RED PINE (PINUS RESINOSA) SEEDLINGS AS AFFECTED BY VARIOUS SOIL TREATMENTS

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INTRODUCTION

Early in the growing season of 1949, the second year seedbeds of red pine (*Pinus resinosa*) and Norway spruce (*Picea abies*), at the Michigan State College Nursery, began to show signs of chlorosis. The chlorosis gradually became more serious until by late summer approximately 95 percent of the seed bed area was affected, and, in some spots, seedlings had died. The normal plants were distributed over the area in small spots. Each spot constituted approximately one to four square feet.

Field observations and studies of the plants failed to indicate the presence of disease organisms or insects, so it was concluded that the problem might be one of soil.

It was the purpose of this investigation to show the cause of the stunted growth, chlorosis, and spotty normal growth; also to show comparative effects of various fertilizer and organic matter treatments by measuring the growth response of red pine seedlings.

REVIEW OF LITERATURE

Clark (1916), by making total plant analyses, determined that white pine (Pinus strobus) 2-0 seedlings, having an average density of 100 per square foot, had removed 94.6 pounds of available nitrogen, 31.8 pounds of phosphoric acid (P_2O_5), and 41.6 pounds of potash (K_2O) from an acre of soil. Retan (1914) showed the beneficial effects of various inorganic fertilizer treatments in combination with cowpeas and oats plowed under as green manure. Retan (1915) also found that a charcoal application to heavy soils improved aeration, drainage, and moisture retention, and also helped to prevent "damping off". Wilde (1946) shows that soil aeration data has the same significance for all soil types. He states that watering should not lower the aeration of the soil below 20 percent by volume for any length of time to prevent denitrification and other soil reduction processes. Toumey and Korstian (1916) recommend the plowing under of legumes and the use of heavy applications of farm manure in maintaining nursery fertility. Wilde (1937) stresses the importance of organic matter in nursery soils, but he also states that manure of any kind is undesirable, because of danger of diseases and of spreading weed seeds. Wilde (1936) also

shows the danger from nematode infection and consequent destruction of seedlings when barnyard manure is used.

Auten (1943) found that acid peat had a favorable effect in correcting alkalinity and in improving density and height of pitch pine (Pinus regida) and shortleaf pine (Pinus echinata) in forest nurseries of the central states. Wilde and Hull (1937) recommend the use of strongly acid peat as a fertilizer and as a buffering material. These workers have shown that strongly acid (pH 5.5 or lower) peat is valuable as a base exchange material and as a nutrient amendment particularly when its nitrogen content is 2 percent or more. The beneficial effect of acid peat in coniferous nursery soils is primarily the result of the change it causes in soil reaction. It is also valuable in providing favorable soil structure. When nursery soils are low in colloids, fertilizer salts are easily leached and lost. When drought occurs, evaporation causes the salts to rise to the surface with a consequent "burning" of the roots of seedlings. Acid peat having a base exchange capacity of 80 or 100 m.e. per 100 grams is considered very satisfactory. All types of peat are of minor significance so far as phosphorus

and potassium are concerned. However, their calcium, sulphur, and iron contents exceed the minimum requirements of coniferous seedlings. The authors recommend that applications be made so that the base exchange value is brought to a desirable level. It should be worked well into the upper 8 inches of the soil.

Eliason (1937) demonstrated that the color of buckwheat, when used as a cover crop, is a fair indication of the need of the soil for nitrogen. Lunt (1938) reports injury to plants by the use of ammonium sulfate on sandy soils of low buffer capacity. On such soils he found concentrated nitrogen salts most effective when used in small doses at frequent intervals. Addition of calcium caused needle burning where phosphorus and potassium were low. Red pine was found to take up less calcium than any other species tested. Lutz and Chandler (1946) point out that large amounts of calcium carbonate cause "damping off" and nutritional disorders in conifers. Mitchell (1934) shows that seedling weight is influenced by seed weight. Root-shoot ratio has been a standard index of seedling quality (Wilde, 1946; Mitchell, 1934; Toumey and Korstian, 1916). Mitchell found root-shoot ratios greater where

nitrogen was a limiting factor. Nitrogen and phosphorus deficiency color symptoms on foliage are similar to those of most agricultural crops (Lutz & Chandler, 1946; Mitchell, 1934; Cook & Millar, 1949).

Wilde (1946) states that green manures are most valuable as "catch" crops for commercial fertilizers by fixing a considerable portion as difficultly soluble organic compounds. These are slowly made available over a period of time with little loss through leaching.

Sandy loams and loamy sands are recommended textures for coniferous nursery soils according to Toumey and Korstian (1916) and Wilde (1946). Wilde states that the soil reaction range 5.0 to 6.0 is optimum for most conifers.

According to Toumey and Korstian (1916) coniferous seedlings absorb nitrogen in greater amounts than they do other elements. They believe the fertilizer ratio used should be 10-4-5 for best results. Concentrations of available nitrogen in excess of 100 pounds per acre in high analysis fertilizers proved to be injurious. Wilde (1938) recommends available nutrients in the ratios of 1-2-5. His analysis of the optimum soil

status for red pine is pH 5.4, base exchange capacity 8.0 m.e. per 100 grams, total nitrogen .12 percent, available nitrogen 30 pounds per acre, available P_2O_5 50 pounds per acre, available K_2O 150 pounds per acre, replaceable calcium 1500 pounds per acre, and replaceable magnesium 300 pounds per acre.

Larson and Stump (1939) experimented with various levels of nutrients on evergreen seedlings and obtained better response from combinations of nitrogen, phosphorus, and potassium than from applications of single elements. In general, it was found that nitrogen increased top growth while phosphorus increased root development. Auten (1943) and Lunt (1938) warn against the use of nitrogen fertilizers applied at seeding and recommend a 25 pound per acre application two to four weeks after emergence.

Roth, Toole, and Hepting (1948) found that inorganic nitrogen fertilizers prevented the severity of little-leaf disease of shortleaf pine when nitrogen was applied at the rate of 200 pounds per acre or higher. Shirley and Meuli (1939) show that the drought resistance of red pine decreases with the supply of available nitrogen in the soil, and that the supply of phosphorus tends to

increase drought resistance.

Kopitke (1941) found that with the level of available nitrogen adjusted at 40 pounds per acre, the effect of potassium on carbohydrate synthesis in red pine seedlings was most favorable. It was found that red pine green tissue has the lowest freezing point ($-1.63^{o}C$) when available K_2O was present in the soil at 80 pounds per acre. Wilde, Nalbandov, and Yu (1948) correlate highly fertilized succulent seedlings with a lower content of alcohol benzine soluble substances and a higher susceptibility to parasitic organisms. A relationship between a low specific gravity value of jackpine (Pinus banksiana) seedlings and heavy fertilization in the seedbeds was shown by Wilde and Voight (1948). The possibility of low specific gravity as an influence in severity of damage to seedlings by drought, frost, sunscorch, winter drying, sleet, and parasites is pointed out.

Mitchell (1939) stresses the importance of a balanced external nutrient supply and correlates this with internal nutrient concentration and consequent yields. According to his findings, "forced" seedlings grown in a well balanced and fertilized environment

are unusually hardy. These seedlings were found to be significantly better than average stock grown on unfavorable sites. They withstood severe winter freezing and thawing, and they suffered less early frost injury than seedlings supplied with a less favorable supply of nutrients.

