the amount of nitrogen, phosphorous, and potassium added to the soil was increased, branching increased.

Table 8 shows the progress of branch development from the appearance of the first branches (8 weeks after transplanting) to the end of the experiment.

Table 8. --The progress of branch development on greenhouse grown slash pine seedlings during a two-month period

Treatment	Time after transplanting				
	8 weeks	11½ weeks	14½ weeks	15½ weeks	17½ weeks
	Number of branches per tree				
Check	0.04	0.29	0.96	1.54	1.71
20NPK	0.50	0.67	1.04	1.37	1.54
40NPK	0.92	1.17	2.71	2.96	3.00
80NPK	0.37	0.58	2.92	3.75	4.00
NPK + minor elements	0.75	0.92	1.33	2.12	2.25
Standard deviation	0.21	0.26	0.51	0.54	0.56
Difference between treatment means to be significant at 5 percent			1.57	1.66	1.72
F value treatment	2.59	1.64	3.37*	3.36*	3.29*

*Significant at 5 percent.

All nutrient treatments, except the 20NPK culture, produced trees with more branches than the check throughout the experiment. Even the aforementioned treatment produced trees with more branches than the check during the first $12\frac{1}{2}$ weeks. Differences in the number of branches per tree between the various cultures were not significant until $14\frac{1}{2}$ weeks after transplanting, and they continued to be significant until the end of the experiment. After $14\frac{1}{2}$ and $15\frac{1}{2}$ weeks, the 40NPK and 80NPK treatments produced trees with significantly more branches than the check or 20NPK treatment. Only the 80NPK treatment produced trees with significantly more branches than the NPK + minor elements treatment at the end of $14\frac{1}{2}$ weeks. After $14\frac{1}{2}$ weeks, the 80NPK culture had trees with significantly more branches than the check, 20NPK, and NPK + minor elements treatments.

Although there were no significant differences in number of branches per tree between the 40NPK and NPK + minor elements treatments, the difference was nearly large enough at $14\frac{1}{2}$ weeks to be significant. Probably the minor elements were contributing factors in reducing the amount of branching. It was evident when the trees were harvested that those from the treatment receiving minor elements were abnormal in the appearance of the foliage. The extreme tips of the primary needles of these trees were brown, and extending back from the brown zone for a distance of 1/8 to 1/4 inch, they were yellow. Needles of trees from all other cultures had a normal green color throughout their entire length.

It is noteworthy that the addition of 20 pounds of nitrogen, phosphorous, and potassium to the soil had no effect on branching. When the amount of nutrients was doubled, branching was increased enough to produce significant effects at $14\frac{1}{2}$ weeks and nearly significant effects thereafter. When the original quantity of nutrients was quadrupled, early branching was not affected significantly, but once the effect of the nutrients was established, it was maintained until the end of the experiment. Although trees receiving 80 pounds of each of the three nutrients developed more branches after $14\frac{1}{2}$ weeks than those receiving 40 pounds, differences in the branching were never significant. Although the differences in branching between the trees from the 20- and 40-pound treatments was significant only after $14\frac{1}{2}$ weeks, the differences were nearly significant at $15\frac{1}{2}$ and $17\frac{1}{2}$ weeks also. Obviously, the increase in nutrients from 20 to 80 pounds per acre has a more pronounced effect on branching than increases either from 20 to 40 and from 40 to 80 pounds per acre.

Although the differences between treatments in the number of branches per tree were not significant, the differences in the number of branched trees per pot were significant at 8 and $11\frac{1}{2}$ weeks, but were not significant later. Branching was slow to develop on trees in the check culture. At the end of 8 weeks, the pots of all cultures receiving supplemental nutrients contained more branched trees than the check culture, and after $11\frac{1}{2}$ weeks the pots of the following treatments contained a greater number of branched trees than the check: 20NPK, 40NPK, and NPK + minor elements. The proportion of branched trees at $11\frac{1}{2}$ weeks ranged from 4 percent for the check to 45.8 percent for the NPK + minor elements; at $14\frac{1}{2}$ weeks, it ranged from 12.5 percent for the check to 50 percent for the NPK + minor elements treatments. There were no significant differences in the number of branched trees produced in the four different nutrient treatments.

Although differences between treatments were not significant, the 1941-42 greenhouse experiment indicated that the addition of variable amounts of nitrogen, phosphorous, and potassium to Norfolk sand resulted in the production of taller, heavier trees. The amount of increase in height and weight is related to the amount of these nutrients added over a range of 20 to 80 pounds per acre of N, P_2O_5, and K_2O. When Cu, Fe, Mn, Zn, and B were added to the 40-pound application of N, P_2O_5, and K_2O, height was depressed, although not siginificantly, and weight showed no change.

The 20-pound application of N, P_2O_5, and K_2O had no effect on branching of the trees; but when the amount of these nutrients was increased to 40 or 80 pounds per acre, branching as expressed by number of branches per tree was greatly stimulated in the late stages of the experiment. As expressed by number of branched trees the stimulating effect of the nutrients was most pronounced during the early stages of the experiment, when all four nutrient cultures produced more branched trees than the check.

1943-44 Experiments

Soil Treatments

Three separate experiments, involving twenty-five different treatments, were set up. Experiment I is a simple factorial design of eight treatments involving three nutrients, N, P_2O_5, and K_2O, at two levels. Experiment II consists of six treatments at three levels of N, P_2O_5, and K_2O in two modes of application, namely: a single application and four equal applications (referred to as "split-application") at intervals of 6 weeks. Experiment III consists of eleven miscellaneous treatments dealing chiefly with colloidal phosphate, peat moss, and wood ashes with or without N, P_2O_5, or K_2O. The details of the character of each treatment are shown in Tables 9, 23, and 33.

Nitrogen was supplied by NH_4NO_3; phosphorous was supplied by KH_2PO_4, except in treatment 12 in which it was supplied by Ca $(H_2PO_4)_2$ H_2O and in treatments 16, 17, 18, 21, and 22 in which colloidal phosphate was the source; potassium was supplied by KH_2PO_4 and KCl. All these materials were C. P. chemicals. The colloidal phosphate used in these and all other experiments contained 20 percent total P_2O_5 and 17 percent Ca. A quick-test analysis (Spurway, 1938) made on this material, leached with distilled water, showed the following composition of the leachate in p. p. m.: P_2O_5, 2.5; Ca, 100; Mg, 4; NO_2, 1; NO_3, 25; and traces of SO_4, K_2O and Na. Tests for Al_2, Cl_2, Mn, NH_4, and Fe were blank. Although the colloidal phosphate was not analyzed for minor elements, there is every reason to believe that it contains such elements. Gaddum and Rogers (1936) in analyzing composite samples of colloidal phosphate for fourteen minor elements found thirteen definitely present and another possibly present.

Origin of Seedlings

Slash pine seed was collected from a vigorous, full-crowned, 12-inch slash pine on the Austin Cary Forest near Gainesville on September 26, 1943. The cones were dried at air temperature and the seed extracted from the cones within 2 weeks. A sufficient quantity of seeds weighing between 38.5 and 41.5 mg. each were weighed individually, stratified in moist acid peat moss, and refrigerated at 40°F. on October 26, 1943. On November 26 the seed was removed from the refrigerator and sown in germinating flats filled with the same soil that was used in the greenhouse pots. Germination was first evident on December 1, reached its peak on December 5, and was 92 percent complete by December 7. Seedlings that germinated after December 11 were discarded. The transferral of the seedlings from the germinating flats to the pots was made on December 31 and January 1.

Nutrient Solutions

On January 7, nutrient solutions were applied to the pots of all cultures except the checks and those in treatments 24 and 25. Wood ashes were applied to the pots in the latter treatments on January 10. Those cultures requiring more than one application of nutrients were treated on February 17, March 30, and May 11[9].

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9. The interval between the application of nutrients in those treatments receiving more than one application was 6 weeks. It was the original plan to harvest the trees 6 weeks after the fourth application of nutrients (June 22), but the abnormal growth, in consequence of 100°F. temperatures in the greenhouse during May, made termination of the experiment on May 26 advisable.

Temperature and Length of Day

A thermograph was installed in the greenhouse on January 28, 4 weeks after the trees were transferred to the pots. A continuous record of temperature was maintained to the end of the experiment. Mean weekly temperatures were computed as averages of the hourly temperatures during the week. The mean temperatures shown in Table 86 (Appendix) for the first 4 weeks are only approximate. They were computed after comparing the outdoor temperatures of a nearby weather station maintained by the Agricultural Experiment Station with greenhouse temperatures of days having typical temperature patterns for that time of year. Length of day, shown in Table 86, was compiled from local daily weather maps of the Weather Bureau. The length of day record shows one aspect of light condition- duration of light. Record of light intensity and quality was not kept.

Reference will be made to Table 86 later in describing certain differences in plant behavior in the 1943-44 and 1944-45 greenhouse experiments.

Experiment I

Soil Treatments

The nature of each soil treatment is shown in Table 9

Table 9. --Nutrient treatments used in Experiment I, 1943-44

Treatment		Nutrients applied January 7		
		N	P_2O_5	K_2O
Number	Designation	Pounds per acre		
7	Check	0	0	0
8*	60NP	60	60	0
9	60NK	60	0	60
10	60PK	0	60	60
11	60N	60	0	0
12	60P	0	60	0
13	60K	0	0	60
14	60NPK	60	60	60

*Treatments 8 to 14 are also referred to in the manuscript as nitrogen-phosphorous, nitrogen-potassium, phosphorous-potassium, nitrogen, phosphorous, potassium, and nitrogen-phosphorous-potassium, respectively.

Length of Stem

The average length of stem of the trees in each treatment in Experiment I after different periods of time is shown in Table 10.

Table 10. --Mean length of stem 6, 12, 18, and 19½ weeks after initial treatment, Experiment I, 1943-44

Treatment	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	19½ weeks
	Length of stem - mm.			
Check	9.4	60.7	175.7	230.1
60NP	10.4	53.6	129.9	173.7
60NK	10.2	54.2	138.6	184.3
60PK	16.2	82.7	211.6	263.2
60N	9.0	34.3	104.0	149.3
60P	10.8	77.7	200.6	254.5
60K	13.8	62.4	173.9	227.1
60NPK	11.5	59.1	164.8	219.9
Standard deviation	1.4	8.3	4.3	12.7
Difference between treatment means to be significant at 5 and 1 percent	4.0 5.5	24.3 33.1	12.7 17.3	36.9 50.3
F value treatment	3.02*	3.27*	70.3**	8.62**

*Significant at 5 percent.
**Significant at 1 percent.

The summary of the analysis of variance for stem length at 6 weeks is presented in Table 91 (Appendix), and the F values for 6, 12, 18, and 19½ weeks derived in the same manner as those in Table 91, are shown in Table 11. The F values show the extent to which the different nutrients

Table 11. --Summary of F values for stem length, Experiment I, 1943-44

Source	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	$19\frac{1}{2}$ weeks
	F values			
Within pots	0.18	0.005	1.66*	0.24
Replication	1.86	0.71	3.30	0.70
N	5.29*	12.64**	336.09**	48.36*
P	2.78	6.7*	87.77**	11.47**
K	9.93**	1.8	41.20**	5.95*
NP	0.09	0.28	0.73	0.00
NK	2.96	0.71	24.44**	4.51*
PK	0.04	0.17	1.14	0.41
NPK	0.07	0.58	1.03	0.00

*Significant at 5%.
**Significant at 1%.

affected the stem length of the trees.

Nitrogen was an influencing factor in the growth of the stem throughout the experiment, but its effect was not the same at all times. During the first 6 weeks, nitrogen increased stem growth significantly. However, the fact that at the end of 12 weeks, stem lengths of the trees in those cultures containing nitrogen were very significantly shorter than those of trees in cultures not containing nitrogen demonstrates that the depressing effect of the nutrient during the second 6 weeks must have been appreciable to change its effect from siginificantly favorable after 6 weeks to very significantly unfavorable after 12 weeks.

Phosphorous was slow to exert an influence on stem length. At the end of 6 weeks it had produced no significant effect, but at 12 weeks it had produced a significant inrrease, and at 18 and $19\frac{1}{2}$ weeks, a very significantly favorable effect (Fig. 1).

The action of potassium was similar to that of nitrogen. It stimulated growth significantly during the first 6 weeks. Its effect was not evident at 12 weeks; but at 18 weeks, potassium had caused a very significant depression of stem length; and at $19\frac{1}{2}$ weeks its depressing effect was significant.

Comparisons of mean stem lengths of trees from each treatment with those from every other treatment are presented in Table 12. At the end of 6 weeks, the trees from the phosphorous treatment were significantly superior in stem length to those from six of the other seven treatments. (Figs. 1 and 2), while seedlings from the potassium treatment were superior to those from two treatments. Seedlings grown in the phosphorous-potassium culture maintained their advantage over those grown in three treatments- the nitrogen-phosphorous, the nitrogen-potassium, and the nitrogen- all of which contained nitrogen, and lost their advantage over the phosphorous treatment by the twelfth week, never to regain it. The plants grown in the phosphorous-potassium culture did not show a consistent relationship to those grown in the check nor to those in the potassium culture, both of which they surpassed only after 6 and 18 weeks. Seedlings from this treatment maintained their advantage over those from the nitrogen treatment, but had lost their superiority over those from the check by the twelfth week, never to regain it.

Trees in the phosphorous culture began to show to advantage at the end of 12 weeks, when they were superior to those in the nitrogen-phosphorous and nitrogen cultures. After 18 weeks these seedlihgs were superior to those in six of the other seven treatments and maintained advantage over those in three, the nitrogen-potassium, nitrogen-phosphorous, and nitrogen treatments to the end of the experiment. It should be noted

Table 12. --Comparison of mean stem lengths of trees at different times after initial treatment in Experiment I, 1943-44

Treatment	Time after initial treatment							
	6 weeks		12 weeks		18 weeks		19½ weeks	
	Treatments superior to treatments in column 1							
	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%
Check	60K	60PK				60PK, 60P		
60NP		60PK	60PK, 60P			Check, 60K, 60P 60PK, 60NPK	60NPK	Check, 60PK, 60P 60K
60NK		60PK	60PK			Check, 60PK, 60P 60K, 60NPK	60K	Check, 60PK, 60P
60PK								
60N	60K	60PK	Check, 60K 60NPK	60PK, 60P		Check, 60NP, 60NK 60PK, 60P, 60K, 60NPK		Check, 60PK, 60P 60K, 60NPK
60P		60PK						
60K						60PK, 60P		
60NPK	60PK					60PK, 60P		60PK

that the three latter treatments contain nitrogen.

The behavior of the trees in the phosphorous-potassium, phosphorous, and potassium cultures indicates that potassium exerts an early stimulating effect on stem growth which is not maintained; that phosphorous is slow to affect stem growth, but once it does, the effect is fairly well sustained; that phosphorous combined with potassium produces early effects which are fairly well sustained. Possibly in the case of this combination, growth is at first stimulated by the potassium, and is later sustained by the phosphorous.

None of the three treatments- 60NP, 60NK, and 60N- which ultimately were inferior in their effect on stem growth to a majority of the other treatments exhibited noticeably this inferiority during the first 6 weeks. Only the 60PK treatment, which was superior to all but one treatment after 6 weeks was superior to the afore-mentioned cultures. The trees in the potassium culture were superior to those in the nitrogen and check cultures. It is noteworthy that at the end of the experiment the trees grown in the nitrogen-phosphorous-potassium culture were significantly superior to those grown in the nitrogen-phosphorous and the nitrogen cultures and lacked 1.3 mm. out of a needed 36.9 mm. (3.5%) in stem length of being significantly superior to those grown in the nitrogen-potassium culture. (Figs. 1 and 2). These facts suggest that nitrogen as a single application of 60 pounds per acre cannot be used alone or in combination with potassium or phosphorous in a single application at this rate to increase stem growth. Actually growth is depressed by such treatments. On the other hand when nitrogen, phosphorous, and potassium are used in combination, growth can be maintained, but not increased.

Trees in none of the treatments were significantly superior to those in the check at the end of the experiment, although the seedlings in both the phosphorous-potassium and the phosphorous treatments, which were significantly superior after 18 weeks, were nearly so at the end.

Branch Development

Data on branch development fall into two categories: (1) number of trees that produce branches, and (2) number of branches per tree. During the first $12\frac{1}{2}$ weeks, observations were limited to the first category, thereafter the second class of observation, which can be used as basis for (1) also, was made.

The data on number of branched trees was expressed, for the purpose of the analysis of variance, in terms of number of branched trees per pot. The data were then converted, for the purpose of presentation, into percentage of branched trees. Differences needed for significance were converted to the same basis.

The number of branched trees in each treatment after different periods of time is presented in Table 13. The proportion of branched trees had a range between the highest and lowest of 35.0 percent at the end of 8 weeks and a range of 45.0 percent at the end of $19\frac{1}{2}$ weeks.

The F values, presented in Table 14, show that significant differences in number of branched trees at various times were caused by phosphorous and potassium, by the interaction between nitrogen and potassium, and by the interaction between nitrogen, potassium, and phosphorous. Phosphorous caused very significant differences from the eighth to the twelfth week. Its influence was not evident at $16\frac{1}{2}$ weeks, but had reappeared at 19 weeks when it produced significant effects. Evidently the chief effect of phosphorous was to stimulate early branching. The effect of potassium was similar to that of

Table 13. --Number of branched trees after different periods of time, Experiment I, 1943-44

Treatment	Time after initial treatment				
	8 weeks	10 weeks	12 weeks	16½ weeks	19½ weeks
	Trees branched - percent of total				
Check	7.5	10.0	12.5	35.0	35.0
60NP	12.5	12.5	12.5	22.5	30.0
60NK	17.5	17.5	22.5	45.0	45.0
60PK	37.5	37.5	37.5	50.0	52.5
60N	12.5	12.5	12.5	27.5	30.0
60P	27.5	27.5	42.5	75.0	75.0
60K	15.0	15.0	17.5	45.0	47.5
60NPK	42.5	47.5	52.5	65.0	65.0
Standard deviation	6.2	6.2	7.0	12.2	8.6
Difference between treatment means to be significant at 5 and 1 percent	18.3 24.9	18.3 24.9	20.0 27.5	35.6 48.4	24.1 32.8
F value treatment	4.17**	4.87*	5.12**	2.51*	3.42*

*Significant at 1 percent.
**Significant at 5 percent.

Table 14. --F values for number of branched trees at different times after initial treatment, Experiment I, 1943-44

Source	Time after initial treatment				
	8 weeks	10 weeks	12 weeks	16½ weeks	19½ weeks
	F values				
Replication	1.13	1.12	.55	.03	.05
N	0.0	0.0	.26	1.71	2.51
P	14.52**	15.91**	16.50**	3.05	6.61*
K	8.79**	9.81**	6.44*	1.71	2.51
NP	.95	.32	1.03	.76	.97
NK	.95	2.01	6.44*	4.77*	5.96*
PK	2.42	3.96	1.03	.08	.34
NPK	1.59	2.01	4.12	3.05	5.73 *

*F value of 4.32 is significant of 5%.
**F value of 8.02 is significant of 1%.

phosphorous, but was not so pronounced. It increased the number of branched trees very significantly at 8 and 10 weeks and significantly at 12 weeks. Thereafter its effect was not significant. The effect of the interaction of nitrogen and potassium did not show up significantly until the twelfth week. This effect, which was to increase the number of branched trees, was maintained to the end of the experiment. The interaction of nitrogen, phosphorous, and potassium gave indications of being the cause of differences in number of branched trees by the twelfth week, but was not demonstrated to be significant until the nineteenth week, when it had reduced the number of branched trees.

Table 15 compares the number of branched trees produced by the various treatments at different intervals of time after the initial treatment. Of special interest is the fact that no treatment was at any time significantly superior to the 60P and 60NPK treatments in number of branched trees, and only these two treatments were significantly superior to the 60PK treatment at the end of the experiment (Fig. 1). The phosphorous-potassium and nitrogen-phosphorous-potassium cultures showed significant superiority over several treatments early. The former lost this advantage late in the experiment, but the latter did not. In contrast, the phosphorous treatment, except for an early significant superiority over the check, did not produce a significant effect on number of branched trees until the twelfth week, and thereafter held this advantage rather consistently.

It is noteworthy, that only the nitrogen-phosphoraus and the nitrogen treatments produced a smaller proportion of branched trees than the check and the differences were far too small to be significant.

Table 15. --Comparison of number of trees branched at different times after initial treatment in Experiment I, 1943-44

Treatment	Time after initial treatment: 8 weeks — Treatments significantly superior to treatments in column 1, at 5%	8 weeks, at 1%	10 weeks, at 5%	10 weeks, at 1%	12 weeks, at 5%	12 weeks, at 1%	16½ weeks, at 5%	16½ weeks, at 1%	19 weeks, at 5%	19 weeks, at 1%
Check	60P	60P 60NPK		60PK 60NPK	60PK	60P 60NPK	60P		60NPK	60P
60NP		60PK 60NPK		60PK 60NPK	60PK	60P 60NPK	60NPK	60P		
60NK	60PK	60NPK	60PK	60NPK	60P	60NPK			60P	
60PK										60P, 60NPK
60N		60PK 60NPK		60PK 60NPK	60PK	60P 60NPK	60P 60NPK			60P 60NPK
60P										
60K	60PK	60NPK	60PK	60NPK	60PK 60P	60NPK				
60NPK										

Number of branches per tree is presented in Table 16. The 60P and 60NPK treatments produced the greatest number of branches per tree and the 60NP and 60N cultures the smallest number. These treatments held the same relative position throughout the experiment, with the exception of the two latter treatments at the end of $12\frac{1}{2}$ weeks, when the difference between the two was inconsequential. The check, 60NK, 60P, 60K, and 60NPK treatments produced marked increases in number of branches per tree between $12\frac{1}{2}$ and $16\frac{1}{2}$ weeks, after which there was little change in number of branches. The 60NP, 60PK, and 60N cultures produced only small gradual changes in number of branches per tree.

The F values in Table 17 show that nitrogen was responsible for significant differences in the number of branches per tree; its effect was to reduce the number of branches. Phosphorous was responsible for very significant differences in number of branches at $12\frac{1}{2}$ weeks but not thereafter; its effect was to increase the number of branches. The interaction between nitrogen and potassium produced significant differences in number of branches at the start, and very significant differences later. Through the experiment this interaction increased branching.

Table 16. --Mean number of branches per tree after different time intervals, Experiment I, 1943-44

Treatment	Time after initial treatment		
	12 weeks	16½ weeks	19 weeks
	Branches per tree - number		
Check	0.15	1.20	1.20
60NP	0.13	0.38	0.55
60NK	0.40	1.15	1.17
60PK	0.63	0.93	0.95
60N	0.15	0.30	0.33
60P	0.80	2.25	2.30
60K	0.23	1.05	1.12
60NPK	0.80	1.60	1.75
Standard deviation	0.18	0.32	0.31
Difference between treatment means to be significant at 5 and 1 percent	0.53 0.72	0.94 1.28	0.91 1.24
F value treatment	4.21**	3.80**	4.00**

**Significant at 1 percent.

Table 17. --F values for number of branches per tree at various time intervals, Experiment I, 1943-44

Source	12 weeks	$16\frac{1}{2}$ weeks	19 weeks
	F values		
Within pots	0.54	0.49	0.62
Replication	1.26	0.37	0.33
N	0.85	5.13	4.42*
P	9.39**	2.22	3.30
K	1.72	0.59	0.54
NP	2.57	0.11	0.05
NK	5.22*	14.55**	15.37**
PK	0.00	0.88	1.04
NPK	2.57	3.12	3.30

*F value at 5% is 4.32.
**F value at 1% is 8.02.

In Table 18 the comparison of treatments shows that two treatments- the 60PK and 60P- stand out as superior. These treatments were at no time inferior to any of the others. Although they produced significantly more branches per tree than the check, 60NP, 60N, and 60K treatments at the end of $12\frac{1}{2}$ weeks, the 60NPK treatment gradually lost its advantage over some of them. At the end of the experiment the nitrogen-phosphorous-potassium treatment was significantly better than the nitrogen-phosphorous treatment and very significantly superior to the nitrogen culture.

From the standpoints of number of branched trees and number of branches per tree, the nitrogen-phosphorous and nitrogen treatments gave the poorest results and the phosphorous and nitrogen-phorphorous-potassium treatments gave the best results (Fig. 1). The experimental error is too large to attach any significance to the depressing effects of the 60NP and 60N treatments, nevertheless, an application of 60 pounds per acre of N and P_2O_5 or of N alone can not be expected to encourage branching.

Stem Diameter

The mean diameters of the stems of trees from each treatment and a comparison of the diameters is presented in Table 19. Diameters range from 2.85 mm. in the 60N treatment to 3.68 mm. in the 60P treatment, the latter being 29 percent larger than the former. Four cultures- 60NK, 60PK, 60P and 60NPK- produced trees with larger diameters than the check, and three cultures- 60NP, 60N, and 60K- produced trees with smaller diameters than the check.

Table 18. --Comparison of number of branches per tree at different intervals, Experiment I, 1943-44

Treatment	Time after initial treatment: 12 weeks — Treatments significantly superior to treatments in column 1 at 5%	12 weeks at 1%	16½ weeks at 5%	16½ weeks at 1%	19 weeks at 5%	19 weeks at 1%
Check	60P,60NPK		60P		60P	
60NP	60P,60NPK		60NPK	60P	60NPK	60P
60NK			60P		60P	
60PK				60P		60P
60N	60P,60NPK			60P,60NPK		60NPK,60P
60P						
60K	60P,60NPK			60P		60P
60NPK						

The analysis of variance yielded F values of 8.69, 17.06, and 17.5 for the effect of nitrogen, phosphorous, and interaction between nitrogen and potassium, respectively. Since an F value of 8.02 demonstrates significant differences at 1 percent, it is evident that all of the above effects are very significant. Potassium with an F value of 3.40 came closest of any of the remaining factors to producing significant effects (F value at 5 percent is 4.32). Nitrogen has a depressing effect, phosphorous a stimulating effect, and the interaction between nitrogen and potassium a stimulating effect on diameter.

The comparison of treatments in Table 19 emphasizes the superiority of the phosphorous treatment and the inferiority of the nitrogen treatment (Figs. 1 and 2). The nitrogen-phosphorous-potassium treatment was superior to the three poorest treatments- nitrogen-phosphorous, nitrogen, and potassium.

Table 19. --Mean diameter of stem and comparison of diameters by treatments, Experiment I, 1943-44

Treatment	Diameter-mm.	Treatments superior to treatments in column 1	
		at 5%*	at 1%**
Check	3.20		60P
60NP	3.10	60PK,60NPK	60P
60NK	3.29		60P
60PK	3.39		60P
60N	2.85	Check	60NK,60PK,60P,60NPK
60P	3.68		
60K	3.19	60NPK	60P
60NPK	3.46		
Standard deviation	0.08		
F value treatment	7.23		

*A minimum difference of 0,27 mm.
**A minimum difference of 0.37 mm.

Dry Weight of Shoot, Root, and Entire Tree and
Root-Shoot Ratio

Mean weight of shoots of the trees from the different cultures and a comparison of shoot weights are presented in Table 20. The 60N treatment with a mean shoot weight of 1.09 gr. produced the lightest shoots and the 60P treatment, with a mean of 2.17 gr. produced the heaviest shoots. The latter weighed nearly twice as much as the former. Four treatments- 60PK, 60P, 60K, and 60NPK- yielded shoots that were heavier and three treatments- 60NP, 60NK, and 60N- yielded shoots that were lighter than the check. Only the shoots from the phosphorous-potassium, and the phosphorous cultures were significantly heavier and only those from the nitrogen-phosphorous and nitrogen treatments were significantly lighter than those from the check.

The analysis of variance of tree shoots produced F values of 41.7, 25.6, 6.39, and 13.5 for nitrogen, phosphorous, potassium and interaction between nitrogen and potassium respectively. This means that the differences in shoot weight produced by potassium were significant and the others were very significant. Nitrogen reduces shoot weight, as does potassium, phosphorous increases shoot weight, and the interaction of nitrogen and potassium increases shoot weight.

The 60N treatment is the poorest, followed in order by the 60NP and 60NK treatments. The 60PK and 60P treatments, with no significant difference between them, were the best. The 60NPK culture was surpassed only by the latter.

Mean weight of roots of the trees from the various cultures and a comparison of root weights are presented in Table 21. The 60N and 60P treatments hold the same relative positions in root weight, lowest and highest, respectively, as they do in shoot weight. Roots from the latter

Table 20. --Mean weight of shoot and comparison of shoot weights by treatments, Experiment I, 1943-44

Treatment	Weight of shoot gr.	Treatments superior to treatments in column 1 at 5%*	at 1%**
Check	1.59	60PK	60P
60NP	1.22	Check,60K	60PK,60P,60NPK
60NK	1.41	60NPK	60PK,60P
60PK	1.98		
60N	1.09	60NK	Check,60PK,60P,60K,60NPK
60P	2.17		
60K	1.61	60PK	60P
60NPK	1.78	60P	
Standard deviation	0.10		
F value treatment	13.19		

*A minimum difference of 0.30 gr.
**A minimum difference of 0.39 gr.

weigh more than twice those from the former. The four treatments which produced heavier tops and the three treatments that produced lighter tops than the check likewise produced heavier and lighter roots, respectively, than the check. Differences between various treatments are not of the same magnitude, however.

The analysis of variance gave F values of 28.5, 9.0, and 5.5 for the effect of nitrogen, phosphorous, and interaction between nitrogen and potassium, values which demonstrate very significant differences caused by the first two and significant differences by the last. Potassium with an F value of 4.27 and interaction of nitrogen, phosphorous, and potassium with an F value of 3.8 were near enough to F values of significance (4.32 is necessary) to ascribe to them an influencing effect.

The effect of nitrogen is to reduce root weight, that of phosphorous to increase it, as is also the effect of the interaction of nitrogen and potassium. These effects are identical to those produced on shoot weight. In their effect on root weight, the phosphorous and nitrogen cultures stand out as the best and poorest, respectively. The 60PK, 60K, and 60NPK treatments are significantly better than the poorer treatments, especially the 60NP and 60N cultures.

Mean weight of entire tree, root-shoot ratio, and comparison of tree weights by treatments are presented in Table 22. The mean weights of the entire trees follow the same pattern in relation to treatments as the shoot and root weights which is logical in view of the similarity of relationships between the two latter factors. The significant effect of potassium, which is evident in shoot weights but not in root weights, is established in the weight of the entire tree.

Table 21. --Mean weight of root and comparison of root weights by treatments, Experiment I, 1943-44

Treatment	Weight of root-gr.	Treatments superior to treatments in column 1	
		at 5%*	at 1%**
Check	0.83		60P
60NP	0.67	60NPK	60PK, 60P, 60K
60NK	0.75	60PK, 60K	60P
60PK	0.98	60P	
60N	0.55	60P, 60K, 60NPK	Check, 60PK
60P	1.19		
60K	0.98	60P	
60NPK	0.91		60P
Standard deviation	0.07		
F value treatment	7.56		

*A minimum difference of o.21 gr.
**A minimum difference of 0.27 gr.

The F values for nitrogen, phosphorous, potassium, and interaction between nitrogen and potassium are 37.1, 18.3, 5.6, and 10.1, respectively. The three largest values are significant at 1 percent, and the smallest, at 5 percent. Nitrogen or potassium reduce total tree weights, phosphorous and interaction of nitrogen and potassium increase weight.

Table 22. --Mean weight of entire tree, root-shoot ratio, and comparison of tree weights by treatments, Experiment I, 1943-44

Treatment	Weight of entire tree gr.	Treatments superior to treatments in column 1 at 5%*	Treatments superior to treatments in column 1 at 1%*	Root-shoot ratio
Check	2.42	60PK	60P	0.52
60NP	1.89	Check	60PK, 60P 60K, 60NPK	0.55
60NK	2.16	60NPK	60PK, 60P	0.53
60PK	2.96			0.49
60N	1.64	60NK	Check, 60PK 60P, 60K, 60NPK	0.51
60P	3.36			0.55
60K	2.59		60P	0.61
60NPK	2.69			0.51
Standard deviation	0.17			0.04
F value treatment	10.93			0.73

*A minimum difference of 0.50 gr.
**A minimum difference of 0.68 gr.

The 60PK, 60P, and 60NPK treatments are inferior to none, and the 60PK and 60P cultures are significantly superior to the check.

An analysis of variance of root-shoot ratios reveals that no significant differences can be attributed to the effects of nutrients.

Summary of Results

This experiment demonstrates that response of young slash pine seedlings to single 60-pound-per-acre applications of N, P_2O_5 and K_2O in Norlolk sand, singly or in various combinations, differs widely. In general, nitrogen had a long-time depressing effect and phosphorous and potassium, a stimulating effect on the trees. However, the stimulating eeffect of the phosphorous treatment cannot be attributed to phosphorous alone since the source material that was used contained calcium, which may have been the cause of the response as much as or more than the phosphorous. The early response of the seedlings in stem growth to nitrogen and potassium was misleading so far as ultimate results were concerned. Although they stimulated growth during the first several weeks, the long-time effect was deterimental.

The general ineffectiveness of the seven nitrogen, phosphorous, and potassium treatments is illustrated by the fact that only one culture- the 60P- produced trees that were significantly superior in nearly all characteristics to those produced by the check. Only in stem length were the trees in the 60P culture not significantly superior to trees in the check culture. The 60PK cultures produced trees that were superior in shoot and total weight to those in the check culture. The 60NPK culture produced more branched trees than the check.

Nitrogen was most damaging, most of the tree features being harmed by it. Branching and root-shoot ratio were not affected. When phosphorous was used with nitrogen, some of the depressing effect of the latter was neutralized. This was particularly true of stem diameter and total weight. Potassium was even more effective in neutralizing the effect of nitrogen. When it was used with the latter, all characteristics of the trees in the culture were superior to those of trees in the nitrogen culture. When phosphorous and potassium were combined with nitrogen a still better-balanced tree was produced.

Potassium alone did not affect materially the type of tree produced, whereas phosphorous did, the latter being particularly effective in increasing branching, stem diameter, and weight of tree. When these two elements were combined in a culture the trees did not respond so well as in the phosphorous culture. The absence of calcium in the former treatment may have been a contributing factor to the lowered quality of the trees in the phosphorous-potassium culture.

It is evident from the above that nitrogen must be used sparingly in Norfolk sand when slash pine seedlings are young if their ultimate quality is not to be impaired. Phosphorous and potassium can be applied to the soil without harm to the seedlings at a rate of 60 pounds per acre of P_2O_5 and K_2O within 4 weeks after the seedlings have germinated. However, no appreciable improvement in the trees can be expected from any of the treatments employed in this experiment.

