The Influence of Soil Characteristics and Fertilizer Treatment on Growth and Chemical Composition of *Pinus resinosa*.

A Thesis

by

D.R. COTTON

Submitted to the Faculty of Graduate Studies and Research of McGill University in partial fulfilment of the requirements for the degree of Master of Science

Department of Soil Science

McGill University

Montreal

Quebec

May, 1964.

SUGGESTED SHORT TITLE

Effect of Soil and Fertilization on Growth of Red Pine

by

D.R. Cotton

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Dr. A.F. MacKenzie of the Department of Soil Science, Macdonald College, under whose direction this research was done, for his assistance during certain phases of the field work and also for his interest and suggestions made during the course of the entire project.

Dr. P.L. Aird of the Canadian International Paper Co. Ltd., Grenville, Quebec, was kind enough to allow samples to be taken from a red pine site which had been treated with fertilizer some two years previously, as well as from another unfertilized red pine plantation. His assistance is acknowledged.

Messrs. W.A. Arbuckle and H. Konrad, both of Montreal, must be thanked for allowing foliage samples to be taken from red pine plantations on their land. The town of Knowlton, Quebec, is thanked for the same reason.

The author gratefully appreciates the aid given him by his wife during the proof reading of the manuscript.

Finally, sincere thanks are due Mrs. W. Stewart for typing this thesis and offering many helpful suggestions pertaining to it.

TABLE OF CONTENTS

INTRODUCTION

Vast areas of abandoned or sub-marginal land exist. In Quebec alone it has been estimated that there are about 1,400,000 acres of abandoned farmland (32). Some of this land is being turned into tree farms and more of it could be so utilized if some problems could be overcome. The chief difficulties existing are mainly those of uneven topography, poor drainage and low fertility status of the soil. This latter problem could be possibly the easiest difficulty to overcome provided adequate knowledge existed of the effects of fertilization on reforested areas.

To assess relative fertility levels of soils for purposes of reforestation methods of soils analysis as well as plant analysis may be useful. These must be developed in conjunction with fertilizer application experiments either in the field or in the greenhouse under a controlled environment. This would enable response to fertilization to be evaluated and would possibly lead to prediction rates of fertilization using soil test values.

Therefore this work was initiated to determine the relative usefulness of the techniques of soil and tissue analyses in predicting red pine (*Pinus resinosa*) response to fertilization in selected Quebec soils.

This project was divided into two main parts. The first section was devoted to the measurement of nutrients (nitrogen, phosphorus, potassium, calcium and magnesium) in established plantations of red pine. Red pine plantations ranging in age from four to eight years were chosen because red pine has been extensively used for reforestation in Quebec and trees of this age would tend to respond more readily to fertilization. The nutrient concentration of the various soils was also determined so that an attempt could be made to correlate soil test values with some nutrient value obtained from the trees.

The second part of the project was a measurement of response to fertilization by red pine seedlings grown in pots in a greenhouse. Here the "fine-earth" fraction of four different plantation soils was used. Two major experiments were done. One involved the response to increasing amounts of nitrogen, phosphorus and potassium with the two elements not under consideration added at the maximum level. The second experiment dealt with the effect of increasing magnesium fertilization adding nitrogen, phosphorus and potassium at the maximum levels.

It was hoped that the information gathered from this project would indicate the suitability of fertilization of red pine areas considered for reforestation.

LITERATURE REVIEW

I FERTILIZATION

A - General:

Rennie (71) has surveyed the literature and published figures giving estimated nutrient-uptake demands of various types of forest trees after growth periods of fifty and one hundred years. The quantities of calcium, potassium and phosphorus taken up decreased in order "hardwood", "other conifer" and "pine forest". All three types of forest studied take up considerably less potassium and phosphorus compared with agricultural crops, but amounts of calcium are not greatly less. He also concluded that continuous timber production would not be possible on the soils studied (mainly moor lands and other sub-marginal areas) unless fertilization was undertaken.

There are various ideas on the purposes of forest fertilization. Aird (2) has listed five specific uses of fertilizers in forestry: (1) nursery management, (2) establishing plantations, (3) disease reduction, (4) increasing seed yields, and (5) forest fertilization for increase of timber yield.

Laurie (35) has broken forest fertilization into categories of: (1) nurseries, (2) at time of planting in the forest, (3) for the amelioration of crops that have gone into check, and (4) in crops that have closed canopy.

Stoeckler and Arneman (81) in an article containing over two hundred selected references, discussed fertilizers under headings of: (1) nurseries and (2) forest trees.

Some workers (7, 26, 39, 97) have devoted themselves directly to nursery fertilization, while others have discussed plantations (3, 32, 33, 34, 45, 48, 96, 98, 101).

More information is available for nurseries since they tend to resemble field or truck garden crops (97) and because the nutrient drain is more severe in nurseries. In plantations each tree extracts nutrients from a much larger volume of soil and also returns nutrients via litter fall.

A brief summary of forest fertilization research and practices in Europe and the United States was given by Tamm (3) and Maki (3). Some indication of the situation in Canada was given by Lafond (34).

In general, however, in North America, there are few field experiments which have been under observation for extended periods (80).

B - Nitrogen Fertilization:

The effect of nitrogen fertilization has been studied using coniferous and deciduous trees. Both field and greenhouse experiments have been used.

In the Pacific Northwest nitrogen fertilization alone (13) and in combination with phosphorus (79) has increased seed production of deciduous trees and Douglas fir, respectively, while in Florida slash pine seeds were produced which yielded taller and heavier seedlings (48).

Nitrogen has also been found to be limiting for hardwoods growing on three soil types of different lime contents in the northeastern United States (6).

In the United States nitrogen fertilization has been beneficial to peach and apple trees only if phosphorus and potassium were adequate (12, 18) and to spruce, in Europe, the response was greatest with adequate phosphorus, but low calcium values (56). In the greenhouse increased drought resistance was imparted to jack pine seedlings (7), but higher nitrogen application rates gave reduced resistance to two year old red pines; with increasing phosphorus levels this was overcome (76).

Growth response, measured by leader length, to nitrogen fertilization was shown by white spruce, black spruce, Douglas fir and jack pine growing on various loams and sands in Eastern Canada (83), while longleaf pine on a sandy soil in Mississippi responded, as measured by root-collar diameter, to urea nitrogen treatments (4).

The Grand'mere plantations in Quebec, consisting principally of white spruce with Norway spruce, either pure or in a mixture, together with small amounts of Scotch pine, jack pine and red pine, have produced a good response, as measured by increased needle length and colour and height growth, to fertilization of nitrogen along with potassium (84).

Excessively high rates of fertilization (300 pounds per acre of readily soluble nitrogen) have led to reduced growth of red pine in the United States, possibly as a result of burning or competition from weeds (69).

Increased tree growth seems to result from nitrogen application to forest soils - this is shown in many references - but there is little information regarding the effect of soil properties on this response. Gessel and Walker (3) have suggested that, for Douglas fir, if the total nitrogen of the surface soil is below 0.10 or 0.12 per cent, the tree will suffer a nitrogen deficiency.

Also, the best form to supply nitrogen has concerned some workers. Leyton (36) found with Stika spruce grown in culture solutions there seemed to be no difference between the form of nitrogen supplied and dry weight production, but nitrate-nitrogen stimulated greater root production than did ammonia-nitrogen.

Weetman (92) found response to nitrogen fertilization, as measured by increase of leader length of black spruce, with no preferential uptake for either the ammonia or nitrate form.

A combination of both forms gave the best growth of <u>Cryptomeria japonica</u> grown in culture solution, but for pine, ammonia-nitrogen was preferred, if the aeration was adequate (65).

With Scotch pine seedlings, ammonia-nitrogen produced the most growth (19).

In Europe the greatest growth response of spruce came from nitrogen fertilization if the soils were adequately supplied with phosphorus and calcium; nitrate-nitrogen was more effective on strongly acid soils low in potassium, while ammonia-nitrogen was best on medium acid soils high in potassium (57, 55).

With pines, again in Europe, response to nitrogen applications on weakly acid or alkaline soils, sufficient in phosphorus, but low in magnesium, was better with the nitrate form. If the phosphorus levels tended toward minimum values then ammonia-nitrogen gave the greatest growth response (58).

The form of nitrogen best suited for fertilization use may depend on soil reaction, for nitrogen was found to be released more slowly from coniferous litter (pH 4.0) than from deciduous litter (pH 4.6) (77). Also sand culture growth of loblolly pine used nitrate-nitrogen more successfully in acid reaction, and ammonia-nitrogen in more nearly neutral pH (1).

C - Phosphorus Fertilization:

Virgin soils are generally low in available phosphorus and as a result when new land is brought into agricultural production, phosphorus is usually needed. Research has further shown that phosphorus is especially important to young plants. Such agricultural experiences suggest that particular attention should be given to the phosphate nutrition of forest trees.

Drought resistance of red pine in greenhouse and nursery studies was improved by increasing the amounts of available phosphorus, providing nitrogen levels were low; with nitrogen present in adequate amounts the same tendency existed, but was not as pronounced (76).

White spruce, on a sandy-loam in Ontario, responded to phosphate and nitrogen fertilization (83), but spruce, in Europe, growing with rich reserves of nitrogen present, have their nitrogen intake lowered by phosphate fertilization; growth was stimulated by phosphorus applications only if nitrogen levels were low (60).

Phosphate fertilization gave increased growth to spruce on neutral or weakly acid sites low in either potassium or magnesium, as well as on acid soils low in both potash and magnesium (61). With strongly acid soils no growth response to applications of Thomas slag or superphosphate resulted unless potassium reserves were favourable; in this case, the former treatment was best (59).

With spruce, again, growing on a limestone sandy-loam a favourable growth effect, continuing for many years, resulted from phosphorus fertilization (52), while pines which displayed calcium and phosphorus deficiencies overcame these and grew better with phosphorus applications (53).

All of the responses noted above, with the exception of Ontario results, were recorded by European workers. Phosphate applications at the time of plantation establishment seemed to provide a stimulating and long lasting effect.

The major difficulty encountered in predicting rates of application seems to centre around obtaining some measure of "available" soil phosphorus.

D - Potassium Fertilization:

Sandy, light textured, acid soils which are well drained are ideally suited for the growth of pine, but on these soils basic nutrients, such as potassium, are leached away as soon as they are released by mineral decomposition (89). Fertilizing with potassium at rates up to three hundred pounds of potassium chloride per acre in pine and spruce stands in northern New York has been found to give increased potassium content in needles, as well as better growth. These effects were still evident sixteen years after fertilizing (27).

On other work with twenty year red pine, again in New York State, adding one hundred and fifty pounds of potassium as the chloride, gave growth responses that were still evident nine years later, and showed a fertilizer efficiency of about fifty per cent. This effect has probably been maintained in part due to the increased return of potassium to the nutrient cycle by litter fall and decomposition (28).

On abandoned farmlands in Quebec, consisting of coarse sandy soils, red and white pine, along with spruce, have tended to display intense deficiency symptoms that could not be completely explained by soil analyses. Leaf analysis indicated potassium and/or magnesium deficiencies in the pines, and potassium deficiency in the spruce. Applications of two hundred pounds of potassium chloride with fifty pounds of magnesium sulphate per acre overcame chlorosis and rapidly stimulated growth (33).

Fertilizing prune trees in California with potassium gave increased potassium uptake in the leaves only until the content of the soil reached four hundred pounds per acre. As the potassium built up in the leaves there was a reduction of calcium (30 to 40 per cent) and magnesium (40 to 50 per cent) contents (38).

With peach and apple trees in New York a deficiency of potassium, and resulting decline in growth, is usually accentuated by adequate amounts of nitrogen (18).

Potash fertilization with spruce in Europe stimulated nitrogen intake on soils abundant with nitrogen, especially those deficient in potassium, but caused a decrease in nitrogen intake on soils low in nitrogen (64).

Potassium uptake by the same spruce was also found to depend on soil phosphorus content; as soil phosphorus values increased so did uptake of potash (63).

The form in which potassium is applied may be of importance. Krause and Wilde, in a series of field experiments in Wisconsin, found that red pine seedlings responded, as measured by increased growth, to potassium fertilization. Potassium metaphosphate gave greater growth than did the chloride salt and was not leached away so readily (31).

E - Calcium Fertilization:

With agricultural soils calcium, for the most part, is rarely deficient as a nutrient since it is used to adjust soil pH close to neutrality or is already present in neutral or alkaline soils. In forestry, however, the soils tend to be acid (down to pH 4.0) and the trees which accumulate calcium tend to be long living, compared to agricultural crops. Thus there is less calcium available at the start, more of it is taken up and held unavailable for a longer period of time, compared to agricultural soils. In a European Scotch pine plantation there were 555 kg/ha of calcium. Of this total 227 kg were present in living trees and only 311 kg in the more decomposed litter. If all living tree boles were harvested 21 per cent of the calcium would be removed (66).

Under conditions such as this calcium may well become limiting as a nutrient.

Liming of red and white pine stands on acid soils (pH 4.7) in New York State had only a slight effect on growth, but increased soil nitrogen contents slightly, available phosphorus greatly and, of course, exchangeable calcium was increased. The greatest value, however, came from the increase in litter fall and the much greater rate of litter decomposition (40).

Liming of spruce in Europe stimulated growth only on soil containing sufficient phosphorus and with a pH of 4.33 to 4.70, providing the lime application corresponded to more than 45 per cent of the actual lime requirement of the soil (62).

A definite response of young pine and spruce was observed in Germany during the course of six years immediately following the treatment of soil with lime (23), but the treatment of lime-deficient soils with varying amounts (2,000 - 5,000 kg/ha) of lime and chalk did not produce any response in pine seedlings during eight years following liming and sowing; 2,000 kg/ha of either lime or chalk was sufficient to obtain satisfactory growth of spruce and larch and to insure their survival with pine (24).

Calcium has also been found to inhibit growth, either directly or indirectly, of spruce growing in Quebec (84).