Hatch (1935) and McComb (1943) point out the value of mycorrhizal symbiotic fungi to the nutrition of pine seedlings and the failure of the establishment of coniferous nurseries on prairie soils without these fungi.

HISTORY OF THE SITE

Past Soil Management

The nursery is located west of Hagadorn Road on Hillsdale sandy loam soil. According to Professor Hudson, Michigan State College farm manager for many years, the site had not received manure or lime for the past ten years. During that period the rotation was oats, timothy-clover mixture, pasture. Previous to the last ten years, the rotation was corn, oats, timothy-clover, pasture. From the standpoint of nutrients and physical condition, the soil was badly depleted when the seedlings were started in 1948.

Previous Treatments of the Nursery Bed

The first season's growth was normal. During the first part of June of the second year, when chlorotic symptoms appeared, the beds were fertilized with ammonium sulfate fed through an overhead sprinkling system at the rate of 200 pounds per acre. The same treatment was made again on one half the seed bed early in July. Neither of the applications had a noticeable effect on the seedlings. The fertilizer treatments were followed by generous sprinklings of water, and the beds were watered throughout the summer of 1949 by this method of overhead watering.

EXPERIMENTAL PROCEDURE

The experimental work discussed in this paper was started on September 1, 1949.

Preliminary Investigations

In early September of 1949, more than 100 borings were made in the red pine bed to determine whether a correlation existed between spotty growth and depth of topsoil, or texture and color of subsoil. No such correlation was noted. (See Table 1.)

Physical condition of the soil where growth was

normal was noticeably superior and somewhat sandier. Topsoil ranged from seven to twelve inches in depth. Roots of normal seedlings penetrated the subsoil in most cases investigated*, but the bulk of the root system was from three to five inches below the surface.

Both surface and subsoil samples were taken on areas of normal and abnormal growth. The results of active soil tests (Spurway, 1949) are shown in Table 2. Reaction was checked by using a Beckman pH meter with water-soil ratio of 2:1. Ten samples each, from representative spots in normal and poor growth, were checked. The results appear in Table 3.

Pigweeds and hardwood seedlings showed signs similar to those characteristic of manganese deficiency on certain field crops, but it is possible that the chlorosis was due to other causes.

Soil Preparation

Soil was taken from areas where red pine seedlings had made poor growth. The areas selected were numerous enough to represent the entire red pine bed. The soil was screened through a 4 mesh screen and thoroughly mixed. Soil representing normal growth was removed from exact spots in which normal seedlings occurred

* Based on 10 samples.

and was prepared likewise. As a check, Oshtemo loamy sand from a good red pine site was chosen for one treatment.

Pot Preparation

Five week old seedlings were used for most of the treatments. These seedlings were grown for another experiment from seed planted on August 13, 1949 in Plainfield sand surface soil. Their likelihood of responding to greenhouse conditions during the normal dormant period seemed greater than that of the 2 year chlorotic seedlings which had begun to "harden off" for the winter. Due to the possibility of response of the affected chlorotic seedlings, a supplementary set of pots and treatments, using this material, was added to the original five week old seedling experiment. Six and seven inch clay pots were used for the experiment. The five week old seedlings were planted in six inch pots. Seven inch pots were used for the affected two year old seedlings. The pots were painted with asphalt varnish. Each of the two size groups of pots were brought to equal weight by the addition of pebbles before the addition of soil. An equal amount

of air dry soil was added to each of the pots in each size group. The six inch pots required 1800 grams of soil, and the seven inch pots required 2700 grams. Those pots involving acid peat and those involving manure treatments were filled by mixing 2/3 of the required soil by weight with the amount of organic material necessary to fill each pot. The organic material (peat and manure) was thoroughly pulverized and mixed by hand before replacing in the pots. The fertilizer and sand treatments were thoroughly hand mixed with soil of their respective pots in like manner. The mycorrhizae used for inoculation was obtained locally from a good red pine site, the soil type of which was Oshtemo loamy sand. Roots of twelve inch red pine transplants were examined for mycorrhizae, and the rootlets containing these symbiotic fungi were stripped off and mixed with the soil used for this treatment.

Treatments

Fertilizer treatments were calculated on an area basis, and the depth of the pots was considered topsoil depth. The three fertilizer analyses were made from ammonium sulfate 20-0-0, superphosphate 0-20-0, and potassium chloride 0-0-50. Minor element treatments

consisting of manganese and iron were applied in the form of manganous sulfate and ferrous ammonium sulfate. The fertilizer materials and rates of application are shown in Table 5. Applications were made at the beginning of the experiment, and a second identical application was applied 3 months later. This second fertilizer application was applied as a nutrient solution immediately following active soil tests (Spurway). Treatments (see Table 5) were set up to show the effect of soil packing (treatment 10), and organic matter amendments on seedling growth. Acid peat (treatments 11, 12, 13, 23) and stable manure (treatments 14, 15, 17, 24) were pulverized and thoroughly mixed with the soil before planting.

Description of Soils

The soil in the affected nursery is classed as Hillsdale sandy loam. The surface soil is light brownish to yellowish underlain by yellowish friable sandy loam and gritty clay. The surface may be somewhat stoney. Fertility is classed as medium. The character of the land is hilly to smooth, rolling, upland with an original forest type of Oak-Hickory.

Oshtemo loamy sand was the soil used as a control.

This soil was selected from an excellent natural red pine site, and these pots, without treatment, were used as a check or index with which to compare the various treatments of the Hillsdale nursery soil. Oshtemo is described by Veatch (1941) as light loamy sands and sandy loams underlain by pervious sand with small amounts of clay and gravel. The fertility is regarded as low to intermediate. This type occurs on level or pitted dry sandy plains and terraces. The natural cover was an open oak-hickory forest with some white pine in the northern areas.

Planting and Culture

All of the pots in the experiment were planted on September 16, 1949. The five week old seedlings were cultured in natural sand prior to transplanting. The chlorotic two year seedlings were selected in such a manner that they were a fair representation of the average size of the affected seedlings and of an average degree of chlorosis occurring in the red pine bed. They were taken directly from the nursery bed and transplanted to the pots.

During the first month of the experiment, outdoor

temperatures were unusually high for the season, and the greenhouse temperature was difficult to control. All of the seedlings apparently suffered some heat damage. Many of the two year seedlings died. In view of this fact, all two year seedlings in the seven inch pots were replanted on October 12. Partial shade was then provided during bright days throughout the balance of the early fall. This was accomplighed by stretching cheesecloth on a frame above the seedlings. Thus mid-day temperatures were kept at a safe level. Greenhouse temperature was maintained between 70° and 80° after October 10. Artificial lighting was used as a daylight supplement for approximately five hours per day after November 20, until the end of the experiment on March 27.

Moisture equivalent was determined for all soils, and soil moisture was maintained as close to this value as practicable by weight adjustments every week to ten days. Clay saucers were coated with asphalt varnish and placed under each pot for watering from below. This watering from below was alternated with watering from above.