Experiment II

The check treatment of Experiment I is used in this experiment for comparative purposes only. The analyses of variance throughout the experiment are based on the six treatments designated to determine the effects on the trees of different quantities of nitrogen, phosphorous, and potassium applied at once at the beginning of the experiment as compared to the same quantities divided into four equal applications.

Soil Treatments

The nature of each soil treatment is shown in Table 23.

Table 23. --Type and time of nutrient application in Experiment II, 1943-44

Treatment		Date of nutrient application											
		January			February 17			March 10			May 11		
No.	Designation	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		Pounds per acre											
1*	60NPK	60	60	60	-	-	-	-	-	-	-	-	-
2	120NPK	120	120	120	-	-	-	-	-	-	-	-	-
3	180NPK	180	180	180	-	-	-	-	-	-	-	-	-
4	(4x)15NPK	15	15	15	15	15	15	15	15	15	15	15	15
5	(4x)30NPK	30	30	30	30	30	30	30	30	30	30	30	30
6	(4x)45NPK	45	45	45	45	45	45	45	45	45	45	45	45

*Treatments 1 to 3 are referred to also as single application and treatments 4 to 6 as split-spplication treatments. Treatment 7 of Experiment I is used for a comparison of trees in Experiment II with untreated (check) trees.

Table 24. --Mean length of stem 6, 12, 18, and $19\frac{1}{2}$ weeks after initial treatment, Experiment II, 1943-44

Treatment	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	$19\frac{1}{2}$ weeks
	Length of stem - mm.			
60NPK	11.8	56.3	150.5	203.8
120NPK	9.3	52.6	134.5	183.4
180NPK	8.7	54.5	145.5	188.5
(4x)15NPK	14.5	64.6	175.2	233.1
(4x)30NPK	12.6	65.5	165.9	211.6
(4x)45NPK	14.1	61.6	162.9	208.8
Check	9.4	60.7	175.7	230.1
Standard deviation	0.9	4.4	9.8	8.3
Difference between treatments means to be significant at 5 and 1 percent	2.8 3.9	13.5 18.6	29.6 41.0	27.1 37.5

Length of Stem

The average length of stem of the trees in each treatment in Experiment II after different periods of time is shown in Table 24. It is obvious that differences in stem length between the different treatments occurred throughout the period of measurement of the trees. The F values in Table 25 taken from the analysis of variance in Table 92 (Appendix) show that the significant differences (actually very significant) are due to method of treatment (split application versus single application) rather than rates or a combination of rates and methods. Similar analyses of variance for the other three dates, the F values for which appear in

Table 25, show very significant differences for methods on two dates, 12 and $19\frac{1}{2}$ weeks after the initial treatment, and a significant difference at 18 weeks. Only at $19\frac{1}{2}$ weeks was the difference due to rates nearly significant. At the rates at which the nutrients were used, namely, 60, 120, and 180 pounds per acre of N, P_2O_5, and K_2O, splitting the amount into four equal applications resulted in greater stem length than a single application.

Table 25. --Summary of statistical significance of length of stem in Experiment II, 1943-44

Source	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	$19\frac{1}{2}$ weeks
	F values			
Within pots	0.69	0.51	0.41	0.62
Replication	6.18**	3.91*	2.45	2.63
Methods	30.55**	7.37*	9.78**	12.38**
Rates	3.21	0.10	0.80	3.45
Methods x rates	1.63	0.19	0.15	2.74

*Significant.
**Very significant.

The extent of significant differences between the mean stem lengths of the trees from any two treatments is shown in Table 26. There were no significant differences between individual treatments 12 weeks after the initial treatment even though, as shown in Table 92, significant differences were caused by the method of applying nutrients. Throughout the experiment, trees in none of the single-application cultures were significantly superior to those in the split-application cultures, whereas seedlings in one or more of the latter treatments were significantly superior to those in the former treatments at the three observation dates shown. Only the 60NPK and (4x)15NPK treatments produced trees that were temporarily superior to those in the check treatment at the end of 6 weeks. Thereafter they had no advantage, and at the end of the experiment, trees in the (4x)30NPK treatment were actually significantly inferior to the untreated plants. Although the trees from the check culture held no significant superiority over the trees from the single-application treatment at the end of 6 and 12 weeks, they were significantly superior in stem length at the end of 18 and $19\frac{1}{2}$ weeks. Evidently the effect of the single-application treatments is cumulative. This is evident in Table 24 which shows the following relationships: (1) mean stem length of trees in the 120NPK and 180NPK treatments is greater, and that in the 60NPK treatment is less than that of the check treatment at the end of 6 weeks; (2) mean stem length of trees in all single-application treatments is less than the mean stem length of the check treatment at the end of 12 weeks. The afore-mentioned differences are not significant, however. At the end of 18 weeks, the differences which were in evidence after 12 weeks, had become significant. It is noteworthy that the trees in the 60NPK treatment which, at the end of 6 weeks, were significantly superior in stem length to those in the check treatment were later significantly inferior.

Although differences in rate of application produced no significant differences in stem length, it should be noted in Table 24 that the trees receiving the smaller rates (60NPK and (4x)15NPK) had longer stems than the trees receiving the larger rates (180NPK and (4x)45NPK) (Figs. 2 and 3).

Table 26. --Comparison of stem length at different periods of time after treatment in Experiment II, 1943-44

Treatment	Time after initial treatment: 6 weeks — Treatments superior to treatments in column 1 at 5%	at 1%	18 weeks — Treatments superior to treatments in column 1 at 5%	at 1%	$19\frac{1}{2}$ weeks — Treatments superior to treatments in column 1 at 5%	at 1%
60NPK	(4x)15NPK		Check		(4x)15NPK, Check	
120NPK	(4x)30NPK	(4x)15NPK (4x)45NPK	(4x)15NPK (4x)30NPK	Check	(4x)15NPK (4x)30NPK	Check
180NPK	60NPK	(4x)15NPK (4x)30NPK (4x)45)NPK	Check			(4x)15NPK Check
(4x)15NPK						
(4x)30NPK					Check	
(4x)45NPK						
Check	60NPK	(4x)15NPK				

Branch Development

Number of branched trees at 8, 10, 12, $16\frac{1}{2}$, and 19 weeks for trees in Experiment II and untreated trees is presented in Table 27. The 180NPK and check cultures which had produced relatively few branched trees at 8 weeks ranked lowest in this respect throughout the experiment. Increase in number of branched trees was gradual from the eighth to the twelfth week, but was marked between 12 and $16\frac{1}{2}$ weeks.

The F values derived from the analysis of variance for branched trees are presented in Table 28. Significant differences are caused only by method of application of nutrients, and they occur in the late stages of the experiment. However, during the early stages differences are not far from significant with F values of 4.10, 3.32, and 4.00 when 4.54 is required at 5 percent. Likewise, the effect of rates of application of nutrients at $16\frac{1}{2}$ and 19 weeks with F values of 3.10 and 3.20, respectively, is not far short of being significant, since an F value of 3.68 would demonstrate significance at 5 percent.

Four applications of nutrients produced branches on a significantly greater number of trees than did one application.

The 180NPK treatment had produced no more branched trees than the check after $16\frac{1}{2}$ weeks, and there was not a signiticant difference between the two treatments after 19 weeks. The former culture was surpassed at $16\frac{1}{2}$ and 19 weeks in number of branched trees by all other cultures receiving supplemental nutrients. The (4x)30NPK culture had produced significantly more branched trees than the 60NPK treatment; the 120NPK, (4x)15NPK, and (4x)45NPK treatments significantly more than the 180NPK treatment; and the (4x)30NPK treatment very significantly more than the 180NPK treatment after $16\frac{1}{2}$ weeks. At 19 weeks the same condition prevailed.

Table 27. --Number of branched trees on different dates, Experiment II, 1943-44

Treatement	8 weeks	10 weeks	12 weeks	$16\frac{1}{2}$ weeks	$19\frac{1}{2}$ weeks
	Trees branched - percent of total				
60NPK	32.5	35.0	35.0	52.5	55.0
120NPK	30.0	32.5	35.0	60.0	65.0
180NPK	10.0	15.0	22.5	35.0	37.5
(4x)15NPK	27.5	32.5	37.5	67.5	70.0
(4x)30NPK	45.0	47.5	50.0	80.0	82.5
(4x)45NPK	35.0	35.0	40.0	65.0	65.0
Check	7.5	10.0	12.5	35.0	35.0
Standard deviation	7.0	7.3	8.0	8.0	8.8
Difference between treatment means to be significant at 5	*	*	*	23.9	26.4
and 1 percent				33.0	36.5

*No significant differences.

Table 28. --F values for number of branched trees at different periods of time after initial treatments, Experiment II, 1943-44

Source	Time after initial treatment				
	8 weeks	10 weeks	12 weeks	16½ weeks	19½ weeks
	F values				
Replication	2.50	2.06	1.17	2.34	2.29
Method	4.10	3.32	4.00	11.20**	7.70*
Rate	2.25	2.10	1.30	3.10	3.20
Method x rate	2.32	1.29	0.60	0.60	0.29

*Significant.
**Very significant.

The mean number of branches per tree for each treatment in Experiment II 12½, 16½, and 19 weeks after the initial treatment is shown in Table 29.

The summary of F values presented in Table 30 shows that method of application of nutrients produced a very significant effect on the number of branches per tree at 16½ and 19 weeks, the split application being superior to a single application.

At 16½ weeks the split-application treatments are significantly superior to the 60NPK treatment, the (4x)30NPK treatment is significantly superior to the 120NPK treatment, and the 120NPK treatment is significantly superior to the 180NPK treatment. At 19 weeks the (4x)15NPK and (4x)45NPK treatments are significantly superior, and the (4x)30NPK treatment is very significantly superior to the 180NPK treatment; and the (4x)30NPK treatment is superior to the 60NPK and 120NPK treatments.

At no time are the differences between the single-application treatments and the check significant. The difference in number of branches

Table 29. --Number of branches per tree 12½, 16½, and 19 weeks after initial treatment, Experiment II, 1943-44

Treatment	12½ weeks	16½ weeks	19 weeks
	Branches per tree - number		
60NPK	0.68	1.35	1.45
120NPK	0.60	1.48	1.50
180NPK	0.48	0.58	0.75
(4x)15NPK	0.80	1.98	2.03
(4x)30NPK	1.10	2.43	2.55
(4x)45NPK	0.65	1.95	1.95
Check	0.15	1.20	1.20
Standard deviation	0.23	0.28	0.31
Difference between treatment means to be significant at 5 and 1 percent	0.70 0.95	0.85 1.18	0.93 1.29

Table 30. --F values from analysis of variance for number of branches per tree, Experiment II, 1943-44

Source	12½ weeks	16½ weeks	19 weeks	5%	1%
	F values				
Within pots	0.68	1.27	1.01		
Replication	0.34	3.04	2.97	3.29	
Methods	2.51	17.11**	14.31**	4.54	8.68
Rates	1.00	2.52	2.20	3.68	
Rates x methods	0.30	0.60	0.62	3.68	

**Very significant.

per tree between the (4x)30NPK and the check treatment is very siginificant throughout the experiment. The other two split-application treatments were not far short of producing significantly more branches per tree than the check culture throughout the experiment.

Diameter of Stem

Mean diameters of the trees at the end of the experiment for each treatment of Experiment II and treatment comparisons are presented in Table 31. An analysis of variance demonstrates a very significant effect of method of nutrient application, the F value being 16.08, while 8.68 is needed for significance at 1 percent. The effects of rates of application and of methods and rates combined were not significant. The split application of nutrients produced trees of larger diameters than the single alplication.

The (4x)45NPK treatment produced trees with very significantly larger diameters than all the single-application treatments, and the (4x)15NPK and the (4x)30NPK treatments produced trees with very significantly larger diameters than the 60NPK and the 120NPK treatments and significantly larger diameters than the 180NPK and (4x)15NPK treatments. The diameters of the trees in all split-application treatments and the 180NPK treatment were either significantly or very significantly larger than those of the check treatment.

Table 31. --Mean diameter of trees in different treatments and a comparison of diameters by treatments, Experiment II, 1943-44

Treatment	Diameter mm.	Treatments superior to treatments in column 1	
		at 5%	at 1%
60NPK	3.35		(4x)30NPK, (4x)45NPK
120NPK	3.34		(4x)30NPK, (4x)45NPK
180NPK	3.44	(4x)30NPK	(4x)45NPK
(4x)15NPK	3.46	(4x)30NPK	(4x)45NPK
(4x)30NPK	3.73		
(4x)45NPK	3.83		
Check	3.20	180NPK, (4x)15NPK	(4x)30NPK, (4x)45NPK
Standard deviation	0.08		
Difference between treatment means to be significant at 5 and 1 percent	0.24 0.33		

Dry Weight of Shoot, Root, and Entire Tree, and Root-Shoot Ratio

The mean dry weights of the shoot, root, and entire tree, and the root-shoot ratio of each treatment in Experiment II are presented in Table 32.

The F values derived from analyses of variance for each of the characteristics mentioned above are presented in Table 33. The method of applying the nutrients produced significant differences in the weight of the shoot and of the entire tree. The trees receiving four applications of nutrients were significantly heavier than those receiving one. Rate of applying nutrients produced significant differences in the weight of the roots, the lighter applications producing trees with heavier roots than the heaviest application. Rate of application produced almost significant effects on root-shoot ratio.

The (4x)30NPK culture which produced shoots 0.39 and 0.42 gr. heavier than the 60NPK and 120NPK treatments, respectively, was significantly superior to the latter treatments. It was very significantly superior in shoot weight and total plant weight to the check.

Trees produced by the 60NPK culture had significantly heavier roots than those produced by the 120NPK and (4x)45NPK treatments, and very significantly heavier roots than those produced by the 180NPK treatment; trees produced by the (4x)30NPK treatment had very significantly heavier roots than those produced by the 180NPK treatment; and trees produced by the (4x)30NPK treatment had significantly heavier roots than those produced by the (4x)45NPK treatment. Only the 60NPK and (4x)30NPK treatments produced trees with heavier roots than the check culture.

Table 32. --Dry weight of shoot, root, and entire tree, and root-shoot ratio for Experiment II, 1943-44

Treatment	Shoot	Root	Total	Root-shoot ratio
	Weight - gr.			
60NPK	1.65	1.04	2.69	0.63
120NPK	1.62	0.83	2.45	0.51
180NPK	1.67	0.72	2.39	0.43
(4x)15NPK	1.83	0.89	2.72	0.49
(4x)30NPK	2.04	1.03	3.07	0.50
(4x)45NPK	1.95	0.79	2.74	0.41
Check	1.59	0.83	2.42	0.52
Standard deviation	0.13	0.06	0.19	0.15
Difference between treatment means to be significant at 5 and 1 percent	0.38 0.53	0.21 0.29	0.58 0.80	

Table 33. --F values for weight of shoot, root, entire tree, and root-shoot ratio for Experiment II, 1943-44

Source	F values					
	Shoot	Root	Entire tree	Root-shoot ratio	5%	1%
Within pots	0.35	0.30	0.32	0.17		
Replication	0.89	4.60*	0.83	5.83**	3.29	5.42
Method	8.59*	0.67	4.89*	3.05	4.54	8.68
Rate	0.28	4.46*	0.46	3.61	3.68	6.36
Method x rate	0.48	2.55	1.18	0.42	3.68	6.36

*Significant.
**Very significant.

Summary of Results

Split-application treatments, in which the nutrients were applied in four equal amounts, produced better trees than single-application treatments, in which the nutrients were applied about four weeks after the seedlings had germinated (Figs. 2 and 3). Single-application cultures produced trees that, in most features, were not significantly different from trees produced by the check treatment. Stem length was affected adversely to a greater extent than other characteristics, the 120NPK and 180NPK treatments producing trees that had significantly shorter stems than those produced in the check culture. The 180NPK culture did produce trees with significantly larger diameters than the check culture. However, the (4x)30NPK and (4x)45NPK cultures produced trees with very significantly larger diameters than the check culture. Trees from the former treatment were significantly superior to those from the check culture in branching, diameter, and weight; and they were the equal of those from the latter in stem length and root-shoot ratio.

This experiment demonstrates that young slash pine seedlings respond more favorably to supplements of nitrogen, phosphorous, and potassium when a given amount of these nutrients is added to the soil in four equal installments at intervals of 6 weeks than when added in one application 4 weeks after the trees have germinated. Thirty-pound applications of each of the three elements gave greater response than 15- or 45-pound applications.

Experiment III

Soil Treatment

The character of each soil treatment is shown in Table 34.

Table 34. --Type and time of nutrient application in Experiment III, 1943-44

Treatment		In advance of planting		Time of nutrient application															
				January 7				February 17				March 30				May 11			
No.	Designation	Colloidal phosphate	Peat moss	N	P_2O_5	K_2O	Wood ashes*	N	P_2O_5	K_2O	Wood ashes*	N	P_2O_5	K_2O	Wood ashes*	N	P_2O_5	K_2O	Wood ashes*
		Tons per acre		Pounds per acre															
15	Check	-	-	-	-	-	-	-	-	-			-	-	-	-	-	-	-
16	20 C. P	20	-	-	-	-	-	-	-	-			-	-	-	-	-	-	-
17	20 C.P.+(4x)15NK	20	-	15	-	15	-	15	-	15	-	15	-	15	-	15	-	15	-
18	20 C.P.+(4x)15N	20	-	15	-	-	-	15	-	-	-	15	-	-	-	15	-	-	-
19	10 Peat	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	10 Peat+(4x)15NPK	-	10	15	15	15	-	15	15	15	-	15	15	15	-	15	15	15	-
21	10 Peat 20 C.P.	20	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	10 Peat 20 C.P.+ (4x)15NK	20	10	15	-	15	-	15	-	15	-	15	-	15	-	15	-	15	-
23	(4x)15N30P75K	-	-	15	30	75	-	15	30	75	-	15	30	75	-	15	30	75	-
24	352 Wood ashes	-	-	-	-	-	44	-	-	-	44	-	-	-	132	-	-	-	132
25	1320 Wood ashes	-	-	-	-	-	132	-	-	-	132	-	-	-	528	-	-	-	528

*The wood ashes derived from turkey oak and blue jack oak was analyzed by the Soils Department, Agricultural Experiment Station, University of Florida. Its composition was $CaCO_3$ equivalent 77.5 percent; P_2O_5, 1.40%; K_2O, 1.64%; lithium, caesium, chromium, vanadium, silver, tin, each $<$.001%; nickel and zinc, each .003-.008 percent; zirconium, .005-.01%; copper, .008- .03%; titanium, .01- .05%; boron, .03- .08%; rubidium, .03- .09%; strontium, barium, iron, manganese, and alumnum, each $>$ .1%.

Length of Stem

The average length of stem of the trees in each treatment of Experiment III at different periods of time after the initial treatment is presented in Table 35.

Table 93 (Appendix) shows how the analysis of variance of stem length was handled for measurements taken at the end of 6 weeks, and Table 36 gives the F values derived from the analyses of variance calculated at the end of 12, 18, and 19½ weeks. Very significant differences in stem length are attributable to soil treatments on each observation date. A comparison of culturesis made in Table 37.

Several facts worthy of note are revealed in Table 37. During the first 18 weeks none of the cultures produced trees that were inferior in stem length to the check treatment. However, at the end of the experiment, the trees in the (4x)15N30P75K treatment (high potash) were inferior to the untreated trees. It should be noted that at the end of 6 weeks, the seedlings in the former culture were superior to the latter. Evidently the (4x)15N30P75K treatment is not satisfactory from the standpoint of sustained growth of the stem. Whereas, only in the instance just noted, was a treatment inferior to the check, it is likewise noteworthy that only a few treatments produced trees with longer stems than the check. At the end of six weeks five treatments- 20C.P.+(4x)15NK, 20C.P.+(4x)15N, 10 Peat, 10 Peat 20 C.P. +(4x)15NK and (4x)14N30P75K- had produced trees with longer stems than the check (Figs. 5 and 6). At the end of the experiment only the treatments containing colloidal phosphate plus nitrogen or nitrogen and potassium were in this category. However, the trees in cultures containing colloidal phosphate and colloidal phosphate, peat, nitrogen and potassium were only 2 mm. short of being significantly superior to those in the check. With

Table 35. --Mean length of stem at different periods of time after initial treatment, Experiment III, 1943-44

Treatment	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	$19\frac{1}{2}$ weeks
	Length of stem - mm.			
Check	10.1	66.9	185.4	237.2
20 C. P.	12.2	85.0	210.9	263.1
20 C. P. + (4x)15NK	15.3	89.5	230.2	282.2
20 C.P.+(4x)15N	16.0	89.7	224.2	274.5
10 Peat	16.4	89.6	171.8	221.7
10 Peat + (4x)15NPK	13.9	70.3	179.5	230.3
10 Peat 20 C. P.	10.2	82.9	199.7	248.1
10 Peat 20 C. P. +(4x)15NK	16.9	96.8	216.9	263.4
(4x)15N30P75K	14.6	67.8	158.4	207.8
352 Wood ashes	8.8	63.3	181.8	232.1
1320 Wood ashes	11.0	70.9	192.2	246.9
Standard deviation	1.31	5.74	9.6	10.1
Difference be-rween treatment meansto be signi-ficant at 5 and	3.8	16.6	27.6	29.2
1 percent	5.1	22.3	37.3	39.3
F value treatment	4.35**	4.13**	5.80**	5.11**

**Significant at 1 percent.

Table 36. --F values from analysis of variance of stem length 12, 18, and 19½ weeks after initial treatment, Experiment III, 1943-44

Source	Time after initial treatment			
	6 weeks	12 weeks	18 weeks	19½ weeks
	F values			
Within jars	0.38	0.26	0.68	0.39
Replication	1.53	2.25	2.33	2.12
Treatment	4.35**	4.13**	5.80**	5.11**

**Very significant.

the exception of the 10 Peat+(4x)15NPK and (4x)15N30P75K treatments, which had an advantage over the check only at the end of 6 weeks, the cultures which produced trees superior in stem length to the check treatment contained colloidal phosphate. Although at the end of 6 weeks, the culture containing colloidal phosphate alone was inferior to the culture containing colloidal phosphate plus nitrogen and the treatment containing colloidal phosphate, peat moss, nitrogen, and potassium, this inferiority was of short duration since at all later dates no treatments were superior to it. Although there are small differences in the stem lengths of the trees in the three colloidal phosphate cultures, the differences are not significant. In other words, colloidal phosphate alone was about as effective in stimulating stem growth as when it was supplemented by nitrogen or nitrogen and potassium. The addition of peat moss to colloidal phosphate with or without nitrogen and potash did not increase the effectiveness of the colloidal phosphate.

Peat moss alone did not affect stem growth, and peat moss plus nitrogen, phosphorous, and potassium influenced growth only temporarily as shown by the superiority of the 10 Peat+(4x)15NPK treatment over the check treatment at the end of 6 weeks.

Wood ashes did not stimulate stem growth. As shown in Table 37, these treatments were at no time superior to the check.

Branch Development

The number of branched trees is expressed as a percentage of total trees in Table 38. The analysis of variance was computed on the basis of numbers of branched trees per pot. Soil treatment produced very significant differences in the number of branched trees between the eighth and twelfth week.

Table 37. --Comparison of stem length, 6, 12, 18, and $19\frac{1}{2}$ weeks after initial treatment

Treatment		Time after initial treatment							
		6 weeks		12 weeks		18 weeks		$19\frac{1}{2}$ weeks	
		Treatments superior to treatments in column 1							
No.	Designation	at 5%	at 1%	at 5%	at 1%	at %5	at 1%	at 5%	at 1%
15	Check	20,23	17,18,22	16	17,18,22	22	17,18	18	17
16	20 C. P.	18,22							
17	20 C. P. + (4x)15NK								
18	20 C. P. + (4x)15N								
19	10 Peat	17,23	18,22	16,17,18	22	21	16,17,18,22		16,17,18,22
20	10 Peat + (4x)15NPK			17,18	22	16	17,18,22	16,22	17,18
21	10 Peat 20 C.P.	23	17,18,22			17		17	
22	10 Peat 20 C.P. +(4x)15NK								
23	(4x)15N30P75K			16,17,18	22	25	16,17,18,21,22	15,25	16,17,18,21,22
24	352 Wood ashes		17,18,22,23	16,21	17,18,22	16,22	17,18	16,22	17,18
25	1320 Wood ashes	17,18	22	17,18	22	18	17	17	

Table 38. --Number of trees branched after different periods of time, Experiment III, 1943-44

Treatment	Time after initial treatment: 8 weeks	10 weeks	12 weeks	$16\frac{1}{2}$ weeks	$19\frac{1}{2}$ weeks
	Trees branched - percent of total				
Check	5.0	15.0	17.5	42.5	42.5
20 C. P.	12.5	30.0	42.5	57.5	57.5
20 C. P. + (4x)15NK	50.0	50.0	60.0	77.5	77.5
20 C. P. + (4x)N	62.5	62.5	62.5	67.5	67.5
10 Peat	12.5	20.0	25.0	70.0	70.0
10 Peat + (4x)15NPK	52.5	52.5	62.5	80.0	80.0
10 Peat + 20 C. P.	32.5	35.0	42.5	55.0	55.0
10 Peat 20 C. P. + (4x)15NK	55.0	55.0	60.0	75.0	75.0
(4x)15N 30P75K	45.0	45.0	47.5	75.0	75.0
352 Wood ashes	5.0	10.0	22.5	67.5	67.5
1320 Wood ashes	2.5	5.0	17.5	55.0	55.0
Standard deviation	3.0	3.0	2.9	3.5	3.5
Difference between treatment means to be significant at 5 and 1 percent	27.6 37.1	27.6 37.1	26.3 35.5		
F value treatment	5.53**	4.35**	4.49**	1.12	1.12

**Significant at 1 percent.

Table 39. --Comparison of number of branched trees at various periods of time after initial treatment, Experiment III, 1943-44

Treatment		Time after initial treatment					
		8 weeks		10 weeks		12 weeks	
		Treatments superior to treatments in column 1					
No.	Designation	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%
15	Check	21	17,18,20,22,23	17,23	18,20,22	23	17,18,20,22
16	20 C. P.	23	17,18,20,22	18			
17	20 C.P.+(4x)15NK						
18	20 C.P.+(4x)15N						
19	10 Peat	23	18,20,22	17	18,20,22		17,18,20,22
20	10 Peat+(4x)15NPK						
21	10 Peat 10 C. P.	18		18			
22	10 Peat 20 C. P. + (4x)15NK						
23	(4x)15N30P75K						
24	352 Wood ashes	21	17,18,20,22,23		17,18,20,21,22,23		17,18,20,22
25	1320 Wood ashes	21	17,18,20,22,23		17,18,19,20,21,22,23		17,18,20,22,23

The fact that no significant difference in the number of branched trees existed after 12 weeks demonstrates that the chief effect of the treatments that affected branching was to encourage early branching. It should be noted that, in the culture containing colloidal phosphate and nitrogen, no more trees were branched at the end of twelve weeks than at the end of eight weeks; and at the end of $19\frac{1}{2}$ weeks, the number was only slightly greater than at 8 weeks. A similar trend is evident in the 20 C. P. +(4x)15NK, 10 Peat +(4x)15NPK, 10 Peat 20 C. P. +(4x)15NK, and (4x)15N30P75K cultures all of which caused extensive early branching. In the check, peat, and wood ashes treatments where branches were particularly slow to develop, a marked increase in number of branched trees occurred between 12 weeks and $16\frac{1}{2}$ weeks.

Table 39 shows between which treatments significant differences in number of branched trees occurred at 8, 10, and 12 weeks after the initial treatment. The pattern of differences is similar to that which was found in stem length up to 12 weeks after the initial treatment. Thereafter, however, there is no similarity. In general, differences in stem length which were exhibited in the early part of the experiment still existed when the trees were harvested. This was not so with respect to branching. Although no treatments were inferior to the check in the number of branched trees, only five treatments- 20 C. P. +(4x)15NK, 20 C. P. +(4x)15N, 10 Peat +(4x)15NPK, 10 Peat 20 C. P. +(4x)15NK and (4x)15N30P75K- were significantly superior to the check from the eighth to the twelfth week, and one treatment- 10 Peat 20 C. P.- was superior only at the end of 8 weeks. The three colloidal phosphate treatments which contained also nitrogen or nitrogen and potassium again stand out; but two treatments- 10 Peat +(4x)15NPK and (4x)15N30P75K- which did not increase stem growth, did stimulate branch development (Fig. 5). It should be noted that the culture in which peat was supplemented by readily available nitrogen, phosphorous, and potassium encouraged early branching, whereas the culture to which only peat was added did not. From this, it appears as though the readily available nutrients rather than the peat moss were responsible for the increase in early branching. The (4x)15N30P75K culture (rather heavy applications of K_2O and P_2O_5) did not produce significantly more branched trees than the colloidal phosphate treatments to which smaller amounts of readily available nitrogen or nitrogen and potassium had been added.

The wood-ash treatments did not affect branching significantly. Although significant differences in number of branched trees do not exist between the check and any of the other treatments at the end of the experiment, Table 38 shows that all treatments exceeded the check in number of branched trees at that time.

Number of branches per tree, recoœded for the first time at the end of 13 weeks, is shown for this and later dates in Table 40. Although considerable differences in the number of branches per tree is evident, the analyses of variance reveal that only at the thirteenth week are these differences significant. Later the standard error of the mean is so large (0.45 in each case) that wide differences- larger than those existing- are necessary to demonstrate significant differences in the means. In this connection it should be noted that number of branched trees showed no significant differences between treatments on the dates of the last two observations.

A comparison of each treatment with every other treatment in the number of branches per tree is presented in Table 41. A comparison of the data in this table with those in Table 39 reveals only minor differences between the two. A majority of the differences in number of branches per tree are at the 5 percent level, whereas all but one of the differences in number of branched trees are at the 1 percent level. The (4x)15N30P75K culture which had produced significantly more trees with branches than the check and 1320 wood ashes treatments at the end of 12 weeks did not yield trees with more branches per tree at the end of 13 weeks. The 10 Peat treatment, which was inferior to several treatments in number of branched trees after twelve weeks was inferior only to the 10 Peat 20 C. P. +(4x)15NK treatment in number of branches per tree after 13 weeks.

The 20 C. P. +(4x)15NK, 10 Peat +(4x)15NPK, and (4x)15N30P75K cultures produced the greatest number of branches per tree. The number was noticeably greater than that of the check, but the differences were not significant.

Stem diameters of the trees in each treatment and a comparison between treatments are presented in Table 42. The definite superiority of the 20 C. P. +(4x)15NK, 20 C. P. +(4x)15N, 10 Peat +(4x)15NK, and 10 Peat 20 C. P. +(4x)15NK treatments is quickly evident from an examination of Table 42. No treatments are superior to them, and several, including the check, are inferior. Three of the four treatments that produced consistently larger diameters than several of the treatments contained colloidal phosphate.

Table 40. --Mean number of branches per tree 13, $16\frac{1}{2}$, and 19 weeks after initial treatment, Experiment III, 1943-44

Treatment	Time after initial treatment		
	13 weeks	$16\frac{1}{2}$ weeks	19 weeks
	Branches per tree - number		
Check	0.23	1.13	1.17
20 C. P.	1.15	1.58	1.83
20 C.P.+(4x)15NK	1.70	2.23	2.27
20 C.P.+(4x)15N	1.38	1.90	2.02
10 Peat	0.63	2.03	2.05
10 Peat+(4x)15NPK	1.45	2.93	2.93
10 Peat 20 C. P.	1.15	1.80	1.70
10 Peat 20 C.P.+ (4x)15NK	1.52	2.15	2.15
(4x)15N30P75K	0.98	2.50	2.55
352 Wood ashes	0.38	2.03	2.05
1320 Wood ashes	0.38	1.58	1.70
Standard deviation	0.30	0.45	0.45
Difference between treatment means to be significant at 5 and 1 percent	0.88 1.18		
F value treatment	2.90*	1.07	1.06

*Significant at 5 percent.

Table 41. --Comparison of number of branches per tree 13 weeks after initial treatment, Experiment III, 1943-44

Treatment		Treatments superior to treatments in column 1	
No.	Designation	at 5%	at 1%
15	Check	16,18,21	17,20,22
16	20 C. P.		
17	20 C. P. + (4x)15NK		
18	20 C. P. +(4x)15N		
19	10 Peat	17,22	
20	10 Peat + (4x)15NPK		
21	10 Peat 20 C. P.		
22	10 Peat 20 C. P. (4x)15NK		
23	(4x)15N30P75K		
24	352 Wood ashes	18,20,22	17
25	1320 Wood ashes	18,20,22	17

Table 42. --Mean diameter of stem and comparison of stem diameters 19½ weeks after initial treatment, Experiment III, 1943-44

Treatment			Treatments superior to treatments in column 1	
No.	Designation	Diameter - mm.	at 5%	at 1%
15	Check	3.46		17,18,20,22
16	20 C. P.	3.68	18	17,22
17	20C.P.+(4x) 15NK	4.14		
18	20C.P.+(4x) 15N	3.95		
19	10 Peat	3.48		17,18,20,22
20	10 Peat + (4x)15NPK	3.90		
21	10 Peat 20C.P.	3.71		17,22
22	10 Peat 20C.P. +(4x)15NK	4.11		
23	(4x)15N30P75K	3.39	16,21	17,18,20,22
24	352 Wood ashes	3.44	21	17,18,20,22
25	1320 Wood ashes	3.48		17,18,20,22
Standard deviation		0.09		
Difference between treatment means to be significant at 5 and 1 percent		0.27 0.36		
F value treatment		9.26**		

**Significant at 1 percent.

Dry Weight of Shoot, Root, Entire Tree, and
Root-Shoot Ratio

The mean weight of the shoot and a comparison of the weights by treatments are presented in Table 43. Mean weights range from 1.62 to 2.84 gr., which means that the average weight of the heaviest trees was more than 75 percent greater than the average weight of the lightest trees. This is a greater difference than is found in height and diameter, in which the superiority of the best over the poorest was 36 and 22 percent respectively. On the other hand, the superiority in early branching of the best over the poorest treatment was 2500 percent. This, together with the noticeably greater density of needles in the superior trees (see Fig. 5), accounts for the marked difference in weight between the heaviest and lightest trees. Trees that branch early have the opportunity to develop longer and heavier branches prior to the time of harvest. This undoubtedly contributes considerable to the weight of these trees.

No treatments produced trees significantly lighter in weight than the check; and three treatments- 20 C. P. +(4x)15NK, 20 C. P. +(4x)15N, and 10 Peat 20 C. P. +(4x)15NK- all of which contained colloidal phosphate, produced trees very significantly heavier than the check. It is noteworthy that the trees from three other treatments- 20 C. P., 10 Peat +(4x)15NPK, and 10 Peat 20 C. P.- with mean weights 0.47, 0.50, and 0.40 gr. greater than the trees from the check were very nearly significantly heavier than the latter. Two of these contained colloidal phosphate.