Before too serious thought is given to applying calcium as a nutrient, much work remains to be done on the effect the pH change will have on the availability of other nutrients such as phosphorus and nitrogen.

F - Magnesium Fertilization:

Magnesium deficiency, limiting growth of red and white pine in Quebec, has been overcome by fertilization with fifty pounds of magnesium sulphate per acre (33).

Several sites in the northeastern United States of red and jack pine have responded successfully to twenty to fifty pounds of magnesium sulphate per acre. The symptoms were reduced or eliminated after a lapse of at least one year, and increased height growth was maintained over a period of at least three years (82).

For the most part magnesium deficiencies have been studied in eastern North America on sandy, acid soils. There appears to be a relation between potassium and magnesium - the so called potassium-magnesium interaction - with the deficiency of one nutrient causing an increased uptake of the other. When fertilization with the deficient nutrient overcomes the shortage then the other nutrient becomes deficient. As a result of this, it would appear that magnesium deficiency would best be studied in relation to potassium nutrition.

II METHODS OF DIAGNOSING NUTRIENT DEFICIENCIES

A - Visual Inspection:

Deficiency symptoms have been published by several workers (7, 11, 27, 33, 54, 90, 99) for the major elements and some minor elements. In general the agreement between researchers has been excellent, but Stone (82) has pointed out that the tip discolouration for magnesium deficiency in red pine is not as pronounced; instead a diffuse, generalized, discolouration results and the needles have a reduced calcium content.

Walker (90) mentions that typical magnesium deficiency symptoms are often accompanied by low levels of needle potassium and relates a case where three years after overcoming magnesium deficiency, a few trees then displayed potassium deficiency symptoms. Conversely magnesium deficiency symptoms were intensified by potassium applications.

Visual symptoms may be caused by a combination of deficiencies, or one may mask the other, or there may be some external agent such as insect damage, disease or drought (7). Also visual symptoms lag behind "hidden hunger", or appear only after deficiencies are severe (10).

B - Soil Analysis:

This method has been well developed for most agricultural crops (5, 16, 67, 74, 91). Agricultural fields tend to be uniform and small in size, especially when compared to forest plantations. Thus in plantations representative sampling becomes difficult, because of the larger areas to sample.

With agricultural crops the assumption is made that most of the nutrient extraction takes place in the top six inches of the soil. Prichett and Robertson (69), using tracer techniques, found that two year old pine fed mainly from the 0 to 3 inch depth; with five year pine there was no appreciable difference between this layer or the 10 to 13 or 20 to 23 inch layers.

While correlation between plough-depth soil test results and resulting yield have been worked out for most agricultural crops little work, other than that for nurseries, has been published for forest trees.

C - Total Tree Analysis:

This procedure may be used to yield an inventory of nutrients within a stand and indirectly a measure of nutrient uptake. Selection of trees poses a problem. Attempts to sample "average" trees yield biased estimates, and so it becomes necessary to sample from "large", "intermediate" and "small" tree classes (43). Complete tree analysis is too cumbersome for a diagnostic tool and probably too damaging for most permanent sample plots.

D - Tissue Testing:

This approach will indicate a nutrient deficiency before the plant shows a deficiency symptom (73). The concentration of a nutrient in a plant as a whole, or any part of it, is a function of soil, climate, plant type, time of growth and possibly other factors. At any one time, however, a chemical analysis of a plant, or a part of a plant, gives an integrated value of all factors that have influenced its nutrient composition. By comparison of the nutrient changes with previously established critical values or levels, the nutrient status of a plant may be ascertained. Plants with nutrient concentrations above the critical values may be considered adequately supplied at the moment, whereas plants within the critical range may be considered inadequately supplied. The longer a deficiency persists and the earlier during the growth cycle it occurs, the greater is the likelihood of a response upon the application of the deficient nutrient. The practical application of plant analysis as a diagnostic tool rests essentially upon the reliability of the critical nutrient levels (88).

With trees generally, and red pines specifically, these critical nutrient levels still remain to be satisfactorily defined.

It has been shown that nutrient concentrations vary with age and particular plant organ. In general per cent nitrogen (12, 20, 41, 44, 46, 50, 86, 94), phosphorus (12, 41, 44, 46, 50, 94), and potassium (12, 20, 21, 25, 41, 44, 46, 50, 72, 94) decrease with age,although an increase (86), as well as a constant value (20) has been reported for phosphorus, while potassium has been said to increase slightly initially, then decline rapidly (38, 86). Per cent calcium content increases with age (9, 12, 20, 21, 41, 44, 46, 50, 86). Magnesium figures have been published showing a definite increase (12, 86), a slight increase (9, 44), and constant values (46, 20), as well as a decline (21).

All of these reports are for trees only, usually apple, peach, tung and prune trees, but some deciduous and pine trees have been included.

Similar variations have been reported for similar organs, usually leaves, on the tree, but from different locations (20, 21, 22, 44, 46, 51, 94).

The interpretation of results with plants in general is not always straight forward, but has been discussed in detail (78).

It was Shear *et al* (75) who noted that, although the absolute values differed between various tung trees, the slopes of gradients existing in individual trees, either along a lateral or down the trunk, remained constant. The only change in gradient came about as a result of soil type or nutrient status. This led them to postulate that under conditions of extreme deficiency for an element a shift towards a zero gradient would be expected; the upper limit would be at right angles. Now as the leaf concentration of an essential element approaches the concentration at which death occurs, leaf abscission results. Under such conditions the gradient of the deficient element is limited by a narrow range, the lower boundary of which is controlled by the vital level, and the upper boundary by the limited availability of the deficient nutrient.

One of the problems of tissue testing, other than position of sampling and time of sampling, that has received considerable work, is drying of the tissue samples.

Drying techniques for plant tissue vary. Air drying (48) has been used while temperatures of 60 degrees (38, 86), 65 to 70 degrees (72), 80 degrees (95), 100 degrees (15) and 105 degrees centigrade (86) have also been used. The most commonly used temperature is 70 degrees centigrade (6, 10, 14, 20, 27, 28, 50, 89, 91). The normal procedure is to spread the plant tissue loosely, or in cheesecloth bags, and dry until constant weight has been obtained, in a circulating air oven, but desiccators (38) have been used and also tissue has been dried for specified times of 3 (89), 24 (28, 39), 48 (37), and 72 hours (27). A drying period of as short as 20 minutes at 100 degrees centigrade, discarding any tissue turning brown, has also been used (15). After drying the tissue is ground, usually in a Wiley mill, to pass a 20, 40 or 60 mesh screen, and then stored in airtight bottles.

E - Analytical Analysis:

Many excellent schemes have been proposed for the analytical work (16, 17, 29, 42, 49, 68, 70, 74, 91, 93, 100). The choice of a procedure depends upon accuracy desired, time available for analysis and, of course, equipment and reagents present.

MATERIALS AND METHODS

I GREENHOUSE EXPERIMENTS

In the fall of 1962 bulk samples of the top six inches of soil were taken from eleven various red pine sites in Quebec. The soil was allowed to air dry and was then sieved through a number ten mesh (1.981mm) screen. On the basis of soil pH, cation exchange capacity, Kjeldahl nitrogen, exchangeable potassium, calcium and magnesium and available phosphorus, four soils, of as widely differing characteristics as possible, were selected for use in a greenhouse experiment. The results of the tests on the selected soils are reported in Table 1:

TABLE 1: Physical and Chemical Analyses of Soils Selected for Greenhouse Studies.

Soil	pH H_2O	pH KCl	Hydroscopic Moisture %	Loss on Ignition %	Fine Sand %	Coarse Sand %	Silt %	Clay %
A	5.26	4.51	1.09	4.20	80.2	1.5	3.3	11.8
B	5.17	4.28	1.98	7.37	33.6	20.0	21.7	13.0
C	5.27	4.17	2.43	10.96	28.4	14.1	24.6	17.8
D	5.03	4.12	1.66	5.45	41.0	29.7	10.4	13.2

Soil	Total N	C.E.C.	Ex. K	Ex. Ca	Ex. Mg	Ex. H	Available P.
	me/100g						
A	9.75	6.3	0.347	0.96	0.350	11.3	0.0492
B	15.65	15.7	0.133	1.12	0.217	13.9	0.0242
C	22.17	21.3	0.198	3.20	0.610	14.3	0.0153
D	12.93	11.3	0.013	0.90	0.123	11.7	0.0250

Soil pH was determined on the supernatant fluid, after shaking and equilibrating four grams of soil with twenty grams of either distilled water or N KCl solution, using a glass electrode and a calomel standard electrode. Kjeldahl nitrogen was determined on five grams of soil by digesting for five hours after clearing in a K_2SO_4-$CuSO_4$-Se catalyst H_2SO_4 mixture and distilling liberated NH_3 into a 2 per cent boric acid solution containing Tschiro's indicator. Titration was with standard 0.01NHCl. Cation exchange capacity was done by the method of Peech, et al (67). Exchangeable potassium was measured by means of flame photometery on the exchange solution resulting from the C.E.C. determination. A measure of available phosphorus was made by extracting five grams of soil with 100ml of 0.5M $NaHCO_3$ solution at pH 8.5 and measuring phosphorus concentration by the chlorostannous-reduced molybdophosphoric blue colour method of Jackson (29).

A measure of the rate of mineralization of nitrogen was obtained by incubating five grams of soil at 30 degrees centigrade for a period of two weeks in stoppered test tubes containing 15ml of distilled water. After incubation 5ml of 4N KCl was added and the tubes shaken for one hour in a horizontal shaker. After filtration a 10ml aliquant was made alkaline with MgO and liberated NH_3 distilled for four minutes in boric acid solution as described previously. Blanks were done using give grams of soil shaken for one hour with 20ml of N KCl.

The water content at field capacity of these four soils was determined in duplicate by uniformly packing the soil in glass tubes 5cms in diameter, adding water to the surface of the soil, corking and allowing free drainage for twenty-four hours. At the end of this time the core was removed, the top 2cms rejected and the moisture capacity, on an air dry basis, determined on the next 5cms.

Plastic pots, with a depth of 10cms and a top diameter of 10cms tapering to a bottom measurement of 6.5cms, capable of holding about 400g of soil, were used. The three holes in the bottom of each pot were sealed with cellulose tape. Three hundred gms of soil were weighed into each pot. Sufficient distilled water was added to bring the soil to the calculated field capacity. The pots were then allowed to stand for forty-eight hours. The soil was removed from each pot, worked by hand, and returned to the pot. The appropriate nutrients, as shown in Table 2, were added as a solution. Stock solutions were prepared so that 5 and 10mls contained the required weight of the element concerned at the low and high levels. The pots were again allowed to stand for forty-eight hours. At the end of this period 50g of soil were added to each pot and the soil again worked by hand. After repotting red pine seeds were sown in the form of a cross. Two seeds were added to each of the five spots of the cross for a total of ten seeds. The depth of planting was one-half to one cm below the surface of the soil.

The date of planting was April 16, 1963. Thus four soils, eight treatments and four replications for the NPK nutrient series, and four soils, three treatments and four replications for the magnesium series were included in the experiment.

The pots were then transferred to the greenhouse, set out with all treatments for one soil and one replicate randomized and all soils and replicates randomized, and watered very slightly.

TABLE 2: Nutrients Added to Soils used in Greenhouse Experiment

		Levels of Fertilizer Treatment lbs/A		
Treatment	Code Symbol	N_2	P_2O_5	K_2O
$N_oP_oK_o$	(1)	0	0	0
$N_2P_2K_o$	K_o	200	100	0
$N_2P_2K_1$	K_1	200	100	75
$N_2P_oK_2$	P_o	200	0	150
$N_2P_1K_2$	P_1	200	50	150
$N_0P_2K_2$	N_o	0	100	150
$N_1P_2K_2$	N_1	100	100	150
$N_2P_2K_2$	Complete	200	100	150
		MgO		
$N_2P_2K_2Mg_o$	Mg_o	0		
$N_2P_2K_2Mg_1$	Mg_1	50		
$N_2P_2K_2Mg_2$	Mg_2	100		

Nitrogen added as $(NH_4)_2SO_4$

Potassium added as KCl

Phosphorus added as H_2PO_4

Magnesium added as $MgSO_4 \cdot 7H_2O$

NOTE: In discussion of results the numbers 0, 1 or 2 will be used to indicate levels of application, while order of numbers will indicate: firstly, nitrogen; secondly, phosphorus; thirdly, potassium.

After germination the cellulose strips were removed and the pots watered every two or three days. Sufficient glass distilled water was applied to each pot to bring the soil to the calculated field capacity. The amount of water added was determined by weighing each pot. During the course of watering the front row of each section (i.e., one replicate of one soil) was moved to the back and all other rows advanced forward one.

On July 17, 1963 two banks of fluorescent lights were installed 16 inches above the soil surface. Each bank consisted of four "Gro-Lux" bulbs alternating with four "cool-white" bulbs. They were connected to an automatic switch and turned off each day for three hours, from 3:00 a.m. to 6:00 a.m. On August 1st the period of darkness was changed from 1:00 a.m. to 6:00 a.m. On December 29 the lights were lifted to a height of 24 inches above the soil and the period of darkness changed to 11:00 p.m. to 6:00 a.m.

As the plants grew the watering was gradually cut down to every third or fourth day, and finally to just once every six or seven days. In all cases, however, sufficient glass distilled water was added to each pot to bring the soil to the calculated field capacity.

The pots were weeded during watering and several times the surface soil was punctured and broken up using a table fork. Great care was taken to avoid damaging the plants. The plants in each pot were thinned after two months of growth to give ideally seven or eight seedlings per pot.

Three days prior to harvesting the pots were well watered. The plants were cut level with the soil surface and the seedlings from each pot (ranging from four to nine, with an average of seven) weighed immediately. The length of each seedling was measured from the cut to the apical point to the nearest 0.1cm and the diameter of the stem, midway between the cut and the lowest needles, was measured to 0.01mm with a micrometer. Average weight, length and diameter per tree per pot was then calculated.