Measurements

At the beginning of the experiment, measurements and

weights of ten average seedlings for each of the following classes were taken:

1. 5 week old seedlings
2. 2 year chlorotic seedlings
3. 2 year normal seedlings

The root measurements, top measurements (root collar to tip), air dry weights, and root-shoot ratios are given in Table 4. These represent initial values at the beginning of the experiment.

On December 20, 1949, height measurements above the soil line were taken of all seedlings to compare treatments by their top growth during the first 3 months. The average length of 10 seedlings by treatment is shown in Table 5. Since the initial leaves of each of the young seedlings dried up and were lost in the normal growth process of these seedlings, some measurements after 3 months appear smaller in the table than the initial measurements taken at the beginning of the experiment. Therefore, the new growth which took place during this period is not satisfactorily revealed by this table at three months growth. However, a comparison of growth by treatment is the purpose here, and the differences in growth are shown by these measurements. While top

growth was taking place at the terminal bud, thus putting out all new leaves, the original seed leaves dried up and eventually dropped off.

Harvesting of Plants

On March 27, 1950, the plants were carefully removed in the following manner: The soil was loosened from the side of each pot with a spatula, and the pot was tapped gently to allow the contents to drop from the pot as one solid ball of soil. The ball was then carefully broken up to avoid breaking rootlets. The seedlings were thus taken up with their complete root systems and placed in beakers of distilled water and labeled according to treatment. By keeping them fresh in this manner, they were in excellent condition for photographing and for handling for measurements. After photographs and measurements were taken, the seedlings were cut off at the root collar, and the roots and the tops were placed in separate paper bags according to treatment. They were dried in a low temperature (110°F) oven for a week, then allowed to come to equilibrium at room temperature for another week before weighing. All weighings were made on an analytical type balance.

Final measurements in millimeters and weights in grams were recorded for all treatments. The root and top lengths as well as the dry tissue weights and the root-shoot ratios are shown in Table 8a for the young seedlings. Table 8b shows the same data for the two year chlorotic seedlings.

A comparison of size of plants as affected by treatment is made in Figures 3 and 4.

Soils of Good Growth and Poor Growth Compared

Soil tests:

In addition to the topsoil-subsoil data in Table 1 and the initial soil test and reaction data presented in Tables 2 and 3 respectively, additional possible differences in the soils of good and poor growth were sought.

Additional active soil tests (Spurway, 1949) for nitrogen, phosphorus, and potassium were made after 3 months. See Table 6. At the same time, measurements were taken as stated above. (Table 5). At the end of the experiment, March 22, active soil tests (Spurway, 1949) were made for nitrogen, phosphorus, potassium; also active and reserve iron and manganese on all treatments. See Table 7.

Soil reaction:

Soil reaction was determined with a pH meter. Results are shown in Table 7.

Moisture equivalent:

Moisture equivalent was determined in duplicate by the centrifuge method (Veihmeyer and Hendrickson, 1931). Determinations were made on the following samples:

1. Hillsdale (poor growth) and 1/3 peat
2. Hillsdale (poor growth) and 1/3 manure
3. Hillsdale (poor growth)
4. Hillsdale (good growth)
5. Oshtemo loamy sand

Samples were placed in moisture equivalent boxes after screening through a 2 mm. screen. They were then allowed to become saturated with water for 24 hours and were permitted to drain for 30 minutes. They were then subjected to a centrifugal force of 1000 times gravity by placing in a centrifuge for 30 minutes at 2440 r.p.m. The percentage of moisture was then calculated on an oven dry basis. See Table 8 9 for results.

Base exchange capacity and percent base saturation:

Base exchange capacity and percent total base saturation was determined (Schollenberger, 1945) on the poor growth Hillsdale soil. Results are shown in Table 9.

Organic matter content:

Organic matter content was determined on the Hillsdale soil samples of good and poor growth for comparison. The dry combustion method was used (Schollenberger, 1945) and organic matter was determined from the organic carbon content by use of the factor 1.724. Values are given in Table 9.

Phosphorus Determination

Symptoms of phosphorus deficiency (Mitchell, 1939; Lutz & Chandler, 1946; Cook & Millar, 1949) appeared on a few of the seedlings after approximately 3 to 4 months in the greenhouse. Therefore, a total phosphorus determination was made (Piper, 1946) based on the weight of air dry plant material for all treatments of the young seedling experiment. The determination was made colorimetrically after dry ashing the plants. Roots and tops of each treatment (10 seedlings) were combined and weighed

to the 3rd decimal place on an analytical balance. The plant material was ashed in a muffle furnace, and the silica was dehydrated with HCl over a warm hot plate. The dehydrated ash was taken up in HCl and diluted to 200 ml. Colorimetric determination was made by use of a "Lumetron" colorimeter after treating the extract with ammonium molybdate and an organic reducing agent. The results appear in Table 10 as percent total phosphorus.

DISCUSSION AND RESULTS

The benefits derived from the use of soil amendments and commercial fertilizers in forest nursery management has long been recognized. (Toumey & Korstian, 1916; Wilde, 1946) Nursery soils require particular attention to avoid depletion of fertility and structural characteristics. The intensive nature of nursery practice is the reason for this. Most nursery soils are worked to a very fine state of tilth. This allows the soil to be more easily eroded. The use of legumes with proper rotations should be practiced to maintain fertility. Since trees are taken up by the roots, there are no plant residues left after a crop of seedlings is removed from a nursery bed. Therefore, it is reasonable to assume that

nursery management without soil amendments and good rotaions is soil depleting.

The stunted growth and chlorotic condition of the 2-0 seedlings of the college forest nursery is probably a result of a combination of adverse soil conditions.

An ideal site for a red pine nursery would demand loamy sands to sandy loam having excellent drainage. A soil without radically different composition of its genetic horizons would be in order (Wilde, 1946). Due to the heterogeneity of the soil profile (see Table 1), it is possible that variations in drainage, aeration, reaction, texture, and chemical composition are such as to cause spotty growth.

Aeration and Drainage

A lack of legumes in past rotations resulted in a soil of poor aggregation, porosity, and structure. The very fine sand and clay particles have a tendency to pack, resulting in seemingly poor aeration and percolation. Due to adverse weather conditions, core samples for porosity were not obtained. However, spots of good growth were of noticeably lighter texture. Percolation rate was checked in the greenhouse by watering 7 inch

pots of good and poor growth soil. Percolation was approximately 20 percent greater in the soil of good growth. The moisture equivalent values presented in Table 9 show that organic matter increased water holding capacity. Values for peat and manure treatments are rather low, probably due to the raw state of the peat and manure used. That good aeration and drainage are important prerequisites to red pine establishment is shown by considering the natural sites on which this species occurs. Even where competition is eliminated, red pine will not tolerate poorly drained or poorly aerated soils.

Due to the poor response of the chlorotic two year seedling experiment, the remaining results and discussion will refer only to the young seedling treatments unless otherwise indicated.

Physical Properties

The effect of organic matter treatments to improve physical properties of the soil is reflected by the excellent growth of the trees where peat was incorporated with the soil. During the first 4 months of the experiment, very good growth resulted where manure was

used, after which a toxicity developed which inhibited growth. Packing the soil depressed growth of the trees. This is shown by the fact that plants subjected to this soil treatment produced the second lowest yields of any in the experiment (Table 10). Total phosphorus was also extremely low in these plants.