When nitrogen and potassium together with colloidal phosphate were added, the trees were significantly heavier than when only colloidal

Table 43. --Mean dry weight of shoot and comparison of shoot weights, Experiment III, 1943-44

Treatment No.	Treatment Designation	Dry weight of shoot gr.	Treatments superior to treatments in column 1 at 5%	at 1%
15	Check	1.83		17,18,22
16	20 C. P.	2.30	17	
17	20 C. P. + (4x)15NK	2.84		
18	20 C. P. + (4x)15N	2.78		
19	10 Peat	1.81	20	17,18,22
20	10 Peat + (4x)15NPK	2.33		
21	10 Peat 20 C.P.	2.23	17,18	
22	10 Peat 20 C. P. +(4x)15NK	2.70		
23	(4x)15N30P75K	1.62		17,18,20,22
24	352 Wood ashes	1.85		17,18,22
25	1320 Wood ashes	1.95		17,18,22
Standard deviation		0.17		
Difference between treatment means to be significant at 5 and 1 percent		0.51 0.69		
F value treatment		5.81**		

**Significant at 1 percent.

phosphate was added to the soil. Nitrogen, when combined in the culture with colloidal phosphate, did not produce trees significantly heavier than the colloidal phosphate treatment, although the difference (0.48 gr.) was nearly significant (0.51 gr. needed for a significant difference).

The dry weight of the roots and a comparison of the weights by treatments are presented in Table 44. The mean weights of the roots range from 0.84 to 1.67 gr., thus the treatment which produced the heaviest tree roots yielded trees whose roots weighed nearly twice as much as those for the treatment producing the lighest roots. The relative difference in average weight between the heaviest and lightest roots is greater than that between the tops.

The analysis of variance of root weight demonstrates a very significant difference between some treatments. Table 44 shows that the 10 Peat 20 C. P. +(4x)15NK treatment is the outstanding one in so far as root weight is concerned, the roots of the trees from this treatment being very significantly heavier that the roots from seven treatments, and significantly heavier than the roots from one treatment. The colloidal phosphate-nitrogen culture is superior to four treatments; but the colloidal phosphate-nitrogen-potassium culture, which in other characteristics showed superiority over just about the same treatments as the former, fails to show significant superiority in root weight over these treatments and is significantly inferior to the peat-colloidal phosphate-nitrogen-potassium culture.

On the whole, there are significant differences in root weight between fewer treatments than in shoot weight,.

The dry weight of the entire tree, comparisons of weights by treatments, and root-shoot ratios are shown in Table 45. The weights fall into

Table 44. --Mean dry weight of root and comparison of root weights, Experiment III, 1943-44

Treatment No.	Treatment Designation	Dry weight of root gr.	Treatments superior to treatments in column 1 at 5 %	at 1%
15	Check	0.84		18,22
16	20 C. P.	1.09		22
17	20 C. P. + (4x)15NK	1.20	22	
18	20 C. P. + (4x)15N	1.44		
19	10 Peat	0.92	18	22
20	10 Peat + (4x)15NPK	1.26		
21	10 Peat 20 C.P.	1.10		22
22	10 Peat 20 C.P. +(4x)15NK	1.67		
23	(4x)15N30P75K	1.07		22
24	352 Wood ashes	0.84		18,22
25	1320 Wood ashes	0.86		18,22
Standard deviation		0.15		
Difference between treatment means to be significant at 5 and 1 percent		0.45 0.56		
F value treatment		3.15**		

**Significant at 1 percent.

Table 45. --Dry weight of entire tree, root-shoot ratio, and comparison of tree weights by treatments, Experiment III, 1943-44

Treatment No.	Treatment Designation	Dry weight of entire tree- gr.	Treatments superior to treatments in column 1 at 5%	at 1%	Root-shoot ratio
15	Check	2.68	16,21	17,18,20,22	0.46
16	20 C. P.	3.39	17,18	22	0.47
17	20 C. P. + (4x)15NK	4.04			0.42
18	20 C. P. + (4x)15N	4.22			0.52
19	10 Peat	2.72	16	17,18,20,22	0.51
20	10 Peat + (4x)15NPK	3.59	18	22	0.54
21	10 Peat 20 C. P.	3.34	17	18,22	0.49
22	10 Peat 20 C. P. + (4x)15NK	4.38			0.62
23	(4x)15N30P75K	2.69	16	17,18,20,21,22	0.66
24	352 Wood ashes	2.70	16	17,18,20,21,22	0.45
25	1320 Wood ashes	2.81	20	17,18,22	0.44
Standard deviation		0.22			0.06
Difference between treatment means to be significant at 5 and 1 percent		0.63 0.85			
F value treatment		8.67**			1.63

**Significant at 1 percent.

three broad classes: below 3 gr., from 3 to 4 gr., and over 4 gr. Trees from the culture with the highest mean weight (4.38 gr.) are more than 63 percent heavier than those from the culture with the lowest mean weight (2.68 gr.).

The trees from the check treatment were not superior in weight to trees from any other cultures and were inferior to those from six cultures, five of which included colloidsl phosphate as all or a part of the treatment. The one treatment not containing colloidal phosphate contained peat moss and readily available nitrogen, phosphorous, and potassium. All cultures which produced trees with a mean weight in excess of 4 gr. contained colloidal phosphate in addition to readily available forms of nitrogen or nitrogen and potassium. The fact that the trees from the 20 C. P. +(4x)15NK and 10 Peat 20 C. P. +(4x)15NK treatments are not significantly heavier than those from the 20 C. P. +(4x)15N treatment raises some doubt as to the value of potassium in treatments containing colloidal phosphate.

It is noteworthy that, whereas the culture containing colloidal phosphate alone is not superior to the check at the end of the experiment in the characteristics discussed previously, it is superior in weight of the entire tree. In contrast, peat moss alone had no effect on tree weights. When colloidal phosphate is added with the peat moss, tree weight is increased enough to make the trees from this treatment superior to those from the check and only 0.01 gr. short of being significantly superior to those from the peat treatment. Obviously, colloidal phosphate is an important factor in influencing tree weight.

Wood ashes produced no significant effect on tree weight.

Root-shoot ratios, although ranging from 0.43 to 0.68, did not show significant differences owing to the large standard error of the error term in the experiment. A study of the root-shoot ratios indicates no trend that can be related to type of treatment.

Summary of Results

This experiment demonstrates convincingly that to improve the quality of slash pine seedlings grown in Norfolk sand, fist, the physical condition of the soil must be improved and secondly, supplemental readily available nitrogen, phosphorous, and potassium must be applied. Neither the addition of colloidal phosphate or peat moss alone nor the addition of readily available nutrients alone produced much response in the seedlings, but when combinations of these were applied to the soil, the response of the trees was outstanding.

Nitrogen, phosphorous, and potassium, when added to soil supplied with 10 tons of peat moss, did not cause as much response in the trees as when added to soil supplied with 20 tons of colloidal phosphate. The peat moss, when combined with colloidal phosphate and readily available nitrogen and potassium, apparently made no contribution to the nutrition of the seedlings as evidenced by the great similarity of trees in the 10 Peat 20 C. P. +(4x)15NK and 20 C. P. +(4x)15NK cultures. The similarity of the trees in the 20 C. P. +(4x)15N and the 20 C. P. +(4x)15NK cultures suggests that potassium has contributed little, if anything, to the nutrition of the trees.

Response of the seedlings to colloidal phosphate and readily available nitrogen or nitrogen and potassium was of about the same degree of magnitude in stem length, branching, diameter, and weight. No significant effect on root-shoot ratio was evident, however.

Wood ashes was ineffective in causing a response by slash pine seedlings.

Calcium and Phosphorous
Analysis of Needles

Trees from four treatments which had produced seedlings significantly different from those of the check in a number of characteristics were chosen for an analysis of phosphorous and calcium. The analyses were limited to those two elements since the colloidal phosphate treatments- high in phosphorous and calcium- had produced such superior trees, and it appeared that these two nutrients might be contributing factors. The treatments chosen were: check, 60N, 60P, 20 C. P., and 20 C. P. +(4x)15NK. The determinations of phosphorous and calcium were made on the needles of a tree selected at random from each replication of each treatment by the methods described by the Association of Official Agricultural Chemists (1940). The results of these analyses are shown in Table 46.

Table 46. --The phosphorous and calcium content of needles of slash pine seedlings grown in treated and untreated Norfolk sand

Treatment	Phosphorous		Calcium	
	Mg. per tree	Percent of dry weight	Mg. per tree	Percent of dry weight
Check	2.30	0.22	5.2	0.50
60N	1.70	0.23	3.5	0.47
60P	2.95	0.21	6.9	0.49
20 C. P.	2.90	0.20	6.7	0.46
20 C.P.+(4x)15NK	4.17	0.22	9.7	0.51
Standard deviation	0.20	0.02	0.25	0.18

The amounts of phosphorous and calcium, expressed in terms of percent of the dry weight of the needles, vary only slightly for trees from different treatments. Wilde (1942: 294) found a similar relationship for phosphorous in one-year-old white ash seedlings grown in four different soil cultures. He reports the P content of these seedlings to be 0.17 to 0.19 percent, which is only slightly less than the 0.20 to 0.23 percent of P in the slash pine needles. In the same report, Wilde shows that the P content of red pine seedlings was increased from 0.17 percent to 0.29 percent by the application of a non-legume green manure.

Analyses of variance applied to the data for both elements reveal no significant difference between treatments, the F value for phosphorous being 0.55, and for calcium being 0.01. The amounts of phosphorous and calcium, when expressed as mg. per tree, show a wide variation between cultures. Analyses of variance demonstrate that the differences between treatments in amounts of calcium and phosphorous in mg. are very significant. A comparison of effect of soil treatment on phosphorous and calcium content of the needles of slash pine seedlings is shown in Table 47.

The superiority of 20 C. P. +(4x)15NK treatment over the other four treatments in the calcium content of the tree needles is evident in Table 47. It was almost equally superior in the phosphorous content of the tree needles. All three cultures containing phosphorous and calcium produced trees with a higher calcium content in the needles than those of the check and the nitrogen cultures. In contrast, only the colloidal phosphate treatment with nitrogen and potassium was superior to the check; and it and the 60P treatment were superior to the nitrogen culture in the content of phosphorous in the tree needles.

The fact that significant differences between the treatments in the percentage of phosphorous and calcium in the seedling needles do not exist, but that significant differences do exist between treatment means in the weight of phosphorous and calcium in the needles reveals that the latter differences are due to differences in the weight of needles produced by trees from different cultures.

It is noteworthy that the 20 C. P. +(4x)15NK treatment produced trees with greater amounts of calcium and phosphorous in the needles than the 20 C. P. treatment. Obviously, the colloidal phosphate by itself did not increase the intake of phosphorous by the plants. However, when nitrogen and potassium were included with the colloidal phosphate, the intake of phosphorous was increased, as was undoubtedly the intake of nitrogen and potassium. Data on height and dry weight, presented previously, showed that when nitrogen, phosphorous, and potassium were added to an otherwise untreated soil no significant effect was produced on these features, but when added to a soil to which colloidal phosphate had been added also, significant increase in height and dry weight occurred. Apparently, nitrogen, phosphorous, and potassium together or colloidal phosphate alone cannot influence the height, dry weight, or nutrient intakes, but in combination they can, Evidently, the colloidal phosphate, possibly through the colloidal fraction, creates in the soil a condition which allows the tree roots to feed more effectively. The mechanism involved is worthy of study.

Table 47. --Comparison of treatments in their effect on phosphorous and calcium content of needles of slash pine seedlings

Treatment	Treatments producing trees with greater P content than treatments in column 1		Treatments producing trees with greater Ca content than treatments in column 1	
	at 5%**	at 1%**	at 5%†	at 1%††
Check		20C.P.+ (4x)15NK		60P, 20 C. P. 20 C.P.+(4x)15NK
60N	60P	20C.P.+ (4x)15NK		Check, 60P, 20C.P 20 C.P.+(4x)15NK
60P	20 C.P.+ (4x)15NK, lacks 0.01 mg.			20 C. P. + (4x)15NK
20 C. P.		20 C.P.+ (4x)15NK		20 C. P. + (4x)15NK
20 C. P. + (4x)15NK				

*A minimum difference of 1.23 mg.
**A minimum difference of 1.71 mg.
†A minimum difference of 0.79 mg.
††A minimum difference of 1.10 mg.

Discussion of Results

The various treatments differed in their effect upon the several characteristics of the trees. Some treatments caused a reduction in stem length and nearly corresponding reductions in stem diameter and dry weight; other treatments caused a reduction in stem length but increases in stem diameter and dry weight; still other treatments caused an increase in all three characteristics. It is often assumed that when stem length of young conifers is increased as a result of nutrient application, corresponding increases in stem diameter and dry weight occur. Recent studies with certain conifers have demonstrated this to be a fact (Bensend, 1943; McComb, 1943). Since the features already mentioned, as well as others, are affected by the treatment to which the trees are subjected and since an improvement in one trait may not be accompanied by a comparable improvement in another, the appraisal of any treatment cannot be made safely on a single feature. Since it is difficult to visualize several features in the aggregate as a basis for comparing the effects of one treatment with another it appeared desirable to develop a composite value that would represent the more important characteristics studied. The results of an attempt to calculate such a composite value are shown in Table 48. Five tree characteristics, each of which is given equal weight, are used to secure the composite tree index value. The values are relative since the trees from the check treatment form the basis for comparison. For each of the five features listed the numerical values were secured as follows: If a treatment mean exceeds the mean of the check by exactly the amount needed to be significant at 5 percent, the treatment mean is scored at 1, and if it exceeds the check by exactly the amount needed to be very significant, the treatment mean is scored 2. Deficiencies of the same magnitudes are scored -1 and -2, respectively. A difference which is less than that needed to be significant is scored proportionately as is a difference which lies between the 5 and 1 percent points. Differences which exceed that needed at 1 percent are scored on a proportionate basis except when the score exceeds 3. The score for branching gives equal weight to number of branched trees and number of branches per tree and is based on observations made at the end of 12 and $12\frac{1}{2}$ weeks, respectively. All other scores are based on measurements made at the end of the experiments. Shoot weight and root weight are not included in the rating since weight of entire tree covers these features.

Table 48. --Rating of treatments in 1943-44 experiments for composite tree index evaluation

Treatment	Numerical rank: Stem length	Branching	Diameter	Weight of entire tree	Root-shoot ratio	Composite tree index
Check	0.0	0.0	0.0	0.0	0.0	0.0
60NP	-2.5	0.0	-0.4	-1.3	0.1	-4.1
60NK	-1.7	0.5	1.3	-0.5	0.4	0.0
60PK	0.9	1.1	1.7	1.3	-0.2	4.8
60N	-3.0	0.0	-1.8	-2.5	0.0	-7.3
60P	0.7	1.9	3.0	3.0	0.1	8.7
60K	0.9	0.1	0.0	0.4	0.9	2.3
60NPK	-0.6	2.3	1.0	0.5	0.0	3.2
60NPK	-0.7	0.9	0.6	0.6	0.9	2.3
120NPK	-1.8	0.8	0.5	0.1	0.0	-0.4
180NPK	-1.3	0.5	1.0	-0.1	0.0	0.1
(4x)15NPK	0.2	1.0	1.2	0.7	0.0	3.1
(4x)30NPK	-0.5	2.0	3.0	2.2	0.0	6.7
(4x)45NPK	-0.6	1.0	3.0	0.7	-0.7	3.4
Check	0.0	0.0	0.0	0.0	0.0	0.0
20 C. P.	0.9	1.1	0.8	1.4	0.0	4.2
20C.P.+(4x)15NK	2.5	2.8	3.0	3.0	-0.3	11.0
20C.P.+(4x)15N	1.8	2.4	3.0	3.0	0.5	10.7
10 Peat	-0.5	0.4	0.1	0.1	0.5	0.6
10 Peat+ (4x)15NPK	-0.2	2.6	3.0	2.2	0.7	8.3
10 Peat 20C.P.	0.3	1.0	0.9	1.1	0.3	3.6
10 Peat 20 C.P. +(4x)15NK	0.9	2.5	3.0	3.0	0.9	10.3
(4x)15N30P75K	-1.0	1.1	+0.3	0.0	0.9	0.7
352 Wood ashes	-0.2	0.2	-0.1	0.0	0.0	-0.1
1320 Wood ashes	0.3	0.1	0.2	0.2	-0.2	0.6

Composite tree index values range from -7.3 to 11.0, a total of 18.3 points. The smallest value was produced where the treatment consisted of a single application of 60 pounds per acre of nitrogen at the beginning of the experiment. Evidently, this amount of nitrogen applied so early was excessive since it interfered with the normal growth and development of the trees. Height growth was depressed most, but diameter and weight were greatly reduced also. Branching and root-shoot ratio were not affected. Whether a similar amount of nitrogen split into two or more applications would have the same effect is not known, and bears investigation.

The addition of 60 pounds of P_2O_5 per acre with the same amount of nitrogen as illustrated by the 60NP treatment reduced somewhat the depressing effects which were so marked with nitrogen alone. The use of potash with nitrogen caused a still further reduction in stem length depression, and branching and stem diameter were increased sufficiently over that produced by nitrogen alone to make the trees in the 60NK treatment equal in composite index value to those from the check. When N, P_2O_5, and K_2O were used together at rates of 60 pounds per acre, each in a single application, stem length was not significantly shorter than that of the check, and branching and stem diameter were sufficiently better to give the trees from the 60NPK culture a greatly improved rating.

Phosphorous or potassium, or a combination of the two, as illustrated by the 60P, 60K, and 60PK treatments, respectively, did not decrease stem length and caused enough improvement in one or more other characteristics to demonstrate the value of these elements in single applications at the start of experiment. The fact that the

60P treatment contained some calcium in the source material makes it impossible to attribute the marked superiority of the trees from this treatment to phosphorous alone. Calcium may have been a contributing factor.

The superiority of small amounts of nutrients applied frequently over the same total quantity applied at once at the start is evident particularly in the larger diameter of trees in the split-application treatments as compared to those in the single-application treatments and to superiority of the former over the latter in stem length. The wastefulness of large single applications of nitrogen, phosphorous, and potassium is evident in the results of the 120NPK and 180NPK cultures. Trees from those treatments, although varying from those from the check in individual features, had comparable composite tree index values.

The higher tree index value of the (4x)30NPK treatment, as compared to the (4x)15NPK and (4x)45NPK treatments, seems to indicate that four applications of 30 pounds each of N, P_2O_5, and K_2O may be somewhere near the optimum insofar as all-round tree quality is concerned. Although this treatment is inferior to the (4x)15NPK treatment in its effect on stem length, it is much superior from the standpoint of increasing diameter and weight.

Colloidal phosphate used at a rate of 20 tons per acre produces definite effects on the trees, especially when nitrogen or nitrogen and potassium are used with it. Colloidal phosphate alone was nearly as effective in changing the quality of trees as the more effective treatments involving the use of readily available nutrients (60P, 60PK, (4x)15NPK). Evidently nitrogen plays a significant role in connection with colloidal phosphate as demonstrated by the superior tree index value of trees in the 20 C. P. +(4x)15N culture over those in the 20 C. P. culture. It is doubtful that potassium is essential in connection with the use of colloidal phosphate in view of the close agreement of trees in the 20 C. P. +(4x)15N and 20 C. P. +(4x)15NK cultures.

Peat moss (10 Peat culture) has little effect on the trees unless nitrogen, phosphorous, and potassium are added (10 Peat +(4x)15NPK culture) in which case branching, diameter, and weight are increased markedly.

The fact that the trees make much better all-round growth and development when readily available nutrients are added in the presence of colloidal phosphate or peat moss than when added in the same quantity to the natural soil ((4x)15NPK culture) indicates that peat moss and colloidal phosphate exert, in some manner, a favorable effect upon nutrition. In the case of the peat moss, the effect cannot logically be attributed to readily available nutrients that it supplies since the peat moss is raw organic matter which can supply little readily available nutrient. In the case of colloidal phosphate, quick test analysis revealed that only calcium occurred in it in water-soluble form in appreciable quantity. Furthermore, calcium is not found in peat moss, and therefore can not therefore be a factor in that material. It is possible that both these materials affected favorably the availability of the nutrients either through the physical complex of the soil itself or indirectly through a physical effect which may increase the permeability of the membranes to nutrients.

The (4x)15N30P75K, treatment which contained a high concentration of potassium, produced no effects out of the ordinary.

Wood ashes in the two different amounts used had little or not effect on the trees.

1944-45 Experiments

Soil Treatment

Since the cultures containing colloidal phosphate in the 1943-44 greenhouse experiments had produced the best quality trees, further study of colloidal phosphate treatments seemed desirable. Experiment I was designed, therefore, to test the effect of varying amounts of colloidal phosphate on the seedlings. The quantity was varied from 0.5 to 25 tons per acre. In the one-ton treatments (see Table 49, treatments 2 and 5), colloidal phosphate was mixed in the upper 4 inches of soil in one culture, and in another, it was scattered on the surface. Fifteen pounds per acre of N and K_2O were applied four times at intervals of 5 weeks. In the cultures in which nitrogen and potassium were used, these elements were mixed in the upper 4 inches of soil in the first application except in treatment 5, in which they were applied to the surface. The subsequent applications of these elements were to the surface. The source of nitrogen and potassium were NH_4NO_3 and KCl, respectively. The materials were C. P. chemicals. The details of the treatments in Experiment I are shown in Table 49.

Since both the colloidal phosphate treatments in Experiment III and the phosphorous treatment (containing some calcium) in Experiment I of the 1943-44 series yielded the largest and heaviest trees, there was some indication that phosphorous or calcium or the combination of these elements might be particularly important in the nutrition of young slash pine seedlings. Two experiments were designed to test the role of these elements. In Experiment II, phosphorous was the only nutrient added to the soil. It was applied at five different rates: 30, 60, 120, 240, and 480 pounds per acre of P_2O_5. In Experiment III, potassium; nitrogen and potassium; and calcium, nitrogen, and potassium were used in combination with phosphorous. The latter element was used at three different rates: 60, 120, and 480 pounds per acre of P_2O_5. In this experiment, nitrogen and potassium were applied four times at 5-week intervals at a rate of 15 pounds per acre of N and K_2O, a total of 60 pounds of each during the experiment. Calcium was applied to the soil prior to planting the trees, at a rate of 200 pounds of Ca per acre.

The phosphorous and calcium, added to the soil in a single application, and the first application of nitrogen and potassium were mixed in the upper 4 inches of soil. The three subsequent quantities of nitrogen and potassium were applied to the surface of the soil. The phosphorous was supplied by H_3PO_4, the calcium by $CaCO_3$. The sources of nitrogen and potassium were the same as in Experiment I. The details of Experiments II and III are shown in Tables 57 and 62.

Experiment IV was designed to determine whether slash pine seedlings would respond differently to a treatment in which a part of the nutrients was mixed in the upper 4 inches of soil than to one in which all nutrients were applied to the surface. Also varied in this experiment was the number of additions of nitrogen and potassium. Eleven and one-half weeks after the trees were planted, boron and manganese were added to half of the pots in treatments 23 and 24. Chemicals used were the same as in the experiments previously described. Details are shown in Table 78.

Origin of Seedlings

In Experiment I, slash pine seed from the lot of seed used in 1943-44 experiments was used. After 6 weeks storage in moist peat moss, the seed was sown in sand flats on September 3, 1944. Germination began 5 days later, but progressed rather slowly during the first 10 days. During the following week germination was greatly accelerated, and during this period, approximately 62 percent of the total germination took place. Because of the rather irregular germination, only those seedlings that germinated during the 7-day period between September 18 and 24 were used in the experiment. The seedlings were transferred from the flats to the pots on October 4, at which time their average age was 2 weeks.

An inadequate supply and relatively poor germination of the seed collected from a single tree in the fall of 1943 made it necessary to use a different lot of seed for Experiment II, III, and IV of the 1944-45 series. The seed used in these experiments was from the 1943 crop, collected from several trees. Due to a shortage of seed of a single weight class, the seed was segregated into four classes with average weights of 32, 35, 38, and 41 mg. After 4 weeks of stratification in moist peat moss, the seed for Experiment II and III was sown on September 15. Seedlings first appeared above the surface 6 days later. Germination occurred rather uniformly during the next 12 days after which it dropped off. Seedlings which germinated during this 12-day period were used in these experiments. They were planted in the soil jars on October 11 and 12, at which time their average age was 16 days. The trees in the first and second replications of each treatment were from 35-mg. seed, those in the third replication were from 38-mg. seed, and those in the fourth replication were from 32-mg. seed.

The seed used in Experiment IV was from the same lot as that used in Experiments II and III. Trees which germinated in a week's time from 35-mg. seed was used exclusively. When they were planted in the soil pots on October 25, the seedlings had an average age of 19 days.

Temperature and Length of Day

A thermographic record of temperature was maintained throughout the experiment. The weekly mean, mean maximum, and mean minimum temperatures were computed in the same manner as in the 1943-44 experiments (see page 41). Since the periods of time during which the four experiments were in progress did not coincide, weekly averages were computed for each experiment. Since Experiment IV was initiated exactly 3 weeks after Experiment I the weekly averages from the fourth through the twenty-second week of the latter experiment are the weekly averages for the first through the nineteenth week of the former. Therefore, mean temperatures from the twentieth through the twenty-seventh week only are shown in Table 89.

The mean weekly length of day during the period of each experiment was computed in the same manner as described previously (see page 41).

The temperature and length of day data are presented in Tables 87, 88, and 89 (Appendix)

Only small differences are evident in the mean weekly, mean weekly maximum, and mean weekly minimum temperatures during the three experimental periods. The averages are a few degrees higher for Experiment IV than for Experiments I, II, and III. When the averages are examined week by week, greater discrepancies are evident. In Experiment I, the highest temperatures occurred during the first 3 weeks of the experiment, and the lowest occurred about midway in the experiment. In Experiment II and III, the highest temperatures were recorded during the first 2 weeks and the last 3 weeks; and the lowest, during the eighth, ninth, and sixteenth weeks. In Experiment IV, temperatures were lowest during the first several weeks, and highest during the last 8 weeks.

In all four experiments, the trend in mean weekly length of day was similar. The hours of daylight became progressively shorter during the first 8 to 11 weeks, to be followed by no change for 3 weeks, after which there was a progressive increase.

The average length of day for Experiments I, II, and III was almost identical. The average length of day for Experiment IV was nearly one-half hour longer due to the relatively long periods of daylight during the last several weeks of this experiment.

Rate of Evaporation

Three sets of Livingston black and white atmometers were used to measure rate of evaporation. One set was placed near each end, and the third set was placed about midway between the ends of the greenhouse bench occupied by the soil pots containing the slash pine seedlings. The three sets showed so little variation in loss of water that average rate of evaporation was calculated. These values are shown in Table 90.

Experiment I

Soil Treatment

The primary object of Experiment I was to determine the effect on slash pine seedlings of different quantities of colloidal phosphate supplemented by periodic applications of nitrogen and potassium. Secondary objectives were to determine whether a surface application of colloidal phosphate would affect the trees in the same way as an application in which it was mixed in the upper 4 inches of the soil, and to determine the extent of the response of the trees to different quantities of colloidal phosphate by comparison with untreated soil (check). The analyses of variance of all tree features studied are based on the four cultures which received different amounts of colloidal phosphate- 0.5, 1.0, 5.0, and 25.0 tons per acre- mixed in the upper 4 inches of soil. The standard deviations secured from these analyses were used to compute the difference between treatment means needed to be significant at 5 and 1 percent, and the latter is used in comparing the trees from the four cultures referred to above as well as the trees from the check and the surface- application of colloidal phosphate treatments.

The character of the soil treatments is shown in Table 49.

Analysis of variance tables are not shown in this discussion or other experiments of the 1944-45 series. The analyses were handled in the same way as those of the 1943-44 series, examples of which are found in the Appendix.

Length of Stem

The mean lengths of stems of the trees in each treatment in Experiment I 10, 15, and 20 weeks after the initial treatment are shown in Table 50. Stem lengths were measured at 5 weeks also, but so little growth had occurred during this period that the inclusion of these data did not seem worthwhile. Throughout the experiment, all cultures containing colloidal phosphate produced trees with longer stems than the check, but the differences between the trees from all the colloidal phosphate treatments and the check were significant only at 10 and 15 weeks. Significant differences were maintained to the end of the experiment only between the check and the culture containing 25 tons of colloidal phosphate. Stem length of the trees varied with the amount of colloidal phosphate in the soil, stem lengths being greatest in the cultures containing the largest amounts; but significant differences in stem lengths occur chiefly between the trees of those cultures with relatively wide differences in the amount of colloidal phosphate. The extent of significant differences in stem length varies with time also. For example, after 10 and 15 weeks the trees in the 25 C. P.

Table 49. --Type and time of nutrient application in Experiment I, 1944-45

Treatment		Time of nutrient application								
		Prior to planting			5 weeks after planting		10 weeks after planting		15 weeks after planting	
		Colloidal phosphate	N	K_2O	N	K_2O	N	K_2O	N	K_2O
No.	Designation	Tons per acre	Pounds per acre							
1	0.5 C. P.	0.5	15	15	15	15	15	15	15	15
2	1.0 C. P.	1.0*	15*	15*	15	15	15	15	15	15
3	5 C. P.	5.0	15	15	15	15	15	15	15	15
4	25 C. P.	25.0	15	15	15	15	15	15	15	15
5	1.0 C. P. (S)	1.0**	15**	15**	15	15	15	15	15	15
6	Check	-	-	-	-	-	-	-	-	-

* Mixed in upper 4 inches of soil.
** Applied to surface of soil.

Table 50. --Mean length of stem 10, 15, and 20 weeks after initial treatment, Experiment I, 1944-45

Treatment	Time after initial treatment		
	10 weeks	15 weeks	20 weeks
	Length of stem - mm.		
0.5 C. P.	13.8	43.6	90.3
1.0 C. P.	15.4	46.6	96.5
5 C. P.	17.5	49.1	100.5
25 C. P.	19.0	55.4	111.9
1.0 C. P. (S)	14.6	42.3	96.1
Check	12.0	39.0	88.8
Standard deviation	0.6	1.4	4.5
Difference between treatment means to be significant at 5 and 1 percent	2.10 3.02	4.47 6.43	14.20 20.49
F value treatment	12.0**	12.8**	4.2*

*Significant at 5 percent.
**Significant at 1 percent.

treatment have very significantly longer stems than those in the 0.5 C. P. and 1.0 C. P. treatments, but after 20 weeks the difference between the stem lengths of trees in the 1.0 C. P. culture and the 25 C. P. culture has been reduced from the 1 to the 5 percent level. The difference between the stem lengths of trees in the 0.5 C. P. treatments was very significant at 10 weeks, significant at 15 weeks, and not significant at 20 weeks. That the effect of colloidal phosphate on the stem growth of the seedlings decreases with the passage of time is illustrated also by the fact that the stems of trees from the 0.5 C. P. cultures were 115 and 102 percent, and those from the 25 C. P. culture were 158 and 126 percent of the length of those from the check at 10 and 20 weeks, respectively. Because of the decline in the effect of the supplemental nutrients, it is obvious that experiments of too short duration might lead to incorrect conclusions.

The difference in the stem length of the trees in the 1.0 C. P. and 1.0 C. P. (S) treatments is very small throughout the experiment, and at no time is it significant.

Branch Development

The number of branched trees at different periods of time after the initial treatment is shown in Table 51. Differences between treatments are greatest at the end of 5 weeks, the only time that the differences were significant. The 25 C. P. culture had produced significantly more branched trees than the 0.5 C. P. and 1.0 C. P. cultures, and very significantly more than the 5 C. P. and check cultures at the end of 5 weeks. The 5 C. P. treatment is out of line with the trend of the cultures containing smaller amounts of colloidal phosphate at this time but was more in line after 8 weeks and subsequent periods. Although the check culture produced fewer branched trees throughout the experiment than the

Table 51. --Number of branched trees 5, 8, 10, 15, and 20 weeks after initial treatment, Experiment I 1944-45

Treatment	Time after initial treatment				
	5 weeks	8 weeks	10 weeks	15 weeks	20 weeks
	Branched trees - percent of total				
0.5 C.P.	20.0	67.5	87.5	97.5	97.5
1.0 C.P.	22.5	80.0	92.5	95.0	95.0
5 C.P.	10.0	77.5	92.5	95.0	95.0
25 C.P.	50.0	90.0	95.0	95.0	95.0
1.0 C.P.(S)	27.5	77.5	85.0	92.5	92.5
Check	7.5	55.0	70.0	80.0	80.0
Standard deviation	7.2	4.4	3.2	-	-
Difference between treatment means to be significant at 5 and 1 percent	22.9 33.0	- -	- -	- -	- -
F value treatment	4.09*	2.32	0.05	-	-

*Significant at 5 percent.

other cultures, the differences between it and other cultures were not significant. More than 90 percent of the trees in all colloidal phosphate treatments were branched after 15 weeks (Figs. 10 and 11).

The mean numbers of branches per tree produced in the various cultures in Experiment I are presented in Table 52. Although there were differences between treatments in the number of branches per tree, significant differences existed only at 8 and 10 weeks. At 8 weeks, the mean number of branches per tree in the 25 C. P. culture is very significantly greater than that in the 0.5 C. P. culture and the check, and significantly greater than that in all other treatments. At 10 weeks, the mean number of branches per tree in the 25 C. P. culture is very significantly greater than that in the 0.5 C. P., 1.0 C. P. (S), and check cultures and significantly greater than that in the 1.0 C. P. and 5 C. P. cultures. Only the 0.5 C. P. culture did not have trees with significantly more branches per tree than the check culture at 8 weeks. Two weeks later, in all colloidal phosphate treatments, the mean number of branches per tree was very significantly greater than that in the check culture. During the next 5 weeks significant differences disappeared between the four treatments to which the analysis of variance was applied. The trees in all four of these cultures had either significantly or very significantly more branches than those in the check culture at 15 as well as at 20 weeks.

Diameter of Stem

Mean stem diameters of trees in different cultures at the end of the experiment are presented in Table 53. The rate of application of colloidal phosphate produced very significant differences in stem diameter. Mean diameter increased with an increase in the amount of soil amendment used. The mean stem diameters of trees in the 1.0 C. P., 5 C. P., and

Table 52. --Mean number of branches per tree, 8, 10, 15, and 20 weeks after initial treatment, Experiment I, 1944-45

Treatment	Time after initial treatment			
	8 weeks	10 weeks	15 weeks	20 weeks
	Branches per tree - number			
0.5 C.P.	1.32	2.40	3.45	3.50
1.0 C.P.	1.92	2.72	3.70	3.70
5 C.P.	1.80	2.62	3.80	3.80
25 C.P.	2.75	3.60	4.32	4.32
1.0 C.P. (S)	1.72	2.27	2.88	2.88
Check	0.82	1.42	2.10	2.12
Standard deviation	0.24	0.20	0.34	0.34
Difference between treatment means to be significant at 5 and 1 percent	0.76 1.09	0.65 0.94	- -	- -
F value treatment	6.24*	6.63*	1.14	-

*Significant at 5 percent.