Since it was necessary to harvest half the plants early the results were analysed as a split-split plot design. Time of growth was taken as the main plot, soil as the sub-plot, and treatment (fertilizer application) as the sub-sub-plot. The actual period of time from date of planting to harvest is given in Table 3.

TABLE 3: Time of Growth from Seeding to Harvest of Red Pine Grown in the Greenhouse.

	Growth Time (Days)	
Series	T_1	T_2
Magnesium	237	349
NPK	243	353

NOTE: While all four periods of growth are different, T_1 refers to "Shorter Growth Time", and T_2 refers to "Longer Growth Time."

II FIELD EXPERIMENTS

Tissue samples for the gradient analysis were taken from four red pine plantations. These were: (1) The Harrington Tree Farm at Harrington, Que., (2) The Canadian International Paper plantation near Brownsburg, Que., (3) The Arundel School Tree Farm at Arundel, Que., and (4) The town of Knowlton's plantation located adjacent to their reservoir several miles outside of Knowlton, Que.

All plantations, except the one at Arundel, were 8 to 10 years of age. At Arundel the plantation was 4 years old. This necessitated a different sampling technique. Three adjacent trees were selected to give one sample. From the first tree the top laterals were removed, from the second and third trees the second and third group of laterals, respectively, were removed. In all, 12 trees giving four samples, were used.

From the selected trees at the remaining three plantations tissue samples were collected as follows: Several laterals were cut off around the tree from the top whorl of branches. These were used to give a composite sample. The second composite sample, from the same tree, was taken from the second whorl down from the top, again sampling from around the tree, but from the first group of laterals in from the tip. The third sampling position from the tree came from the third whorl from the top, again a composite sample from around the tree, but using the second group of laterals in from the tip. The fourth sample was taken from the fourth whorl, third lateral in. Thus advantage was taken of possible gradients down the tree as well as along branches. At the Canadian International Paper plantation 6 random trees were sampled, at the Knowlton site 5 random trees were sampled.

The same sampling technique was used at the Harrington Tree Farm site except that 5 to 8 trees were sampled from each of the following fertilizer treatments: Control, N, P, K, Mg, NPK and NPKMg. The fertilizer treatments, that had been applied by spreading the fertilizers around the tree, just inside the drip line, three years earlier, were: N, 4 ozs of urea per tree; P, 4 ozs of 20 per cent superphosphate; K, 3 ozs of 60 per cent KCl; and Mg, 4 ozs of Epsom salts per tree.

In addition several other red pine sites, of different ages, were sampled for the current year's growth, from the top laterals. At all sites sampled for tissue, anywhere from 3 to 5 samples of the top 6 inches of soil were taken for analytical testing. At Harrington these soil samples were all taken from the control row.

The needles were removed from the spur branches in the laboratory and dried at 70 degrees centigrade in a circulating air oven to constant weight. The samples were then ground in a Mikro Samplmill through a 20 mesh screen and stored in capped glass bottles. To ensure oven dryness, just prior to weighing approximately 2g were spread over the bottom of small aluminum weighing dishes, dried overnight at 70 degrees centigrade, and cooled in a desiccator.

For nitrogen determinations 0.2000g of sample were weighed out and placed in a 25ml Kjeldahl flask. Two grams of catalyst (K_2SO_4:$CuSO_4$:Se::50.0:5.0:0.5) were added along with 5ml of concentrated H_2SO_4 and contents of flasks were gently boiled for five hours after clearing. All digestions were done in duplicate and four blanks (catalyst plus acid) per eighteen samples. After digestion the flasks were cooled and the contents transferred quantitatively to 50ml volumetric flasks and made to volume with ammonia-free distilled water. An aliquant of 10ml was transferred to the Parnas-Wagner apparatus, 7ml of 40 per cent NaOH added and the resulting, liberated, ammonia distilled over in 10ml of the 2 per cent indicator containing (5ml of a solution of 0.250g of methyl blue plus 0.375g of methyl red dissolved in 300ml of 95 per cent ethyl alcohol, per litre of boric acid), boric acid solution, contained in a 50ml Erlenmeyer flask. Approximately 20ml of distillate were collected with the tip of the silver condenser tube below the surface of the boric acid solution. The flask was removed, the tip of the tube washed with a few milliliters of distilled, ammonia-free, water and the contents titrated to the greyish end point using standard 0.01N HCl. All distillations were done in duplicate. Results were expressed in milliequivalents of nitrogen per 100g of oven dried tissue.

One gram of sample material (dried as previously, just prior to weighing), for the determination of phosphorus, potassium, calcium and magnesium, was wet ashed in a 25ml Kjeldahl flask using the method of Middleton and Stuckley (49). All ashings were done in duplicate. After digéstion the contents of the flask were transferred to a 100ml volumetric flask and made to volume using distilled water. Aliquants of this solution were used to determine phosphorus, potassium, calcium and magnesium contents.

A suitably sized aliquant was placed in a phosphorus-free 50ml volumetric flask and the chlorostannous reduced molybdo-phosphoric blue colour measured, as described by Jackson (29), with an Evelyn colorimeter. For phosphorus measurements it was found necessary to use double distilled water, the second distillation being done in an all glass still and condenser. The aliquant used was such that the $SO_4^{=}$ anion concentration was too low to give rise to interference.

Potassium measurements were made with a Beckman, model DU, flame spectrophotometer. The standard solutions of 0 to 100ppm potassium were contained in a sulphuric acid solution of concentration equal to that of the samples. Initially, amounts of sodium, phosphorus, calcium and magnesium were added to give concentrations approximately equal to those of the sample, but since this procedure did not alter greatly the emission readings the practice was discontinued.

Calcium and magnesium measurements were made with the EDTA titration described by Ward and Johnston (91) with the following modifications. The normality of the standard EDTA solution was 0.0100. In the calcium-alone titration 1ml of 20 per cent sucrose solution was added to overcome any magnesium interference. The indicators were added as a solution rather than as solids. Three drops of Eriochrome Black T (Fisher, E-512) indicator (9.5g of indicator plus 4.5g of hydroxylamine hydrochloride in 100ml of 90 per cent ethyl alcohol) were used for the calcium plus magnesium titration and five drops of the Calcon (Fisher, C-569) indicator (0.1g of indicator plus 0.9g of hydroxylamine hydrochloride in 20ml of 90 per cent ethyl alcohol) for the calcium-alone titration. The Eriochrome Black T indicator was found to be stable for several months whereas the Calcon indicator was prepared every two or three days.

All results were expressed in milliequivalents of element per 100g of oven dried tissue. For this calculation phosphorus was assumed to have a valency of one. Strictly speaking this would yield millimoles and not milliequivalents.

In order to simplify comparisons between results obtained in this work and other published sources the mean values, for current year's growth from the topmost lateral, were expressed as per cent of oven-dry needle material (Appendix Table A19).

The soils were analysed on an air dry, fine earth, basis for material greater than 1.981mm, for Kjeldahl nitrogen, pH, cation exchange capacity by the method of Swindale and Fieldes (85), exchangeable potassium, calcium and magnesium by flame photometry and EDTA titration after extracting by the method of Bower, et al (8), available phosphorus by extracting with $NaHCO_3$ buffered at pH 8.5 (29), and exchangeable hydrogen by the procedure of Mehlich (47).

RESULTS AND DISCUSSION

I GREENHOUSE STUDIES

A - Magnesium Series:

The mean values per seedling per pot for fresh weight, length and diameter (Appendix Tables A1, A2 and A3) were used to determine the effects of magnesium fertilization on the growth of red pine. The results were analysed on the basis of a split-split plot design (Table 4).(1)

The difference in time (112 days) between the two growing periods had no significant effect on fresh weight, diameter or length of seedling. There was, however, only one degree of freedom available for estimation of both error mean square and source mean square. The F values do indicate that for red pine seedlings during the period of growth between approximately 8 and 11 months of age the trend is for length of seedling to increase more rapidly than diameter.

The soils themselves had a highly significant effect on fresh weight and a significant effect on diameter of the red pine seedlings.

Magnesium treatments had no effect on the measurements taken as characteristic of growth, but the interaction of treatments, soils and time of growth did have a significant effect on fresh weight. This would probably be due to the strong influence of the soils.

(1) All statistical calculations were based on methods listed by Snedecor, G.W., Statistical Methods, 5th. Ed., 1956. Iowa State College Press, Ames, Iowa.

TABLE 4: Analysis of Variance on the Effect of Time of Growth, Soils and Magnesium Fertilization on the Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown in the Greenhouse(1).

Source	df	SS			MS			F		
		Length	Diameter	Weight	Length	Diameter	Weight	Length	Diameter	Weight
Time of Growth	1	0.7600	0.2837	0.9747	0.7600	0.2837	0.9747	143.40	27.54	70.33
Replications	1	0.2160	0.0008	0.0004	0.2160	0.0008	0.0004	40.76	0.08	0.27
Error A	1	0.0053	0.0103	0.0014	0.0053	0.0103	0.0014	-	-	-
Soils	3	1.5858	0.5611	1.2568	0.5286	0.1870	0.4189	4.38	5.63*	21.75**
Soils x Time	3	0.1297	0.0557	0.0406	0.0432	0.0186	0.0135	0.36	0.56	0.70
Error B	6	0.7250	0.1992	0.1156	0.1208	0.0332	0.0193	-	-	-
Treatments	2	0.0098	0.0024	0.0015	0.0049	0.0012	0.0008	0.06	0.16	0.10
Treatments x Time	2	0.1701	0.0189	0.0489	0.0851	0.0095	0.0245	1.01	1.23	3.12
Treatments x Soil	6	0.1529	0.0302	0.0759	0.0255	0.0050	0.0127	0.30	0.65	1.62
Treatments x Time x Soil	6	0.0353	0.0950	0.1488	0.0059	0.0158	0.0248	0.07	2.04	3.17*
Error C	16	1.3508	0.1240	0.1254	0.0844	0.0078	0.0078	-	-	-
Total	47	5.1407	1.3779	2.7901	-	-	-	-	-	-

(1) All values have been rounded off for inclusion in this table

* Denotes significance at the 95 per cent level

** Denotes significance at the 99 per cent level

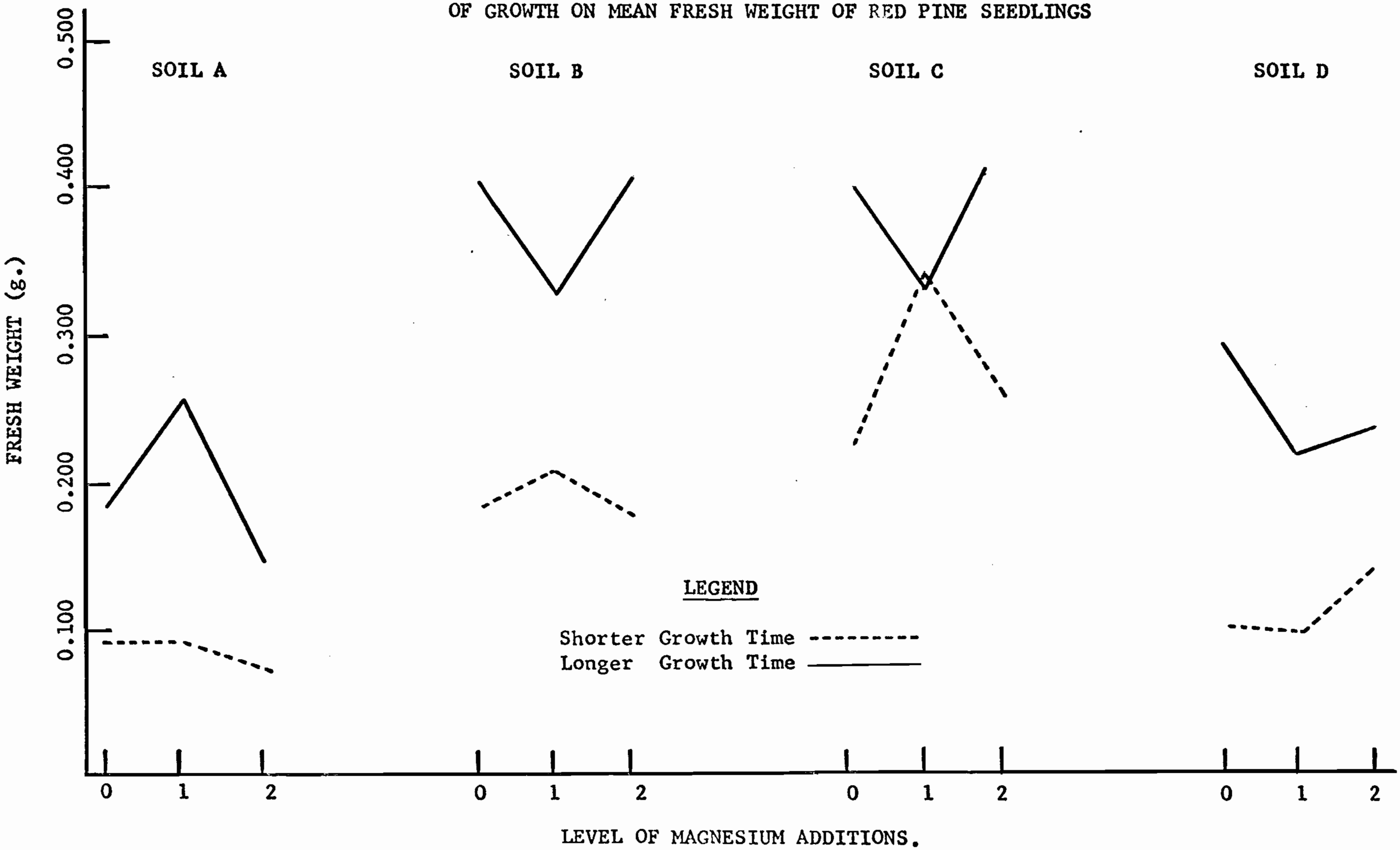
Using the new Duncan multiple range test it was found that for both fresh weight and diameter there was no difference between soils B and C or A and D, but that soils B and C gave higher values than did soils A and D.