Soil Reaction

The optimum soil reaction range for red pine has been determined by Wilde (1946) to be between pH 5.0 and 6.0. This was borne out by the fact that treatment 16, 1/3 alkaline sand (pH 8.0), resulted in the lowest yield of plant material (Table 8a). These seedlings remained stunted and unhealthy in appearance throughout the experiment, and they exhibited phosphorus deficiency symptoms by a purpling of the older needles. The total phosphorus content of the seedlings of this treatment was rather low (Table 10). Where acid peat was used as a physical treatment (treatment nos. 11, 12, 13), reaction was lowered by more than one pH unit. Nitrogen added as ammonium sulfate solution in treatment 9 contributed to lowering the pH. (See Table 3 for original pH values; also Table 7, treatment nos. 19, 3, 4). The relationship between seedling yield and soil reaction is illustrated graphically by Figure 1.

Effect of Organic Matter and Fertilizer

According to Wilde, optimum organic matter content should be approximately 2 percent. Results on the untreated Hillsdale soil (Table 9) correspond favorably with this figure.

Yield was appreciably higher where fertilizer was used with peat than in the case of fertilizer used alone (Tables 8a, 10). Where peat alone was used, yield was approximately the same as where the soil was untreated (treatment 19, Table 10). However, the phosphorus content of the plants was higher, and the root-shoot ratio and the general appearance of the plants were more favorable where peat was used (Tables 7, 8a and 10). This was probably caused by the effect of the peat in lowering soil reaction a full pH unit. Where fertilizer as 1000 pounds per acre of 10-4-5 was added with peat, higher yields, higher total phosphorus, and improved plant appearance resulted. Still better results were obtained where the higher strength fertilizer 10-12-12 was applied .

Manure treatments resulted in improved growth and appearance during the first 3 or 4 months after planting. After February 1, 1950, they began to show signs of yellowing at the needle tips. This condition became more acute as time went on. By March 1, some seedlings thus treated had died. Apparently this condition was caused by an excess of nitrates resulting in acute toxicity. According to Wilde (1946), optimum available nitrogen content should be approximately 30 pounds per acre. According to soil tests (Table 7) made by the Spurway method of soil testing, nitrates were more than five times this value. It is also conceivable that in the process of nitrification, intermediate products played a role in toxicity. Where peat was used, nitrates were high only in treatment no. 12 which had been treated with 10-4-5, 1000 pounds per acre and where the reaction was pH 4.5.

Where fertilizer treatments only were used, at 300 pounds per acre the 10-6-6 analysis yielded best results both for height and weight values. Where the level was increased to 1000 pounds per acre, average heights and weights were about equal for 10-6-6 and 10-12-12 analyses. Values for the 10-4-5 analysis were somewhat lower. Where only nitrogen was applied as ammonium sulfate solution,

yield increase was somewhat lower than it was where the treatment was 300 pounds of complete fertilizer.

Minor Elements

Minor elements (manganese and iron) had little apparent effect on results (Tables 5, 8a, 10).

Mycorrhizae

Mycorrhizal development was best on the roots of plants grown on the untreated Oshtemo loamy sand (no. 20). Some development of mycorrhizae was also evident in all pots involving acid peat. The roots of all plants bearing mycorrhizal fungi were healthy appearing having a light brown color and an abundance of fibrous rootlets (treatments 11, 12, 13). A generally healthy appearance of these seedlings prevailed throughout the experiment.

Base Exchange

According to Wilde (1946), optimum base exchange capacity for red pine nursery soil is 8.0 milliequivalents per 100 grams of soil. Taking this value as a criteria, it would seem that the most desirable method

of raising the base exchange capacity would be by the addition of the proper amount of acid peat. This would seem especially beneficial since the peat improves soil physical properties and may be used to regulate soil reaction.

Height Growth

The effect of treatments on the height of the plants was apparent toward the latter part of the experiment. Apparently the seasonal dormant characteristics of the species influenced the time of growth response in spite of the ideal growing conditions in the greenhouse.

Weights

Mean weights are probably the most satisfactory measure of growth in young seedlings, since needle drop or a rapid rate of needle growth is likely to give top measurements a distorted picture of actual growth gain. Total yields expressed as air dry weights (Table 10) and root and top weights (Table 8a) were considerably affected by treatments. The combination of 1/3 peat by volume and 10-12-12 fertilizer at the rate of 1000 pounds per acre proved far more effective than did any other treatment.

Root-Shoot Ratios

Root-shoot ratios are given in Table 8a with individual top and root lengths and weights. Root-shoot ratio is considered to be an index of planting stock quality for seedlings two years or older. However, root-shoot ratios for very young seedlings such as those used in this experiment would tend to give wide ratios, since initial growth does not tend toward root development as does growth after the first season. Fertilizer treatments also tend to stimulate top growth more than root growth especially in the earlier months of growth. This is illustrated by treatments 11, 12, 13, and 20 in Table 8a. Root-shoot ratio has a tendency to be greater where nitrogen is limiting (See Tables 7 and 8a).

Total Phosphorus

According to Mitchell (1939), white pine seedlings showed optimum growth where their total phosphorus content was approximately .67 percent. The results of this experiment show the same to be true of red pine. This fact is illustrated by the graph in Figure 2 where optimum growth as measured by dry seedling weight is approximately at the point where total phosphorus is .67

percent. It is interesting to note that during the third and fourth months after planting in the greenhouse, treatment numbers 1, 3, 4, 9, 10, 14, 16, and 19 showed varying degrees of abnormal purpling of the needles. This is characteristic of phosphorus deficiency symptoms of coniferous seedlings as described by Mitchell (1939), and Lutz and Chandler (1946).

The extremely high phosphorus content (.98 percent) of the seedlings grown on untreated Oshtemo sand from an excellent natural red pine site is worthy of attention. The excellent development of ectotropic mycorrhizae on the rootlets of these seedlings may be an explanation to the high phosphorus content of the plants. According to Mitchell (1934), mycorrhizae tend to develop on the short roots of seedlings more abundantly in less fertile soils. It is thought that roots react to nutrient unbalance by becoming mycorrhizal. Absorptive powers of rootlets are increased manyfold by mycorrhizal development (Mitchell, 1934; Hatch, 1936; McComb, 1943). Plant analysis shows nitrogen, phosphorus, and potassium content of seedlings having abundant nycorrhizal development to be significantly higher than plants having few mycorrhizae. The difference in total phosphorus in this case was threefold (Lutz and Chandler, 1946). Mycorrhizal inoculation has been found to be necessary for successful establishment of coniferous nurseries in prairie soils (Hatch, 1935, 1936). Mycorrhizae were stimulating to growth and activity of roots, and they allowed roots to absorb more phosphorus which was apparently limiting to growth in prairie soils. Mycorrhizal plants contained twice as much nitrogen and potassium and four times as much phosphorus as plants without mycorrhizae (McComb, 1943). Therefore, it would be reasonable to assume that the high phosphorus content in the seedlings of treatment 20 (Oshtemo sand) could be at least partially due to the efficiency of mycorrhizal roots in absorbing phosphorus.