Table 53. --Mean stem diameter of trees receiving different treatments in Experiment I, 1944-45

Treatment	Diameter of stem- mm.	Treatments superior to treatments in column 1 at 5%	at 1%
0.5 C. P.	4.24		1.0 C.P. 5 C.P., 25 C.P.
1.0 C. P.	4.48		25 C.P.
5 C. P.	4.54		25 C.P.
25 C. P.	4.84		
1.0 C. P. (S)	4.34	5 C. P.	25 C.P.
Check	3.99		All others
Standard deviation	0.05		
Difference between treatment means to be significant at 5 and 1 percent	0.16 0.23		
F value treatment	24.88**		

**Significant at 1 percent.

25 C. P. cultures were very significantly larger than those in the o.5 C. P. treatment; and those in the 25 C. P. culture were very significantly larger than those in the 1.0 C. P. and 5. C. P. cultures. The mean stem diameters of trees in all colloidal phosphate treatments were very significantly larger than those of the check treatment (Figs. 10 and 11). Stem diameters of trees in the 1.0 C. P. (S) treatment were exceeded significantly by those of the 5 C. P. and 25 C. P. treatments. The mean stem diameter of the trees grown in the one-ton surface-applied colloidal phosphate culture was not significantly different from that of the trees grown in the culture in which the one-ton application of colloidal phosphate had been mixed in the upper 4 inches of soil.

Dry Weight of Shoot, Root, and Entire Tree,
and Root-Shoot Ratio

The mean weights of the shoot, root, and entire tree and the root-shoot ratios of trees produced by the various cultures are shown in Tables 54, 55, and 56. Comparisons of the trees from the different cultures are shown also in these tables. Small weight increases are evident in the shoot, root, and entire tree with each increase in the amount of colloidal phosphate in the culture. The increases in weight are not proportional to the increases in the amount of colloidal phosphate in the cultures. The greatest relative increase in weight of shoot and entire tree occurs with an increase of only 0.5 ton between the 0.5- and 1.0-ton levels, which results in 10 percent increase in shoot weight and a 7 percent increase in weight of entire tree. An addition of 20 tons of colloidal phosphate, increasing the total quantity from 5 to 25 tons, results in an 18 percent increase in shoot weight and a 13 percent increase in weight of entire tree. The definite superiority in weight of shoot, root, and entire

Table 54. --Mean shoot weight and comparison of these weights by treatments, Experiment I 1944-45

Treatment	Weight of shoot-gr.	Treatments superior to treatments in column 1	
		at 5%	at 1%
0.5 C. P.	1.51	5 C. P.	25 C. P.
1.0 C. P.	1.66		25 C. P.
5 C. P.	1.76		25 C. P.
25 C. P.	2.07		
1.0 C. P. (S)	1.60		25 C. P.
Check	1.41	1.0 C. P.	5 C.P., 25 C.P.
Standard deviation	0.07		
Difference between treatment means to be significant at 5 and 1 percent	0.22 0.31		
F value treatment	12.05**		

**Significant at 1 percent.

Table 55. --Mean root weight and comparison of these weights by treatments, Experiment I, 1944-45

Treatment	Weight of root-gr.	Treatments superior to treatments in column 1 at 5%	Treatments superior to treatments in column 1 at 1%
0.5 C. P.	1.27	5 C. P.	25 C. P.
1.0 C. P.	1.29	5 C. P.	25 C. P.
5 C. P.	1.47	25 C. P.	
25 C. P.	1.69		
1.0 C. P. (S)	1.45	1.0 C. P.	25 C. P.
Check	1.19		1.0 C. P. (S), 5 C.P., 25 C.P.
Standard deviation	0.05		
Difference between treatment means to be significant at 5 and 1 percent	0.16 0.24		
F value treatment	14.3**		

**Significant at 1 percent

Table 56. --Mean weight of entire tree, root-shoot ratio, and comparison of weights by treatments, Experiment I, 1944-45

Treatment	Weight of entire tree -gr.	Treatments superior to treatments in column 1 at 5%	Treatments superior to treatments in column 1 at 1%	Root-shoot ratio
0.5 C. P.	2.78		5 C.P. 25 C.P.	0.84
1.0 C. P.	2.95	5 C.P.	25 C.P.	0.78
5 C. P.	3.23		25 C.P.	0.84
25 C. P.	3.76			0.82
1.0 C. P. (S)	3.05		25 C.P. 1.0 C.P.	0.91
Check	2.60		1.0C.P.(S) 5C.P., 25C.P	0.85
Standard deviation	0.07			0.04
Difference between treatment means to be significant at 5 and 1 percent	0.24 0.34			
F value treatment	37.2**			0.20

**Significant at 1 percent.

tree of trees in the 25-ton colloidal phosphate treatment is evident in Tables 54, 55, and 56. Trees from this treatment were very significantly heavier in all weight features to trees from all except one culture containing smaller quantities of colloidal phosphate, and in this one case (root weight of trees in the 5 C. P. culture) the roots were significantly heavier (Figs. 10 and 11). The 5-ton treatment produced trees of significantly greater top and root weight and of very significantly greater total weight than the 0.5-ton treatment, and of significantly greater root and total weight than the 1.0-ton treatment.

The differences in all weight features between the trees from the check culture and the 5 C. P. and 25 C. P. cultures are very significant. In no instance were trees of the 0.5 C. P. treatment significantly heavier than trees of the check culture. The trees of the 1.0 C. P. cultures are significantly superior in shoot weight and very significantly superior in total weight, and those of 1.0 C. P. (S) treatment are very significantly superior in root and total weight to trees of the check culture.

There is no significant difference in any of the weight categories between the trees of the two different 1-ton colloidal phosphate treatments.

Significant differences in root-shoot ratio do not exist between the trees of any of the treatments.

Summary of Results

Slash pine seedlings responded to soil treatments involving colloidal phosphate applications ranging from 0.5 to 25 tons per acre. The amount of response varied with the amount of colloidal phosphate used and with different tree characteristics, and was not always significant. Only the 25-ton culture caused enough response in stem growth to yield a significant difference in stem length at the end of the experiment between it and all except the 5-ton treatment. The difference in stem length between trees in the 5-ton and 25-ton cultures did not fall far short of being significant, however.

In branch development, trees in the 25-ton culture took the lead immediately. At 8 weeks, this culture had produced significantly more branched trees and significantly more branches per tree than any other culture. It maintained this advantage in number of branched trees at 10 weeks, but had lost it by 15 weeks. At the end of the experiment, all treatments had produced a high percent of branched trees and a large number of branches per tree. In the last feature all colloidal phosphate cultures surpassed the check culture, although not significantly, and the 25 C. P. culture ranked highest.

Differences in stem diameter and total weight were rather consistently related to the amount of colloidal phosphate added to the soil. As the amount of this material was increased, diameter of the stem and weight of tree increased, although not proportionately. The trees in the 25-ton culture had significantly larger stems and greater weights than those in all other cultures.

Root-shoot ratio was not significantly affected by amount of colloidal phosphate in the culture.

The 25-ton treatment produced the best trees but in many respects trees from this culture were not significantly superior to those from the 5-ton culture.

Colloidal phosphate applied to the surface of the soil at a rate of 1 ton per acre produced about the same effect on the trees as the same quantity of this material mixed in the upper 4 inches of soil.

When the trees were rated by the composite tree index scale, (see Table 48) values of 4.2, 6.8, 8.2, 11.3, and 8.3 were secured for trees in the 0.5 C. P., 1.0 C. P., 5 C. P., 25 C. P., and 1.0 C. P. (S) treatments, respectively. The value of 11.3 for the 25 C. P. culture is comparable to the 11.0 for the 20 C. P. +(4x)15NK culture of the 1943-44 experiment.

Experiment II

The analyses of variance of all tree characteristics in this experiment are based on the six cultures involving different quantities of P_2O_5 ranging from 0 to 480 pounds per acre.

Soil Treatments

The character of the soil treatments is shown in Table 57.

Length of Stem

Mean lengths of stems at three 5-week intervals for trees in each treatment are presented in Table 58. Differences in stem length between trees in various treatments are very small and not significant at any time in the experiment. No trend is even indicated. Only one treatment produced trees with longer stems than the check, but the difference in stem length between trees of these two cultures was never more than 7 percent. It is noteworthy that the various treatments maintained their relative positions in stem length throughout the experiment, that is, the treatment which ranked lowest at 10 weeks held the same position at 15 and 20 weeks, and the one which ranked highest at 10 weeks held that position at 15 and 20 weeks.

Increasing the amount of phosphorous in the soil did not affect stem growth (Figs. 12 and 13).

Branch Development

Branch development as expressed by number of branched trees and number of branches per tree is shown in Tables 59 and 60. Differences between cultures in number of branched trees are evident throughout the experiment, these differences becoming progressively more pronounced from the fifth to the fifteenth week, the differences being significant at 15 weeks. At that time the 240P culture had produced very significantly more branched trees

Table 57. --Type and time of nutrient application in Experiment II, 1944-45

Treatment		Applied prior to planting
		P_2O_5
No.	Designation	Pounds per acre
7	30P	30
8	60P	60
9	120P	120
10	240P	240
11	480P	480
12	Check	-

Table 58. --Mean length of stem 10, 15, and 20 weeks after initial treatment, Experiment II, 1944-45

Treatment	Time after initial treatment		
	10 weeks	15 weeks	20 weeks
	Length of stem - mm.		
30P	14.5	51.0	104.0
60P	14.2	48.5	95.8
120P	14.5	50.0	101.8
240P	13.5	46.4	90.5
480P	16.3	54.3	106.7
Check	15.2	52.6	106.4
Standard deviation	0.9	2.8	5.6
F value treatment	1.14	1.13	1.33

than the 60P culture and significantly more than the check culture. The 480P culture had produced significantly more branched trees than the 60P culture. There appears to be a tendency toward a gradual increase in number of branched trees with an increase in the amount of phosphorous in the culture up to 240 pounds of P_2O_5, after which there is a drop. This trend is somewhat confused, however, by the behavior of the trees in the 60P culture.

Differences in number of branches per tree between the five treatments were at no time significant, but came nearest to being so in the earlier stages of the experiment (see F values, Table 60). The heavier applications of phosphorous tended to stimulate branching, but as time elapsed, the trees in the cultures receiving lighter applications recovered from their early disadvantage. Trees in all cultures receiving supplementary phosphorous had more branches per tree than those in the check culture at the end of the experiment, but differences between treatments were not significant.

Stem Diameter, Dry Weights, and
Root-Top Ratios

The mean stem diameter, dry weights, and root-top ratio of trees in each treatment of Experiment II are shown in Table 61. Differences between treatment means in all five categories included in Table 61 are small, and in no case are they significant. Although in stem diameter and the three weight categories the 480P culture yielded trees superior to those in the other phosphorous cultures, only in diameter is a consistent trend in the values evident, the diameters showing a gradual increase with increases of phosphorous in the culture. However a significant difference in diameter does not exist between any two treatments means.

Table 59. --Number of branched trees 5, 8, 10, 15, and 20 weeks after initial treatment, Experiment II, 1944-45

Treatment	Time after initial treatment				
	5 weeks	8 weeks	10 weeks	15 weeks	20 weeks
	Branched trees - percent of total				
30P	5.0	22.5	22.5	27.5	30.0
60P	0.0	12.5	12.5	12.5	20.0
120P	2.5	15.0	20.0	32.5	37.5
240P	2.5	45.0	45.0	47.5	47.5
480P	5.0	32.5	32.5	37.5	37.5
Check	5.0	17.5	20.0	22.5	30.0
Standard deviation	3.2	7.8	7.8	7.0	7.2
Difference between treatment means to be significant at 5 and 1 percent				21.6 30.3	
F value treatment	0.43	2.60	2.57	3.41*	1.98

*Significant at 5 percent

Table 60. --Mean number of branches per tree 8, 10, 15, and 20 weeks after initial treatment, Experiment II, 1944-45.

Treatment	Time after initial treatment: 8 weeks	10 weeks	15 weeks	20 weeks
	Branches per tree - number			
30P	0.25	0.55	0.68	1.05
60P	0.12	0.30	0.65	0.85
120P	0.15	0.30	0.52	1.00
240P	0.45	0.70	0.78	0.78
480P	0.42	0.72	0.90	1.02
Check	0.25	0.38	0.52	0.68
Standard deviation	0.12	0.14	0.19	0.24
F value treatment	1.44	1.89	0.48	0.25

Table 61. --Mean stem diameter, dry weight, and root-shoot ratio in Experiment II, 1944-45

Treatment	Diameter of stem	Dry weight: Shoot	Root	Total	Root-Shoot Ratio
	mm.	grams			
30P	3.54	1.29	0.74	2.03	0.57
60P	3.58	1.16	0.72	1.88	0.62
120P	3.64	1.25	0.78	2.03	0.62
240P	3.65	1.19	0.76	1.95	0.64
480P	3.70	1.33	0.82	2.15	0.62
Check	3.56	1.26	0.75	2.01	0.60
Standard deviation	0.07	0.07	0.04	0.12	0.03
F value treatment	0.73	0.82	1.07	0.54	0.44

Summary of Results

Varying the amount of P_2O_5 in the soil cultures from 30 to 480 pounds had little effect on young slash pine seedlings. Only in one tree characteristic- number of branched trees- was there a temporary significant difference. Stem diameter showed the most consistent relationship to the amount of phosphorous in the cultures, stem diameter increasing with increases in quantity of phosphorous. However, the increases in diameter are not proportional to the increases in phosphorous, and the differences in stem diameter between trees in different treatments are not significant.

Slash pine seedlings failed to respond to varying amounts of phosphorous alone. Rated by the composite tree index scale, the 30P, 60P, 120P, 240P, and 480P cultures have values of -0.2, -0.3, 0.6, 0.2, and 1.5, respectively.

Experiment III

Soil Treatment

The type and time of nutrient application in each treatment is shown in Table 62.

The analyses of variance are based on the twelve treatments involving the use of various quantities of P_2O_5 with and without uniform amounts of other nutrient elements. The treatment effect can be broken down into three parts: (1) effect of varying quantities of P_2O_5 in treatments; (2) effect of different nutrient elements used in combination with phosphorous; and (3) the effect of the interaction between the quantity of phosphorous and the nutrients used in combination with it. These three categories are referred to in the tables and text as "rate", "combination", and "rate x combination", respectively.

The mean values of different characteristics of the trees in the check treatment are shown in all tables for comparative purposes.

Length of Stem

The mean lengths of stems of trees at different periods of time after the initial treatment are presented in Table 63. As shown in the table, there were no significant differences in stem length between different treatments, between various rates at which phosphorous was applied, between various combinations of nutrients used to supplement the phosphorous, or between the interaction between the last two factors.

Actual differences in stem length of trees in various treatments were very small throughout the experiment. The maximum difference between two cultures at 10 weeks (60P and 480P) was 15 percent, and at 20 weeks was 11.3 percent. All treatments did not maintain their relative positions throughout

Table 62. --Type and time of nutrient application in Experiment III, 1944-45

Treatment		Time of nutrient application									
		Prior to planting				5 weeks after planting		10 weeks after planting		15 weeks after planting	
		P_2O_5	N	K_2O	Ca	N	K_2O	N	K_2O	N	K_2O
No.	Designation	Pounds per acre									
8	60P	60	-	-	-	-	-	-	-	-	-
9	120P	120	-	-	-	-	-	-	-	-	-
11	480P	480	-	-	-	-	-	-	-	-	-
12	Check	-	-	-	-	-	-	-	-	-	-
13	60P-K	60	-	15	-	-	15	-	15	-	15
14	120P-K	120	-	15	-	-	15	-	15	-	15
15	480P-K	480	-	15	-	-	15	-	15	-	15
16	60P-NK	60	15	15	-	15	15	15	15	15	15
17	120P-NK	120	15	15	-	15	15	15	15	15	15
18	480P-NK	480	15	15	-	15	15	15	15	15	15
19	60P-Ca NK	60	15	15	200	15	15	15	15	15	15
20	120P-Ca NK	120	15	15	200	15	15	15	15	15	15
21	480P-Ca NK	480	15	15	200	15	15	15	15	15	15

Table 63. --Mean length of stem 10, 15, and 20 weeks after initial treatment, Experiment III, 1944-45

Treatment	Time after initial treatment		
	10 weeks	15 weeks	20 weeks
	Length of stem - mm.		
60P	14.2	48.5	95.8
120P	14.5	50.0	101.8
480P	16.3	54.3	106.7
60P-K	15.4	49.8	100.4
120P-K	15.7	49.5	99.1
480P-K	15.1	49.2	100.3
60P-NK	16.1	50.8	99.0
120P-NK	15.1	47.0	98.1
480P-NK	15.8	49.2	96.5
60P-Ca NK	16.1	48.2	97.2
120P-Ca NK	14.8	47.3	97.4
480P-Ca NK	15.7	49.7	101.9
Check	15.2	52.6	106.4
Standard deviation	0.9	2.7	5.1
F value treatment	0.68	0.49	0.42
F value rate	0.71	0.71	0.51
F value combination	0.65	0.50	0.49
F value rate x combination	0.69	0.65	0.40

the experiment. The trees in the 480P treatment had the longest stems on each observation date, however. The trees in the cultures containing nitrogen and potassium and in those containing calcium, nitrogen, and potassium had somewhat shorter stems than trees in most other cultures at the end of the experiment, whereas trees in some of the former cultures had longer stems than those in the latter treatments at 5 weeks.

When the mean stem lengths of the trees in the twelve cultures of Experiment III are compared with the mean length of those in the check treatment, it is obvious that the supplemental nutrients were not effective in stimulating stem growth. On the contrary, in all except one instance, they had a tendency to have a depressing effect on stem growth although the effect was not significant (Figs. 14, 15, 16, 17).

Branch Development

Branch development as expressed by the proportion of branched trees and by number of branches per tree is shown in Tables 64 and 69. Table 64 shows a wide range in the number of branched trees produced by different soil treatments, and except for 5 weeks after the initial treatment, the differences between treatments were very significant. The rate at which phosphorous was used as well as the combination of nutrient elements used with phosphorous produced either significant or very significant differences in the number of branched trees.

The influence of rate at which phosphorous was used on the number of branched trees is brought out effectively in Table 65. As the amount of phosphorous was increased, the number of branched trees increased. An anlaysis of this table reveals that the 480-pound rate was very significantly superior to the 60-pound rate in number of branched trees produced. The former rate was significantly superior to the 120-pound rate at 8 weeks and very significantly superior at 10 weeks, but lost the advantage later.

Table 64. --The number of branched trees 5, 8, 10, 15, and 20 weeks after the initial treatment, Experiment III, 1944-45

Treatment	Time after initial treatment				
	5 weeks	8 weeks	10 weeks	15 weeks	20 weeks
	Branched trees - percent of total				
60P	0.0	12.5	12.5	12.5	20.0
120P	2.5	15.0	20.0	32.5	37.5
480P	5.0	32.5	32.5	37.5	37.5
60P-K	0.0	17.5	40.0	47.5	47.5
120P-K	2.5	32.5	35.0	42.5	45.0
480P-K	2.5	22.5	37.5	42.5	45.0
60P-NK	7.5	35.0	40.0	50.0	50.0
120P-NK	10.0	35.0	52.5	55.0	57.5
480P-NK	17.5	60.0	72.5	75.0	75.0
60P-Ca NK	7.5	52.5	55.0	57.5	60.0
120P-Ca NK	12.5	50.0	60.0	65.0	70.0
480P-Ca NK	22.5	70.0	80.0	80.0	80.0
Check	5.0	17.5	20.0	22.5	30.0
Standard deviation	5.6	6.8	7.0	6.8	7.2
Difference between treatment means to be significant at 5 and 1 percent	-.	20.0	20.1	19.6	20.7
	-	26.9	27.0	26.4	27.8
F value treatment	1.80	7.62**	8.17**	7.46**	5.78**
F value rate	2.77	6.21**	7.70**	6.20**	4.34*
F value combination	1.12	21.24**	22.46**	20.34**	16.47**
F value rate x combination	1.81	1.29	1.19	1.44	0.92

*Significant at 5 percent.
**Significant at 1 percent.

Table 65. --The number of branched trees 5, 8, 10, 15, and 20 weeks after initial treatment in relation to rate of phosphorous application, Experiment III, 1944-45

Rate	Time after initial treatment				
	5 weeks	8 weeks	10 weeks	15 weeks	20 weeks
	Branched trees - percent of total				
60	3.8	28.1	36.9	41.9	44.4
120	7.5	33.1	41.9	48.8	52.5
480	11.8	45.0	55.6	58.7	59.4
Difference between rate means to be significant at: 5 and 1 percent.		10.0 13.5	10.0 13.5	9.8 13.2	10.4 13.9

Table 66. --The number of branched trees 5, 8, 10, 15, and 20 weeks after initial treatment in relation to combination of elements used with phosphorous, Experiment III, 1944-45

Combination	Time after initial treatment				
	5 weeks	8 weeks	10 weeks	15 weeks	20 weeks
	Branched trees - percent of total				
P	2.5	16.6	21.7	27.5	31.7
P-K	1.7	24.2	37.5	44.2	45.8
P-NK	11.7	43.3	55.0	60.0	60.8
P-CaNK	14.2	57.5	65.0	67.5	70.0
Difference between combination means to be significant at 5 and 1 percent		11.6 15.5	11.6 15.5	11.3 15.2	12.0 16.1

Table 67. --A comparison of the effect of various nutrient combinations on the number of branched trees in Experiment III, 1944-45

Combination	Combinations superior to combinations in column 1							
	Time after initial treatment							
	8 weeks		10 weeks		15 weeks		20 weeks	
	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%
P		P-NK P-CaNK		P-NK P-CaNK		P-K P-NK P-CaNK	P-K	P-NK P-CaNK
P-K		P-NK P-CaNK		P-NK P-CaNK		P-NK P-CaNK	P-NK	P-CaNK
P-NK	P-CaNK							
P-CaNPK								

Table 68. --Comparison of number of branched trees at 8 and 20 weeks by treatments, Experiment III 1944-45

	Time after initial treatment			
	8 weeks		20 weeks	
	Treatments superior to treatment in column 1			
Treatment	at 5%	at 1%	at 5%	at 1%
60P	480P, 120P-K	60P-NK, 120P-NK 480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK	60P-K 120P-K 480P-K	60P-NK, 120P-NK 480P-NK, 60P-CaNK 120P-CaNK 480P-NK
120P	60P-NK 120P-NK	480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK
480P	60P-CaNK 120P-CaNK	480P-NK 480P-CaNK		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK
60P-K		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK		480P-NK 480P-CaNK
120P-K	60P-CaNK 120P-CaNK	480P-NK 480P-CaNK		480P-NK 480P-CaNK
480P-K		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK
60P-NK	480P-NK	480P-CaNK		480P-CaNK
120P-NK	480P-NK	480P-CaNK		
480P-NK				
60P-CaNK				
120P-CaNK	480P-CaNK			
480P-CaNK				
Check		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK		480P-NK, 60P-CaNK 120P-CaNK 480P-CaNK

The influence of the elements used in combination with phosphorous on the number of branched trees is shown in Table 68. As the number of elements used in combination with phosphorous was increased, the number of branched trees increased. The addition of potassium did not cause enough increase in number of branched trees to result in a significant difference between the P and P-K treatments during the first 10 weeks, but thereafter the difference was significant. This and other relationships are evident in Table 67. When nitrogen or nitrogen and calcium are included in the nutrient culture, the number of branched trees becomes significantly greater than when only phosphorous or phosphorous and potassium make up the nutrient culture (Fig. 15). The P-CaNK cultures are only temporarily significantly superior in numbers of branched trees to the P-NK cultures at 8 weeks.

An examination of the data on number of branched trees by individual treatments in Table 64 also bears out the relationships discussed in the foregoing paragraphs. Comparisons of the effect of various soil treatments on the number of branched trees on two dates are presented in Table 68. The relationships between treatments on the two dates are similar. In general, there are significant differences in number of branched trees between fewer treatments at 20 weeks than at 8 weeks. This signifies that although branching was slow in being initiated by some cultures, the deficiency in number of branched trees was overcome somewhat with the passing of time. Particularly evident in Table 68 is the general superiority in number of branched trees of the cultures that received supplemental nitrogen and potassium.

Table 69 shows much variation through the experiment among the different soil treatments in the number of branches per tree. The differences are greatest in the early stages of the experiment. At 8 weeks the 480P-CaNK

Table 69. --The number of branches per tree 8, 10, 15, and 20 weeks, after the initial treatment, Experiment III, 1944-45

Treatment	Time after initial treatment: 8 weeks	10 weeks	15 weeks	20 weeks
	Branches per tree - number			
60P	0.12	0.30	0.60	0.85
120P	0.15	0.30	0.52	1.00
480P	0.42	0.72	0.90	1.02
60P-K	0.35	0.82	1.08	1.08
120P-K	0.38	0.70	1.00	1.18
480P-K	0.30	0.78	1.12	1.60
60P-NK	0.52	0.78	1.00	1.12
120P-K	0.48	0.80	0.98	1.15
480P-NK	1.42	2.08	2.28	2.35
60P-CaNK	1.12	1.60	1.82	2.00
120P-CaNK	0.98	1.30	1.65	1.75
480P-CaNK	1.55	2.15	2.32	2.35
Check	0.25	0.38	0.52	0.68
Standard deviation	0.18	0.21	0.22	0.29
Difference between treatment means to be significant at 5 and 1 percent	0.52 0.70	0.62 0.83	0.79 1.06	0.83 1.12
F value treatment	7.30**	8.34**	4.84**	3.45**
F value rate	6.93**	10.82**	6.46**	5.08*
F value combination	18.62**	18.98**	11.39**	7.07**
F value rate x combination	1.76	2.18	1.03	0.92

*Significant at 5 percent.
**Significant at 1 percent.

culture (greatest number of branches) had produced trees with nearly thirteen times as many branches per tree as the 60P culture (lowest number of branches). At 20 weeks, however, trees in the former culture had approximately three times as many branches as trees in the latter. Similar, although less pronounced, trends are evident in other treatments.

Mean number of branches per tree at various times in relation to rate of application of phosphorous is presented in Table 70. An analysis of this table reveals that trees in the 480-pound-application cultures had very significantly (or significantly) more branches per tree than trees in either the 60-pound- or 120-pound- application cultures throughout the experiment. There were no significant differences in number of branches per tree between the 60- and 120-pound-application cultures.

Mean number of branches per tree at various times in relation to combination of elements used with phosphorous is presented in Table 71. Distinct differences in mean number of branches are evident between cultures containing different combinations of supplemental nutrients. The greatest differences are between the P and P-CaNK cultures. At 8 weeks, the latter had produced trees with more than five times as many branches as the former, and at 20 weeks, with more than twice as many. Differences between other combinations are less pronounced, although as shown in Table 72, many of the differences are either significant or very significant. In all four combinations, relative differences in number of branches per tree decreased with elapsed time; but the differences in terms of actual numbers of branches were nearly the same at 20 weeks as at 8 weeks. The pronounced effect of the inclusion of nitrogen and calcium in the nutrient treatment on number of branches per tree is evident in Table 72. It is noteworthy that the P-CaNK cultures produced significantly more branches per tree than the

Table 70. --Number of branches per tree at different times after initial treatment in relation to rate of phosphorous application, Experiment III, 1944-45

Rate	Time after initial treatment: 8 weeks	10 weeks	15 weeks	20 weeks
	Branches per tree - number			
60	0.53	0.88	1.19	1.26
120	0.49	0.78	0.98	1.27
480	0.92	1.43	1.66	1.83
Difference between rate means to be significant at 5 and 1 percent	0.26	0.31	0.37	0.42
	0.35	0.42	0.50	0.56

Table 71. --Number of branches per tree at different times after initial treatment in relation to combination of elements used with phosphorous, Experiment III, 1944-45.

Combination	Time after initial treatment: 8 weeks	10 weeks	15 weeks	20 weeks
	Branches per tree - number			
P	0.23	0.44	0.68	0.96
P-K	0.34	0.77	1.07	1.28
P-NK	0.81	1.22	1.42	1.54
P-CaNK	1.22	1.68	1.93	2.03
Difference between combination means to be significant at 5 and 1 percent	0.30	0.37	0.46	0.48
	0.41	0.49	0.61	0.64

P-NK cultures, thus demonstrating that calcium played a significant role in this aspect of branching (Figs. 15 and 17). It should be noted that when only potassium was added with phosphorous, number of branches per tree was not affected significantly.

Comparison of number of branches per tree by individual soil treatments is presented in Table 73. It should be noted that none of the phosphorous treatments and only one of the phosphorous-potassium treatments (480P-K) produced trees with significantly more branches than the check, that only one of the phosphorous-nitrogen-potassium cultures (480P-NK) produced trees with more branches than the check, and that all phosphorous-calcium-nitrogen-potassium treatments produced trees with more branches than the check. The aforementioned five treatments are surpassed in number of branches per tree by no culture at the end of the experiment. Of these five cultures, the 60P-CaNK culture had increased branching with the greatest economy of nutrient materials.

In general, those cultures which were most effective in increasing the number of branched trees were also the most effective in increasing the number of branches per tree.

Diameter of Stem

Mean diameter of stems of trees and a comparison of stem diameters of trees in different treatments are presented in Table 74. The largest mean diameter is 10.4 percent greater than that of the check culture. The analysis of variance reveals that rate, combination, and treatment are responsible for significant differences in stem diameter. The 480-pound application of phosphorous produced trees significantly larger in diameter (3.85 mm.) than the 120-pound application (3.75 mm.) and very significantly larger than those of the 60-pound application (3.68 mm.). The difference of

Table 72. --A comparison of the effect of various nutrient combinations on the number of branches per tree in Experiment III, 1944-45

Combination	Time after initial treatment							
	8 weeks		10 weeks		15 weeks		20 weeks	
	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%
P		P-NK P-CaNK		P-NK P-CaNK		P-NK P-CaNK	P-NK	P-CaNK
P-K		P-NK P-CaNK	P-NK	P-CaNK		P-CaNK		P-CaNK
P-NK		P-CaNK	P-CaNK		P-CaNK		P-CaNK	
P-CaNK								

Table 73. --A comparison of the number of branches per tree by soil treatment 8 and 20 weeks after initial treatment, Experiment III, 1944-45

	Time after initial treatment			
	8 weeks		20 weeks	
	Treatments superior to treatments in column 1			
Treatment	at 5%	at 1%	at 5%	at 1%
60P		480P-NK 60P-CaNK 120P-CaNK 480P-CaNK	120P-CaNK	480P-NK 60P-CaNK 480P-CaNK
120P		480P-NK 60P-CaNK 120P-CaNK 480P-CaNK	60P-CaNK	480P-NK 480P-CaNK
480P	120P-CaNK	480P-NK 60P-CaNK 480P-CaNK	60P-CaNK	480P-NK 480P-CaNK
60P-K	120P-CaNK	480P-NK 60P-CaNK 480P-CaNK	60P-CaNK	480P-NK 480P-CaNK
120P-K	120P-CaNK	480P-NK 60P-CaNK 480P-CaNK		480P-NK 480P-CaNK
480P-K	120P-CaNK	480P-NK 60P-CaNK 480P-CaNK		
60P-NK	60P-CaNK	480P-NK 480P-CaNK	60P-CaNK	480P-NK 480P-CaNK
120P-NK	60P-CaNK	480P-NK 480P-CaNK	60P-CaNK	480P-NK 480P-CaNK
480P-NK				
60P-CaNK				
120P-CaNK	480P-CaNK			
480P-CaNK				
Check		480P-NK 60P-CaNK 120P-CaNK 480P-CaNK	480P-K 120P-CaNK	480P-NK 60P-CaNK 480P-CaNK

Table 74. --Mean diameter of stem by treatments and comparison of difference in stem diameters between treatments, Experiment III, 1944-45

Treatment	Diameter of stem - mm.	Treatments superior to treatments in column 1 at 5%	Treatments superior to treatments in column 1 at 1%
60P	3.58	120P-K, 60P-NK 60P-CaNK	480P-K, 480P-NK 120P-CaNK, 480P-CaNK
120P	3.64	480P-K	480P-NK, 120P-CaNK 480P-CaNK
480P	3.70	480P-NK, 120P-CaNK 480P-CaNK	
60P-K	3.60	60P-NK 60P-CaNK	480P-K, 480P-NK 120P-CaNK, 480P-CaNK
120P-K	3.77		
480P-K	3.86		
60P-NK	3.78		
120P-NK	3.73	480P-NK, 480P-CaNK	
480P-NK	3.91		
60P-CaNK	3.78		
120P-CaNK	3.90		
480P-CaNK	3.93		
Check	3.56	120P-K, 60P-NK 60P-CaNK	480P-K, 480P-NK 120P-CaNK, 480P-CaNK
Standard deviation	0.06		
Difference between treatment means to be significant at 5 and 1 percent	0.18 0.24		
F value treatment	3.91**		
F value rate	7.55**		
F value combination	7.81**		
F value rate x combination	0.75		

**Significant at 1 percent.

0.07 mm. in diameter between the trees in the 60- and 120-pound-application cultures is not great enough to be significant. Trees in the P-NK and P-CaNK cultures with mean diameters of 3.80 and 3.87 mm., respectively, have very significantly larger diameters than those in the P cultures with a mean diameter of 3.64 mm.; those in the P-K (mean diameter 3.74 mm.) and P-CaNK cultures have significantly larger diameters than those in the P and P-K cultures, respectively. It is evident that diameters can be increased by relatively large amounts of phosphorous or by nutrient cultures containing nitrogen, phosphorous, and potassium, or these elements together with calcium.

The inferiority of the check, phosphorous, and 60P-K treatments with respect to diameter of stem of the trees is shown clearly in Table 74 by the relatively large number of cultures which produced trees with larger stem diameters than these treatments. On the other hand, only one culture containing nitrogen (120P-NK) produced trees that were exceeded in mean stem diameter by other treatments.

Although diameter of stem can be increased significantly by any one of several soil treatments, it can be accomplished most efficiently when at least three - N, P, and K - of the four nutrient elements are applied (Figs.15 and 17). Large increases can be secured only by a considerable increase in the amount of available phosphorous in the culture.