The interaction, time of growth x treatment x soils, was plotted in Figure I. Variability existed between treatment levels and time of growth (Figure I). The differences due to magnesium fertilization increased with increasing age of the seedlings. This is consistent with published results in that the effects of magnesium fertilization did not manifest themselves soon after application, but became more pronounced as time progressed (82).

Another reason for the failure of red pine seedlings to respond to magnesium fertilization might have been that excessive rates of nitrogen, phosphorus and potassium might have been added.

The mean weight and diameter of red pine seedlings in the magnesium series was higher, than in the NPK series, for soils B, C and D. This may be seen by referring to Table 6, page 38. Since the means for the NPK series are over all levels of nitrogen, phosphorus and potassium while in the magnesium series the means are only over the upper levels of these three nutrients, this suggested that a response to magnesium might have occurred if lower levels of nitrogen, phosphorus and potassium were used. With the data available, however, this could not be tested statistically.

FIG. 1. EFFECT OF SOIL, MAGNESIUM ADDITION LEVELS AND TIME OF GROWTH ON MEAN FRESH WEIGHT OF RED PINE SEEDLINGS



For most of the sources of error the fresh weight values gave larger F values than the diameter measurements which in turn gave larger F values than the length measurements. This suggests, firstly, it is easier to detect differences in treatment effects by means of weight measurements; secondly, if it is impossible to obtain fresh weight figures, as in a continuing greenhouse experiment, it would be best to base the effects of treatments on growth using diameter measurements rather than length (height) of red pine seedling. This is discussed in more detail later.

The soils themselves were seen to have a highly significant effect on fresh weight and a significant effect on diameter. The effect of soil is also discussed in more detail later.

B - NPK Series:

The mean values per seedling per pot for fresh weight, length and diameter (Appendix Tables A4, A5 and A6) were used to determine the effect of nitrogen, phosphorus and potassium fertilization on the growth of red pine. The data was analysed on the basis of a split-split plot design (Table 5).

Only with diameter measurements did time of growth have a significant effect. This was primarily an effect of the small error sum of squares and the fact that only one degree of freedom was associated with source of variation.

Soils had a highly significant effect on both fresh weight and diameter, but not length of seedling. The interaction of

TABLE 5: Analysis of Variance on the Effect of Time of Growth, Soils and Nitrogen, Phosphorus and Potassium Fertilization on Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown in the Greenhouse[1].

Source	df	SS			MS			F		
		Length	Diameter	Weight	Length	Diameter	Weight	Length	Diameter	Weight
Time of Growth	1	.6050	.4219	1.0134	.6050	.4219	1.0134	2.42	2110.0*	47.94
Replications	1	.1596	.0010	.0001	.1596	.0010	0.0001	0.64	5.00	0.01
Error A	1	.2502	.0002	.0211	.2502	.0002	0.0211	-	-	-
Soils	3	.2478	1.3446	2.1034	.0826	.4498	0.7011	0.88	97.22**	105.70**
Soils x Time	3	.2362	.0810	.1101	.0787	.0270	0.0367	0.74	5.84*	5.53*
Error B	6	.5634	.0277	.0398	.0939	.0046	0.0066	-	-	-
Treatments	7	4.0120	.3636	.6867	.5731	.0519	0.0981	5.57**	7.86**	9.54**
Treatments x Time	7	.8041	.1379	.1726	.1149	.0197	0.0247	1.12	2.98**	2.40*
Treatments x Soils	22	3.3088	.4194	.6829	.1576	.0200	0.0325	1.53	3.03**	3.16**
Treatments x Time x Soils	21	1.3343	.2458	.3113	.0635	.0117	0.0148	0.62	1.77*	1.44
Error C	56	5.7645	.3700	.5762	.1029	.0066	0.0103	-	-	-
Total	127	17.2859	3.4152	5.7144	-	-	-	-	-	-

(1) Values have been rounded off for inclusion in this table
* Denotes significance at the 95 per cent level
** Denotes significance at the 99 per cent level

soils and time of growth was significant for the same two measurements of fertilizer response.

Treatments had a highly significant effect on fresh weight, length and diameter of seedlings. The treatments-time interaction was significant on fresh weight and highly significant on diameter measurements. The added effect on the diameter measurements was probably due to the influence of time of growth.

Only with fresh weight and diameter was the interaction of treatments with soil highly significant. This was to be expected, however, since both interaction components individually gave highly significant effects on fresh weight and diameter measurements.

The only third order interaction that was significant occurred with the diameter measurements. This was again probably due to the original effect of time of growth.

The effect of soils on fresh weight and diameter measurements of red pine seedlings was examined using a Duncan multiple range test. In both cases the seedlings on soils B and C had larger measurements than those on soils A or D. The same was true for the magnesium series, but there the seedlings growing on soils B and C or soils A and D were not significantly different. With the NPK series there was no significant difference between the seedlings on soils B or C with regard to diameter, or between seedlings on soils A or D with regard to fresh weight (Table 6).

The values underlined have no significant difference between them. This convention will be used in all following tables containing results analysed by the new Duncan multiple range test.

TABLE 6: Mean Values of Diameters and Fresh Weights of Red Pine Seedlings on Four Soils Used in Greenhouse Experiments.

Range of Values

Highest Group ———— Lowest Group

Diameter (mm)	Soil C	Soil B	Soil A	Soil D
Mg Series	1.13	1.08	0.88	0.91
NPK Series	1.09	1.07	0.93	0.84
Weight (g)				
Mg Series	0.695	0.578	0.286	0.375
NPK Series	0.587	0.472	0.295	0.279

In general better growth was obtained on soils C and B, with no difference between them, than on soils A and D, with no difference between them. The reason for growth difference may be due to better structure and aeration in soils B and C as indicated by lower bulk densities, high organic matter content and more equal distribution of clay, silt and sands (Table 7).

TABLE 7: Some Characteristics of Soils Used in Greenhouse Work.

Characteristic	Soil C	Soil B	Soil A	Soil D
Bulk Density (g/ml)	0.77	0.85	0.97	0.92
Loss on Ignition (%)	10.96	7.37	4.20	5.45
Organic Matter (%Nx20)	6.21	4.38	2.73	3.62
pH	5.27	5.17	5.26	5.03
Clay (%)	17.8	13.0	11.8	13.2
Silt (%)	24.6	21.7	3.3	10.4
Fine Sand (%)	28.4	33.6	80.2	41.0
Coarse Sand (%)	14.1	20.0	1.5	29.7

TABLE 8: Effect of Treatment on Growth of Red Pine as Measured Against the Control by Means of LSD Tests

Measurement / Soil	LSD Value 5%	LSD Value 1%	Treatments[1] Control	0-2-2	1-2-2	2-0-2	2-1-2	2-2-0	2-2-1	2-2-2
Length (cm)	0.45	0.61								
Soil A			3.98	4.33	4.34	4.18	3.87	4.15	3.99	3.68
Soil B			3.55	4.48**	4.50**	4.03*	4.08*	3.78	4.14*	4.19**
Soil C			3.72	4.31*	4.17*	3.93	3.96	4.21*	4.35**	3.92
Soil D			3.87	4.44**	3.98	4.02	4.08	3.67	3.76	4.02
Diameter (mm)	0.115	0.154								
Soil A			.938	.873	1.035	.918	.920	.898	.943	.900
Soil B			.890	1.175**	1.113**	1.108**	1.053**	.968	1.080**	1.150**
Soil C			.988	1.153**	1.210**	.898	1.000	1.095	1.220**	1.188**
Soil D			.850	.888	.888	.770	.833	.783	.885	.845
Fresh Weight (g)	0.143	0.191								
Soil A			.296	.226	.385	.299	.292	.271	.326	.269
Soil B			.280	.569**	.504**	.442*	.469*	.377	.572**	.564**
Soil C			.443	.624*	.676**	.245**(2)	.548	.653**	.789**	.722**
Soil D			.252	.366	.359	.171	.277	.189	.344	.274

(1) Treatments now expressed using the numerical code discussed in Materials and Methods section.

* Denotes significance at the 95 per cent level.

** Denotes significance at the 99 per cent level.

(2) Denotes a decrease in fresh weight.