<u>2-0 Chlorotic Seedlings</u>

The two year chlorotic seedlings taken from the nursery bed did not greatly respond to treatment. Little top growth took place throughout the experiment. Some root growth took place, however. The effect of nitrogen treatments in lowering the root-shoot ratio are evident in all treatments involving nitrogen application in the form of manure, peat, and complete fertilizer (see Tables 8b and 4). All root-shoot ratios were narrowed on these seedlings, however, due to root growth only.

SUMMARY AND CONCLUSIONS

A greenhouse experiment was set up to determine the cause of chlorosis and the stunted growth which occurred in the red pine forest nursery of Michigan State College. Soil from the affected area was prepared and placed in clay pots. Five week old seedlings were used for one part of the experiment, and two year old chlorotic seedlings from the affected nursery were used for the other part.

Treatments consisted of various levels of complete fertilizer, peat, manure, sand, and combinations of peat and fertilizer. Little response occurred from the two year old chlorotic seedlings. The "new" five week old seedlings responded very well to treatment. In the case of fertilizer treatments only, the 10-6-6 analysis gave best results in both height growth and in yield. Acid peat with 10-12-12 fertilizer at the rate of 1000 pounds per acre gave the highest yield. Plants appeared vigorous and healthy where peat was used. Peat applied at the rate of 1/3 by volume lowered the reaction by more than a full pH unit. A correlation between pH and yield was noted. A pH range of 5.5 to 6.5 appeared to give best results. Manure treatments developed toxic symptoms after the fourth month of the experiment. This was probably due to the effect of excess nitrates and intermediate compounds produced in the process of nitrification. Depressing effects on yield by high reaction was reflected by the treatments involving alkaline sand. Abundance of available nitrogen decreased root-shoot ratios due to its effect in stimulating top growth.

Oshtemo loamy sand was used as a control, and it produced the second highest yield. Mycorrhizal development was excellent on seedlings grown in this soil, and some mycorrhizae were present on all treatments involving peat.

Phosphorus deficiency symptoms developed on several of the treatments which received low fertilizer applications. No apparent deficiency was evident where peat was used. A good correlation between total phosphorus content of seedlings and yield was noted. High phosphorus content of seedlings grown on Oshtemo loamy sand may be correlated with exceptional mycorrhizal development and the ability of these symbiotic fungi to assist in taking up phosphorus from the soil.

The possibility of phosphorus deficiency as well as

the need of better physical properties and a somewhat lower reaction for the problem soil was presented by the results of this experiment.

Table 1. A comparison of soil in areas of good and poor growth.

(Soil color-texture-growth relationship)

Number of boring	Topsoil depth	Subsoil texture	Subsoil color
1*	6"	sand	light brown
2**	7"	sand	gray brown
3*	7"	sand	light brown
4**	6"	sand	gray brown
5*	8"	sand	brown
6**	11"	sand	gray brown
7*	11"	loamy sand	light brown
8**	10"	clay	brown
9*	9"	clay loam	light brown
10**	10"	clay	light brown
11*	9"	loamy sand	light brown
12**	10"	sand	medium brown
13*	10"	loamy sand	light brown
14**	11"	sand	light brown
15*	10"	clay	medium brown
16**	11"	sand	medium gray
17*	10"	clay	mottled gray
18**	11"	clay	yellow brown

* Areas of poor growth

** Areas of good growth

Table 1. continued

Number of boring	Topsoil depth	Subsoil texture	Subsoil color
19*	8"	sand	medium brown
20**	9"	sand	gray
21*	10"	loamy sand	light brown
22**	11"	sand	medium gray
23*	10"	loam	medium brown
24**	11"	sand	gray
25*	8"	loamy sand	medium brown
26**	12"	sand	gray brown
27*	7"	loamy sand	light brown
28**	14"	clay	gray mottled
29*	8"	sand	light brown
30**	11"	sand	medium gray
31*	7"	sand	gray
32**	11"	sand	medium gray
33*	8"	sand	light brown
34**	11"	loamy sand	gray brown
35*	8"	loam	light brown
36**	10"	sand	yellowish
37*	9"	sandy loam	medium brown
38**	10"	loam	medium gray
39*	10"	sandy loam	medium brown

* Areas of poor growth

** Areas of good growth

Table 1. continued

Number of boring	Topsoil	Subsoil texture	Subsoil color
40**	9"	sand	light brown
41*	12"	sand	medium gray
42**	11"	sand	gray
43*	9"	sand	light gray
44**	9"	loam	light gray
45*	11"	sand	light gray
46**	9"	sandy loam	gray brown
47*	11"	sand	light gray
48**	9"	sand	yellow brown
49*	8"	sand	reddish brown
50**	7"	sand	gray brown
51*	10"	sand	yellow brown
52**	11"	loamy sand	gray
53*	11"	sand	medium gray
54**	8"	sand	gray brown
55*	10"	sand	medium gray
56**	8"	sand	gray
57*	9"	sand	red brown
58**	11"	sand	medium gray
59*	9"	sand	reddish-yellow
60**	9"	sand	light gray

* Areas of poor growth
** Areas of good growth

Table 2. Results* of active soil test (Spurway Method) of soil from nursery bed at the beginning of the experiment, September 16, 1949.

	Normal Growth		Poor Growth	
	Surface Ppm.	Subsoil Ppm.	Surface Ppm.	Subsoil Ppm.
Nitrates	4	3	10	5
Iron	0	0	0	0
Phosphorus	trace	3/4	trace	5
Potassium	3	2	3	3
Calcium	50	100	40	100
Magnesium	6	6	6	6
Manganese	0	0	0	0
Chlorides	30	30	30	30
Sulphates	20	20	20	20
Nitrites	0	0	0	0
Aluminum	0	0	0	0

* All values are in parts per million in soil extract-soil-water ratio 1:4.

Table 3. Beckman pH meter readings on soils from areas of good and poor growth.

Sample No.	Normal Growth	Poor Growth
1	6.1	6.7
2	6.2	6.1
3	6.7	6.4
4	6.8	6.6
5	6.9	6.0
6	6.5	6.4
7	6.4	6.0
8	6.3	6.0
9	6.5	6.5
10	6.9	6.2

Table 4. Mean lengths* and weights** and root-shoot ratios of seedlings at the beginning of the experiment, September 16, 1949.

Age of Seedlings	Length (mm.)		Weight (g.)		Root-shoot Ratio
	Root	Top	Root	Top	
New***	39.7	60.9	.02	.12	.18
2 yr. stunted	226.5	92.5	1.24	2.72	.45
2 yr. normal	242.1	163.5	3.45	10.42	.33

* Mean value--10 items
** Total value--10 items
*** 5 weeks old

Table 5. Heights* of seedlings after approximately 3 months in the greenhouse, December 20,

New Seedlings (6" pots)

No.	Treatment	Height (mm)
1	10-4-5, 300 lbs./A	41.4
2	10-6-6, 300 lbs./A	49.0
3	10-12-12, 300 lbs./A	44.9
4	10-4-5, 1000 lbs./A	40.0
5	10-6-6, 1000 lbs./A	44.3
6	10-12-12, 1000 lbs./A	43.5
7	10-4-5, 1000 lbs./A and Mn, 100 lbs./A	43.4
8	10-4-5, 1000 lbs./A and Fe, 100 lbs./A	45.0
9	$(NH_4)_2SO_4$ solution, 200 lbs./A	43.1
10	Soil** firmly packed	40.3
11	1/3 peat	39.9
12	1/3 peat and 10-4-5, 1000 lbs./A	41.0
13	1/3 peat and 10-12-12, 1000 lbs./A	47.4
14	1/3 manure	40.6
15	1/3 manure and 0-20-0, 250 lbs./A and 0-0-50, 100 lbs./A	43.6
16	1/3 sand (pH 8.0)	34.8
17	1/4 sand (pH 8.0) and 1/4 manure	34.6
18	Soil of good growth, no treatment	45.8

* Mean value--10 items
** "Soil" refers to soil of poor growth unless otherwise indicated.