Dry Weight of Shoot, Root, and Entire Tree, and
Root-Shoot Ratio

The mean dry weights of shoot, root, and entire tree, and root-shoot ratio of trees in each treatment in Experiment III are presented in Table 75. There is considerable difference in the mean weights of the trees from the cultures yielding the lightest and the heaviest trees, but outside

Table 75. --Mean dry weight of shoot, root, and entire tree and root-shoot ratio of trees in Experiment III, 1944-45

Treatment	Dry Weight Shoot	Root	Total	Root-Shoot Ratio
	Grams			
60P	1.16	0.72	1.88	0.62
120P	1.25	0.78	2.03	0.62
480P	1.33	0.82	2.15	0.62
60P-K	1.25	0.82	2.07	0.66
120P-K	1.26	0.80	2.06	0.63
480P-K	1.37	0.86	2.23	0.63
60P-NK	1.29	0.85	2.14	0.66
120P-NK	1.25	0.81	2.06	0.65
480P-NK	1.38	0.88	2.26	0.64
60P-CaNK	1.30	0.75	2.05	0.58
120P-CaNK	1.32	0.83	2.15	0.63
480P-CaNK	1.43	0.91	2.24	0.64
Check	1.26	0.75	2.01	0.60
Standard deviation	0.07	0.04	0.09	0.04
Difference between rate means to be significant at 5 and	0.10	0.06	0.14	
1 percent	0.13	0.09	0.18	
F value treatment	1.27	1.50	1.40	0.53
F value rate	4.22*	3.94*	3.86*	0.19
F value combination	1.34	1.58	2.04	1.03
F value rate x combination	0.25	0.06	0.07	0.39

*Significant at 5 percent.

of these two extremes, differences are relatively small. Because the standard deviation is large, the analysis of variance reveals no significant difference due to treatment. Differences in weights caused by the rate at which phosphorous was used were significant. The 480-pound application produced roots (0.87 gr.) and shoots (1.38 gr.) very significantly heavier than the 60-pound application (0.78 and 1.24 gr.) and significantly heavier than the 120-pound application (0.81 and 1.27 gr.). The same relationships held for the weight of the entire tree.

Four treatments yielded trees with lighter shoots, one treatment yielded trees with lighter roots, and two treatments yielded trees with lighter total weight than the check; but the differences were very small and not significant.

Differences in root-shoot ratio were small, and in no way were they significant. All except one culture (60P-CaNK) yielded trees with slightly larger root-shoot ratios than the check culture.

Summary of Results

Stem length, root-shoot ratio, and weight were not affected significantly by type of treatment. However, weight was influenced by the rate of application of phosphorous, the 480-pound-application cultures producing heavier trees than both the 60-pound- and the 120-pound- application cultures.

Differences in stem diameter are significant and are due to rate, combination, and treatment. Diameter increased with increased increments of phosphorous and with an increase in the number of elements used in the nutrient culture. High rates of phosphorous supplemented by nitrogen, potassium, and calcium resulted in trees of larger diameter.

Branch development was related to rate, combination, and treatments in much the same way as stem diameter. This seems to indicate that these two features may be related.

An increase in branching may be an indication of superior tree vigor. Certainly an increase in diameter means a sturdier plant, especially when height has not increased along with diameter. Since the superiority in these characteristics was not made at the expense of the root system no depreciation in tree quality has occurred. Thus trees with superior branching and diameter might prove to be the best planting stock.

Trees in the 60P-K, 120P-K, 480P-K, 60P-NK, 120P-NK, 480P-NK, 60P-CaNK, 120 P-CaNK, and 480P-CaNK cultures have composite tree index values of 1.0, 2.1, 4.8, 2.9, 2.0, 6.6, 3.5, 5.5, and 6.8, respectively. Trees produced in cultures containing calcium were on the whole the best.

Experiment IV

Soil Treatment

The type and time of nutrient application are shown in Table 76.

Length of Stem

Mean lengths of stems at four intervals of time after the initial treatment of the soil are shown in Table 77. Differences in mean stem length are small throughout the experiment, and were significant only at $26\frac{1}{2}$ weeks, when trees in the 60P+(4x)15NK culture were significantly taller than those in the check, and those in the 60P+(4x)15NK(S) and the 60P+(2x)30NK cultures were very significantly taller than those in the check. In other words, all cultures receiving supplemental nutrients produced trees at the end of the experiment that were either significantly or very significantly taller than those in the check. There were no significant differences in stem length of trees in the three cultures receiving supplemental nutrients. At 10 and $26\frac{1}{2}$ weeks, the trees in the check treatment were 8.8 percent shorter than those in the cultures which had produced the tallest trees; but on the first date, the 60P+(4x)15NK culture had the tallest trees, while on the last date, the 60P+(4x)15NK(S) culture had the tallest trees. The culture to which all nutrients had been applied to the surface of the soil had produced the tallest trees at the end of the experiment, but this superiority was attained during the last $6\frac{1}{2}$ weeks of the experiment.

Branch Development

Number of branched trees and mean number of branches per tree for the four treatments in Experiment IV are presented in Tables 78 and 79, respectively. Differences in number of branched trees due to treatment were

Table 76. --Type and time of nutrient application in Experiment IV 1944-45

Treatment		Time of nutrient application										
		Prior to planting			5 weeks after planting		10 weeks after planting		$11\frac{1}{2}$ weeks after planting		15 weeks after planting	
		P_2O_5	N	K_2O	N	K_2O	N	K_2O	B	Mn	N	K_2O
No.	Designation	Pounds per acre										
22	60P+(4x)15NK	60	15	15	15	15	15	15	-	-	15	15
23*	60P+(4x)15NK(S)	60	15	15	15	15	15	15	1	20	15	15
24	60P+(2x)30NK	60	-	-	-	-	30	30	1	40	30	30
25	Check	-	-	-	-	-	-	-	-	-	-	-

*All nutrients applied to surface of soil, while first application of nutrients in Treatments 22 and 24 were mixed in upper 4 inches of soil.

Table 77. --Mean length of stem 10, 15, 20, and $26\frac{1}{2}$ weeks after initial treatment, Experiment IV, 1944-45

Treatment	Time after initial treatment			
	10 weeks	15 weeks	20 weeks	$26\frac{1}{2}$ weeks
	Length of stem - mm.			
60P+(4x)15NK	19.7	40.7	84.0	171.8
60P+(4x)15NK(S)	18.4	38.0	83.8	177.8
60P+(2x)30NK	18.4	41.4	85.8	174.8
Check	18.1	39.0	82.9	163.5
Standard deviation	0.7	2.0	4.1	2.1
Difference between treatment means to be significant at 5 and 1 percent				6.6 9.6
F value treatment	1.12	0.62	0.09	5.59*

*Significant at 5 percent

significant and in number of branches per tree were very significant throughout the experiment. Branch development occurred earliest in the culture that received all nutrients as surface applications (60P+(4x)15NK(S)). Trees in this treatment maintained this superiority. Although the extent of the superiority of the 60P+(4x)15NK treatment to other treatments in number of branched trees varied during the experiment, it was significantly superior to the 60P+(2x)30NK culture and very significantly superior to the check culture at 10 weeks and at 26½ weeks. Likewise, the extent of the superiority of the 60P+(4x)15NK(S) culture to the other cultures varied in the course of the experiment. It was very significantly superior to the 60P+(2x)30NK and the check cultures at 5 weeks and significantly superior to the former and very significantly superior to the latter at 26½ weeks. The number of branched trees in the 60P+(2x)30NK culture was never significantly greater than that of other cultures in the experiment, but it was nearly significantly greater than that of the check at 26½ weeks.

Only the 60P+(4x)15NK(S) treatment showed significant superiority to one or more treatments throughout the experiment in the number of branches per tree, trees in this culture having either significantly or very significantly more branches than those in the 60P+(2x)30NK and check cultures at all times. Trees in the 60P+(4x)15NK culture showed significant superiority to trees in the check culture at 20 weeks and maintained this superiority to the end of the experiment. At no time did the 60P+(2x)30NK treatment have significant superiority over any treatment in number of branches per tree.

It is obvious that two 30-pound applications of N and K_2O are not so effective in stimulating branching as four 15-pound applications of these elements.

Table 78. --Number of branched trees at five intervals of time after initial treatment, Experiment IV 1944-45

Treatment	Time after initial treatment				
	5 weeks	10 weeks	15 weeks	20 weeks	26½ weeks
	Branched trees - percent of total				
60P+(4x)15NK	20.0	35.0	40.0	55.0	65.0
60P+(4x)15NK(S)	30.0	60.0	60.0	65.0	72.5
60P+(2x)30NK	2.5	15.0	22.5	37.5	47.5
Check	0.0	7.5	10.0	22.5	30.0
Standard deviation	4.4	8.3	5.6	6.6	5.6
Difference between treatment means to be significant at 5 and 1 percent	13.6 19.5	26.1 37.5	18.3 26.3	20.1 28.9	17.9 25.7
F value treatment	10.50**	8.23**	14.72**	7.97**	11.53**

**Significant at 1 percent.

Table 79. --Number of branches per tree at four intervals of time after initial treatment, Experiment IV 1944-45

Treatment	Time after initial treatment: 10 weeks	15 weeks	20 weeks	26½ weeks
	Branches per tree - number			
60P+(4x)15NK	0.75	0.92	1.28	1.48
60P+(4x)15NK(S)	1.32	1.45	1.70	1.92
60P+(2x)30NK	0.22	0.48	0.80	1.10
Check	0.15	0.32	0.50	0.78
Standard deviation	0.22	0.21	0.23	0.25
Difference between treatment means to be significant at 5	0.70	0.68	0.73	0.79
and 1 percent	1.01	0.98	1.05	1.15
F value	6.16*	5.66*	5.35*	3.89*

*Significant at 5 percent.

Diameter of Stem, Dry Weight of Shoot, Root, and
Entire Tree, and Root-Shoot Ratio

Mean diameter of stem, dry weights of shoot, root, and entire tree, and root-shoot ratio for trees in each culture of Experiment IV are presented in Table 80. Difference in means due to treatment effect were significant for shoot and total weight. All three cultures receiving supplemental nutrients produced trees with larger diameters and greater root weights than those in the check culture, but none were significantly superior. Differences in diameter due to soil treatment, were not far from being significant (F value 3.86 for treatment would mean significant at 5 percent).

All cultures receiving supplemental nutrients yielded trees with significantly heavier tops than did the check culture. The treatment in which all nutrients were applied to the surface ((60P+(4x)15NK(S)) yielded trees with the heaviest shoots, and they were very significantly heavier than the tree shoots from the check culture. Trees from the former treatment were significantly heavier than those from 60P+(4x)15NK culture (differences between these treatments are the method of applying the nutrients and the addition of Mn and B in Treatment 23). Trees from this treatment were also significantly surpassed in shoot weight by trees from the 60P+(2x)30NK treatment.

Significant differences between total weights of trees in different cultures are not so numerous as those between shoot weights. Both the 60P+(4x)15NK and the 60P+(4x)15NK(S) cultures yielded trees of significantly greater total weight than the check, and the 60P+(4x)15NK(S) culture produced trees of significantly greater weight than trees from the 60P+(2x)30NK culture.

Table 80. --Mean diameter, dry weight of shoot, root, and entire tree, and root-shoot ratio of trees of each treatment in Experiment IV, 1944-45

Treatment	Diameter of stem mm.	Dry Weight Shoot grams	Root	Total	Root-Shoot ratio
60P+(4x)15NK	4.57	2.58	1.38	3.96	0.56
60P+(4x)15NK(S)	4.64	2.88	1.32	4.20	0.48
60P+(2x)30NK	4.53	2.53	1.26	3.79	0.52
Check	4.33	2.20	1.22	3.42	0.55
Standard deviation	0.08	0.09	0.09	0.16	0.01
Difference between treatment means to be significant at 5 & 1 percent		0.29 0.42		0.52 0.74	
F value treatment	3.20	9.90**	0.57	4.12*	2.23

*Significant at 5 percent.
**Significant at 1 percent.

Effect of Boron and Manganese

The design of the experiment did not make possible an analysis of the effect of boron and manganese on such features as height, branching, and weight of trees. The purpose of adding thse elements, the latter in two different quantities, nearly 12 weeks after the experiment was initiated, was to determine if they could be added in small quantity without apparent visible harm. That these elements had affected the trees was evident 2 weeks after they were applied, when the tips of the needles had begun to turn brown in color. The trees in the cultures that had received 40 pounds of Mn showed symptoms similar to those in the sultures that had received 20 pounds of Mn per acre. At the end of the experiment, the extreme tips of the needles were brown for a distance of 1/16 to 1/8 inch. Behind the brown zone was a yellow-zone of similar length. On some tree, the primary needles were dead for a distance of ½ to 1 inch from the tips. No evidence whatsoever was found of foliage abnormalities on trees in cultures to which boron and manganese had not been added.

The fact that the quantity of boron used was less than 0.2 percent and that of manganese was 3.7 and 7.4 percent, respectively, of the maximum combined concentration of nitrogen, phosphorous, and potassium used in one of the 1943-1944 greenhouse experiments in which no visual evidence of damage to the seedlings occurred, indicates that one or both of these materials must be toxic at very low concentration. It is at least apparent that the amounts used were in excess of what the trees could withstand.

NURSERY EXPERIMENTS

The nursery experiments were conducted in the nursery operated by the School of Forestry on the Austin Cary Forest. This nursery, approximately one-fourth acre in area, was developed in 1938 by removing the forest cover, chiefly longleaf and slash pine, from the site, grubbing out the tree stumps, and plowing and cultivating the soil. An overhead sprinkling system was installed in 1939. Since then, approximately one-half of the nursery has been used to produce trees each year. The remainder has been idle or produced some type of leguminous crop. Although some kind of commercial fertilizer was applied each year to the area in trees and in cover crop, records of the exact nature of the fertilizers used are not available. Insofar as can be determined, a 5-8-5 fertilizer[10] was most often used.

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10. The numerals refer to the percent of N, P_2O_5, and K_2O respectively, in the fertilizer.

Manure has been applied to a small portion of the nursery. In general, the quality of the trees produced here prior to 1942 was below average.

The soil in the nursery is classified as Norfolk fine sand. Analyses of the physical and chemical properties of the soil, made by the same methods employed in the analysis of the greenhouse soil, gave the following data:

Mechanical Analysis	
Sands - percent	91
Silt + clay - percent	9
Soil organic matter - percent	1.83 ± 0.15*
Moisture equivalent - percent	4.55 ± 0.25
Pore space - percent	
Total	57.0
Small pores	35.5
Large pores	21.5

Base exchange capacity - m.e./100 gr.	3.32± 0.31
Exchangeable Ca - m.e./100 gr.	1.69± 0.13
Exchangeable Mg - m.e./100 gr.	0.91± 0.17
Exchangeable K - m.e./100 gr.	0.43± 0.08
Approximate percent base saturation	91
Phosphorous (sodium acetate soluble)- p.p.m.	
Untreated soil	9.0
Soil + 1 ton colloidal phosphate	8.5
Soil + 20 tons colloidal phosphate	16.0
Soil reaction - pH	5.55

*Standard deviation of the mean.

The nature of some of the problems involved in the management of the soil are indicated by its small content of silt and clay, low organic matter content, low moisture-holding capacity, and low base-exchange capacity. Inorganic plant nutrients, especially the more soluble forms of nitrogen and potassium, are readily leached from the soil. Methods of soil management which will increase the content of organic matter and the base-axchange capacity of the soil are essential to economical use of any type of fertilizer. It is noteworthy that the exchange complex has a high degree of saturation, approximately one-half of which is taken up by calcium. The relatively large amount of exchangeable bases undoubtedly is derived from the bases contributed by frequent, heavy application of well water containing these elements.

1942 Nursery Experiment

Plans for the 1942 nursery experiment, made in February 1942, had to be developed without the benefit of any results from the 1941-42 greenhouse experiment which had been in progress only a few weeks.

Preparation and Seeding of Plots

The area in the nursery to be occupied by this experiment was plowed, disked, and harrowed late in February. The areas to be occupied by the seed beds were elevated approximately two inches above the general land surface by removing the top soil from the paths between the beds and placing it on the seed beds[11]. After levelling, the surface of the beds

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11. Because this elevation of the seed beds accentuates the drying of the soil and causes erosion along the edges of the bed, seed beds in later experiments were not raised.

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was rolled to compact the soil. Two areas, each 100' x 4'3" were devided into 20 plots, each 4' x 4'3", separated by a 1-foot isolation strip. The forty plots made possible four replications of each of the ten soil treatments. The plots to be used for each treatment were selected at random.

Those plots treated with colloidal phosphate and those treated with organic soil were prepared on March 10. All plots were given an application of calcium arsenite bait for protection against the southern mole cricket (Scapteriscus acletus R. & H.) and changa (Scapteriscus vicinus Scudd.). On March 17, the day prior to seeding, the plots which were to be given treatments 1 and 3 (see Table 81) received an application of fertilizer[12].

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12. The seed was sowed in 4-foot rows, spaced 8 inches apart, at a rate

of 115 evenly distributed seeds per row. The seeds were transferred from a seeding lath into slits in the soil approximately 1/8- to 1/4-inch deep and 1/2 inch wide. The seed was not covered with soil, but the entire beds were mulched with a light covering of longleaf pine needles. The specific source of the seed secured from the 1941 seed crop was unknown. Its quality, as evidenced by appearance and germination in the nursery, appeared good.

The seed beds were screened to provide protection against birds.

Care and Treatment of Seed Beds

Except when rainfall was adequate to maintain satisfactory soil moisture conditions, the seed beds were watered daily in late afternoon for the first 2 months. Twice between the seeding and germination of the seed, on March 17 and 27, 2-inch rains were recorded.

Germination was first noted 9 days after the seed was sowed, and was practically complete 13 days later. The stand of seedlings was fairly uniform except for a few small spots where birds or excessive pine-needle mulch had done some damage which resulted in reduced seedling density.

The first fertilizer applied after seeding contained some material not coluble in water. It was therefore applied by hand to the surface of each plot. Enough water to wash the fertilizer thoroughly from the seedlings was applied immediately after the fertilizer application, and within 2 hours a heavy application of water was provided from the overhead sprinkling system. The fertilizer used later consisted of KNO_3 and KCl which are water-soluble. It was dissolved in water, and applied from a sprinkling can.

Weeding was begun 5 weeks after seeding, and thereafter, weeds were removed at weekly intervals until mid-August, after which weeding was practically dispensed with.

Observations, Sampling, and Measurements

Observations of color and general vigor of the seedlings in each plot were made when they were approximately 2 and 6 weeks old.

A sampling to determine seedling density (number of trees per square foot) was to have been made for the purpose of ascertaining the effect of treatment on this feature, but damage by birds and mole crickets, [13]

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13. Several attempts at control of the mole crickets were not entirely successful, and localized damage occurred throughout the summer.

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which was not uniformly distributed, was affecting seedling survival as much as, or more than, the fertilizer treatment. Because of this condition, actual count of seedlings was not made, but instead, an ocular estimate of seedling density was made at the end of the growing season.

Prior to lifting the seedlings on December 20 and 21, twelve seedlings (two per row), from which certain data were taken, were selected at random. The following data for each tree were recorded: (1) height from ground surface to tip of terminal bud (to 1.0 mm.); (2) number of branches;[14]

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14. So few trees developed lateral branches that the data, after examination, were not analyzed.

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(3) number of normally developed terminal buds.[15]

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15. Some seedlings continue their growth so late in the autumn that the terminal buds which they develop are abnormal. A normal bud of a first-year

slash pine has reddish-brown bud scales and extends above any primary needles which may originate below its base. The abnormal type of bud, which apparently is not fully mature, has green bud scales and generally is not easily visible because it is overtopped by numerous primary needles. This type of bud is generally associated with the less sturdy seedlings which are characterized by a small proportion of secondary needles, if any.

When the seedlings were lifted from the nursery, special care was taken to prevent loss of any of the root from the sample trees. Soil was thoroughly washed from the roots, and the trees were allowed to dry partially before being transferred to a drying oven where they were handled in the same manner as the trees from the greenhouse experiments.

Soil Treatments

The ten soil treatments were designed to test the effect on the trees of (1) improvement in the physical characteristics of the soil, (2) the timing of fertilizer applications, (3) split versus single application of fertilizer, and (4) organic versus inorganic sources of nitrogen. For improvement of the physical qualities of the soil, colloidal phosphate and a soil high in organic matter from a cypress pond were chosen. The former was mixed in the upper 6 inches of soil at a rate of 20 tons per acre. The latter was applied as a 3-inch layer after a layer of the original soil of equal thickness had been removed. The organic soil was then mixed with the 3 inches of original soil directly beneath it, thus creating a mixture which was 50 percent organic soil. The effect of applying fertilizer just prior to seeding was compared with the results of applying it 5 weeks after seeding. Split applications of fertilizer were restricted to nitrogen and potassium, both of which are leached from the soil easily. Nitrogen was applied entirely in inorganic form and in equal amounts of inorganic and organic forms.

In the initial applications in treatments receiving inorganic nitrogen, equal amounts of nitrogen were supplied by sulphate or ammonia and nitrate of soda. Superphosphate supplied the P_2O_5 in all treatments receiving phosphorous except the treatment receiving colloidal phosphate.

The nitrogen and potassium applied in subsequent treatments came chiefly from potassium nitrate, with a small part of the potassium being derived from muriate of potash. Milorganite was the source of organic nitrogen in the one treatment (number 3) receiving an organic source of nitrogen. Commercial fertilizers were used throughout.

The quantity of nutrients applied (except where colloidal phosphate and organic soil were sources), and the time of their application, are shown in Table 81, as are also the descriptive designations used in the report.

Measured Characteristics

The mean heights, dry weights, number of terminal buds, and root-shoot ratios for trees from the ten treatments in the 1942 nursery experiment are shown in Table 82. Soil treatment had some effect on all features of the trees, but the differences between the trees of some treatments were small. The tallest trees, produced by the organic soil treatment, were more than 29 percent taller; and the shortest trees, produced by the 60N90P100K (5 weeks after seeding) treatment were more than 12 percent shorter than trees produced by untreated soil. A test of the significance of the differences by an analysis of variance revealed that a significant difference exists in the treatment mean heights. The trees produced by the organic soil

Table 81. --The quantities of nutrients applied and the time of their application in 1942 Nursery Experiment

Treatment		Prior to seeding			5 weeks after seeding (2 weeks after completion of germination)			10 weeks after seeding		15 weeks after seeding		20 weeks after seeding	
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	K_2O	N	K_2O	N	K_2O
Number	Designation	Pounds per acre											
1	60N90P100K (prior to seeding)	60	90	100	-	-	-	-	-	-	-	-	-
1a	60N90P100K (5 weeks after seeding)	-	-	-	60	90	100	-	-	-	-	-	-
2	15N90P55K	-	-	-	15	90	55	-	-	-	-	-	-
3	60N90P100K (50% organic N)	60	90	100	-	-	-	-	-	-	-	-	-
4	15N90P55K +15NK	-	-	-	15	90	55	15	15	-	-	-	-
5	15N90P55K (2x)15NK	-	-	-	15	90	55	15	15	15	15	-	-
6	15N90P55K (3x)15NK	-	-	-	15	90	55	15	15	15	15	15	15
7	20C.P. 15N55K (3x)15NK	-	*	-	15	-	55	15	15	15	15	15	15
8	Organic soil	-	+	-	15	90	55	15	15	15	15	15	15
Check	Check	-	-	-	-	-	-	-	-	-	-	-	-

*20 tons per acre of colloidal phosphate
+3 inch layer of organic soil

Table 82. --The mean height, dry weight, number of terminal buds, and root-shoot ratios of 1-year slash pine seedlings grown in Austin Cary Nursery in different soil treatments

Treatment	Height mm.	Dry Weight gr.	Terminal Buds number	Root-shoot Ratios
60N90P100K (prior to seeding)	99.1	1.42	0.79	0.40
60N90P100K (5 weeks after seeding)	91.4	0.98	0.42	0.38
15N90P55K (5 weeks after seeding)	101.6	1.35	0.83	0.39
60N90P100K (50% organic N)	106.7	1.98	0.83	0.34
15N90P55K+15NK	106.7	1.76	1.31	0.38
15N90P55K+(2x)15NK	106.7	1.85	1.08	0.39
15N90P55K+(3x)15NK	104.1	1.53	0.67	0.36
20C.P.15N15K+(3x)15NK	116.8	2.39	1.19	0.34
Organic soil	134.6	3.26	1.98	0.30
Check	104.1	1.86	0.79	0.37
Standard deviation	7.3	0.34	0.65	0.03
Difference between treatment means to be significant at 5 and 1 percent	20.3 27.9	0.98 1.33		
F value treatment	2.64*	3.48**	0.45	1.78

*Significant at 5 percent.
**Significant at 1 percent.

treatment are very significantly taller than those produced by all treatments except one, the colloidal phosphate treatment. The colloidal phosphate treatment produced trees significantly taller than those produced by one treatment- 60N90P100K (5 weeks after seeding) treatment. Differences in heights of seedlings between other treatments were not significant. It is noteworthy that only those treatments which alter the physical condition of the soil yielded trees with greater heights than those from the untreated soil, and that trees from only one of these were significantly taller than those from the check.

Dry weights show much the same relationship to treatment as do heights. Trees produced by all cultures excepting the colloidal phosphate treatment were inferior in weight to the trees produced by the organic soil culture. Trees from the 60N90P100K (5 weeks after seeding) treatment were inferior in weight to those from the colloidal phosphate culture.

The mean number of terminal buds per tree, although differing widely with soil treatment, shows no significant difference between the treatment means. The wide variation between individual trees in the number of buds is the cause of the lack of significant differences. It should be noted that the organic-soil treatment which produced the tallest and heaviest trees also ranks first in number of terminal buds. Likewise, those treatments which rank lowest in height and weight rank lowest also in number of terminal buds.

Root-shoot ratios show small differences between treatments, and these differences are not significant. Although there is no marked trend in the root-shoot ratios, it is noteworthy that the treatments producing the tallest and heaviest trees have the lowest root-shoot ratios. This indicates that, proportionately, the top benefits more from the supplemental nutrients than the roots.

Observed Characteristics

Ocular estimates of color and general vigor of the seedlings during the first 2 months furnishes observational data which help to supplement and interpret the statistical data. The most conspicuous abnormality in color and vigor 2 months after seeding was found in the seedlings growing in plots treated with 60 pounds of nitrogen, 90 pounds of P_2O_5, and 100 of K_2O 5 weeks after seeding. Two of the four plots of this treatment were described as below average in vigor. The tips of the cotyledons of most of the seedlings in the four plots of this culture were brown. This condition suggests that the seedlings were "burned" by the fertilizer. It is noteworthy that this treatment produced trees of least height and weight, and with the fewest terminal buds.

In marked contrast were the trees in plots receiving the organic soil and colloidal phosphate treatments. Two of the four plots in both of these treatments were described as containing trees considerably above average in vigor. The foliage of these trees was blue-green in contrast to the green and yellow-green of trees growing in differently treated soil. The other two plots, although not exhibiting differences in vigor and needle color as marked as the plots just described, did appear somewhat superior in vigor. Trees from these treatments were taller and heavier and had developed more terminal buds at the end of the experiment than trees from other cultures.

Trees growing in the plots of the other seven treatments exhibited no vigor or color characteristics which distinguished those of one treatment from another.

Just prior to harvesting the trees, differences in seedling density were evident among the various plots. Note was made of the plots in which seedling density was exceptionally low. The results of this tabulation were as follows:

Treatment	Number of plots of exceptionally low seedling density
60N90P100K (prior to seeding)	3
60N90P100K (5 weeks after seeding)	4
15N90P55K	1
60N90P100K (50% organic N)	0
15N90P55K 15NK	0
15N90P55K (2x)15NK	1
15N90P55K (3x)15NK	1
20 C. P. 15N15K (3x)15NK	1
Organic soil	0
Check	2

Exceptionally low seedling density is most evident in the two treatments- 60N90P100K (prior to seeding) and 60N90P100K (5 weeks after seeding)- receiving heavy initial applications of fertilizer. Evidently too great concentration of nutrients, especially the readily available ones- nitrogen and potassium- was responsible for high seedling mortality. The highest seedling densities were noted in one plot of the colloidal phosphate and two plots of the organic soil treatment.

Summary and Implications of Results

Although the results of 1942 nursery experiment are not very conclusive on all aspects of fertilization that were studied, the effects of some phases of soil improvement are fairly definite and in others, some trend is indicated.[16]

16. Later experience demonstrated that differences in response to nutrient treatments are greater when other nursery practices are nearest to the optimum for seedling development. Cultural practices were not ideal in 1942.

In general, slash pine seedlings were not benefitted by the addition of readily available nutrients, regardless of method of application, when nothing was done to change the physical condition of the soil. On the other hand, when organic soil was added together with inorganic nutrients, significant differences developed in the trees. They were taller, heavier, and had more terminal buds than trees grown in untreated cultures or in those receiving inorganic nutrients only. Colloidal phosphate with inorganic nutrients improved the trees, but they were not significantly superior to those grown in untreated soil or soil to which other nutrients had been added. Apparently, leaching of readily available nutrients is too rapid in otherwise untreated soil to allow the seedlings to derive any benefit when they are added either entirely at the time of seeding or 5 weeks after seeding or in split applications at 5-week intervals. Such frequent watering is necessary in the absence of rainfall that leaching is almost continuous. Leaching is accentuated when heavy falls of rain occur. An examination of the rainfall records during the experiment reveals that on one occasion, a 2-inch rain fell within a few hours after the application of fertilizer, and on another occasion, a 1.20-inch rain fell soon after fertilization.

Although significant differences in the measured characteristics of the trees produced by the two 60N90P100K treatments and the check are not evident, seedlings of these three treatments show a tendency toward inferiority, and seedling mortality was heavier in these cultures. Even though the effects of these treatments were not regarded as detrimental, they are certainly uneconomical.

Although no significant difference exists between the seedlings produced by the two 60N90P100K treatments, those produced when the nutrients were applied 5 weeks after seeding show an inferiority to those produced when the nutrients were applied just prior to seeding. The 2-inch rain which fell soon after the latter treatment may have caused enough leaching of the readily available nutrients to minimize damage to the seedlings which began making their appearance 9 days later. Practically no rain fell for nearly a month following the application of the 60N90P100K treatment 5 weeks after seeding, consequently the seedlings- mostly 13 to 26 days old- were probably under the influence of a relatively high concentration of nutrients for several days since the gentle fall of water in relatively small quantity from the overhead sprinkling system probably caused rather slow leaching.

When the nitrogen and potassium were added in two to four applications, the trees were not notably different from those developed with no soil treatment. Those receiving two and three applications of these nutrients were superior in height, weight, and bud development to those receiving the entire supply of nitrogen and potassium prior to seeding or 5 weeks after seeding. The differences were not significant, however.

The culture in which 50 percent of the nitrogen was of organic origin produced somewhat better trees than the two cultures receiving the same quantity of nitrogen (and equal amounts of phosphorous and potassium) of inorganic origin. Again, the differences are not significant. The fact that the only variable in the nutrients used in these three treatments was the nitrogen source suggests that too much readily available nitrogen is more likely to be harmful to young slash pine seedlings than too much readily available potassium.

In considering the effect of the organic soil, it is well to keep in mind that this material does more than change the physical characteristics of the original soil. It has equally important effects on the chemical and biological features, some of which may be very complex. The organic soil increases the base exchange capacity; it adds various nutrients, especially nitrogen, part of which is organic; and it adds new microorganisms and possibly growth hormones. The original soil is, therefore, radically changed. This is evident by the great superiority of the trees produced in the organic soil treatment over all except the colloidal phosphate treatment.

1945 Nursery Experiment

Experimental technique and cultural methods used in this experiment were similar to those employed in the 1942 Nursery Experiment. Techniques in the 1945 Nursery Experiment which differed from those in the previous experiment are discussed briefly below. Each of the two seed beds was divided into eighteen plots, each 5' x 4'3" (Fig. 18). Isolation strips were not left between plots. The disadvantage of having plots involving different soil treatments joining each other was disposed of by eliminating a 6-inch strip at each end of every plot in the random selection of sample trees. The two seed beds provided thirty-six plots, thus making possible the use of nine soil treatments, each replicated four times.

A Planet Jr. seed drill was used to sow the seed, on March 12, in rows running lengthwise of the beds, the rows being spaced 7 inches apart. The drill was regulated to provide distribution of seed at a rate of approximately twenty-five seeds per linear foot, the objective being to secure, ultimately, ten to fifteen trees per foot. The seed was secured from the Florida Forest Service, and its specific source was not known. Germination was first in evidence on March 20.

Precipitation records at the nursery site reveal that no rain fell during March and that only 0.30 inch fell between April 1 and April 22. It was necessary, therefore, during the first 6 weeks of the experiment, to maintain adequate soil moisture by supplying water from the sprinkling system. The first application of nitrogen and potassium, and of phosphrous in Treatment 8, on April 19 was followed on April 23 by a rainfall of 2.71 inches during a 12-hour period, and on April 29 by one of 1.66 inches during a 6-hour period. May was relatively dry, with precipitation totalling 1.88 inches for the month, all of which fell during the first 16 days.

No rain fell for nearly 2 weeks after the application of nutrients on May 24. On June 7, 1.79 inches of rain fell. Rainfall was plentiful during June, the total fall being 7.51 inches. Precipitation was light during the first half of July, totalling 0.98 inch which fell in four showers. Since the third application of nutrients was made on June 28, and since no single rain storm between that date and August 1 produced more than 0.73 inch, the nutrients were not acted upon by heavy rains. The fourth application of nutrients on August 2 was followed by a 3.24-inch rain within 12 hours. Total precipitation for July was 3.54 and for August was 9.80 inches.

Prior to lifting them in January, fifteen trees, from which data on various features were secured later, were selected at random and marked for future use. Length of stem from the cotyledons to the tip of the terminal bud (to ± 1.0 mm.) and number of terminal buds were recorded before the trees were lifted. Each tree was classified on the basis of predominance of primary and secondary needles. After the trees were lifted and washed, the diameter of each was measured (to ± 0.01 mm.) with a micrometer, and the green weight of the entire tree was weighed (to ± 0.01 gr.). Time did not permit drying the trees and securing dry weight separately on shoots and roots.

Soil Treatments

Since slash pine seedlings had responded most in the greenhouse experiments to soil treatments containing colloidal phosphate, especially when nitrogen and potassium were included, and since they had made some response to similar treatments in a previous nursery experiment, the 1945 Nursery Experiment was designed primarily to test similar treatments in the nursery. Colloidal phosphate was used at rates of 1 and 20 tons per acre.

Nitrogen and potassium were applied either two or four times at rates of either 15 or 30 pounds per acre of N and K_2O each time. In one culture, $Ca(H_2PO_4)_2H_2O$, which when used alone in a greenhouse culture had produced marked response by slash pine seedlings, was used in combination with nitrogen and potassium. C. P. chemicals were used as sources of nitrogen and potassium in all treatments that were supplied with these elements and of phosphorous in Treatment 8. NH_4NO_3 and KCl supplied the nitrogen and potassium, respectively. Details of nine soil treatments are shown in Table 83.