FIG.2. EFFECT OF SOIL, FERTILIZER TREATMENT AND LEVELS

ON MEAN DIAMETER OF RED PINE SEEDLINGS

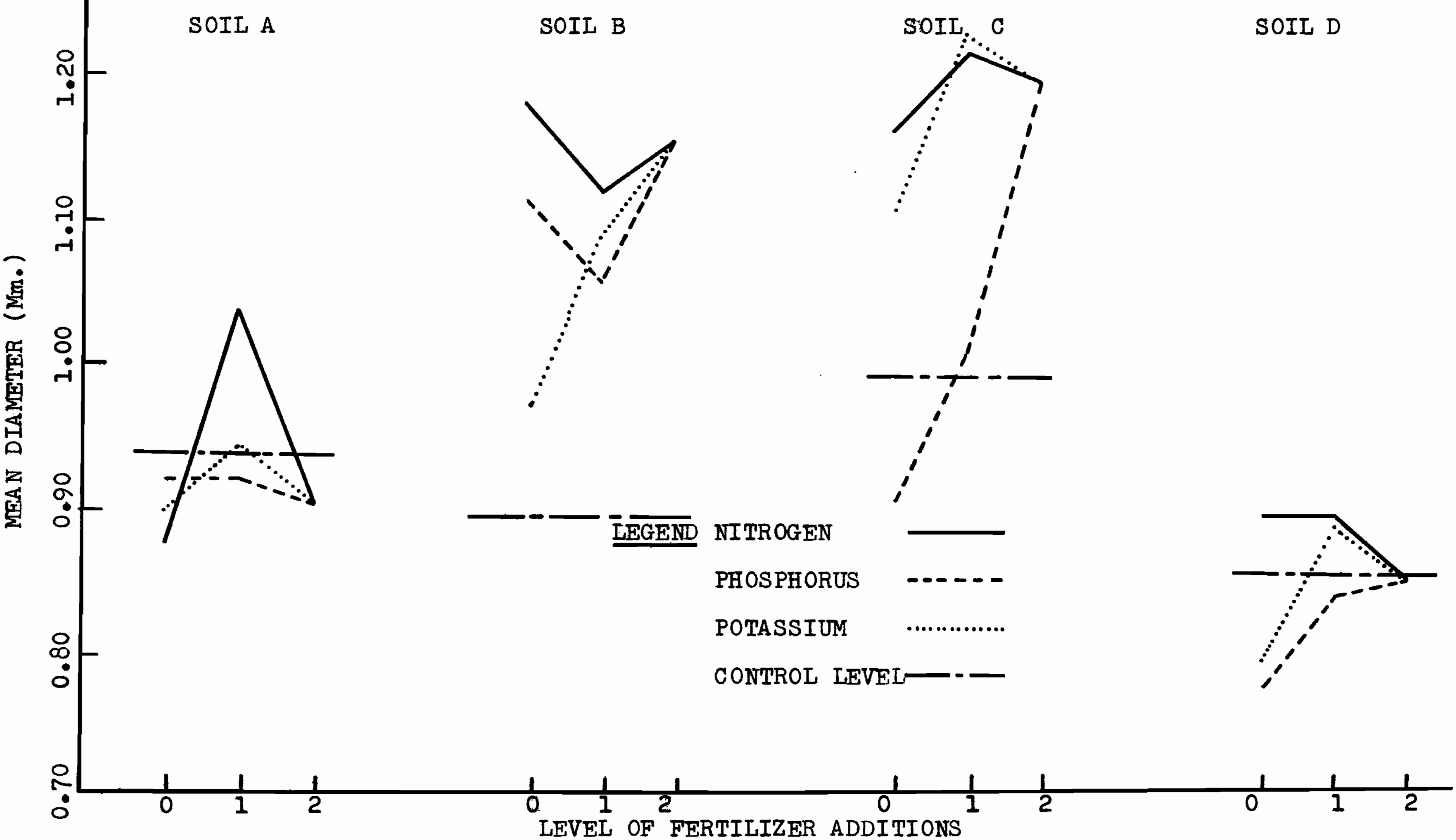


FIG. 3. EFFECT OF SOIL, FERTILIZER TREATMENT AND LEVELS ON MEAN LENGTH OF FED PINE SEEDLINGS

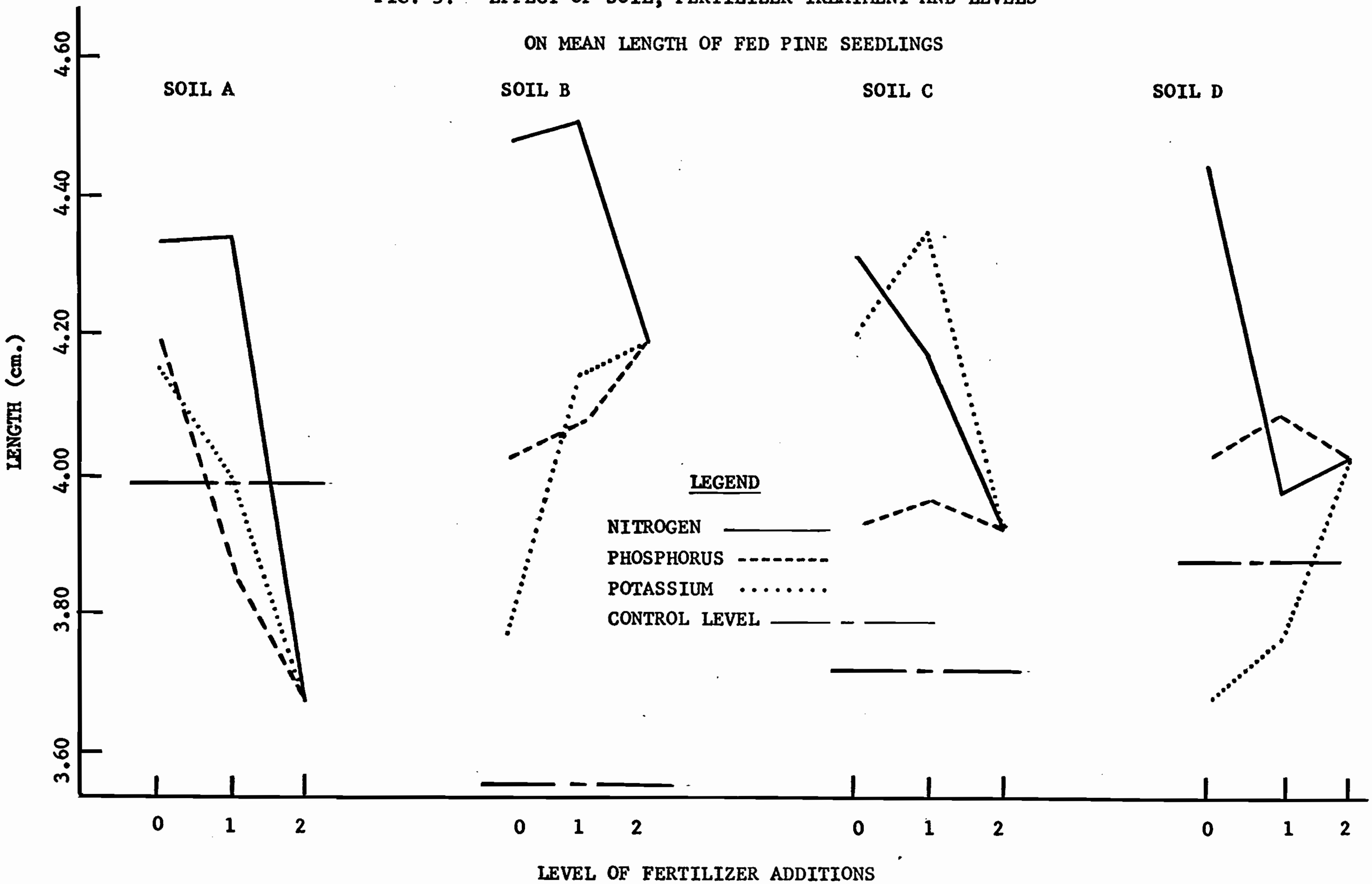
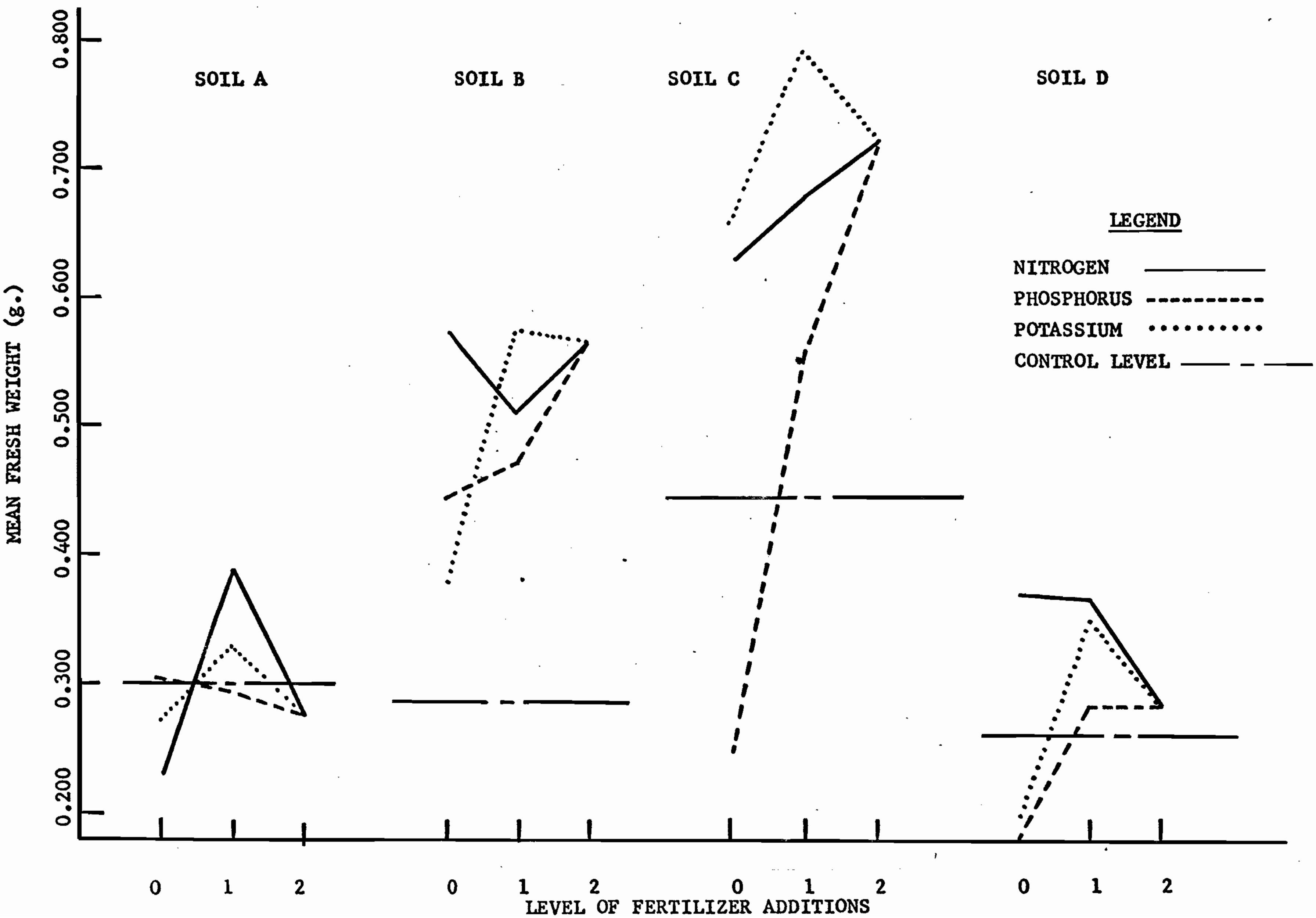


FIG. 4. EFFECT OF SOIL, FERTILIZER TREATMENT AND LEVELS ON MEAN FRESH WEIGHT OF RED PINE SEEDLINGS



The effect of fertilizer treatment on growth of the red pine seedlings for the four soils is given numerically in Table 8 and graphically in Figures 2, 3 and 4.

For soil A the LSD test showed no significant effect of treatment on fresh weight, length or diameter of seedling. A significant increase in fresh weight and diameter of seedling was obtained by increasing nitrogen from 0 to 100 pounds per acre; increasing from 100 to 200 pounds per acre caused a significant decrease of length and diameter of the red pine seedlings when tested by the Duncan multiple range test (Table 9).

TABLE 9: Effect of Levels of Fertilizer, on Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown on Soil A, as Measured by the Duncan Multiple Range Test.

Measurement	Treatment							
	Highest							Lowest
Diameter	122	221	000	212	202	222	220	022
(mm)	1.035	.943	.938	.920	.918	.900	.898	.873
Length	122	022	202	220	221	000	212	222
(cm)	4.34	4.33	4.18	4.15	3.99	3.98	3.87	3.68
Fresh Weight	122	221	202	000	212	220	222	022
(g)	.385	.326	.299	.296	.292	.271	.269	.226

Red pine seedlings grown on soil A then showed a response to the intermediate level of nitrogen, but not to phosphorus or potassium.

Soil B showed seedling growth responses as measured by fresh weight, length and diameter of seedling to all treatments except the 2-2-0. This indicated a response to potassium. Since the experiment was not a complete factorial the interpretation of the LSD results was somewhat difficult. Using length of seedling as a criterion of growth highly significant growth responses were obtained with the 0-2-2, 1-2-2 and 2-2-2 treatments and significant responses were obtained with the 2-0-2, 2-1-2 and 2-2-1 treatments. This suggested maximum response to potassium would be obtained with the upper potassium level only if phosphorus was supplied at the upper rate; also, increasing rates of nitrogen would have no effect, either positive or negative.

Using diameter measurements as indications of growth no assumptions regarding phosphorus could be drawn since all treatments, excepting the 2-2-0, gave highly significant responses when compared to the control.

With fresh weight values as a growth criterion treatments 0-2-2, 1-2-2, 2-2-1 and 2-2-2 gave highly significant responses while treatments 2-0-2 and 2-1-2 gave significant increases in seedling fresh weight. Once again the suggestion was that for maximum growth response potassium was necessary along with phosphorus at the upper level; nitrogen also seemed to have no effect whatsoever.

When the data was analysed by means of the Duncan multiple range test information regarding levels of fertilizer was obtained (Table 10).

TABLE 10: Effect of Levels of Fertilizer, on Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown on Soil B, as Measured by the Duncan Multiple Range Test.

Measurement	Treatment							
	Highest							Lowest
Diameter	022	222	122	202	221	212	220	000
(mm)	1.175	1.150	1.113	1.108	1.080	1.053	.968	.890
Length	122	022	222	221	212	202	220	000
(cm)	4.50	4.48	4.19	4.14	4.08	4.03	3.78	3.55
Fresh Weight	221	022	222	122	212	202	220	000
(g)	.572	.569	.564	.504	.469	.442	.377	.280

The significant responses were obtained for fresh weight and diameter. In both cases increasing potassium from the 0 level to the 1 level gave significant increases. Figure 2 showed that the response of diameter of seedling was almost linear with soil B. It could well be that applications of potassium in excess of 2 (150 lbs K_2O/A) would give further increases in diameter.

Results from soil C were difficult to analyse with regard to the levels of fertilizers. Only treatment 2-2-1 had a highly significant effect on length of seedling. Treatments 0-2-2, 1-2-2 and 2-2-0 had significant effects while 2-0-2, 2-1-2 and 2-2-2 had no effect on the length of the red pine seedling. This suggested that there was a response to phosphorus at the upper level of phosphorus application only if nitrogen and potassium amounts were favourable. In all three cases where nitrogen and potassium were present at the upper levels there was no response even though phosphorus levels were 0, 1 and 2 respectively.

With diameter measurements the same effects were noted. Maximum levels of phosphorus gave response only if the combinations of nitrogen and potassium were present.

Using fresh weight measurements the response of red pine to phosphorus fertilization is even more striking with regard to the nitrogen and potassium amounts. A treatment of 2-0-2 caused a highly significant decrease in fresh weight while all other maximum phosphorus levels resulted in highly significant increases if nitrogen was present.

The Duncan multiple range test was used to obtain indications of the levels of fertilizers which caused growth response (Table 11).

TABLE 11: Effect of Levels of Fertilizers, on Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown on Soil C, as Measured by the Duncan Multiple Range Test.

Measurement	Treatment							
	Highest							Lowest
Diameter	221	122	222	022	220	212	000	202
(mm)	1.220	1.210	1.188	1.153	1.095	1.000	.988	.898
Length	221	022	220	122	212	202	222	000
(cm)	4.35	4.31	4.21	4.17	3.96	3.93	3.92	3.72
Fresh Weight	221	222	122	220	022	212	000	202
(g)	.789	.722	.676	.653	.624	.548	.443	.245

No significant responses of length of seedling were obtained by increasing levels of nitrogen, phosphorus or potassium with the two nutrients not under consideration held at the maximum rates. This would suggest, along with LSD values, that with the intermediate rather than the maximum level of potassium there might be a response to phosphorus as measured by increased length of seedling.

With diameter measurements the only significant increases were caused by increasing the phosphorus level from 1 to 2.

Significant increases in fresh weight of seedling resulted from increasing phosphorus levels from 0 to 1 and again from 1 to 2.

This information in conjunction with the LSD results and by the trends indicated in Figures 2, 3 and 4 suggested that for soil C a fertilizer treatment of 0-2-1 would lead to improved growth of red pine seedlings.

With soil D the only significant response occurred with the increased seedling length resulting from the 0-2-2 treatment.

The Duncan multiple range test showed no significant increases in fresh weight, length or diameter as a result of increased levels of nitrogen, phosphorus or potassium (Table 12).

TABLE 12: Effect of Levels of Fertilizer, on Mean Fresh Weight, Length and Diameter of Red Pine Seedlings Grown on Soil D, as Measured by the Duncan Multiple Range Test.

Measurement	Treatment							
	Highest							Lowest
Diameter	022	122	221	000	222	212	220	202
(mm)	.888	.888	.885	.850	.845	.833	.783	.770
Length	022	212	202	222	122	000	221	220
(cm)	4.44	4.08	4.02	4.02	3.98	3.87	3.76	3.67
Fresh Weight	022	122	221	212	222	000	220	202
(g)	.366	.359	.344	.277	.274	.252	.189	.171

What the Duncan test did show, however, was that growth response, measured as increase in diameter and fresh weight, was better with treatments 0-2-2 and 1-2-2 than with treatment 2-0-2. For increase in seedling length treatment 0-2-2 was better than 0-0-0, 2-2-1 or 2-2-0.

This indicated that potassium or phosphorus are needed for a balanced nutrient content.

C - Relation of Fertilizer Requirements to Soil Test Values:

The response of red pine on these four soils, along with their major nutrient status, has been summarized in Table 13. Included also is the soil from the Harrington site. In field trials red pine growing on this soil responded to application of potassium applied at rates of 100 pounds of K_2O per acre.[(1)]

On the limited basis of only five soils the total nitrogen content necessary for adequate growth may be predicted readily.

A Kjeldahl nitrogen level of 10.82me/100g of air dried soil is adequate while a level of 9.75 is not, hence the minimum would be in between. This value is very close to results published by the University of Washington for Douglas fir. Their results indicated that if total nitrogen content of the soil is less than 0.10 or 0.12 per cent (7.14 or 8.57me/100g soil) the tree will suffer a deficiency (3).

In addition to total nitrogen some measure of mineralization of nitrogen was made by incubating soil samples under anaerobic conditions for a period of two weeks at 30 degrees centigrade and measuring the NH_3 produced. Soil A which responded to nitrogen fertilization produced the smallest amount of incubatable nitrogen. While it was not possible to give critical values these results suggested that some measure of the production of NH_3 in soils may be of use in determining rates of nitrogen to apply.