Table 5. continued

No.	Treatment	Height (mm.)
19	Soil of poor growth, no treatment	41.4
20	Oshtemo loamy sand, no treatment	45.3
	Chlorotic 2-0* Seedlings (7" pots)	
21	10-4-5, 1000 lbs./A	92.8
22	1/3 sand (pH 8.0)	82.6
23	1/3 peat	81.3
24	1/4 manure	77.1
25	10-12-12, 1000 lbs./A	75.3
26	1/3 Oshtemo sand and mycorrhizae	72.2
27	10-4-5, 1000 lbs./A and Mn, 100 lbs./A	64.4
28	10-4-5, 1000 lbs./A and Mn, 100 lbs./A and Fe, 100 lbs./A	78.7
29	Soil of poor growth, no treatment	68.5
30	Soil of good growth, no treatment	190.3

* 2 years in seed bed; 0 years in transplant bed

Table 6. Active soil tests (Spurway) after 3 months in the greenhouse

Treatment	Parts per million in soil extract*				
	N	P	K	Mn	Fe
10-4-5, 300 lbs./A	0	0	4	0	0
10-4-5, 1000 lbs./A	trace	trace	15	0	0
10-12-12, 1000 lbs./A	0	trace	7	0	0
10-4-5, 1000 lbs./A and Mn 100 lbs./A	trace	trace	6	0	0
$(NH_4)_2SO_4$ solution, 200 lbs./A	0	trace	4	0	0
Soil packed	0	1/2	4	0	0
1/3 peat	2	0	8	0	0
1/3 peat & 10-12-12, 1000 lbs./A	2	trace	20	0	0
1/3 manure	10	1/2	25	0	0
good growth soil-none	15	0	5	0	0
poor growth soil-none	0	0	6	0	0
Oshtemo (natural site) none	0	0	3	0	0

* Soil-water ratio 1:4

Table 7. Results of soil tests (Spurway) taken at the end of the experiment, March 22, 1950.

Ppm. in soil extract--soil water ratio 1:4

	Active						Reserve		
Treat. No.	N	P	K	NH_3	Mn	Fe	Mn	Fe	pH
1	0	½	5	0	0	0	1	2	6.50
2	0	½	6	0	0	0	1	2	6.02
3	0	½	10	0	0	0	1	2	6.50
4	0	1	6	0	0	0	1	2	5.32
5	10	1½	5	0	0	0	1	2	5.35
6	25	1½	5	0	0	0	1	2	5.30
7	0	1	4	0	tr.	0	2	2	5.58
8	0	1	3	0	0	0	1	2	5.50
9	0	½	5	0	0	0	1	2	5.59
10	0	½	3	0	0	0	1	2	7.05
11	tr.	½	8	tr.	0	0	tr.	1	6.15
12	20	3/4	7	tr.	0	0	tr.	5	4.55
13	5	2½	10	2	½	0	1	4	5.75
14	25	5	25	2	0	0	tr.	tr.	7.05
15	25	5½	25	tr.	0	0	tr.	tr.	6.75
16	0	½	4	0	0	0	tr.	tr.	8.02
17	4	5	10	tr.	0	0	tr.	tr.	7.21

Table 7. continued

	Active						Reserve		
Treat. No.	N	P	K	NH_3	Mn	Fe	Mn	Fe	pH
18	0	tr.	2	0	0	0	tr.	tr.	6.50
19	0	½	3	0	0	0	tr.	tr.	7.10
20	0	½	2	0	0	0	0	4	6.15
21	5	1	3	0	0	0	tr.	tr.	5.22
22	0	tr.	1	0	0	0	tr.	tr.	8.00
23	0	½	2	2	0	0	tr.	1	6.35
24	15	4½	15	2	0	0	tr.	tr.	7.15
25	2	4	4	tr.	0	0	1	2	5.38
26	0	tr.	5	tr.	0	0	tr.	tr.	6.80

Table 8a. Root and top measurements*, weights**, and root-shoot ratios of new seedlings at the end of the experiment, March 28, 1950

Treat. No.	Length (mm.) Top	Root	Weight (g.) Top	Root	Root-shoot Ratio
1	59	186	.426	.531	1.25
2	74	221	.652	.662	1.03
3	62	152	.508	.748	1.47
4	62	192	.566	.568	1.00
5	77	200	.803	.734	.91
6	80	187	.935	.810	.87
7	62	181	.622	.688	1.10
8	62	205	.590	.790	1.34
9	58	201	.506	.722	1.42
10	54	134	.411	.498	1.21
11	65	229	.516	.532	1.03
12	93	183	.886	.490	.55
13	113	177	1.331	.684	.51
14	55	156	.427	.355	.83
15	66	154	.598	.519	.87
16	54	229	.415	.480	1.15
17	56	197	.455	.481	1.08
18	70	251	.650	.798	1.22

* Mean value--10 items

** Total value--10 items

Table 8a. continued

Treat. No.	Length (mm.) Top	Root	Weight (g.) Top	Root	Root-shoot Ratio
19	56	203	.460	.627	1.36
20	98	279	1.028	1.050	1.02

Table 8b. Root and top measurements*, weights**, and root-shoot ratios of 2 year affected seedlings taken at the end of the experiment, March 28, 1950.

Treat. No.	Length (mm.) Top	Length (mm.) Root	Weight (g.) Top	Weight (g.) Root	Root-shoot Ratio
21	98	306	4.537	3.772	.83
22	87	223	3.590	3.634	1.01
23	89	309	3.958	3.372	.85
24	87	246	3.162	2.525	.80
25	92	297	3.328	2.578	.77
26	85	307	2.503	2.952	1.18
27	89	274	3.351	2.304	.68
28	85	249	3.650	2.251	.62
29	93	331	2.820	2.750	.97
30	162	491	10.730	9.342	.87

* Mean value--10 items

** Total value--10 items

Table 9. Moisture equivalents of greenhouse soil treatments; Organic matter, base exchange capacity and percent base saturation of nursery soil used in experiment.

Soil	M.E.	% O.M.	B.E.C. (m.e./100 g.)	% Base Saturation
Hillsdale (poor growth)	11.6	2.2	7.03	85
Hillsdale (good growth)	15.8	2.9	--	--
1/3 peat	15.0	--	--	--
1/3 manure	13.9	--	--	--
Oshtemo loamy sand	5.8	--	--	--

Table 10. Overall lengths*, total weights**, and total phosphorus content of new seedlings at the end of the experiment, March 28, 1950.