Length of Stem, Diameter, and Green Weight

The mean lengths of stem, diameters, and green weights of the trees in each treatment are presented in Table 84. The analyses of variance of each of the three features reveal that there are very significant differences between the treatment means of stem length, but no significant differences between those of diameter and weight. The F values of 2.11 and 1.90, respectively, were not much below the 2.36 needed to demonstrate significant differences. It is the author's belief that certain factors which caused marked differences between individual trees within plots of the same soil treatment were responsible for the lack of significant differences in the means of stem diameter and tree weight. Under nursery conditions, a limited number of seeds germinate long after the majority have germinated. Those that germinate late, being younger than the majority of seedlings, do not attain the size of those that germinated earlier. This accounts for part of the variation among seedlings. It was observed also that seedling density varied within plots (Fig. 18). Even more important is the fact that seedling density differed with soil treatment. The plots representing the soil treatments which produced the shortest, smallest diameter, and lightest (in weight) trees had the lowest seedling

Table 83. --Type and amount of nutrient application in 1945 Nursery Experiment

Treatment		Prior to seeding	Time of nutrient application								
			5½ weeks after seeding			10½ weeks after seeding		15½ weeks after seeding		20½ weeks after seeding	
		Colloidal phosphate	P205	N	K20	N	K20	N	K20	N	K20
No.	Designation	Tons per acre	Pounds per acre								
1	20C.P.+(4x)15NK	20	-	15	15	15	15	15	15	15	15
2	20C.P.+(2x)30NK	20	-	30	30	-	-	30	30	-	-
3	20C.P.+(4x)30NK	20	-	30	30	30	30	30	30	30	30
4	20C.P.	20	-	-	-	-	-	-	-	-	-
5	1C.P.+(4x)15NK	1	-	15	15	15	15	15	15	15	15
6	1C.P.+(4x)30NK	1	-	30	30	30	30	30	30	30	30
7	1C.P.	1	-	-	-	-	-	-	-	-	-
8	60P+(4x)15NK	-	60	15	15	15	15	15	15	15	15
9	Check	-	-	-	-	-	-	-	-	-	-

Table 84. --Mean length of stem, diameter, and green weight of trees in 1945 Nursery Experiment

Treatment	Length of stem mm.	Diameter of stem mm.	Green weight gr.
20C.P.+(4x)15NK	162.8	4.28	8.72
20C.P.+(2x)30NK	141.6	3.99	8.28
20C.P.+(4x)30NK	171.7	4.26	10.09
20C.P.	159.2	4.00	8.37
1C.P.+(4x)15NK	132.9	3.50	6.03
1C.P.+(4x)30NK	138.0	3.80	7.17
1C.P.	112.2	3.25	5.04
60P+(4x)15NK	134.5	3.80	6.72
Check	113.6	3.44	5.88
Standard deviation	10.6	0.25	1.17
Difference between treatment means to be significant at 5 and 1 percent	31.0 42.0		
F value treatment	3.53**	2.11	1.99

**Significant at 1 percent.

density. For their height, trees in the low-density plots appeared to have relatively sturdy shoots, and they had wide-spreading root systems. Had they grown in high-density plots their stems probably would have been thinner and their roots less extensive. Thus, seedlings grown in low-density plots would conceivably gain some advantage in diameter and weight over those grown in high-density plots, an advantage caused by the differences in seedling density. This would tend to reduce the difference in treatment means. This, combined with the wide variation between individual seedlings in the same treatment (due partly to density variations within plots), makes the standard deviation large, and may account for a lack of significant differences between treatment means of stem diameter and tree weight. In other words, the effect of the treatment on seedling density created a variable factor which confused the effect of treatment on certain characteristics of the trees. In view of these facts and the closeness of the F values of treatment for diameter and weight to those needed for significance at 5 percent, the author believes the diameter and weight differences caused by treatment can be assumed to be significant.

At length of stem, trees in the 20 C. P. +(4x)30NK culture were outstanding. These trees were very significantly taller than those in the check and the 1 C. P. treatments (Fig. 21), and significantly taller than those in the 1 C. P. +(4x)30NK, and 60P+(4x)15NK cultures. They were nearly significantly taller than those in the 20 C. P. +(2x)30NK culture.

Trees in the 20 C. P. +(4x)15NK and the 20 C. P. cultures were very significantly taller than those in the check and the 1 C. P. cultures (Fig. 19). Those in the 20 C. P. +(4x)15NK culture lacked only a little of being significantly taller than those in the 1 C. P. +(4x)15NK and

1 C. P.+(4x)30NK treatments, and those in the 20 C. P. cultures were not far short of being significantly taller than those in the two 1-ton colloidal phosphate treatments supplemented by nitrogen and potassium.

Although none of the 1-ton colloidal phosphate treatments yielded trees with longer stems than the check (Fig. 20), it is noteworthy that when the colloidal phosphate was supplemented by nitrogen and potassium, stem length was increased, although not significantly (Fig. 22).

The value of colloidal phosphate in large quantity is evident from the significant superiority in height of the trees in 20 C. P. over those in the check culture. Furthermore, trees in the former culture were not significantly inferior in height to those in any other culture and actually surpassed those in one culture (20 C. P. +(2x)30NK).

Although there is no significant difference in the mean heights of trees in the 20 C. P. +(4x)15NK and 20 C. P. +(2x)30NK cultures, there is enough difference to indicate that 60 pounds of nitrogen and potassium per acre split into four applications is more effective in its effect on slash pine seedlings than this amount split into two applications. It is possible that some of the value to the seedlings of the first 30-pound application was lost on account of the heavy rain which fell soon thereafter.

Although differences in mean diameters and weights of trees in difference treatments are not significant, these features of trees in the various cultures have much the same realtionship to each other as did the stem lengths. It is noteworthy that the mean diameters and weights of trees in the four cultures receiving 20 tons of colloidal phosphate were greater than those of trees in the other five cultures.

Number of Terminal Buds and Percent of Trees with Primary Needles Dominant

Over a period of several years observations on slash pine seedlings growing in forests and in nurseries has lead the author to believe that tree vigor in young slash pine trees is expressed to some extent by the number of terminal buds. Wakeley (1935) used the prevalence of primary needles as one criterion of the quality of planting stock. In his classification of grades of planting stock, the foliage of grade-3 slash pine seedlings is composed solely of primary needles. Number of terminal buds and prevalence of primary needles should constitute useful criteria in judging planting-stock quality.

The mean number of terminal buds and the percent of trees with primary needles dominant are shown in Table 85 for each treatment. Very significant differences exist between treatments in the first feature, and significant differences exist in the latter. Trees in the 20 C. P. +(4x)30NK treatment are outstanding in both categories. These trees are either significantly or very significantly superior to trees of all other treatments in number of terminal buds. With none of the trees in this treatment having primary needles dominant, they ranked best in this respect, and they were significantly superior to trees in the check and 1 C. P. cultures.

Trees in the 20 C. P. +(4x)15NK culture had significantly more terminal buds than trees in the 1 C. P. and check cultures. With only 5.0 percent of the trees having primary needles dominant, the former culture ranked second best and was significantly superior to the 1 C. P. culture.

The number of terminal buds and the percent of trees having primary needles dominant add further evidence on the superiority of trees in the 20 C. P. +(4x)30NK treatments.

Summary of Results

The experiment demonstrates rather conclusively that the quality of slash pine seedlings grown in a nursery in a Norfolk fine sand can be

Table 85. --The mean number of terminal buds per tree and the percent of trees with primary needles dominant in the 1945 Nursery Experiment

Treatment	Terminal buds	Trees with primary needles dominant ✝
	Number per tree	Percent of total
20C.P.✝(4x)15NK	1.43	5.0
20C.P.✝(2x)30NK	1.00	11.7
20C.P.✝(4x)30NK	2.15	0.0
20.C.P.	1.13	13.3
1C.P.✝(4x)15NK	0.88	16.7
1C.P.✝(4x)30NK	1.27	8.3
1C.P.	0.50	28.3
60P✝(4x)15NK	0.75	13.3
Check	0.72	21.8
Standard deviation	0.24	7.5
Difference between treatment means to be significant at 5 and 1 percent	0.71 0.96	21.8 29.6
F value treatment	4.11**	2.90*

✝The foliage of these trees consists either solely or more than 50 percent primary (unfascicled) needles.
*Significant at 5 percent.
**Significant at 1 percent.

greatly improved by the addition to the soil of 20 tons per acre of colloidal phosphate, which should be mixed in the upper 4 inches of soil. Since the trees grown in a culture containing 20 tons per acre of colloidal phosphate alone were as good as, and in one case better than (although not significantly so), those grown in cultures containing nitrogen and potassium as well as 20 tons of colloidal phosphate, it has not been demonstrated that supplemental nitrogen and potassium are needed to produce superior trees. It is possible, however, that the trees grown in cultures supplied with all three nutrient elements may be better balanced physiologically. This cannot be determined until a suitable basis for analyzing physiological balance is developed. The survival and early growth of approximately 4500 trees from this experiment in two field plantations may eventually throw light on the matter.[17] Although there are

17. Field survival and growth of trees grown in colloidal phosphate nursery cultures may be affected also by the colloidal phosphate which adheres very tightly to the roots when the trees are lifted from the nursery. Various nutrients which might affect seedling survival and growth may be adsorbed on the colloids adhering to the roots. This might well be an important value of the colloidal phosphate treatments in the nursery.

no significant differences between the trees grown in the three 20-ton colloidal phosphate cultures supplied with nitrogen and potassium, certain trends are at least indicated. Two 30-pound-per-acre applications of nitrogen and potassium were not beneficial. On the other hand, four 15-pound of four 30-pound applications resulted in some improvement in the trees. Whether the increased cost of the four 30-pound applications over the two

30-pound applications would be justified is open to question. In view of the fact that the trees did not respond effectively to two applications of nitrogen and potassium but did to four applications, the question may be raised as to whether a greater number than four applications of these elements might be even more effective. More frequent applications might maintain a higher average amount of these easily leached elements in the soil, even though the total amount added was the same. Only further investigation can furnish the answer.

One-ton-per-acre applications of colloidal phosphate either with or without nitrogen and potassium have little effect on slash pine seedlings. This is equally true of a 60-pound application of phosphorous supplemented by four 15-pound applications of nitrogen and potassium.

SUMMARY OF ALL EXPERIMENTS

The response of slash pine seedlings during their first season's growth to various nutrient treatments in Norfolk soils was studied under greenhouse and nursery conditions. The greenhouse soil was a Norfolk sand; the nursery soil, a Norfolk fine sand. Fifty-five soil treatments were used in the greenhouse experiments during three seasons, and nineteen treatments were used in the nursery experiments during two seasons.

The two soils in which the research was done did not differ appreciably in physical and chemical characteristics. Both were low in silt plus clay (8 percent in the sand and 9 percent in the fine sand), in soil organic matter (2.18 and 1.83 percent, respectively), and had low moisture equivalents (5.39 and 4.55 percent, respectively). The latter feature was increased by adding colloidal phosphate to the soil, especially when as much as 25 tons per acre was added to the upper 4-inch layer of soil. The increase of 34 percent in the moisture equivalent of the Norfolk sand to which a 25-ton application of colloidal phosphate had been added is caused by the high moisture equivalent of the phosphate (47.6 percent), 87 percent of which is material of silt and clay size. The effect of colloidal phosphate on the physical composition of the soil is demonstrated by the extensive surface cracking which occurred when samples of Norfolk sand to which 5 and 25 tons of colloidal phosphate had been added were oven-dried subsequent to complete saturation of the soil.

Both soils have low base-exchange capacity, the Norfolk sand, 4.34, and the Norfolk fine sand, 3.32 m. e. /100 gr. of soil. They differ markedly in their percent of base saturation, that of the former being approximately 19 and that of the later, approximately 91 percent. The high percent of base saturation of the Norfolk fine sand is undoubtedly caused by bases added to the soil in the copious application of well water to this soil in the nursery. The exchange capacity of the Norfolk sand is not affected materially by additions of colloidal phosphate to the soil. Available phosphorous, based on sodium-acetate-soluble phosphorous is low in both soils, 8.0 p.p.m. in the Norfolk sand and 9.0 p.p.m. in the Norfolk fine sand. When large quantities of colloidal phosphate are added to the soil, available phosphorous is increased by 0.35 to 0.80 p.p.m. for each ton added.

Both soils are acid. The pH is 5.18 and 5.55 for the sand and fine sand, respectively. That colloidal phosphate has a buffering effect on the soil was evident in less reduction in pH of soils to which this material had been added than in untreated soil when they were leached with 0.05 N HCl, and in the slower change in pH, after leaching, in the colloidal-phosphate-treated soil than in the untreated soil.

In the comprehensive greenhouse experiments, an attempt was made to minimize any effect that seed size might have on the results by grouping seeds into weight classes having weight ranges of 3.0 mg. When more than one weight class of seed was used, seedlings from only one weight class were planted in each replication of soil treatments. Seedlings were uniformly spaced in the soil pots. The trees were generally transferred from the germinating flats to the soil pots when their average ages were 2 to 4 weeks. Most of the trees were grown in the pots for approximately 20 weeks. Temperature records were taken during the 1943-44 and 1944-45 greenhouse experiments, and evaporation was recorded during the latter experiment. Data on stem length of each tree were recorded at 5- or 6-week intervals, and data on branching of each tree were recorded at 2- to 4-week intervals after branching started. Diameter of stem and dry weights of shoot and root were recorded after the trees were harvested. Total weight and root-shoot ratio were computed from the root and shoot weights.

In the 1941-42 Greenhouse Experiment, certain aspects of which were not well controlled, slash pine seedlings were grown in untreated soil and in soil to which 20, 40, or 80 pounds per acre of N, P_2O_5, and K_2O had been added in advance of planting. One culture contained in addition to 40 pounds per acre of N, P_2O_5, and K_2O- Cu, Zn, Mn, Fe, and B. This experiment revealed differences in the mean heights, weights, and root-shoot ratios of trees in the different cultures, but none of the differences were significant. Mean heights and weights increased with increases in the quantity of nutrients applied to the soil in the absence of minor elements. Root-shoot ratios showed no trend. Minor elements affected tree heights adversely, they had no effect on tree weight, and they increased root-shoot ratio. Branching was noticeably affected. Significant differences in the mean number of branches per tree were caused by soil treatment. The culture containing 80 pounds per acre of N, P_2O_5, and K_2O produced trees with the most branches (4.00 per tree at $17\frac{1}{2}$ weeks), and the 40-pound culture was second highest (3.00 per tree). Although differences in branching were evident at 8 and $11\frac{1}{2}$ weeks, the differences were not significant until $14\frac{1}{2}$ weeks had elapsed, after which the differences continued to be significant. In later greenhouse experiments, more often differences in branching were significant early in the experiments but were not significant later. In respect to height, dry weight, and root-shoot ratio, the results of this experiment corroborated those of later experiments. Single-applications of nitrogen, phosphorous, and potassium over the range of quantities used in this experiment do not influence these tree characteristics significantly.

The 1943-44 Greenhouse Experiments were three in number. Experiment I was a simple factorial design involving eight single-application treatments at two levels of N, P_2O_5, and K_2O. Experiment II consisted of six treatments involving three levels of N, P_2O_5, and K_2O applied by two methods- single application and split application (four in number). Experiment III consisted of eleven miscellaneous treatments involving chiefly colloidal phosphate and peat moss, with and without supplemental N, P_2O_5, or K_2O.

Experiment I furnished additional evidence on the ineffectiveness of single-application soil treatments. Only one of the seven treatments involving supplemental nutrients- the one containing 60 pounds of phosphorous and a small amount of calcium- produced trees superior in some respects to those produced by the check. Nitrogen used by itself as a single application of 60 pounds per acre was definitely harmful to most of the features studied. Root-shoot ratio, which in all experiments was unaffected by soil treatment was one exception. It is noteworthy that the harmful effects of nitrogen are decreased when either or both phosphorous and potassium are used with it. In most of the features studied, trees in soil treatments involving 60 pounds of P_2O_5, 60 pounds each of P_2O_5 and K_2O, and 60 pounds each of N, P_2O_5, and K_2O were superior to trees in the check, but not significantly so. Significant differences between cultures in the number of branched trees and in the mean number of branches per tree were evident throughout the experiment, but only the 60P culture was significantly superior to the check in both characteristics.

Experiment II demonstrated the superiority of split-application treatments (four in number) over single-application treatments of nitrogen, phosphorous, and potassium. Although stem length and root-shoot ratio were not significantly improved by any type of nutrient treatment used, stem diameter, branching, and weight were increased significantly by the split-application treatments. For all-round improvement in tree characteristics, a treatment involving four 30-pound-per-acre applications of N, P_2O_5, and K_2O was best.

Experiment III demonstrated that the response of slash pine seedlings was greatest when a large quantity (20 tons per acre) of colloidal phosphate and small amounts of readily available nitrogen and potassium (four applications of 15 pounds each of N and K_2O) were added to the soil. Response to a 10-ton-per-acre application of peat together with four 15-pound-per-acre applications of N, P_2O_5, and K_2O was almost equally good. When colloidal phosphate and peat were used alone the response was much less. The former, when used alone, produced substantial effects on branching and total dry weight of the trees, both effects being significant. Its effects on stem length and on diameter were favorable, but insufficient to demonstrate significance. The lack of a definite response by slash pine seedlings to a similar treatment with nitrogen, phosphorous, and potassium in Experiment II (the (4x)15NPK culture) together with their limited response to colloidal phosphate or peat suggests that the greater response to combinations of either colloidal phosphate or peat and readily available nutrients must be caused by a physical effect of the former materials on the soil, on the tree roots, or on both.

Possibly these materials act as buffers, holding nutrients in reserve so that they become available slowly and continuously. Whatever the effect, it is evident by the increased size of the trees, that the trees' feeding efficiency is improved. Analysis of needles of trees from several cultures revealed that tree needles from cultures containing colloidal phosphate did not have higher concentrations of phosphorous and calcium than those from cultures not supplied with colloidal phosphate. The needles of trees taken from colloidal phosphate cultures yielded more phosphorous and calcium than those from a check culture only because the weight of the needles from the former was heavier than that of needles from the check.

Wood ashes in quantities of 352 and 1320 pounds per acre had little or no effect on slash pine seedlings. A treatment with a high concentration of potassium (four applications of 75 pounds of K_2O) reduced stem length and increased branching significantly, but its overall effect was more or less neutral.

The 1943-44 Greenhouse Experiments demonstrated that slash pine seedlings grown in Norfolk sand are benefitted most when the physical character of the soil is improved by the addition of 20 tons of colloidal phosphate to the surface four inches and the supply of readily available nitrogen and potassium is increased. A later nursery experiment demonstrated that response was greater when four 30-pound applications were used than when four 15-pound applications were used, but the difference in response was not significant.

A composite tree index value was developed for rating the trees in each treatment on the basis of all features studied. In the 1943-44 experiment these values ranged from -7.3 to 11.0. In a culture of the

1944-45 Experiment a value of 11.4 was secured. These two high values were attained by trees from similar cultures, the difference being 20 tons of colloidal phosphate in one culture and 25 tons in the other.

Stem length was more often affected adversely by the addition of readily available nutrients, especially high concentrations in a single application or nitrogen alone or combined with phosphorous or potassium, than were other characteristics. Branching was never decreased by nutrient applications, but certain soil treatments produced no appreciable effect on branching. High concentrations of nutrients from a single application of nitrogen alone or combined with phosphorous or potassium were least effective in stimulating branching. An increase in the branching of widely spaced trees grown in pots in a greenhouse is probably an indication of increased vigor in the trees. Stem diameter was affected by soil treatment in much the same way as branching, that is, it was increased by the addition of nutrients to the soil in nineteen of the twenty-three cultures to which nutrients were added. In twelve of the cultures the increases over the check were significant. Tree weights were reduced by four treatments- 180NPK, 60NK, 60NP, and 60N- in the last two, significantly so. Nine treatments produced trees of significantly greater weight than the check. Soil treatment had little effect on root-shoot ratio, not a single treatment yielding trees with root-shoot ratios that were significantly different from the check.

Only Experiment I of the 1944-45 series yielded results that added much of consequence to those of the 1943-44 series. In this experiment, a 25-ton application of colloidal phosphate, supplemented by four 15-pound applications of N and K_2O, produced the best trees; but they were not significantly superior in all characteristics to those of all treatments involving smaller amounts of colloidal phosphate. In diameter and weight, trees from the 25-ton culture were significantly superior to trees from the 5-ton culture but not in stem length, branching, nor root-shoot ratio. Trees from the former culture were superior in stem length, diameter, and weight to trees from cultures containing only 0.5 or 1.0 ton of colloidal phosphate.

Increasing the amount of P_2O_5 from 30 to 480 pounds per acre produced no significant effects on slash pine seedlings in Experiment II, 1944-45.

Although stem length was not affected significantly in Experiment III, 1944-45, by different rates at which phosphorous was used (from 60 to 480 pounds per acre of P_2O_5) nor by various combinations of elements (K, NK, and CaNK) used with phosphorous, other features were affected significantly. Branching was increased significantly. Number of branched trees and number of branches per tree increased with increased amounts of phosphorous and number of elements in the cultures. Diameter of stem was affected in the same manner. Weights of shoot, root, and entire tree were affected significantly by the rate at which phosphorous was used.

No significant differences in the various tree characteristics were found between trees grown in a culture in which the phosphorous and part of the nitrogen and potassium were mixed in the upper 4 inches of soil and one in which all nutrients were applied to the surface (Experiment IV, 1944-45)

Boron at a rate of 1 pound per acre and manganese at rates of 20 and 40 pounds per acre, applied $11\frac{1}{2}$ weeks after the trees were planted, were damaging to slash pine seedlings. The ends of the needles turned brown and yellow a few weeks after these elements were applied to the soil, and the extent of the discoloration increased with the passing of time. Similar results occurred when larger quantities of Cu, Mn, Zn, Fe, and B were applied to the soil in the 1941-42 Greenhouse Experiment.

The nursery experiments corroborated the conclusion reached in the greenhouse experiments that slash pine seedlings do not respond noticeably to the application of readily available nutrients in Norfolk soil unless the physical condition of the soil is improved. In the 1942 Experiment a 20-ton-per-acre application of colloidal phosphate, supplemented by four 15-pound per acre applications of N and K_2O, yielded better trees than the check, but they were not significantly superior. Organic soil, which probably changed the soil biologically as well as physically and chemically, caused a marked increase in height and dry weight of seedlings.

The 1945 Nursery Experiment was more conclusive than the 1942 Experiment on the effect of colloidal phosphate treatments on stem length of slash pine seedlings. It showed also that four supplements of 30 pounds each of N and K_2O produced trees with longer stems and greater weights than four supplements of 15 pounds, but the differences in these features between the two treatments were not significant. One-ton applications of colloidal phosphate, with or without supplements of nitrogen and potassium, did not affect the trees significantly. Trees grown in a culture which contained 20 tons of colloidal phosphate were nearly as tall, had nearly as large stem diameters, and were nearly as heavy as those grown in cultures with the same amount of colloidal phosphate plus four supplements of 15 or 30 pounds per acre of N and K_2O. In the greenhouse experiment, differences between trees from such cultures were greater. Number of terminal buds per tree was significantly greater in cultures containing 20 tons of colloidal phosphate and four supplements of 15 or 30 pounds per acre each of N and K_2O than in the check.

Differences between the trees in different treatments were not so great in some respects in the nursery as in the greenhouse. This was due in part, undoubtedly, to variables which could not be controlled so effectively in the nursery as in the greenhouse. Few trees in the nursery developed branches. This restricted branch development is probably caused by the less favorable growing conditions in the nursery than in the greenhouse brought about by the close spacing of the trees in the nursery rows. In nursery-grown seedlings, relative vigor is probably expressed at the end of the growing season by number of terminal buds rather than by branching.

Although it has been demonstrated that the quality of nursery-grown slash pine seedlings can be improved by the application of 20 tons of colloidal phosphate with or without 60 or 120 pounds per acre each of N and K_2O divided into four equal amounts, no evidence has been secured as to whether so large an amount is essential for substantial improvement in tree quality. The data on the 5- and 25-ton colloidal phosphate cultures in the 1944-45 Greenhouse Experiments suggest that 10- or 15-ton applications might be adequate. Further research in needed to determine what quantity of colloidal phosphate is most economical in terms of improved tree-seedling quality.

For nursery use on Norfolk soils, and possibly similar well-drained sandy soils, in the production of slash pine seedlings, an application of at least 15 tons of colloidal phosphate per acre mixed thoroughly in the upper 4 inches of soil is recommended. Four supplements of 15- to 30-pounds per acre of N and K_2O, added at intervals of 5 weeks, should be applied.

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FIGURES*

*The scale shown in the photographs is graduated in inches and tenths of inches.

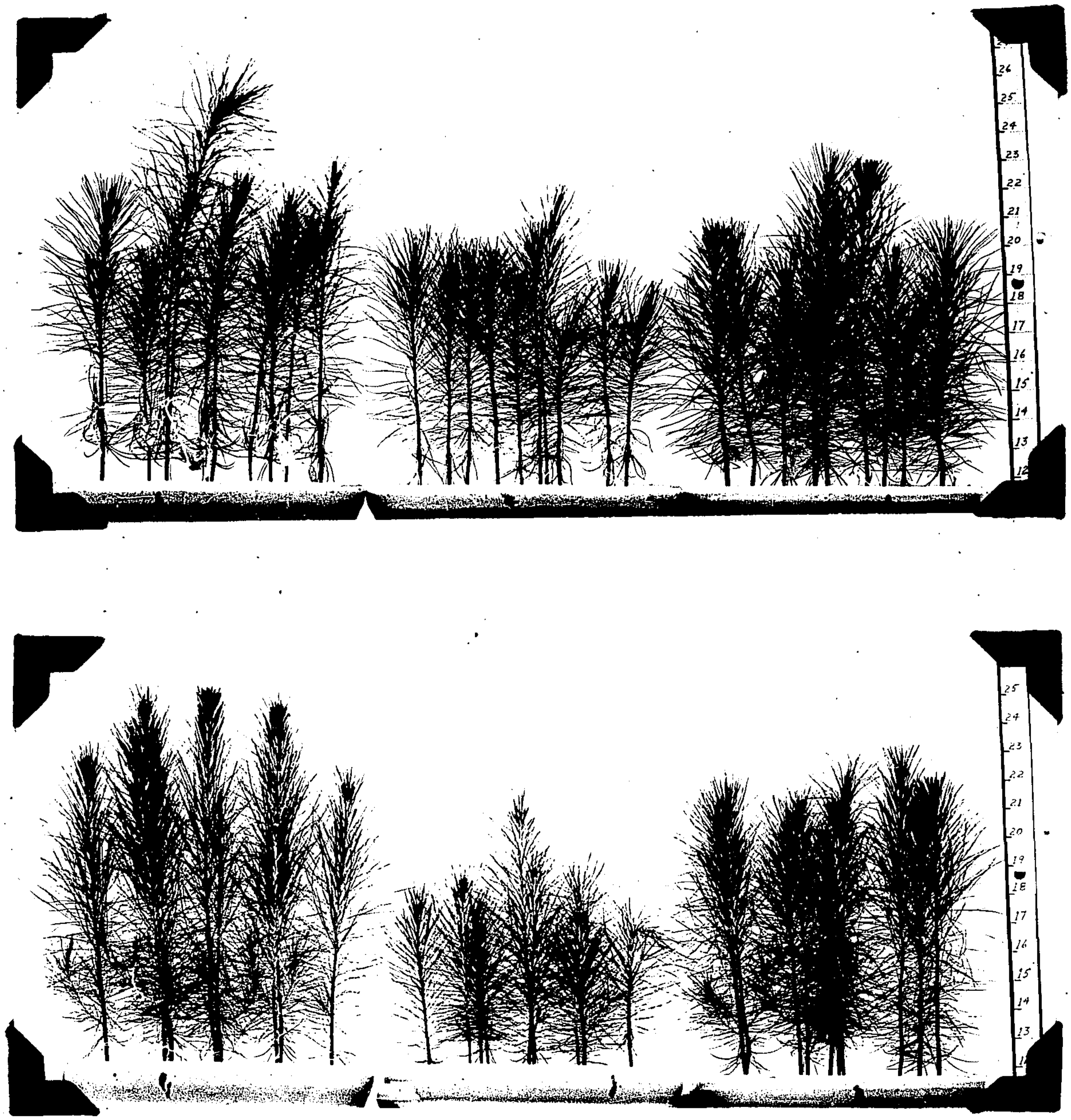


Fig. 1. --Experiment I, 1943-44. Upper, left to right. Trees in check, 60NP, and 60NK treatments. Lower, left to right. Trees in 60PK, 60N, and 60P treatments. Trees in 60N cultures are short, have few branches, have stems of small diameter, and are light in weight. Trees in the 60P treatment are tall, sturdy, and are well branched. Trees in the check and 60NP cultures are spindly and have sparse foliage, while trees in the 60NK, 60PK and 60P cultures are sturdy and have dense foliage.

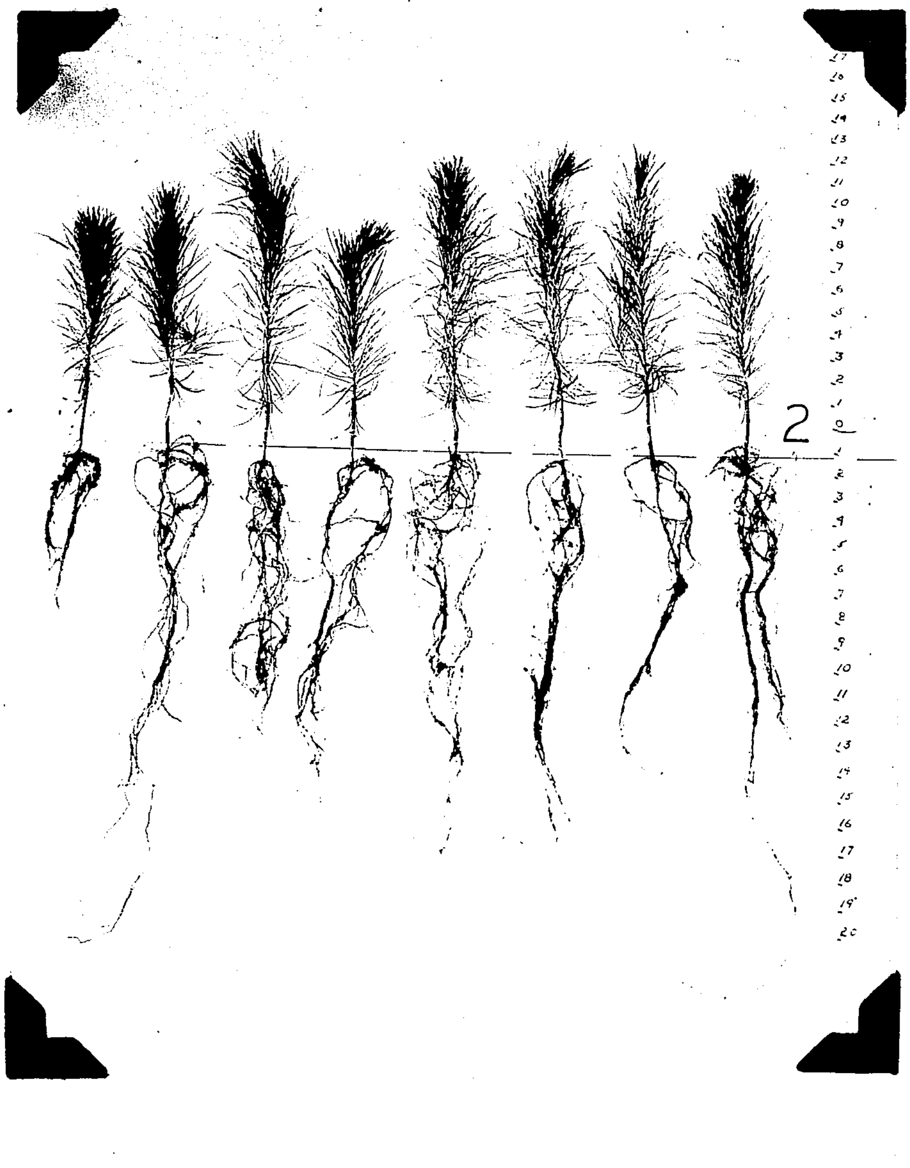


Fig. 2. --Experiment I, 1943-44. Representative trees. Left to right. Trees from 60NP, 60NK, 60PK, 60N, 60P, 60K, 60NPK, and check cultures.

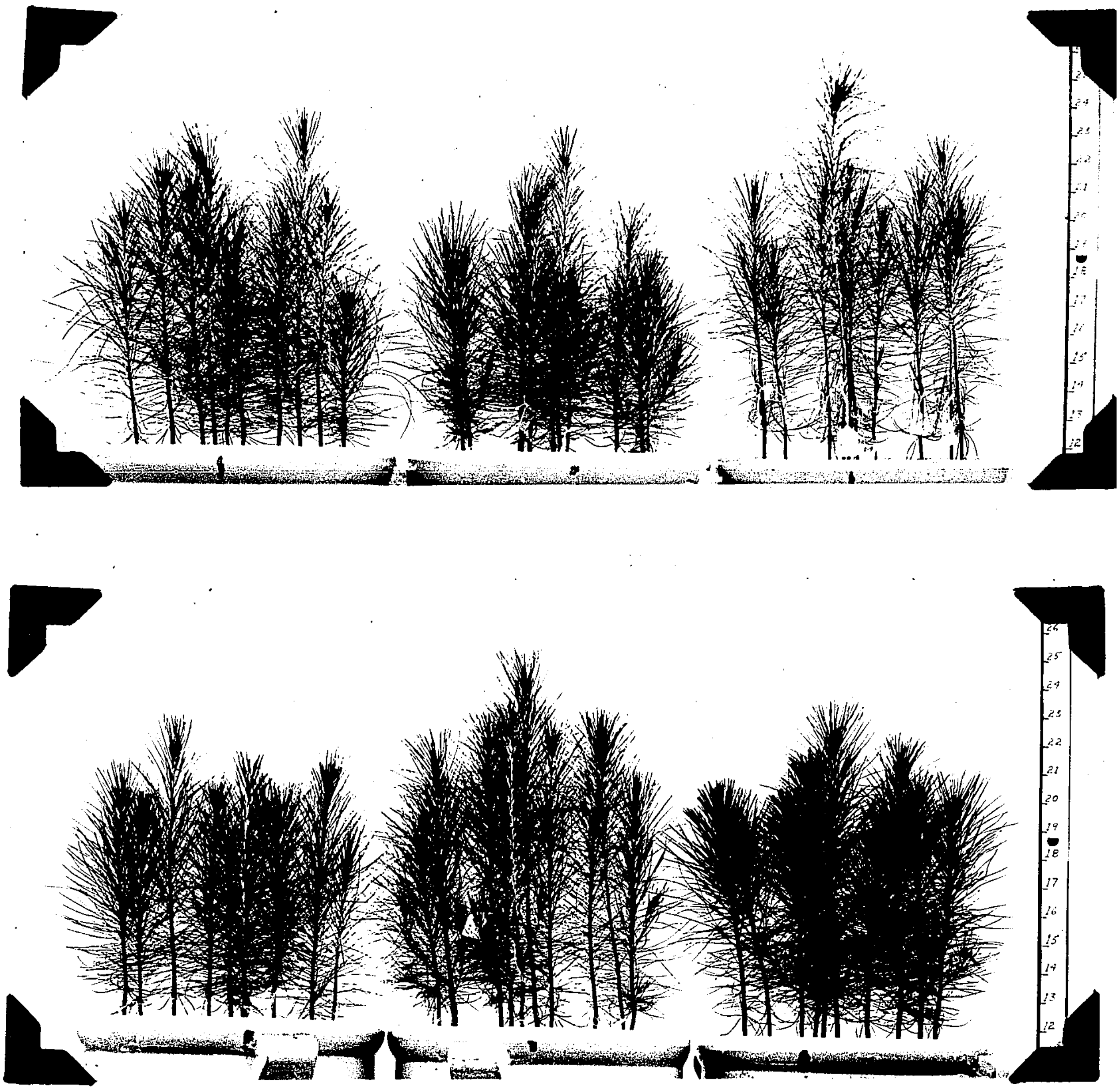


Fig. 3. --Experiment II, 1943-44. Upper, left to right. Trees in 60NPK, 120NPK, and check treatments. Lower, left to right. Trees in 180NPK, (4x)15NPK, and (4x)30NPK treatments. The poorest trees were produced by the 180NPK treatment, the best by the (4x)30NPK treatment. Split-application cultures produced better trees than the single-application treatments.