(1) Personal Communication - Dr. P.L. Aird, Woodlands Research, Canadian International Paper Co. Ltd., Grenville, Quebec.

TABLE 13: Response of Red Pine on Soils to Fertilizers and Nutrient Contents of Those Soils.

Soil	Fertilizer Response and Rates (lbs/A.)	Nitrogen Total Kjeldahl (me/100g soil)	Nitrogen Incubatable NH_3 (me/100g soil)	Available Phosphorus me/100g soil	Available Phosphorus ug/g soil	Exchangeable Potassium (me/100g soil)	Exchangeable Magnesium (me/100g soil)
A (C.I.P.)	N (100)	9.75	10.75	0.0492	15.24	0.347	0.350
B (Knowlton)	K_2O (75) (1)	15.65	22.06	0.0242	7.50	0.133	0.217
C (Arbuckle)	P_2O_5 (100) K_2O (75)	22.17	40.64	0.0153	4.74	0.198	0.610
D (Konrad)	Indications only (2)	12.93	21.93	0.0250	7.74	0.013	0.123
(Harrington)	K_2O (100)	10.82	-	0.0426	13.20	0.107	0.161

(1) Indications were obtained which suggested there would be a response to 100 lbs/A of P_2O_5

(2) Indications were obtained which suggested there might be responses to P_2O_5, K_2O and MgO treatments if nutrient balance was obtained.

Note: Name in brackets following soil designation indicates name of plantation from which samples came.

With an available phosphorus ($NaHCO_3$ extractable at pH 8.5 on air dried soils) level of 0.0153me/100g of soil there was a response of red pine seedlings to an application of 100 pounds of P_2O_5 per acre. With soil levels of 0.0242, 0.0250, 0.0492 and 0.0426 there was no response to phosphate fertilization, but indications were that soil B (0.0242) and soil D (0.0250) might respond to P_2O_5 rates of 50 pounds per acre, (Figures 3 and 4). Soil D appeared to require phosphorus if nitrogen and potassium were added.

With the data at hand, however, soils with available phosphorus levels greater than 0.043me/100g were adequately supplied, soils with levels around 0.015 were deficient and soil levels of near 0.025 would probably respond to phosphorus fertilization.

Prediction of exchangeable potassium requirements for soils used to grow red pine was straightforward with one notable exception. Soils with exchangeable potassium values of 0.133, 0.198 and 0.107me/100g of soil responded to K_2O applications of 75, 75 and 100 pounds per acre respectively. A soil testing 0.347 showed no response. This suggested that critical exchangeable soil potassium values are between 0.2 and 0.3me/100g. These values are higher than results obtained at Cornell University for red pine. Their results indicated that a soil is adequately supplied if the exchangeable potassium value exceeds 0.05me/100g (3).

The exception, noted above, was soil D. No response to potassium fertilization resulted even though the exchangeable soil value was a low 0.013me/100g. This soil was analysed, using four separate soil samples from the field, four times with results of 0.014, 0.013, 0.017 and 0.008me/100g obtained.

Indications were obtained of the necessity for potassium fertilization in the presence of nitrogen and phosphorus with this soil.

Soils with exchangeable magnesium levels of 0.610, 0.350, 0.217 and 0.161me/100g showed no response to magnesium applications. Results (Table 6, Table 13) indicated that soil D with 0.123me/100g exchangeable magnesium might respond to applications of magnesium if correct levels of phosphorus and potassium were applied. If a response resulted this would indicate that an exchangeable magnesium value of 0.123me/100g is near the critical region and lower exchangeable magnesium values would indicate a probable response to that nutrient.

D - Relation of Fertilizer Requirements to Nutrient Content of Current Year's Needles from Topmost Lateral:

The fertilizer response of the four soils used in the greenhouse experiment along with the potassium deficient Harrington soil and the nutrient content of the current year's needles from the topmost lateral has been summarized in Table 14.

Soil A was the only soil that gave increased growth to red pine seedlings after nitrogen fertilization. Red pines growing on the site from which this soil was sampled had a nitrogen concentration of 92.6me/g in the current year's needles. Trees with lower nitrogen concentrations in the tissue (89.8 and 67.0me/100g) on soils B and D did not respond to nitrogen fertilization.

TABLE 14: Response of Red Pine on Soils to Fertilizers and Nutrient Concentration of Red Pine Current Year's Needles from Topmost Lateral.

Soil	Fertilizer Response and Rates (lbs/A)	Nutrient Concentration (me/100g tissue) of Current Needles			
		Nitrogen	Phosphorus	Potassium	Magnesium
A (C.I.P.)	N (100)	92.6	4.48	11.94	6.90
B (Knowlton)	K_2O (75) (1)	89.8	4.10	8.12	5.98
C (Arbuckle)	P_2O_5 (100) K_2O (75)	110.6	4.02	8.82	7.34
D (Konrad)	Indications only (2)	67.0	3.55	4.63	5.95
(Harrington)	K_2O (100)	92.1	3.78	7.68	6.49

(1) Indications were obtained which suggested that there would be a response to 100 lbs/A of P_2O_5

(2) Indications were obtained which suggested that there might be responses to P_2O_5, K_2O and MgO treatments if nutrient balance was obtained.

Note: Name in brackets following soil designation indicates name of plantation from which samples came.

On the basis of this limited number of samples it was concluded that no relationship existed between the nitrogen content in me/100g of tissue from the current year's needles and nitrogen deficiency.

The results indicated that there was no relation between phosphorus content of the current year's needles and phosphorus deficiency. This was because red pine with a phosphorus concentration 4.02me/100g of tissue responded to phosphate fertilization while pines with tissue values of 4.10 and 3.55 indicated a response, while other pines containing 3.78 and 4.48meK/100g did not respond.

With potassium sites containing the highest and lowest concentration in the current year's needles were the only two which did not respond to potassium fertilization. The failure of red pine, containing 4.63meK/100g of tissue, to respond to fertilization might have been due to deficiencies of other nutrients or any response may have been masked by the same reason.

It was concluded that critical levels for foliage potassium were around 9.0meK/100g tissue because pines containing 11.94me/100g showed no response while pine trees with concentrations of 7.68, 8.12 and 8.82me/100g of tissue responded to K_2O rates of 100, 75 and 75 pounds per acre respectively.

Critical values of magnesium in current year's tissue of red pine would appear to be around 6.0me/100g of tissue since the only tissue that indicated a possible response to magnesium applications contained 5.95meMg/100g of tissue. Trees with magnesium-in-tissue values of 5.98, 6.49, 6.90 and 7.34me/100g did not respond.

E - Selection of Measurement Suited for Indicating Growth Responses:

Fresh weight would intuitively give the most favourable indication of how a plant responded to fertilizer treatments since it integrates many variables. In a continuing greenhouse experiment it would not be possible to obtain this measurement. Foresters generally measure response in two ways: leader length and diameter at breast height (D.B.H.). These two measurements when used together give some indication of volume of bole and thus, indirectly, weight. They would correspond to length and diameter of seedling.

Mention was made in the section dealing with the magnesium series of which measurement gave the best indication of growth and/or response. F values were found to be generally higher for fresh weight than for diameter, which in turn were generally higher than for length. In the NPK series of experiments the order was generally diameter, followed closely by fresh weight and lastly seedling length. In an attempt to indicate which measure would be best suited for demonstrating differences between treatments correlation values were calculated (Table 15).

TABLE 15: Correlation Between Various Growth Measurements on Red Pine Seedlings Fertilized with Nitrogen, Phosphorus and Potassium.

Attributes Correlated	r value	t value	Remarks
Fresh Weight-Diameter	0.944	15.64	Highly significant
Fresh Weight-Length	0.426	2.58	Significant
Diameter-Length	0.485	3.04	Highly significant

Diameter measurements appeared to give a closer indication to fresh weight response than length of seedling in this experiment. This same suggestion has been put forth with regard to trees in a plantation.

II FIELD EXPERIMENTS

A - Correlation Between Position on Tree and Nutrient Concentration:

It was decided to determine if nutrient concentration gradients existed in trees and were linear. This was done using tissue nutrient concentrations (Appendix Tables A7-A16 inclusive) from all sampled trees in the plantations (Table 16).

TABLE 16: Correlation Between Position on Tree and Nutrient Content

Nutrient	r	t
Nitrogen	-0.340	5.28**
Phosphorus	-0.335	5.20**
Potassium	-0.674	13.34**
Calcium	0.680	13.57**
Magnesium	0.105	1.54

** Denotes significance at the 99 per cent confidence level.

The correlation coefficients (r) obtained for nitrogen, phosphorus and calcium were highly significant and indicated that there was a relationship between nutrient content of these elements and location on the tree. In other words a linear concentration gradient existed for these nutrients. This was not true for magnesium.

A negative value for r indicated a decrease in nutrient content with descent of the tree (increasing age) whereas a positive r showed an increase. With the case of magnesium it could not be shown that a linear gradient existed, but a sign test showed that the magnesium content increased as one sampled down the tree. The trend, by the same test, was for the magnesium content to increase at first, then level off and finally to increase again, but at a slightly greater rate.

B - Effect of Fertilizer Treatment on Gradients:

Since concentration gradients were found to exist, the mean gradients from the fertilizer combinations sampled at the Harrington site (Appendix Tables A9-A15 inclusive) were examined, to see if fertilization had any effect on concentration gradients (Table 17).

TABLE 17: Effect of Fertilization on Mean Gradient for Various Nutrients at the Harrington Site.

Nutrient	Fertilizer Treatment							F
	Control	N	P	K	Mg	NPK	NPKMg	
Nitrogen	-4.19	-2.82	-3.72	-4.77	-4.64	-5.91	-3.02	0.74
Phosphorus	-0.25	-0.20	0.01	-0.28	-0.14	-0.30	-0.23	2.33
Potassium	-0.85	-0.51	-0.60	-1.37	-0.69	-1.13	-1.35	7.08**
Calcium	2.35	4.09	2.41	3.12	3.15	3.63	3.32	0.58
Magnesium	0.22	-0.04	0.16	0.19	0.23	-0.17	0.24	0.36

** Denotes significance at the 99 per cent confidence level.

The only nutrient slopes which differed significantly as a result of treatment were those for potassium - an element known to be deficient(2).

Treatments receiving potassium fertilization had the highest negative concentration gradient values when tested for significance by means of the Duncan multiple range test as modified by Kramer (30) (Table 18).

TABLE 18: Effect of Fertilizer Additions on the Potassium Concentration Gradients at the Harrington Site.

Fertilizer Additions	K	NPKMg	NPK	Control	Mg	P	N
Mean Gradients	-1.37	-1.35	-1.13	-0.85	-0.69	-0.60	-0.51

The fertilizer additions underlined showed no significant difference between them.

(2)Unpublished Results, Dr. P.L. Aird, Woodlands Research, Canadian International Paper Co. Ltd., Grenville, Quebec.

The known response to potassium fertilization referred to earlier in a personal communication was determined by measurement of leader length. There was no effect present the year after fertilization and the next year only the potassium fertilized trees showed growth response at the 5 per cent level. Figures were not available for the next year's growth, but it may well be that the other potassium-containing treatments would show their effects later. Response to potash applications is not always immediately measureable as reported by several workers (34, 90).

The concentration gradients for the trees that received potassium applications, and were known to be deficient in potassium since the trees responded to potassium fertilization, were all significantly more negative (with no difference between them) than the gradients from the other trees tested. Therefore the concentration gradient may be a satisfactory method of determining possible response to potassium fertilization.

<u>C - Comparison of Various Concentration Gradients from Different Plantations</u>:

Of the four plantations sampled it was known that the Harrington site responded to potassium fertilization. Visual examination of the other three sites indicated healthy trees. So to compare the slopes between plantations (Appendix Tables A7, A8, A9 and A16) only the control row, from the Harrington site, was used (Table 19). Even though there was no significant linear concentration gradient for magnesium (Table 16) the magnesium concentration gradients were included for the sake of completeness.

TABLE 19: Comparison of Various Concentration Gradients from Different Plantations.

Nutrient	Plantation Site				F
	Harrington Control	Arundel	Knowlton	C.I.P.	
	me/100g/Position				
Nitrogen	-4.19	-1.72	-2.19	-2.67	1.64
Phosphorus	-0.25	-0.56	-0.20	-0.25	1.31
Potassium	-0.85	-0.70	-1.07	-1.57	6.15**
Calcium	2.35	2.44	4.76	4.65	7.58**
Magnesium	0.20	0.14	0.18	0.17	0.01

** Denotes significance at the 99 per cent confidence level.

For the four plantations sampled only the concentration gradients for potassium and calcium were highly significantly different.

The modified Duncan multiple range test when applied to the potassium and calcium concentration gradients showed that for potassium there was no significant difference, at the 99 per cent level, between the C.I.P. and Knowlton concentration gradients, but they were more negative than the Harrington Control and Arundel concentration gradients. Also there was no difference between the Knowlton, Harrington Control and Arundel concentration gradients. With calcium there was no difference between the Knowlton and C.I.P. concentration gradients, but these were greater than the Arundel or Harrington Control values (Table 20).

TABLE 20: Analysis of Means of Potassium and Calcium Concentration Gradients at the 99 per cent Confidence Level.

Nutrient	Plantation and Concentration Gradient			
Potassium:	C.I.P. -1.57	Knowlton -1.07	Harrington Control -0.85	Arundel -0.70
Calcium:	Knowlton 4.76	C.I.P. 4.65	Arundel 2.44	Harrington Control 2.35

These values for the potassium concentration gradients suggest, assuming that the theory of the upper concentration gradient (absolute value) being limited by availability of the nutrient in the soil is valid, and knowing that the Harrington site responded to potassium fertilization, that the Arundel site will also respond to application of potassium. By the same reasoning these results suggested that the Knowlton site might respond to potassium applications. The Arundel and Harrington Control calcium concentration gradients suggest, again if the hypothesis of gradients is valid, a lower availability of exchangeable calcium in the soil. Nemec (64) working with spruce in Europe has suggested that a low availability of exchangeable calcium in the soil may depress potassium uptake.