Treatment	Overall length (mm.)	Total weight (g.)	% total phosphorus
10-4-5, 300 lbs./A	245	0.957	.084
10-6-6, 300 lbs./A	295	1.314	.263
10-12-12, 300 lbs./A	214	1.256	.128
10-4-5, 1000 lbs./A	254	1.134	.136
10-6-6, 1000 lbs./A	277	1.737	.340
10-12-12, 1000 lbs./A	267	1.745	.532
10-4-5, 1000 lbs./A and Mn, 100 lbs./A	243	1.310	.220
10-4-5, 1000 lbs./A and Fe, 100 lbs./A	267	1.389	.260
$(NH_4)_2SO_4$ solution, 200 lbs./A	259	1.288	.170
Packed soil	188	0.909	.085
1/3 peat	294	1.048	.189
1/3 peat and 10-4-5, 1000 lbs./A	276	1.376	.216
1/3 peat and 10-12-12, 1000 lbs./A	290	2.015	.665
1/3 manure	211	0.782	.137
1/3 manure & 0-20-20, 250 lbs./A; 0-0-50, 100 lbs./A	220	1.117	.282

* Average value--10 items
** Total value--10 items

Table 10. continued

Treatment	Overall length (mm.)	Total weight (g.)	% total phosphorus
1/3 sand (pH 8.0)	283	0.895	.143
¼ sand (pH 8.0) and ¼ manure	253	0.936	.180
Good growth soil--no treatment	321	1.448	.405
Poor growth soil--no treatment	259	1.087	.152
Oshtemo loamy sand--no treatment	377	2.078	.980

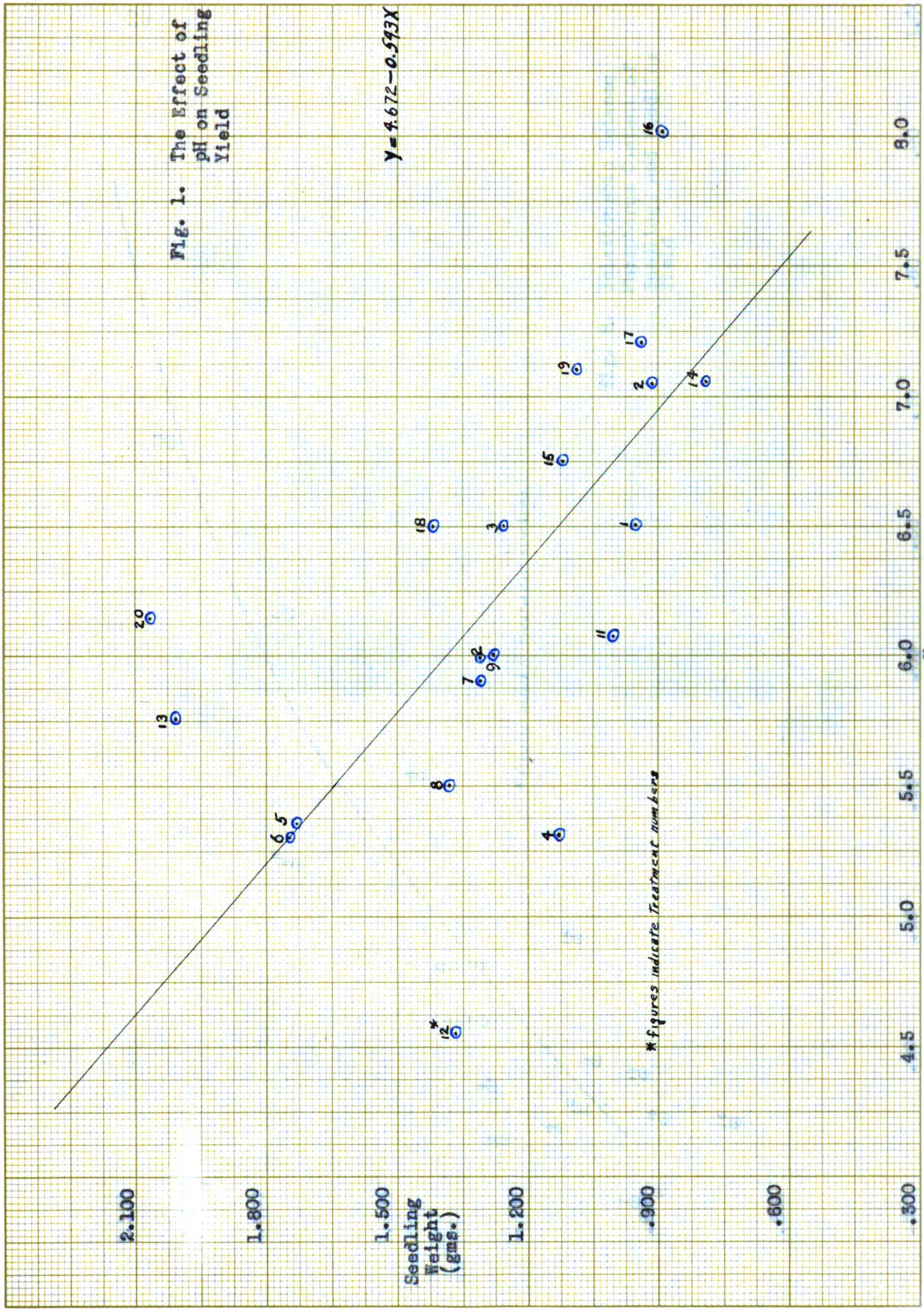
Fig. 1. The Effect of pH on Seedling Yield
Y=4.672−0.593X
Seedling Weight (gms.)
2.100
1.800
1.500
1.200
.900
.600
.300
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
pH
*figures indicate Treatment numbers
20
13
6
5
18
8
7
2
9
3
12*
4
15
1
11
19
17
2
14
16