Fig. 4. --Experiment II, 1943-44. Representative trees. Left to right. Trees from 60NPK, 120NPK, 180NPK, (4x)15NPK, (4x)30NPK, (4x)45NPK and check cultures.

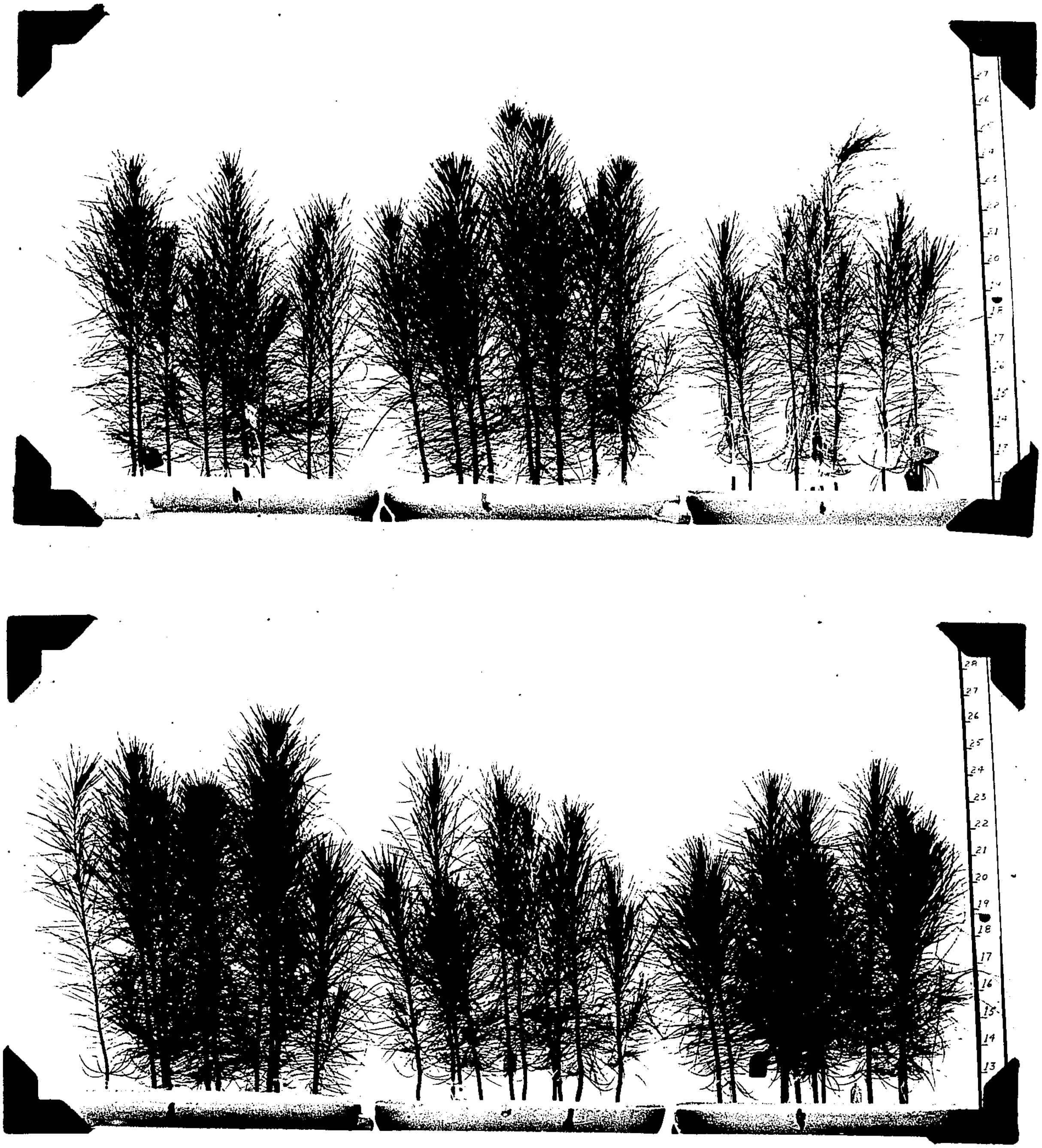


Fig. 5. --Experiment III, 1943-44. Upper, left to right. Trees in the 20 C. P., 20 C. P. +(4x)15NK and check treatments. Lower, left to right. Trees in the 20 C. P. +(4x)15N, 10 Peat, and 10 Peat +(4x)15NPK. Trees in the 20 C. P. +(4x)15NK, 20 C. P. +(4x)15N, and 10 Peat +(4x)15NPK cultures ranked highest in all features studied. Note the sturdy appearance, dense foliage, and extensive branching of these trees.

Fog. 6. --Experiment III, 1943-44. Representative trees. Left to right. Trees from 20 C. P., 20 C. P. +(4x)15NK, 20 C. P. +(4x)15N, 10 Peat, 10 Peat +(4x)15NPK, 10 Peat 20 C. P., 10 Peat 20 C. P. +(4x)15NK and check treatments.

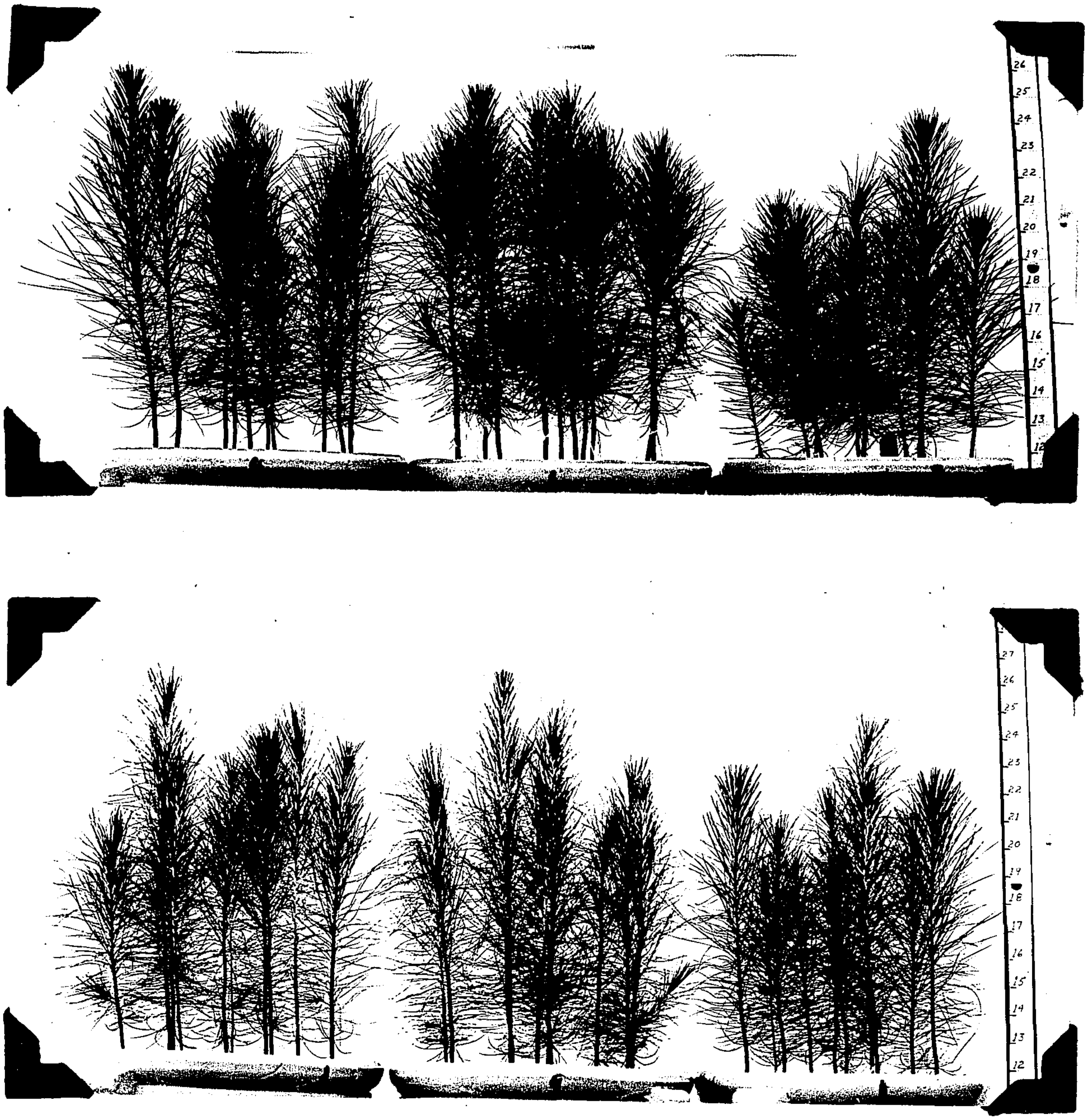


Fig. 7. --Experiment III, 1943-44. Upper, left to right. Trees in the 10 Peat 20 C. P., 10 Peat 20 C. P. +(4x)NK, and (4x)15N30P75K treatments. Lower, left to right. Trees in the 352 wood ashes, 1320 wood ashes and check treatments. Trees in the 10 Peat 20 C. P. +(4x)NK cultures are well developed and comparable to those in the 20 C. P +(4x)NK, and 20 C. P. +(4x)N cultures. Trees in the wood-ashes treatments branched more than those in the check treatment but were otherwise similar to those in the latter.

Fig. 8. --Left to right. Trees in the 20 C. P. +(4x)15NK, 10 Peat 20 C. P. +(4x)15NK, and 60N cultures. These pots illustrate certain extremes in development of slash pine seedlings. The trees in the 20 C. P. +(4x)15NK culture had developed numerous branches and they were tall and sturdy. Trees in the 10 Peat 20 C. P. +(4x)15NK culture were the tallest through the duration of the experiment. The pot representing 60N culture produced the smallest trees.

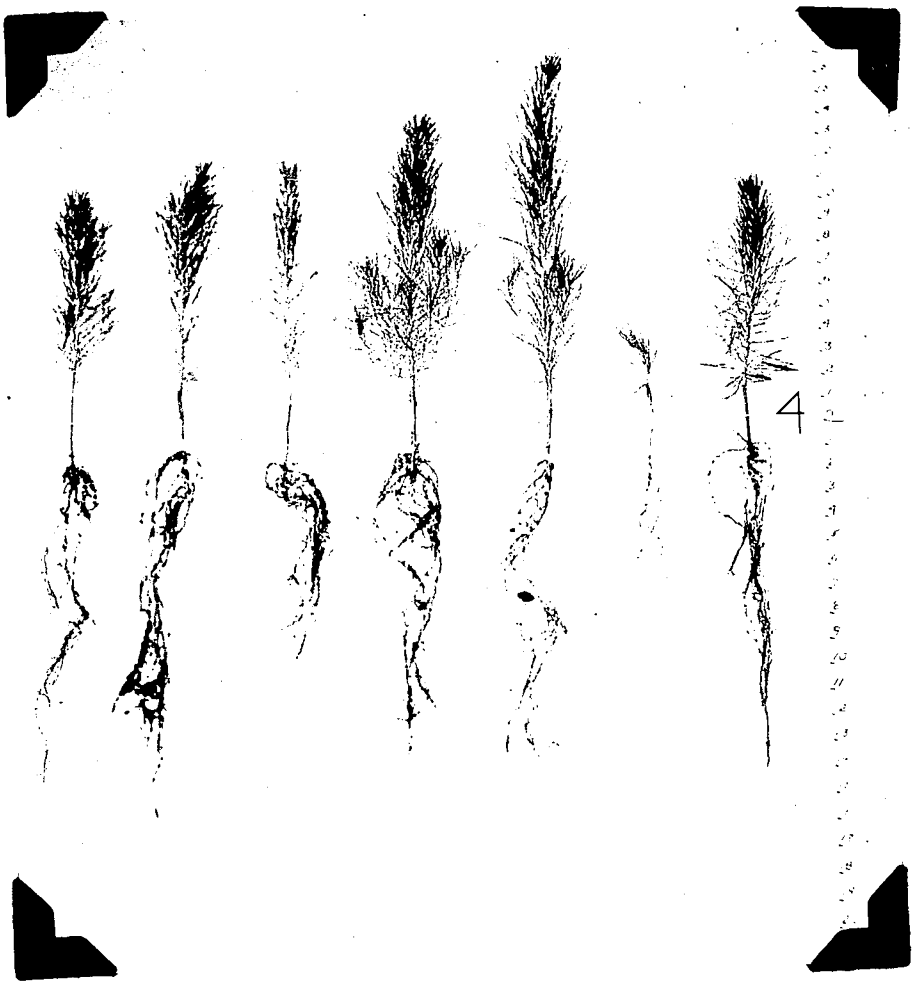
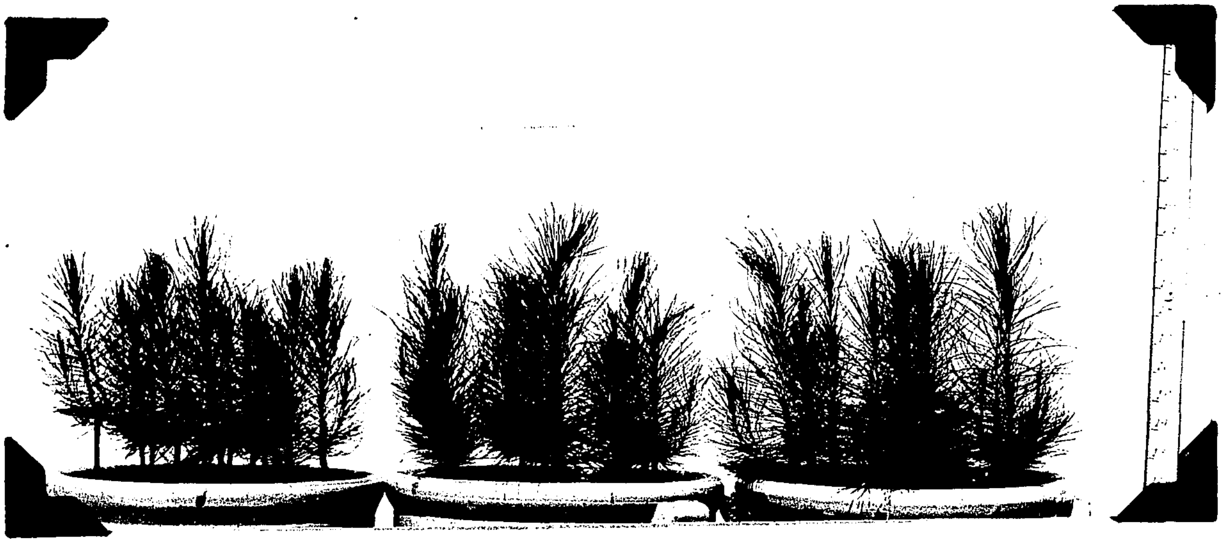


Fig. 9. --Left to right, representative trees from the (4x)15N30P75K, 352 wood ashes, and 1320 wood ashes treatments; a heavily branched tree from the 20 C. P. +(4x)NK treatment, the tallest tree from the 10 Peat 20 C. P. +(4x)15NK culture, the smallest tree from the 60N culture; and a representative tree from the check treatment.



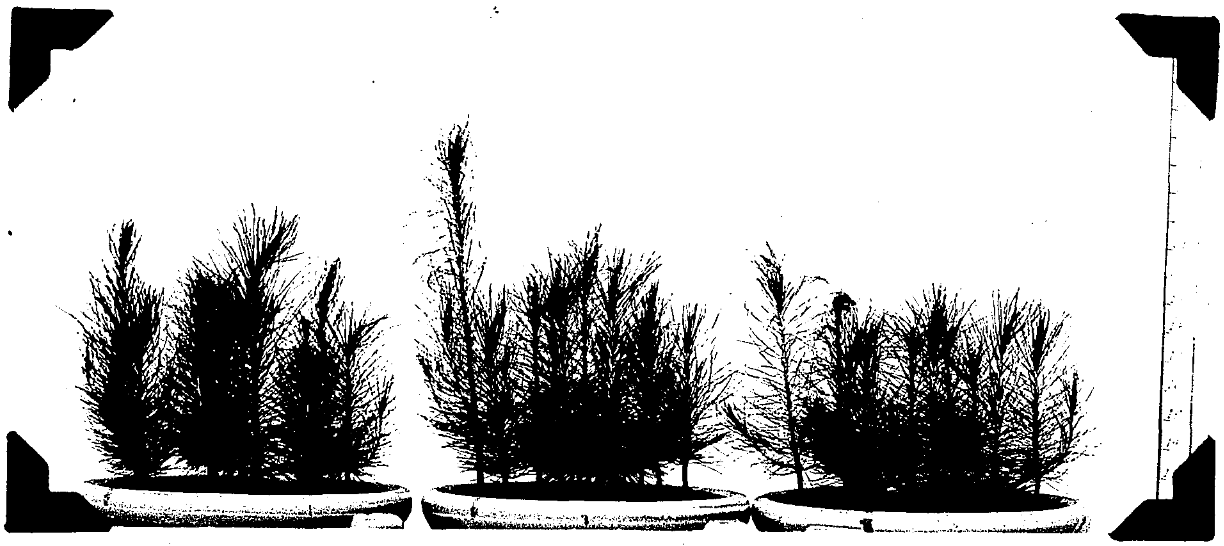


Fig. 10. --Experiment I, 1944-45. Upper, left to right. Trees in the 0.5 C. P., 1.0 C. P., and 5 C. P. cultures. Lower, left to right. Trees in the 1.0 C. P., 1.0 C. P.(S), and check cultures. Although visible differences in the trees from these treatments are not obvious trees in the colloidal phosphate treatments were heavier, larger in diameter, and branched more than those in the check culture. The 25 C. P. culture (see Fig. 11) produced the best trees.

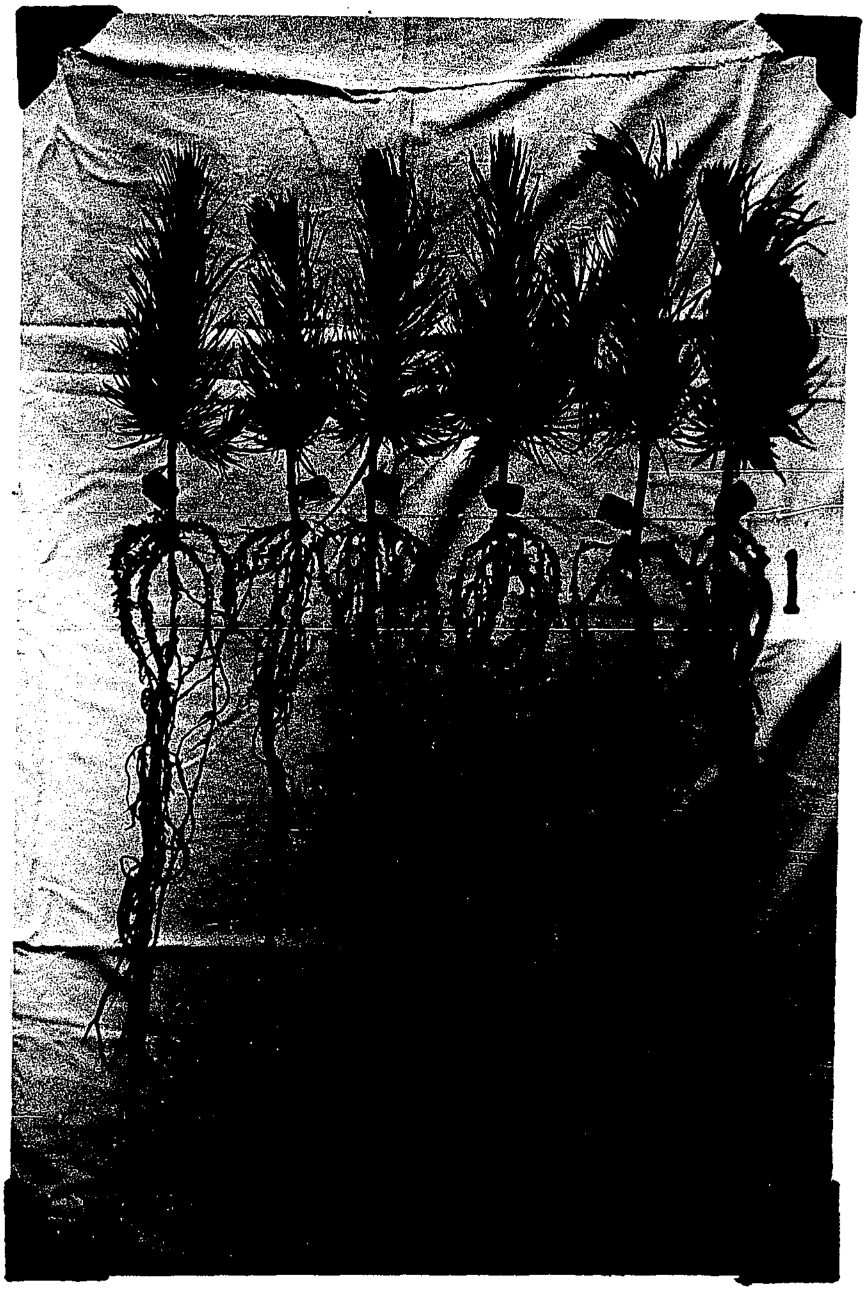


Fig. 11. --Representative trees from the 0.5 C. P., 1.0 C. P., 5 C. P., 25 C. P., 1.0 C. P.(S), and check cultures from left to right. Experiment I, 1944-45.

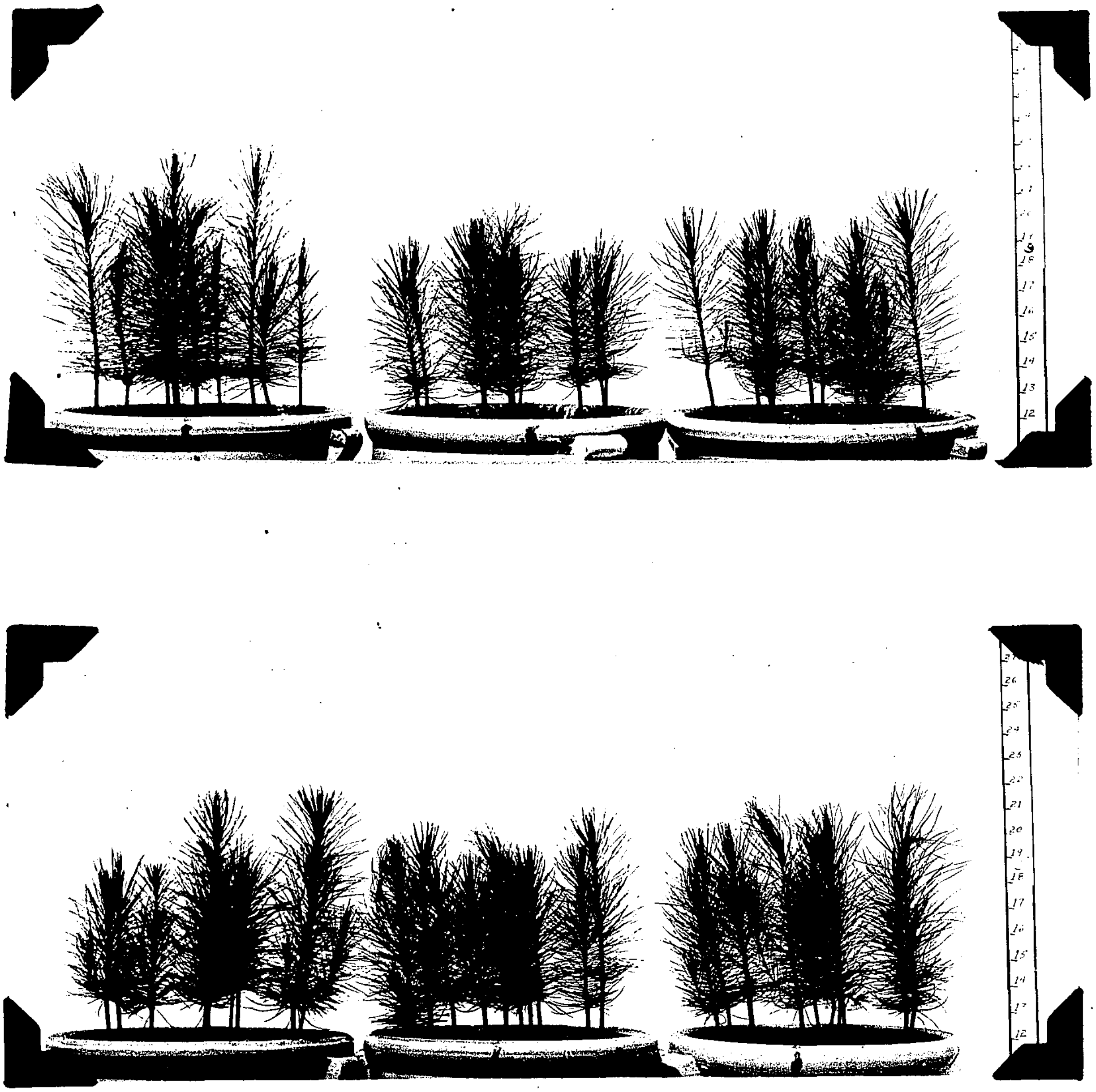


Fig. 12. --Experiment II, 1944-45. Upper, left to right. Trees in the 30P, 60P, 120P treatments. Lower, left to right. Trees in the 240P, 480P, and check treatments. The trees in the above cultures were similar in all features. No significant differences exist in the trees in these treatments.

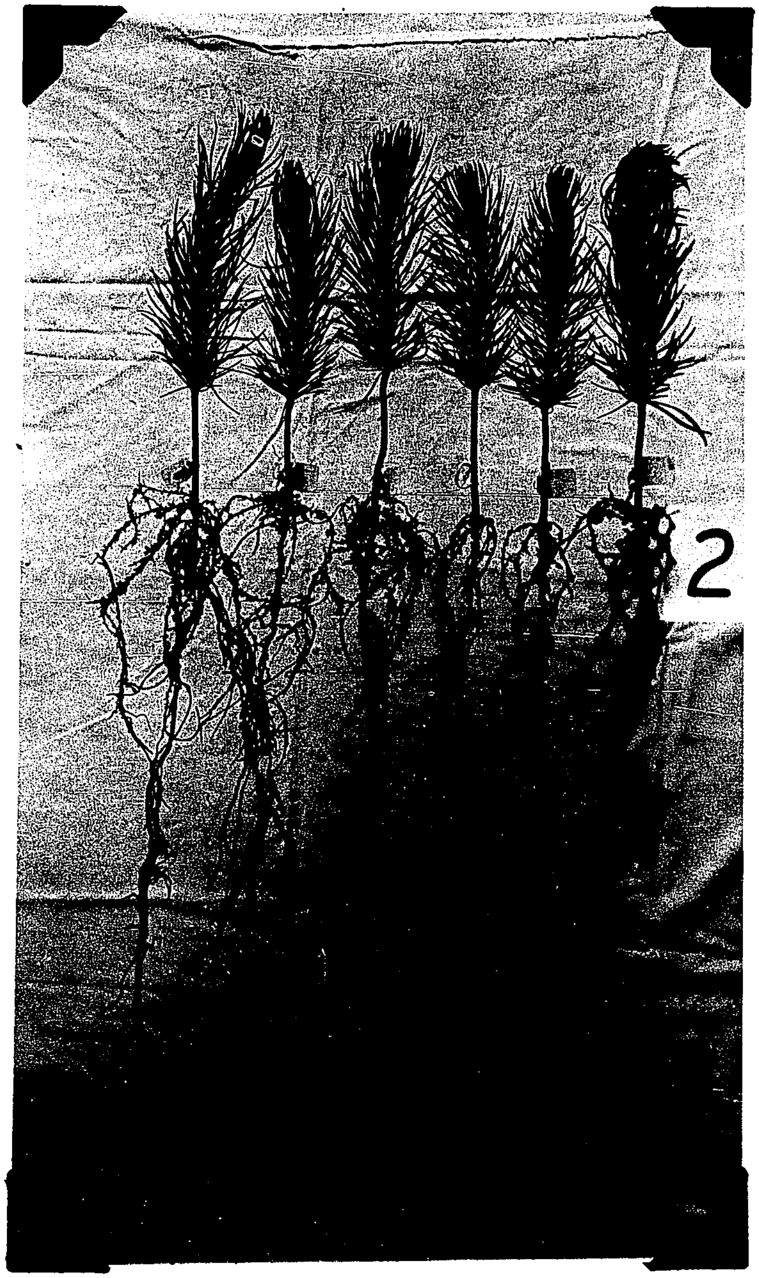


Fig. 13. --Representative trees from the 30P, 60P, 120P, 240P, 480P and check cultures from left to right. Experiment II, 1944-45.

Fig. 14. --Experiment III, 1944-45. Upper, left to right. Trees in the 60P-K, 120P-K, and 480P-K cultures. Lower, left to right. Trees in the 60P-NK, 120P-NK, and 480P-NK cultures.

Fig. 15. --Experiment III, 1944-45. Left to right. Trees in the 60P-CaNK, 120P-CaNK, and 480P-CaNK. Althought differences in the trees in the various treatments in Figs. 13, 14, and 15 are not obvious, significant differences exist in stem diameter and branching between the different treatments. Cultures supplied all four nutrients produced trees with largest stem diameters and the most branching

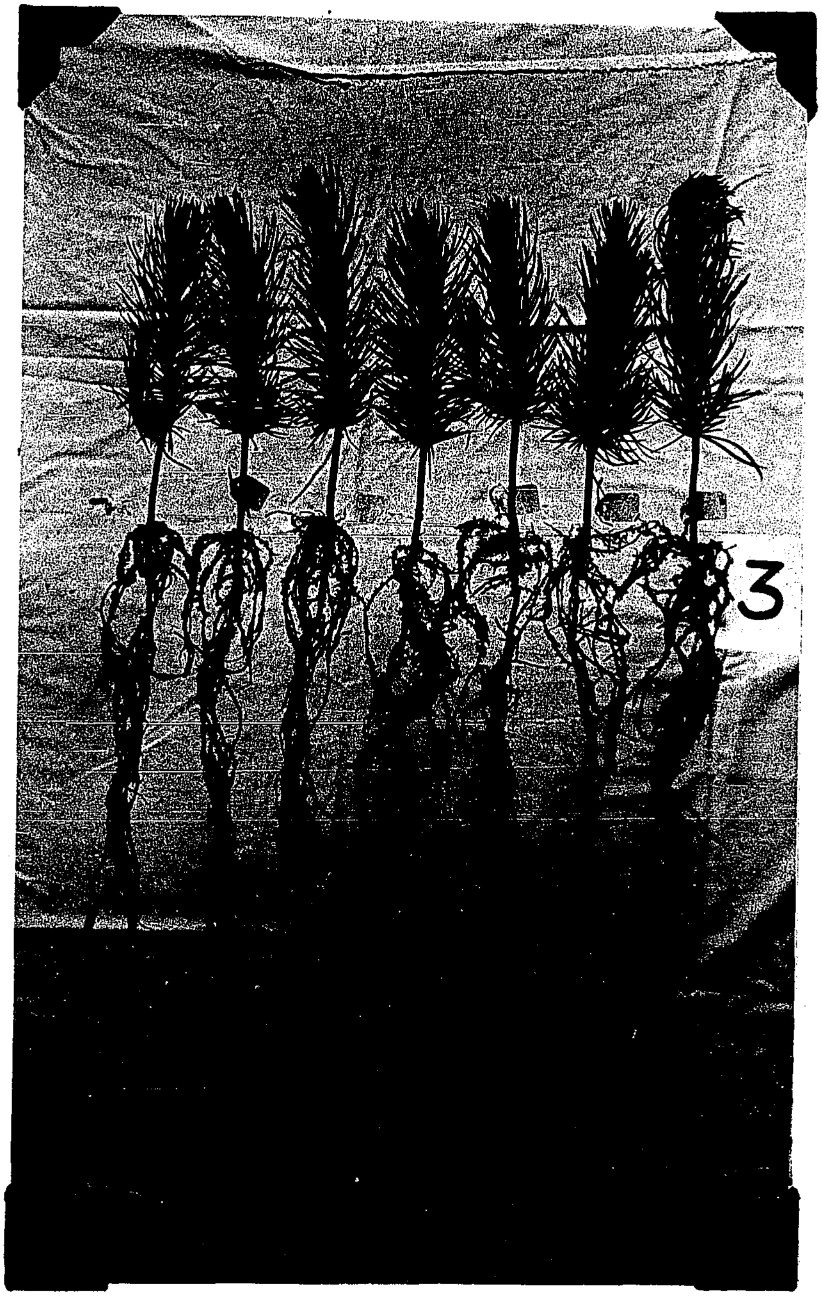


Fig. 16. --Representative trees from the 60P-K, 120P-K, 480P-K, 60P-NK, 120P-NK, 480P-NK, and check cultures (left to right), Experiment III, 1944-45.

Fig. 17. --Representative trees from the 60P-NK, 120P-NK, 480P-NK, 60P-CaNK, 120P-CaNK, 480P-CaNK, and check treatments (left to right), Experiment III, 1944-45.