An analysis of the concentration gradients of the potassium fertilized trees at Harrington (Appendix Table A12) with the unfertilized trees at the other plantations (Appendix Tables A7, A8 and A16) was calculated (Table 21). The results indicated that only the potassium concentration gradients were highly significantly different.

TABLE 21: Analysis of Variance of Calcium and Potassium Concentration Gradients Using Potassium Fertilized Trees from Harrington and Unfertilized Trees from Arundel, Knowlton and C.I.P. Plantations.

Nutrient	Site				F.
	Harrington K Fertilized	Arundel	Knowlton	C.I.P.	
	Nutrient Concentration Gradient				
Potassium	-1.37	-0.70	-1.07	-1.57	7.56**
Calcium	3.12	2.44	4.76	4.65	2.17

** Denotes significance at the 99 per cent confidence level.

There was no statistical difference in calcium concentration gradients. The unfertilized trees on the Harrington site had the lowest calcium concentration gradient. With K fertilization the gradient increased.

The potassium concentration gradients were analysed by the modified Duncan multiple range test (Table 22).

TABLE 22: Analysis of Mean Values of Potassium Concentration Gradients Given in Table 21.

Site:	C.I.P.	Harrington K Fertilized	Knowlton	Arundel
Concentration Gradient:	-1.57	-1.37	-1.07	-0.70

There was no difference between the C.I.P., Harrington and Knowlton concentration gradients, but these were more negative than the Arundel value. Also no difference existed between the Knowlton and Arundel values. As before, assuming that the concentration gradient was indicative of potassium response these results suggested that the Arundel site would respond to potassium fertilization, while the Knowlton site was difficult to interpret.

Soil from the Knowlton and C.I.P. sites was used in the greenhouse studies discussed previously. Soil A, from the C.I.P. site, did not respond to potassium, while soil B, from Knowlton, did respond to the intermediate level of potassium application. These results were in agreement with predictions made using the concentration gradient analysis.

Thus the use of concentration gradient analyses appears promising for the prediction of tree growth or response to potassium fertilization.

The extension of this approach to other nutrients requires further study on areas known to be deficient to these nutrients.

D - Comparison of Variation in Concentration Gradients with Variation in Nutrient Content of Current Year's Red Pine Needles.

For the determination of a concentration gradient at least three and preferably four samples must be collected and analysed per tree. Since this would require extra work and time it was desired to determine if the calculation of concentration gradients would aid in overcoming the nutrient variation that has been found to exist in trees (Appendix Table A20). Calculations of coefficients of variability were done (Table 23).

TABLE 23: Coefficients of Variability Calculated for Current Year's Tissue Analysis and Concentration Gradients of Harrington Site:

	Nutrient Element				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Tissue	15.5%	10.0%	30.6%	11.8%	11.9%
Gradient	9.7	9.8	19.1	18.4	32.3

These results indicated that concentration gradients might be subject to less variation than nutrient content of the current year's needles and also that for a deficient nutrient - in this case potassium - the variation between trees was greater than for a nutrient present in adequate amounts.

E - Correlation of Soil Test Values and Nutrient Content of Current Year's Needles:

Soil sampling is easier than foliage sampling and indeed may be the only alternate in reforestation schemes. Therefore an attempt was made to correlate soil test values, from nine sites, with the nutrient content of the current year's needles at the tree top (Appendix Tables A17 and A18). Also since all soil tests were done on the fine earth fraction the soil values were changed to field values by multiplying fine earth values by the per cent material finer than 1.981mm. Again tests for correlation were made (Table 24).

TABLE 24: Correlation of Soil Test Values (Fine Earth and Field Conditions) and Nutrient Content of Current Year's Needles at Tree Top.

	Fine Earth Fraction			Field Conditions		
Nutrient	r	t	Probability (1)	r	t	Probability
Nitrogen	0.615	2.06	8.2	0.773	3.22*	< 5.0
Phosphorus	0.634	2.17	7.9	0.464	1.39	21.2
Potassium	0.742	2.93*	< 5.0	0.703	2.61*	< 5.0
Calcium	0.629	2.14	7.4	0.445	1.32	36.2
Magnesium	0.985	4.78**	< 1.0	0.825	3.86**	< 1.0

* Denotes significance at the 95 per cent probability level

** Denotes significance at the 99 per cent probability level

(1) Denotes chances out of 100 of obtaining such a linear correlation due to chance alone.

The needle content correlated with the soil test value, from the fine earth fraction, for potassium and magnesium at the 95 and 99 per cent confidence levels respectively. These two nutrients correlated at the same level with the "field conditions" and total nitrogen was correlated with field values at the 95 per cent confidence level.

Since only a small number of samples were used probabilities were also reported. Thus 90 per cent of the time the analysis of the fine earth fraction for Kjeldahl nitrogen, available phosphorus (extractable at pH 8.5) and exchangeable potassium, calcium and magnesium would be related to total values of these elements respectively in the current year's needles from the tree top.

A comparison of t values between the fine earth fraction and field conditions for each nutrient showed that in all cases, save that of nitrogen, the correlation was poorer for the field condition. This was not anticipated, in fact the reverse was expected.

This may have been due to sampling or the method of calculating field conditions. Three to five separate soil samples were taken from each plantation. On each individual sample nutrient status and per cent material finer than 1.981mm was determined. The mean value of the nutrient content and the mean value of the material finer than 1.981mm was then used to arrive at the measure of nutrient status under field conditions. This was done since only a mean value of nutrient content of current year's tissue was available.

It would have been preferable to take soil samples adjacent to the tree sampled and calculate correlation values in that way.

The nutrient content of the fine earth fraction was related, by calculation, to field condition on a weight basis only. Had the calculation been made on a weight-volume basis, using bulk density of the soil, significant correlations may have been obtained. In practice this is the manner in which a tree must absorb nutrients. That is to say while actual quantity of nutrient per unit weight would be important, more support would be placed on the volume of soil through which that quantity of nutrient was distributed. In the series of greenhouse experiments that were conducted it was found that soils themselves played a significant part, and those with the lower bulk densities appeared to be best suited for growth of red pine.

The fact that the correlation between current year's tissue content and soil test values on the fine earth fraction was the best of the two correlations should not be overlooked. This indicated that by means of soil testing on the fine earth fraction it might be possible to obtain indications of the nutrient status of red pine.

F - Correlation of Concentration Gradients with Soil Test Values:

Since the concentration gradient theory stated that the upper level of the gradient depended upon availability in the soil of the nutrient under consideration, it would be expected that a correlation between the concentration gradients and nutrient availability in the soil might exist.

A normal distribution of slopes did not exist since only values of less than ninety and more than zero (absolute measurements) degrees are possible. To overcome this difficulty a transformation of data was required. This was done as follows: The slopes were changed to angles (absolute values were used since the sign of the concentration gradient only indicates whether the content increases or decreases with age and may be changed simply by replotting the data) and these angles were then expressed as a percentage of ninety degrees. Now the per cent values were transformed using the aresin transformation procedure.[4]

The four plantations previously discussed, along with one site, Arbuckle (Appendix Table A19), used in preliminary experiments were used. Values of concentration gradients from the Arbuckle site had not been used previously in gradient analysis since only two trees had been sampled. With the Harrington site only trees from the control row were used and soil values, of course, came from the same row. The correlations were calculated (Table 25).

(4) Snedecor, G.W. Statistical Methods, 5th. Ed., 1956. 318-319. Iowa State College Press, Ames, Iowa.

TABLE 25: Correlation Between Soil Test Values (Fine Earth and Field Conditions) and Nutrient Gradients (Transformed).

	Fine Earth Fraction			Field Conditions		
Nutrient	r	t	Probability	r	t	Probability
Nitrogen	0.857	2.87	6.9	0.816	2.45	9.4
Phosphorus	0.944	5.02*	2.4	0.808	2.38	9.8
Potassium	0.666	1.55	22.8	0.795	2.27	11.2
Calcium	0.707	1.73	16.7	0.741	1.92	16.2
Magnesium	0.567	1.19	33.5	0.549	1.14	35.2

* Denotes significance at the 95 per cent level.

It should be noted that again there was no significant linear relation for magnesium, but it has been included in the above table for the sake of completeness.

With the other four nutrients the agreement was good between concentration gradients and soil test values considering the few degrees of freedom available. The sample was too limited, however, for complete comparison of the two measurements.

The phosphorus concentration gradients were significantly correlated with the fine earth soil test values.

The results obtained, however, indicated that the concentration gradient was related to the available or exchangeable nutrient status of the soil.

/

CONCLUSIONS

I GREENHOUSE STUDIES

A - Magnesium Series:

Magnesium fertilization had no effect on growth (as measured by fresh weight, length and diameter) of red pine seedlings grown in the greenhouse on four soils which had received high levels of nitrogen, phosphorus and potassium fertilization.

An increase in growth time from 237 to 349 days had no effect on growth responses.

Soils had a highly significant and significant effect on mean seedling fresh weight and diameter respectively, but none on seedling length.

Indications were found by fresh weight and diameter measurements over all levels of fertilization for a possible response of seedling growth on one soil to magnesium fertilization, if nitrogen, phosphorus and potassium levels and balance were correctly adjusted.

B - NPK Series:

Soils had a highly significant effect on mean fresh weight and diameter of red pine seedlings. The larger mean fresh weight and diameter was attributed to better structure and aeration of the soils, as indicated by lower bulk density, higher organic matter content and more equal contents of silt, clay and sand particles.

The effect of fertilizer treatment and level was highly significant on mean fresh weight, length and diameter of red pine seedlings.

Of the four soils used one showed a response, by increased growth of seedling, to nitrogen fertilization; one to potassium applications with a suggestion of seedling response to phosphorus; one to increased seedling growth as a result of phosphorus and potassium fertilization and, finally, one soil gave indications of deficiency of phosphorus, potassium and magnesium with the need for the correct ratios of these nutrients necessary for increased red pine seedling growth.

C - Relation of Fertilizer Requirements to Soil Test Values:

On the basis of the limited results available soils with total nitrogen content equal to or greater than 10.82me/100g of air dried soil were adequately supplied with nitrogen for the growth of red pine. A value of 9.75 was too low for adequate growth. Indications were obtained that a measure of production of NH_3 by soils, under anaerobic conditions, might be of value in determining the nitrogen status of the soil if critical values could be established.

Available phosphorus ($NaHCO_3$ extractable at pH 8.5 from air dried soils) levels of 13.2ug/g of soil appeared to be adequate for growth of red pine, values of 4.7 were deficient and levels of 7.7 indicated a probable response to phosphorus applications.

A soil value of 0.347me/100g of exchangeable potassium was adequate for red pine growth while red pines growing on soils with exchangeable potassium levels of 0.133, 0.198 and 0.107 responded to K_2O applications of 75, 75 and 100 lbs/A respectively. An exception to this was a soil testing 0.013me/100g of exchangeable potassium in which red pine showed no response to potash fertilization.

Results suggested that exchangeable magnesium values of 0.12me/100g of soil, or less, could be indicative of magnesium deficiency for growth of red pine seedlings. Further work, however, would be necessary to evaluate accurately such a value.

D - Relation of Fertilizer Requirements of Red Pine Seedlings to Nutrient Content of Current Year's Needles from Topmost Lateral:

With the limited results available no relation appeared to exist between nitrogen or phosphorus requirements and concentration of that element in the current year's tissue sampled from the topmost lateral of red pine trees.

Response to potassium occurred if content in tissue was 8.82, 8.12 or 7.68me/100g. This suggested a critical level of around 9.0; below this a probable response to potassium would result. Trees from two different sites had potassium values of 11.94 and 4.63meK/100g of tissue from needles on the topmost lateral. Neither responded to potassium fertilization, but seedlings growing on soil from the latter site gave indications that a response would result if nutrient balance could be obtained. This suggested, then, that tissue concentrations of potassium in the current year's needles from the topmost lateral of red pine were adequate if the value was around 12me/100g of tissue.

The critical level for magnesium was thought to be around 6.0me of Mg/100g of tissue since red pines containing 7.34, 6.90, 6.49, 5.98 and 5.95meMg/100g of tissue did not respond statistically to magnesium fertilization, but the pine tissue with the level of 5.95 indicated a possible response if other nutritional difficulties could be overcome. Further work would be required to verify this level.

E - Selection of Measurement Suited for Indicating Growth Response:

Diameter measurements were suggested over length measurements as an estimation of fresh weight of red pine seedlings since the correlation between diameter and fresh weight was highly significant, but the correlation between length and fresh weight of seedlings was only significant.

II FIELD EXPERIMENTS

A - Correlation Between Position of Tissue Sample on Tree and Nutrient Concentration:

Highly significant linear correlations were obtained for nitrogen, phosphorus and potassium contents with position on red pine which decreased with descent of tree and for calcium which increased in concentration with descent. Magnesium concentration with position was not correlated linearly,but concentration increased with descent of tree.

B - Effect of Fertilizer Treatments on Gradients:

From a red pine site known to be deficient in potassium the nitrogen, phosphorus, calcium and magnesium concentration gradients did not differ significantly with treatment. The potassium gradients did differ with treatments. Those trees that received potassium, either alone or in combination with other nutrients, developed concentration gradients that were significantly more negative. This indicated that the difference of potassium concentration between the topmost portion of the trees and sections lower down became greater. Also suggested was that the upper value of the potassium concentration gradient was limited by potassium content of the soil.

C - Comparison of Various Concentration Gradients from Different Plantations:

Concentration gradients from four different sites (using only unfertilized trees from the potassium deficient site) were found to be significantly different only for potassium and calcium. In both cases the gradients from the potassium deficient site and one other (Arundel) were found to be statistically less negative and less positive for potassium and calcium respectively. Comparing concentration gradients from the same four sites (but replacing the gradient values of unfertilized trees with those of potassium fertilized trees from the potassium deficient site) only the potassium gradients differed significantly. The gradients of the potassium fertilized trees were found to be no different from all sites except that of Arundel; the Arundel site which had concentration gradients less negative initially was the only site significantly different in potassium concentration. This indicated that this site might also respond to applications of potassium and that concentration gradients might be used to predict tree growth, or response to fertilizer applications might be extended to other nutrients with further study.