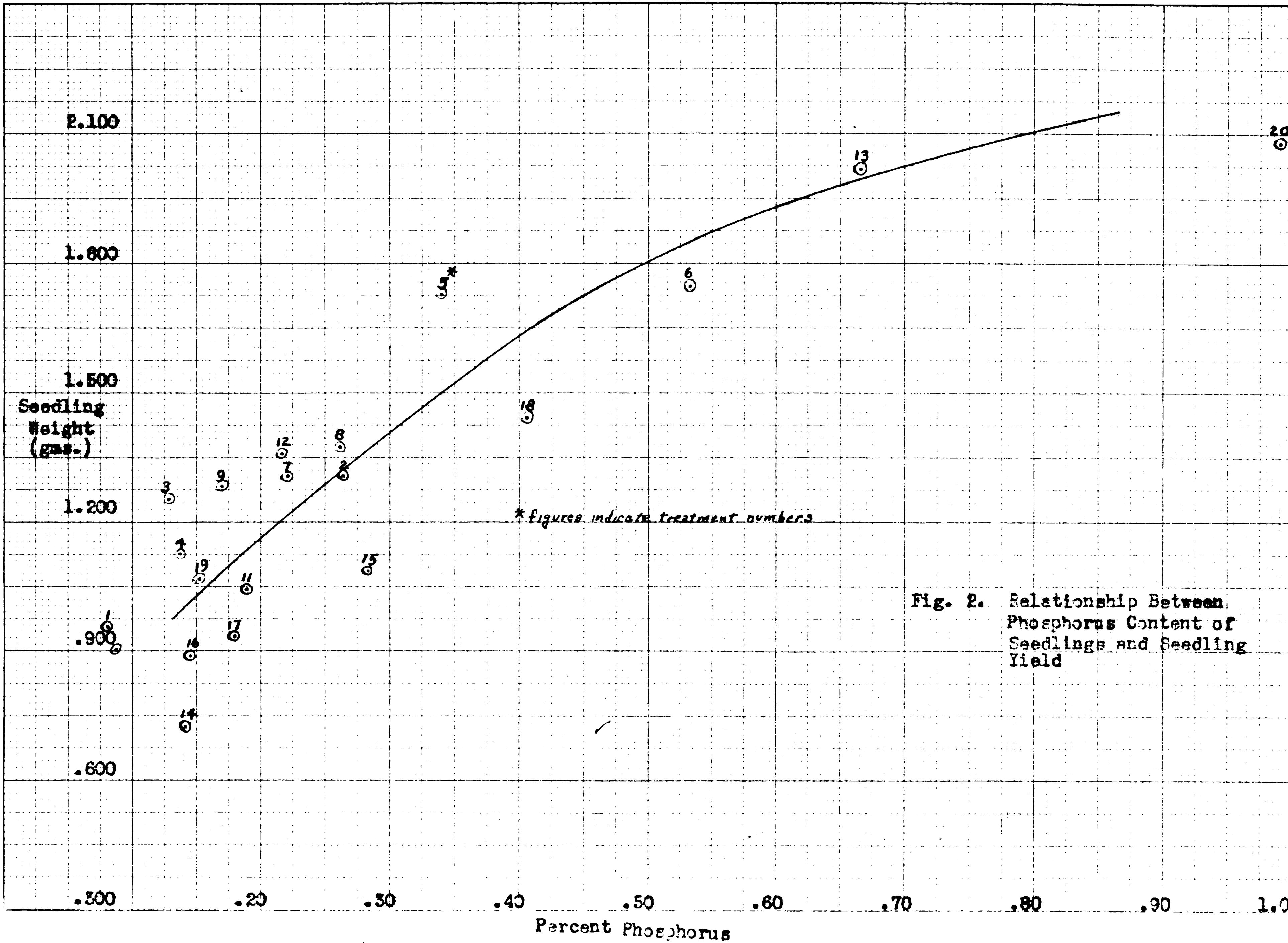

Fig. 2. Relationship Between Phosphorus Content of Seedlings and Seedling Yield

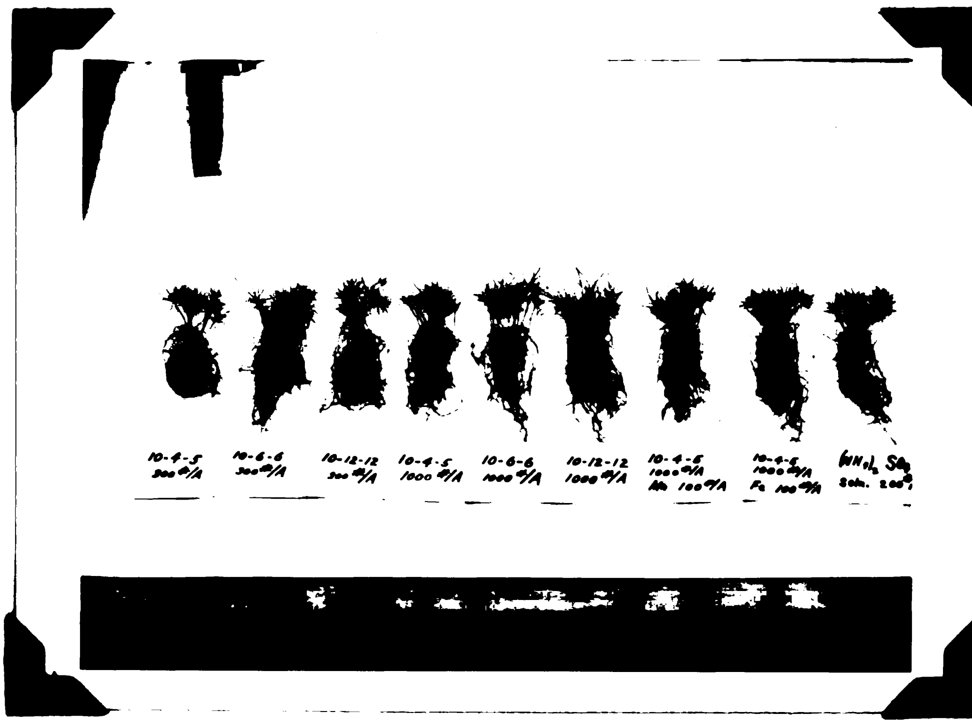

Figure 3. Seedlings at the end of the experiment showing the effect of the treatments on root and top growth.

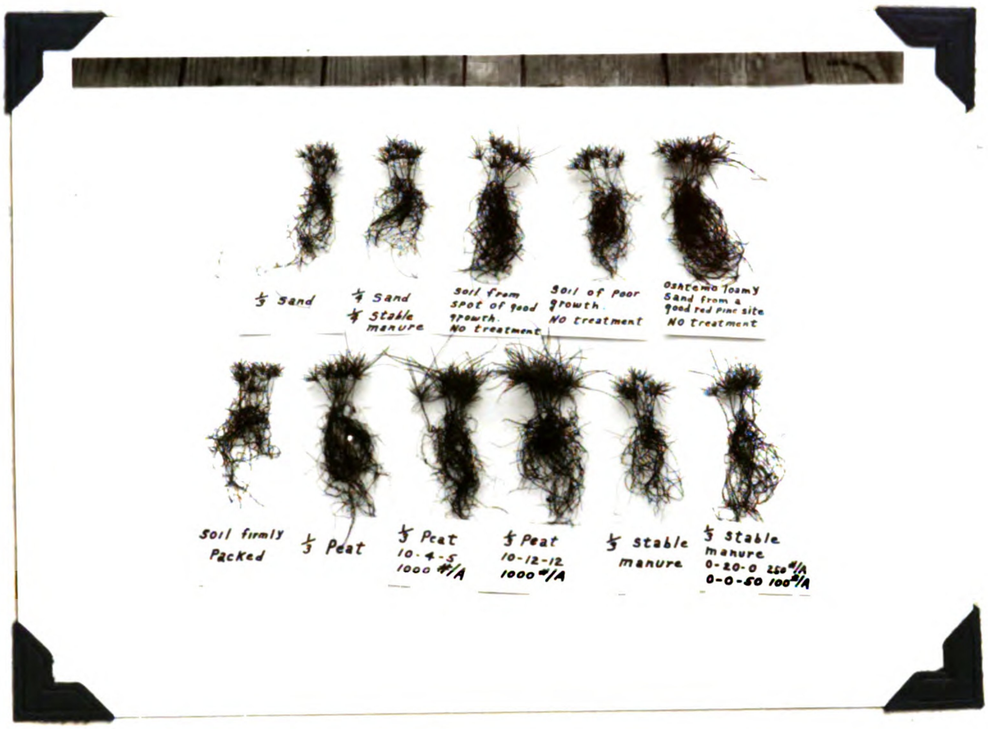

Figure 4. Seedlings at the end of the experiment showing the effect of the treatments on root and top growth.

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