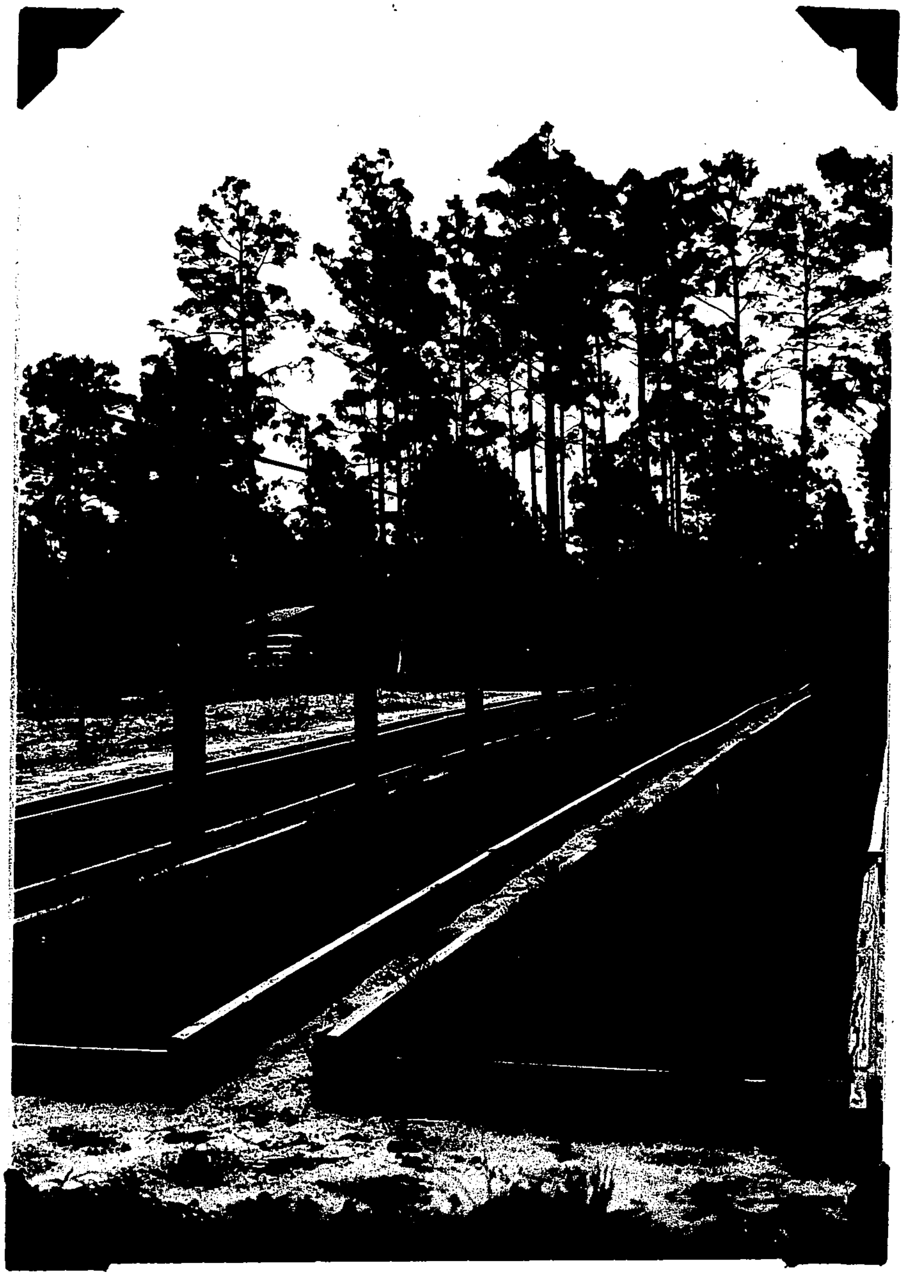


Fig. 18. --The two seed beds of the 1945 experiment in the Austin Cary Forest Nursery in January 1946. Differences in seedling density and size are most conspicuous in the right-hand bed.

Fig. 19. --Trees in plot 19 are in the 20 C. P. +(4x)30NK and those in plot 20 are in the 20 C. P. culture. Trees are sturdy and well developed in both plots. Seedling density is highest in the 20 C. P. +(4x)30NK culture.

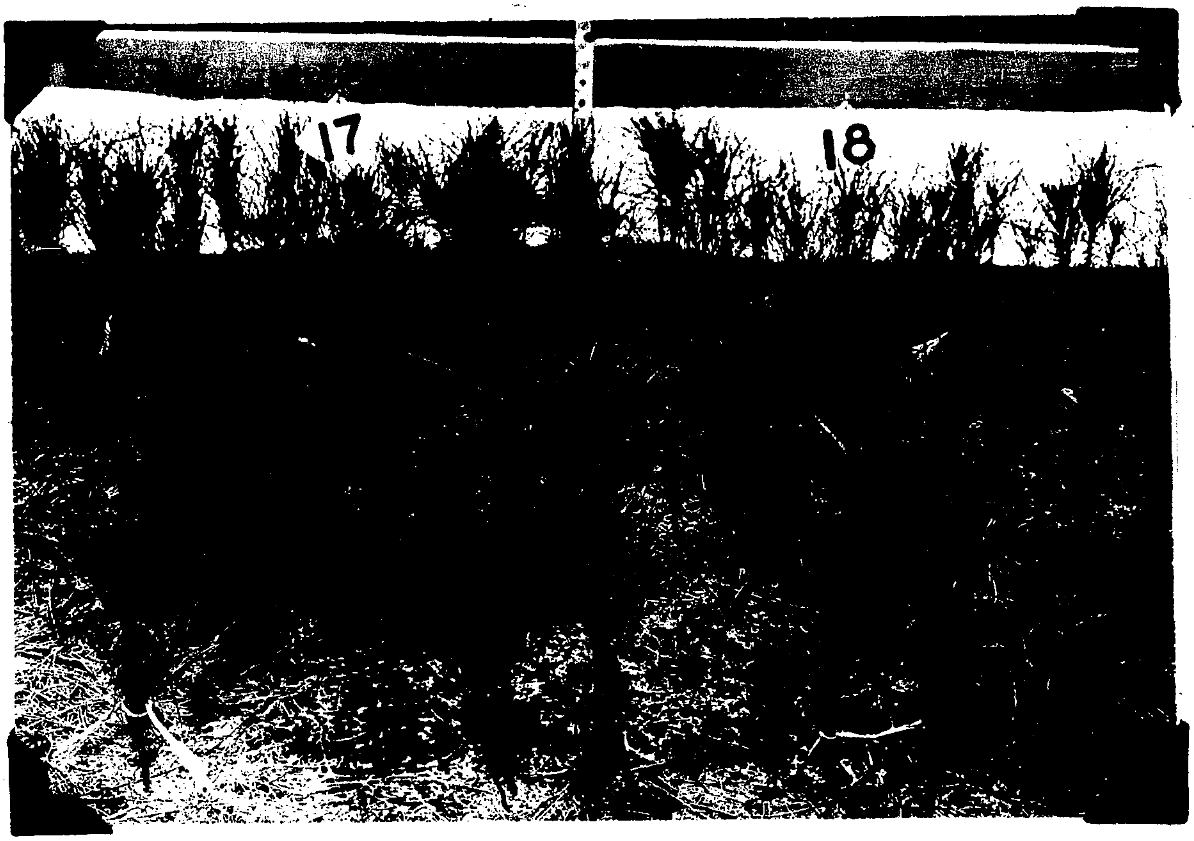


Fig. 20. --Trees in plot 17 are in a check and those in plot 18 are in a 1.0 C. P. +(4x)30NK culture. Density is thin in both plots. The experimental data showed little difference between the trees in these treatments.

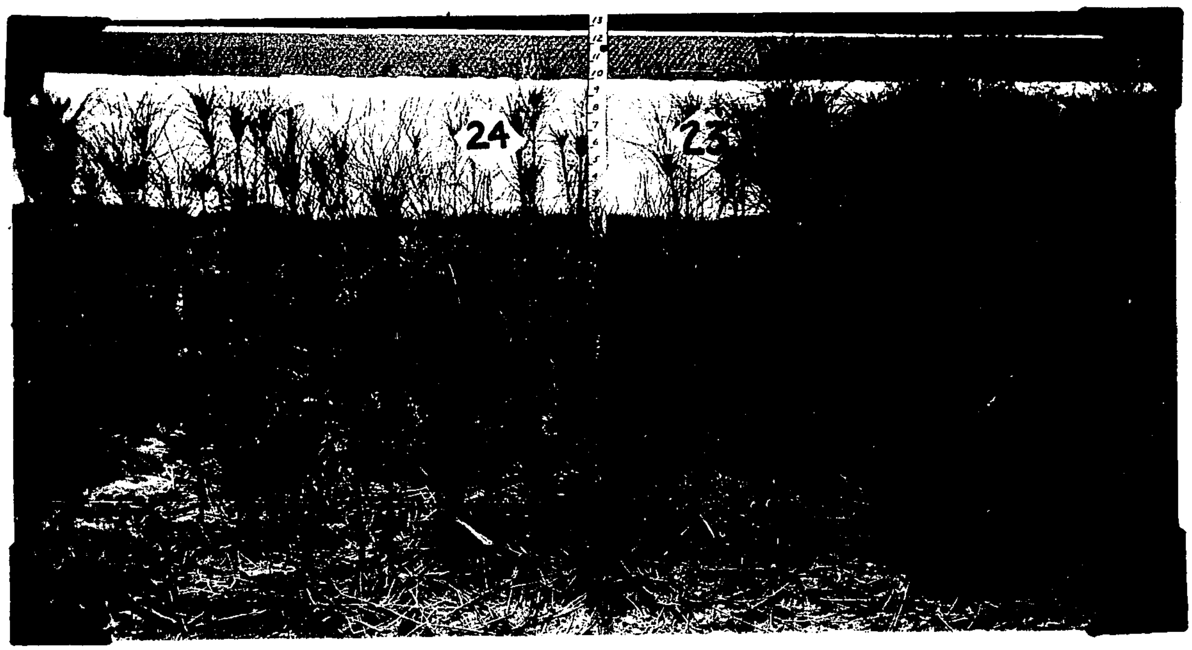


Fig. 21. --Trees in plot 23 are in a 20 C. P. +(4x)15NK and those in plot 24 are in a 1.0 C. P. culture. Seedlings in the former are well developed and they form a dense stand, while those in the latter are small and rather spindly, and they form a rather thin stand.

Fig. 22. --Seedlings at left are in a 1 C. P. +(4x)30NK and those at the right are in a 1 C. P. culture. Although seedlings in the former were not significantly superior to the latter they were taller, heavier, and had larger diameters. Seedlings in the 1 C. P. culture form a denser stand than those in the 1 C. P. +(4x)30NK culture.

APPENDIX

Effect of Temperature and Length of Day on Seedling Characteristics

It was evident during the 1944-45 Greenhouse Experiments that the slash pine seedlings were developing differently than had the trees in the 1943-44 Greenhouse Experiments. Since the soil in all pots was maintained at the same moisture content, and since seed from the same lot was used in all the 1943-44 experiments and one of the 1944-45 experiments, soil moisture and seed source can be dismissed as possible causes of differences in seedling behavior during the two seasons in at least some of the experiments. At the time of harvesting the trees those in three of the four 1944-45 experiments and those in all the 1943-44 experiments were within a few days of the same age. Therefore, differences in the trees at the end of these experiments cannot be attributed to age differences. Certain aspects of the environment under which the trees grew did differ during the two seasons. An examination of Tables 86, 87, 88, and 89 reveals rather pronounced differences in temperature and length of day during the various experiments. Temperatures were consistently higher and lengths of days were longer during the 1943-44 experiments than during the 1944-45 experiments. For the 21 weeks of the former experiment, the mean weekly temperature was 10 and 11 degrees F. higher, the mean maximum weekly temperature was 17 degrees F. higher, and the mean minimum weekly temperature was 9 degrees F. higher than those for the 22 weeks of Experiments I, II, III of the 1944-45 series. Mean weekly length of day for the former was 1.20 to 1.21 hours longer than for the latter. It is evident that the trees grew under different temperature and length-of-day

Table 86. --Weekly temperature and length of day during 1943-44 Greenhouse Experiment

Week of Experiment	Weekly temperature - degree F. Mean	Mean maximum	Mean minimum	Mean weekly length of day (hours*)
1	71	89	61	10.28
2	69	82	61	10.37
3	67	86	61	10.48
4	70	94	64	10.63
5	71	85	61	10.77
6	73	86	63	10.95
7	73	87	65	11.15
8	81	98	72	11.35
9	77	95	67	11.55
10	75	80	65	11.75
11	75	91	66	11.97
12	83	99	65	12.18
13	82	94	75	12.40
14	73	93	62	12.62
15	82	100	73	12.82
16	88	99	81	13.00
17	89	104	82	13.20
18	84	103	74	13.38
19	84	103	73	13.52
20	90	110	78	13.70
21	90	115	79	13.88
Mean	78	95	69	12.00

*Length of time between sunrise and sun set.

Table 87. --Weekly temperature and length of day during Experiment I, 1944-45

Week of Experiment	Weekly temperature - degree F. Mean	Mean maximum	Mean minimum	Mean weekly length of day(hours*)
1	80	98	69	11.63
2	70	84	60	11.47
3	73	84	65	11.25
4	67	86	55	11.01
5	68	77	61	10.88
6	66	76	59	10.72
7	65	74	59	10.58
8	62	70	55	10.43
9	63	70	57	10.25
10	60	66	55	10.25
11	64	74	57	10.23
12	66	75	60	10.23
13	68	77	62	10.23
14	62	70	57	10.33
15	67	74	58	10.42
16	65	72	59	10.55
17	64	76	55	10.68
18	66	77	59	10.85
19	69	83	59	11.03
20	72	86	63	11.23
21	73	86	64	11.43
22	76	91	66	11.63
Mean	68	78	60	10.79

*Length of time between sunrise and sun set.

Table 88. --Weekly temperatures and length of day during Experiments II and III, 1944-45 Greenhouse Experiment

Week of Experiment	Weekly temperatures - degree F			Mean weekly length of day(hours*)
	Mean	Mean maximum	Mean manimum	
1	70	81	62	11.43
2	72	87	63	11.22
3	68	85	56	11.05
4	67	76	60	10.85
5	55	76	59	10.68
6	63	71	57	10.52
7	64	70	58	10.42
8	62	70	56	10.32
9	60	66	55	10.25
10	64	74	58	10.23
11	67	76	61	10.23
12	68	76	62	10.23
13	62	70	57	10.33
14	67	74	58	10.43
15	66	73	60	10.58
16	63	75	53	10.70
17	67	77	61	10.80
18	70	86	59	11.00
19	73	85	64	11.27
20	73	86	64	11.47
21	76	91	66	11.67
22	72	89	60	11.89
Mean	67	78	60	10.80

*Length of time between sunrise and sun set.

Table 89. --Weekly temperatures and length of day during Experiment IV, 1944-45 Greenhouse Experiment

Week of Experiment	Weekly temperature - degree F Mean	Mean maximum	Mean minimum	Mean weekly length of day(hours*)
1				11.10
2				10.90
3				10.73
4				10.68
5				10.45
6	See Table 51 from the fourth to the			10.33
7				10.27
8	twenty-second week			10.23
9				10.23
10				10.23
11				10.33
12				10.38
13				10.53
14				10.67
15				10.82
16				11.00
17				11.22
18				11.40
19				11.60
20	74	90	62	11.82
21	81	100	68	12.03
22	74	90	62	12.25
23	79	93	68	12.47
24	72	86	63	12.67
25	81	92	73	12.87
26	80	94	72	13.07
27	82	96	73	13.25
Mean	69	81	61	11.24

*Length of time between sunrise and sun set.

Table 90. --Evaporation from Livingston atmometers during the 1944-45 Greenhouse Experiments

Week	Evaporation from atmometers - ml. Black	White	Difference
1	178	144	34
2	156	126	30
3	128	98	30
4	178	134	44
5	141	101	40
6	141	100	41
7	114	84	30
8	101	67	34
9	101	65	36
10	57	49	8
11	116	72	44
12	89	55	34
13	62	36	26
14	58	34	24
15	85	52	33
16	62	37	25
17	84	45	39
18	69	42	27
19	110	63	47
20	90	53	37
21	100	67	33
22	130	92	38
23	168	127	41
24	172	134	38
25	193	154	39
26	177	140	37
27	125	98	27
28	178	126	52
29	159	113	46
30	169	131	38
Total	3691	2639	1052

conditions during the two seasons. Either or both of these factors could be the chief cause or causes of the differences between the trees produced in the 1943-44 season and those produced during the 1944-45 season.

Data on characteristics of trees from four comparable treatments from each of the two seasons were selected to illustrate differences between the trees grown under different temperatures and lengths of days. These data are presented in Table 91. The combined data from the eight treatments were not analyzed statistically, but many of the differences, especially those in stem length, are so large as to leave little doubt as to their significance. Stem lengths of trees in the four 1944-45 experiments are 38 to 46 percent of those in the 1943-44 experiments. With respect to branching, trees in all treatments of the latter experiment did not hold a consistent relationship to those in the former. More trees branched, and the number of branches per tree was greater in the check and 25 C. P. +(4x)15NK treatments of Experiment I, 1944-45 than in the check and 20 C. P. +(4x)15NK treatments of the 1943-44 experiment. The difference in number of branched trees between the two colloidal phosphate treatments probably is not significant, however. Treatments in Experiment III, 1944-45, produced fewer branched trees and fewer branches per tree than similar cultures in Experiment II, 1943-44. Differences in number of branched trees probably are not significant, but differences in number of branches per tree probably are. Diameters of trees in all four cultures in the 1944-45 experiments exceed those of the four cultures in the 1943-44 experiment. The former exceed the latter by 11 to 12 percent. Shoot weights of trees from all cultures in the 1943-44 experiment are greater (13 to 14 percent) than those from the 1944-45 cultures. In contrast, root weights of trees from two treatments- check and

Table 91. --The mean of measured characteristics of trees grown in several selected soil treatments under different temperature and length-of-day conditions.

Measured Characteristics	1943-44 Experiment III Check	1944-45 Experiment I Check	1943-44 Experiment III 20C.P. + (4x)15NK	1944-45 Experiment I 25C.P. + (4x)15NK	1943-44 Experiment II Check	1944-45 Experiment III Check	1943-44 Experiment II (4x)15NPK	1944-45 Experiment III 60P-NK
Stem length mm.	237.2	88.8	282.2	111.9	230.1	106.4	233.1	99.0
Trees branched % of total	42.5	80.0	77.5	95.0	35.0	30.0	70.0	50.0
Branches per tree - number	1.17	2.12	2.27	4.32	1.20	0.68	2.03	1.12
Stem diameter - mm	3.46	3.99	4.14	4.84	3.20	3.56	3.46	3.78
Shoot weight -gr	1.83	1.41	2.84	2.07	1.59	1.26	1.83	1.29
Root weight -gr	0.84	1.19	1.20	1.69	0.83	0.75	0.89	0.85
Total weight -gr	2.67	2.60	4.04	3.76	2.42	2.01	2.72	2.14
Root - shoot ratio	0.47	0.85	0.43	0.82	0.52	0.60	0.49	0.66

20 C. P. +(4x)15NK- of the former are less (29 and 27 percent, respectively, than those from similar treatments in Experiment I, 1944-45. Because the tree roots in the cultures in the latter experiments are heavier, and the tree shoots are lighter, than those in the former experiment root-shoot ratios of these 1944-45 trees are much larger (nearly double) than those of these 1943-44 trees. On the other hand, root weights of trees in the check and (4x)15NK cultures of the 1943-44 experiment are slightly less than those of trees in Experiment III, 1944-45. Again the root-shoot rotios of the 1944-45 trees are larger than those of the 1943-44 trees. Total weights of trees in all four cultures of the 1944-45 experiments are 2 to 21 percent lighter than those in the four cultures of the 1943-44 experiments. It is noteworthy that trees grown under low temperatures and short days, although making 46 percent or less of the stem growth of trees grown under higher temperatures and longer days, are only 2 to 21 percent lighter in weight.

While the low temperature and short days were not conducive to stem elongation, root growth is not handicapped, as a matter of fact, apparently it is benefitted.

It is evident that when slash pine seedlings are grown during periods of relatively low temperature and short days they grow differently than when grown during periods of higher temperatures and shorter days. This fact should be kept in mind in the interpretation of data on greenhouse-grown seedlings.

Statistical Analysis of Data

The experiments were so designed that all data on tree characteristics could be subjected to analyses of variance. In some cases, data on soil characteristics could be handled in the same manner. The summaries of three analyses of variance are shown in Tables 92, 93, and 94. These illustrate three different types of experiment used in the 1943-44 Greenhouse Experiment. They show how the degrees of freedom were segregated. In all cases, the variance due to variation within pots and within replications has been segregated from the total variance. When the variance due to treatment could be subdivided, as in Experiments I and II, 1943-44, this was done. Such subdivision was possible also in Experiment III, 1944-45. The error variance (sum of squares of error divided by the number of degrees of freedom in the error) is used as the estimate of the variance of the parent population. By comparing the error variance with the variance of any of the other sources of variance, the presence or absence of significant differences can be detected from the F value. Since the primary object of the experiments was to determine whether various soil treatments would cause significant differences in the response of slash pine seedlings, the significance of this source was examined in detail. In order to determine between which treatments a significant difference exists, it is necessary to express what constitutes a significant difference in terms of the units in which the tree feature was measured. In the case of stem length, the unit is millimeters. Thus by expressing in millimeters the difference in stem length needed between two treatment means to show significance, it is possible to determine between which treatments a significant difference exists. The method of making this calculation, using the data from Table 94, is shown in the formula which follows:

Table 92. --Analysis of variance for stem length at 6 weeks
Experiment I, 1943-44

Source†	Degrees of freedom	Sum of squares	Mean square	F values Experiment	F values 5%	F values 1%	Standard deviation
Total	319	7598.0					
Within pots	288	4002.9	13.89	.18	1.61	1.94	
Replication	3	421.1	140.36	1.86	1.86	3.07	
N	1	398.3	398.3	5.29*	4.32	8.02	
P	1	209.6	209.6	2.78	4.32	8.02	
K	1	747.2	747.2	9.93**	4.32	8.02	
NP	1	7.5	7.5	.09	4.32	8.02	
NK	1	222.8	222.8	2.96	4.32	8.02	
PK	1	3.4	3.4	.04	4.32	8.02	
NPK	1	5.8	5.8	.07	4.32	8.02	
Error	21	1579.4	75.20				1.37

*Significant at 5%
**Significant at 1%
†In this simple factional experiment, the effects of any nutrient or the interaction between nutrients is secured from the single degree of freedom involved in comparing those treatments that show the effect of nutrient (or interaction of nutrients) with those treatments that do not show the effect of that nutrient (or interaction of nutrients). In this type of experimental design, four treatments will show the effect of a particular nutrient, and four treatments will show no effect of that nutrient.

Table 93. --Analysis of variance for stem length 6 weeks after initial treatment, Experiment II, 1943-44

Source	Degrees of freedom	Sum of squares	Mean square	F values: Experiment	F values: 5%	F values: 1%	Standard deviation
Total	239	6571.5					
Within pots	216	4413.9	20.43	.69			
Replication	3	542.6	180.86	6.18	3.29	5.42	
Methods	1	893.2	893.2	30.55	4.54	8.68	
Rates	2	187.8	93.9	3.21	3.68	6.36	
Methods x rates	2	95.6	47.8	1.63	3.68	6.36	
Error	15	438.4	29.23				0.9

Table 94. --Summary of analysis of variance for stem length 6 weeks after initial treatment, Experiment III, 1943-44

Source	Degrees of freedom	Sum of squares	Mean square	F values: Experiment	F values: 5%	F values: 1%	Standard deviation
Total	439	15907.82					
Within jars	396	10496.50	26.50	.38	1.44	1.74	
Replication	3	318.68	106.22	1.53	2.92	4.51	
Treatment	10	3014.49	301.45	4.35**	2.18	3.00	
Error	30	2078.15	69.27				1.3

**Very significant

$$\text{F value treatment} = \frac{\text{mean square treatment}}{\text{mean square error}}$$

$$= \frac{301.45}{69.27} = 4.35$$

Since the F value treatment is larger than 3.00, the difference between two or more treatment means is significant at one percent.

Standard deviation of treatment mean

$$= \sqrt{\frac{\text{error mean square}}{\text{number of items}}}$$

$$= \sqrt{\frac{69.27}{40}} = 1.3$$

Standard deviation of difference between two means = standard deviation $\sqrt{2}$ = $1.3 \times \sqrt{2} = 1.838$

t at 5 percent for 30 D. F. = 2.042

t at 1 percent for 30 D. F. = 2.75

Difference between two treatment means to be significant = t x standard deviation of difference between two means

$$= 2.042 \times 1.838 = 3.9 \text{ (at 5 percent)}$$

$$= 2.75 \times 1.838 = 5.1 \text{ (at 1 percent)}$$

Based on the foregoing, if a difference in stem length between two treatments means is 3.8, the difference between these means is significant at 5 percent; if the difference is 5.1, the difference between the means is significant at 1 percent.

The standard deviations shown in all tables are the standard deviations of the treatment means.

Loss of Water in Greenhouse
Through Evaporation and Transpiration

Records of the amount of water that was added to each pot, and of the weights of each pot at various intervals during the experiments and at their termination made possible the calculation of the loss of water through evaporation and transpiration from each pot in the greenhouse experiments of 1943-44 and 1944-45. These data were the basis for calculating the mean loss of water per pot and per gram of oven-dry plant tissue for each soil treatment. This information is presented in Tables 95 to 98, inclusive. Since the 1943-44 experiments and Experiments I, II, and III of the 1944-45 series extended over approximately the same length of time (about 20 weeks), differences in mean total water loss from the pots in the various treatments of these experiments can be attributed chiefly to differences in temperature during the two seasons and differences in the dry weights attained by trees in the different cultures. The relationship between these two factors is discussed elsewhere and is shown by supporting data in Tables 86 to 91, inclusive.

Table 95 shows that significant differences in total water loss exist between the soil treatments. The cultures which produced the heaviest trees lost the most water, due, obviously, to the greater transpiration by the larger trees. It is noteworthy that the water loss per gram of dry plant itssue is least in the cultures that produced the heaviest trees. The maximum loss of 1.345 liters occurred in the 60N culture and the minimum loss of 0.678 liter occurred in the 10 Peat 20 C. P. +(4x)15NK culture. These cultures produced the lightest and heaviest trees, respectively. The mean weight of trees in the former were 37.4 percent of that in the latter, but the mean water loss per gram of dry plant tissue in the former was 1.98 times that in the latter. This large difference in water loss is due, no doubt, to the greater proportion of water lost through evaporation in the culture which produced the smallest trees,

Table 95. --Mean loss of water per pot and per gram of dry plant tissue for each treatment during 1943-44 Greenhouse Experiments

Treatment	Loss of water: Per pot (Liters)	Loss of water: Per gram of dry tissue (Liters)
Check	24.86	1.023
60NP	22.32	1.187
60NK	23.83	1.103
60PK	28.20	0.953
60N	22.06	1.345
60P	27.85	0.834
60K	26.02	0.997
60NPK	24.90	0.922
60NPK	24.97	0.928
120NPK	23.77	0.970
180NPK	23.11	0.967
(4x)15NPK	26.68	0.981
(4x)30NPK	26.21	0.854
(4x)45NPK	25.58	0.933
Check	26.00	0.970
20C.P.	28.12	0.829
20C.P.+(4x)NK	30.70	0.760
20C.P.+(4x)N	30.48	0.722
10 Peat	25.83	0.950
10 Peat+(4x)15NPK	26.76	0.745
10 Peat 20C.P.	27.58	0.826
10 Peat 20C.P.+(4x)NK	29.70	0.678
(4x)15N 30P 75K	23.72	0.882
352 Wood ashes	26.28	0.973
1320 Wood ashes	26.32	0.937
Standard deviation	0.69	
Difference between treatment means to be significant at 5 and 1 percent	1.95 2.58	
F value treatment	11.21**	

**Significant at 1 percent.

and to the more efficient use of water by trees in the culture which produced the largest trees.

The effect of temperature on water loss can be seen by comparing the 10 Peat +(4x)15NPK culture (Table 95) of the 1943-44 experiment with the 25C. P. culture of the 1944-45 experiment (Table 96); and the 352 wood ashes treatment (Table 95) with the 0.5 C. P. treatment (Table 96). The tree weights are comparable, 3.59 and 3.76 gr.; respectively, and 2.70 and 2.78 gr.; respectively. The 10 Peat +(4x)15NPK culture lost 26.76 liters of water per jar, and the 25 C. P. culture lost 23.77 liters per jar. Their respective losses per gram of dry plant tissue were 0.745 and 0.632 liters. The 352 wood ashes treatment had losses of 26.28 and 0.973 liters, and the 0.5 C. P. culture had losses of 21.45 and 0.772 liters, respectively, for total and per gram of dry plant tissue. The losses were considerably less during the cooler 1944-45 season than the 1943-44 season.

Table 96 shows that significant differences in total water loss per pot are caused by soil treatment. On the other hand, Tables 97 and 98 show that there are no significant differences in total water loss caused by soil treatment in Experiments II, III, and IV. In the case of Experiments II and III, the lack of a significant difference in water loss is consistent with the absence of a significant difference in dry weight of trees. The water losses for the fifteen treatments in Experiment II and III were remarkably uniform. The culture with the smallest loss was only slightly over 5 percent below the culture with the largest loss of water.

The tremendous increase in loss of water during a period of $6\frac{1}{2}$ weeks is illustrated by comparing the water losses in Experiment IV with those of

Table 96. --Mean loss of water per pot and per gram of dry plant tissue for each treatment during Experiment I, 1944-45

Treatment	Loss of water: Per pot	Loss of water: Per gram of dry tissue
	Liters	
0.5C.P.	21.45	0.772
1.0C.P.	21.99	0.745
5C.P.	22.56	0.698
25C.P.	23.77	0.632
1.0C.P.(S)	22.72	0.745
Check	21.83	0.840
Standard deviation	0.28	
Difference between treatment means to be significant at 5 and 1 percent	1.16 1.83	
F value treatment	8.42**	

**Significant at 1 percent.

Experiments II and III (Tables 97 and 98). The loss during $6\frac{1}{2}$ weeks was nearly equal to the loss during the previous 20 weeks. The large loss during the former period is caused by the increased size of the trees and the higher temperatures.

Expressed in terms of surfaces inches of water (comparable to measurement of precipitation), the loss of water varies from a minimum of 13.8 inches in the 60P treatment (Table 97) to a maximum of 23.9 inches in the 20 C. P. +(4x)15NK culture in a 20-week period. These losses are equivalent to average weekly losses of 1.19 and 0.69 inches, respectively. The maximum loss during a period of $26\frac{1}{2}$ weeks is 28.1 inches, or an average weekly loss of 1.06 inches. These figures, although not directly applicable to nursery conditions because of differences in temperature, wind movement, relative humidity, and seepage between a greenhouse and nursery environment, may be suggestive of the amount of water that must be supplied a nursery soil to maintain soil moisture adequate to satisfactory growth of slash pine seedlings. No loss from seepage occurred in the greenhouse because moisture in the soil was regulated to prevent such loss. Since in the greenhouse during the periods of experiments, wind movement was less, temperatures, on the whole, lower, and relative humidity probably not much different from those in the nursery during a growing season, water loss would probably be less in the greenhouse than in the nursery. Water loss in a nursery on Norfolk soil (exclusive of excessive loss by seepage and in some cases by run-off during heavy rains) would probably average more than the 1.19 surface inches which occurred in the 1943-44 experiment. Loss of water probably would be less than this amount during the first 8 weeks when stem growth is negligible. The author believes that slash pine seedlings growing in a

Table 97. --Mean loss of water per pot and per gram of dry plant tissue for each treatment during Experiment II and III, 1944-45

Treatment	Loss of water: Per pot	Loss of water: Per gram of dry tissue
	Liters	
30P	18.48	0.910
60P	17.82	0.948
120P	18.10	0.892
240P	18.42	0.945
480P	18.79	0.874
Check	18.76	0.933
60P-K	18.37	0.887
120P-K	18.72	0.908
480P-K	18.75	0.841
60P-NK	18.58	0.869
120P-NK	18.28	0.887
480P-NK	18.64	0.825
60P-CaNK	18.23	0.889
120P-CaNK	18.36	0.854
480P-CaNK	18.64	0.832
Standard deviation	0.28	
F value treatment	1.01	

Table 98. --Mean loss of water per pot and per gram of dry plant tissue for each treatment during Experiment IV, 1944-45

Treatment	Loss of water: Per pot	Loss of water: Per gram of dry tissue
	Liters	
60P+(4x)15NK	35.81	0.904
60P+(4x)15NK(S)	36.22	0.862
60P+(2x)30NK	34.84	0.919
Check	34.50	1.009
Standard deviation	0.52	
F value treatment	2.36	

nursery on Norfolk or similar soils must be supplied from 1- to 1.5 surface inches of water per week to maintain a moisture condition which is optimal for growth. Heavy rains must probably be discounted by as much as 50 percent or more, depending on their intensity and duration and the moisture condition of the soil in considering their effectiveness in supplying a nursery with water.

Annual Use of Phosphorous by One-Year Slash Pine Seedlings

An acre of nursery seed beds is capable of producing at least 1,000,000 one-year slash pine seedlings. Assuming a dry weight of 4 grams per tree for high-quality slash pine nursery stock, the weight of an acre of nursery stock is 8,810 pounds. Since the phosphorous content of slash pine needles was found to be approximately 0.22 percent by dry weight (Table 46) and limited analysis of root and stem tissues yielded 0.22 and 0.12 percent phosphorous by dry weight, the average phosphorous content of the entire tree is 0.19 percent. On this basis, the 8,810 pounds of plant tissue contains 16.74 pounds of phosphorous. This represents the amount of phosphorous taken from the soil by the seedlings.

The Economics of Nursery Use of Colloidal Phosphate

The chief cost of colloidal phosphate is the transportation cost from the mine to the place where it is to be used. Total cost, including cost of application should not exceed $6.00 per ton. The cost of a 20-ton application is $120.00. Assuming that this amount will be effective for at least 10 years in maintaining the production of high-quality slash pine nursery stock and will likewise benefit cover crops which may be alternated with crops of slash pine seedlings, the cost may be spread over a 10-year period. However, since the primary objective is to benefit the slash pine seedlings, the cost should be charged entirely against five crops of slash pine seedlings. This gives an annual cost of $24.00 per year to be charged against 1,000,000 seedlings. This is equal to $0.024 per 1000 trees. The $0.024 represents approximately one percent of the total cost of producing one-year slash pine nursery stock.