D - Comparison of Variation in Concentration Gradients with Variation in Nutrient Content of Current Year's Red Pine Needles:

Coefficients of variation were similar between gradients and single tissue values for all non-deficient nutrients from the potassium deficient site. With potassium the coefficient of variation of the tissue analysis was almost one and one-half times as great as the coefficient of variation of the gradients. It was concluded that in the case of deficient nutrients concentration gradient analyses were more uniform than analyses of current year's tissue. Thus in the determination of nutrient deficiencies in red pine plantations gradient analyses may prove to be of more value, once critical levels are established, than tissue analyses.

E - Correlation of Soil Test Values and Nutrient Content of Current Year's Tissue:

Total soil nitrogen content in field-condition soil was significantly correlated with nitrogen content in current year's tissue. Correlations for potassium and magnesium concentrations in needles' tissue were significant and highly significant, respectively, with exchangeable potassium and magnesium in both the fine-earth fraction and calculated field-condition soil. Indications were that extractable phosphorus and exchangeable calcium contents of the fine-earth fraction were more closely correlated with current year's needle tissue contents than were the same phosphorus and calcium values corrected for actual field conditions.

F - Correlation of Concentration Gradients with Soil Test Values:

The correlation between nutrient concentration gradients in the tree tissue and soil test values was significant only for phosphorus in the fine-earth fraction of the soils after a transformation was used on the concentration gradient data.

Indications were that the concentration gradient was related to the available or exchangeable nutrient values obtained from the soil analyses, but the sample was too limited for complete comparison of all concentration gradients with soil test values.

G - Suitability of Fertilization of Red Pine Plantations:

Results obtained indicated that a growth response to nitrogen, phosphorus and potassium would occur if total nitrogen was below 10.8me/100g of soil, available phosphorus (Bray p2 method) below 13.2ug/100g of soil and exchangeable potassium below 0.35me/100g of soil. A suggestion was obtained that exchangeable magnesium values below 0.12me/100g of soil could be indicative of magnesium deficiency. Using foliar analysis of current year's needles from the topmost laterals, no critical levels could be established for nitrogen or phosphorus. Response to potassium and magnesium fertilization would appear to occur if the current year's needles, from the topmost laterals, were below 12.0 and 6.0me/100g of oven dried (70°C) tissue respectively.

BIBLIOGRAPHY

1 Addoms, R.F.

Nutritional studies on lobloly pine.

Plant Physiol. 12:199-205 (1937).

2 Aird, P.L.

Fertilizers in forestry and their use in hardwood plantation establishment.

Pulp Pap. (Mag.) Can. 57:376, 379-381, 384 (1956).

3 American Potash Institute.

Forest fertilization...a new era.

Reprint CC-10-58. American Potash Institute, Inc. (1958).

4 Anonymous.

Fertilizing longleaf seedlings with urea nitrogen in south Mississippi.

Rep. sth. For. Exp. Sta. 1952:42-44 (1953).

5 Atkinson, H.J., Giles, G.R., MacLean, A.J., and Wright, J.R.

Chemical methods of soil analysis.

Contribution 169 (rev.), Chem. Div., C.D.A. (1958).

6 Baird, G.E.

The nutrient content of the foliage of forest trees on three soil types of varying limestone content.

Proc. Soil Sci. Soc. Amer. 10:419-422 (1946).

7 Bensend, D.W.

Effect of nitrogen on growth and drought resistance of jack pine seedlings.

Minn. Univ. Agr. Exp. Sta. Tech. Bull. No. 163:1-63 (1943).

8 Bower, C.A., Reitemeier, R.F., and Fireman, M.

Exchangeable cation analysis of saline and alkali soils.

Soil Sci. 73:251-261 (1952).

9 Boynton, D., Cain, J.C. and Compton, O.C.

Soil and seasonal influences on the chemical composition of McIntosh apple leaves in New York.

Proc. Amer. Soc. Hort. Sci. 44:15-24 (1944).

10 Breoshart, H. and van Schouwenburg, J. Ch.

Early diagnosis of mineral deficiencies by means of plant analysis.

Neth. J. Agric. Sci. 9:108-117 (1961).

11 Cain, J.C.

Some interrelationships between calcium, magnesium and potassium in one-year-old McIntosh apple trees grown in sand culture.

Proc. Amer. Soc. Hort. Sci. 51:1-12 (1948).

12 Cain, J.C. and Boynton, D.

Some effects of season, fruit crops and nitrogen fertilization on the mineral composition of McIntosh apple leaves.

Proc. Amer. Soc. Hort. Sci. 51:13-22 (1948).

13 Chandler, R.F.

The influence of nitrogenous fertilizer application upon seed production of certain deciduous trees.

J. For. 36:761-766 (1938).

14 Chandler, R.F.

Amount and mineral nutrient content of freshly fallen needle litter of some northwestern conifers.

Proc. Soil Sci. Soc. Amer. 8:409-411 (1944).

15 Chapman, G.W.

Leaf analysis and plant nutrition.

Soil Sci. 52:63-81 (1941).

16 Chapman, H.D., and Pratt, P.F.

Methods of analysis for soils, plants and waters.

Published by Univ. Calif., Division of Agr. Sci. (1961).

17 Cotton, R.H.

Determination of nitrogen, phosphorus and potassium in leaf tissue.

Jour. Ind. and Eng. Chem. (Anal. Ed.). 17:734-738 (1945).

18 Cullinan, F.P. and Batjer, L.P.

Nitrogen, phosphorus and potassium interrelationships in young peach and apple trees.

Soil Sci. 55:49-60 (1943).

19 Demortier, G. and Fouarge, J.

Studies on the nitrogen, phosphate and potassium nutrition of Scots pine seedlings.

Bull. Inst. agron. Gembloux 7:173-193 (1938).

(As abstracted in World Forestry Series, Bull. No. 2, Ref. 122, (1956).)

20 Drosdoff, M.

Leaf composition in relation to the mineral nutrition of tung trees.

Soil Sci. 57:281-291 (1944).

21 Emmert, F.H.

The soluble and total phosphorus, potassium, calcium and magnesium of apple leaves as affected by time and place of sampling.

Proc. Amer. Soc. Hort. Sci. 64:1-8 (1954).

22 Emmert, F.H.

A comparison of different leaf samples and the total and soluble tests as indicators of apple tree nitrogen, potassium and magnesium nutrition.

Proc. Amer. Soc. Hort. Sci. 69:1-12 (1957).

23 Fabricius, L.

Experiments on the liming of forest soils. I.

Forstwiss. 261. 61:129-137 (1939).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 140 (1956).)

24 Fabricius, L.

Experiments on the liming of forest soils. II.

Forstwiss. 261. 61:228-237 (1939).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 141 (1956).)

25 Frear, D.E., Anthony, R.D., Haskins, A.L. and Hewetson, F.N.
Potassium content of various parts of the peach tree and their correlation with potassium fertilization - a sampling study.
Proc. Amer. Soc. Hort. Sci. 52:61-74 (1948).

26 Hansen, T.S.
Use of fertilizers in a coniferous nursery.
J. For. 21:732-5 (1923).

27 Heiberg, S.O. and White, D.P.
Potassium deficiency of reforested pine and spruce stands in northern New York.
Proc. Soil Sci. Soc. Amer. 15:369-376 (1950).

28 Heiberg, S.O., Leyton, L. and Lowenstein, H.
Influence of potassium fertilization level on red pine planted at various spacings on a potassium deficient site.
For. Sci. 5:142-153 (1959).

29 Jackson, M.L.
Soil Chemical Analysis.
Prentice-Hall, Inc., Englewood Cliffs, N.J. (1958).

30 Kramer, C.V.
Extension of multiple range tests to group means with unequal numbers of replication.
Biometrics 12:307-310 (1956).

31 Krause, H.H., Wilde, S.A.

Uptake of potassium by red pine seedlings and losses through leaching from fertilizers of various solubility.

Proc. Soil Sci. Soc. Amer. 24:513-515 (1960).

32 Ladouceur, G., and Grandtner, M.

Les terres à reboiser du Québec méridional.

Bull. No. 4, Laval Univ. For. Res. Found. (1961).

33 Lafond, A.

Les déficiences en potassium et magnésium de quelques plantations de _Pinus strobus_, P. _resinosa_ et P. _glauca_ dans la province de Québec.

Cont. No. 1, Laval Univ. For. Res. Found. (1958).

34 Lafond, A.

Forest fertilization in Canada - a symposium.

Bull. No. 5, Laval Univ. For. Res. Found. (1962).

35 Laurie, M.V.

The place of fertilizers in forestry.

J. Sci. Food of Agr. 11:1-8 (1960).

36 Leyton, L.

The effect of pH and forms of nitrogen on the growth of Stika spruce seedlings.

Forestry 25:32-40 (1952).

37 Leyton, L., and Armson, K.A.

Mineral composition of the foliage in relation to the growth of Scots pine.

For. Sci. 1:210-218 (1955).

38 Lilleland, O., and Brown, J.G.

The potassium nutrition of fruit trees. II. leaf analysis.

Proc. Amer. Soc. Hort. Sci. 36:91-98 (1938).

39 Lunt, H.A.

The use of fertilizer in the coniferous nursery with special reference to <u>Pinus resinosa</u>.

Bull. Conn. agric. Exp. Sta. 416:722-766 (1938).

40 Lunt, H.A.

Liming and twenty years of litter raking and burning under red (and white) pine.

Proc. Soil Sci. Soc. Amer. 15:381-390 (1951).

41 Lynd, J.Q., Turk, L.M., and Cook, R.L.

Mineral deficiencies diagnosed with foliar analysis and plant tissue tests.

Jour. Amer. Soc. Agron. 42:402-407 (1950).

42 MacKay, D.C., and Bishop, R.F.

A comparison of acetic acid-soluble and total nutrient levels in plant tissue as indicators of nutritional status.

Can. J. Plant Sci. 42:229-237 (1962).

43 Madgwick, H.A.I.

Nutritional research: some problems of the total tree approach.

Proc. Soil Sci. Soc. Amer. 27:598-600 (1963).

44 McClung, A.C., and Lott, W.L.

Mineral nutrient composition of peach leaves as affected by leaf age and the presence of a fruit crop.

Proc. Amer. Soc. Hort. Sci. 67:113-120 (1956).

45 McIntyre, A.C., and White, J.W.

The growth of certain conifers as influenced by different fertilizer treatments.

Jour. Amer. Soc. Agron. 22:558-567 (1930).

46 McVicker, J.S.

Composition of white oak leaves in Illinois as influenced by soil type and soil composition.

Soil Sci. 68:317-328 (1949).

47 Mehlich, A.

Use of triethanolamine acetate-barium hydroxide buffer for the determination of some base exchange properties and lime requirement of soil.

Proc. Soil Sci. Soc. Amer. 3:162-166 (1939).

48 Mergen, F., and Voigt, G.K.

Effects of fertilizer applications on two generations of slash pine.

Proc. Soil Sci. Soc. Amer. 24:407-409 (1960).

49 Middleton, G., and Stuckey, R.E.

The preparation of biological material for the determination of trace metals.

Analyst 78:533-542 (1953).

50 Mitchell, H.L.

Trends in the nitrogen, phosphorus, potassium and calcium content of the leaves of some forest trees during the growing season.

Black Rock Forest Papers, Bull. 1-30-44 (1936).

51 Myers, A.T., and Brunstetter, B.C.

Spectrographical determination of mineral composition of the tung leaf as influenced by the position on the plant.

Proc. Amer. Soc. Hort. Sci. 47:169-174 (1946).

52 Němec, A.

Experiments relating to the influence of phosphate fertilizers on the growth of spruce on the Pläner limestone soils in the forest district Pátec on the Elbe.

Ann. Acad. tchécosl. Agric. 11:36-48 (1936).

(As abstracted in C.A. 30.3932 (1936).)

53 Němec, A.

Studies on the deficiency symptoms in pine in the forest nursery Revnice.

Ann. Acad. tchécosl. Agric. 11:531-534 (1936).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 354 (1956).)

54 Němec, A.

Deficiency appearances in pine seedlings.

Forstwiss Centr. 58:798-808 (1936).

(As abstracted in C.A. 31.3618 (1937).)

55 Němec, A.

The effect of a one-sided nitrogen fertilization upon the growth of spruce in forest nurseries.

Ann. Acad. tchécosl. Agric. 12:32-47 (1937).

(As abstracted in C.A. 31.5498 (1937).)

56 Němec, A.

The effect of a one-sided nitrogen fertilization on the nutrition of spruce plants in forest nurseries. I. The effect on the uptake of nitrogen.

Ann. Acad. tchécosl. Agric. 12:141-149 (1937).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 358 (1956).)

57 Němec, A.

The effect of a one-sided nitrogen fertilization on the nutrition of spruce plants in forest nurseries. III. The effect on the uptake of potassium. IV. The effect on the uptake of calcium.

Ann.Acad. tchécosl. Agric. 12:385-391, 391-398 (1937).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 360 (1956).)

58 Němec, A.

The effect of a one-sided nitrogen fertilization on the nutrition of spruce plants in forest nurseries. V. The effect on the uptake of magnesia.

Ann. Acad. tchécosl. Agric. 12:545-557 (1937).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 362 (1956).)

59 Němec, A.

The effect of a one-sided phosphate application on the growth of nursery spruce.

Ann. Acad. tchécosl. Agric. 12:631-641 (1937).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 363 (1956).)

60 Němec, A.

The effect of a one-sided phosphate fertilization on the nutrition of spruce plants in forest nurseries. I. The effect on nitrogen uptake.

Ann. Acad. tchécosl. Agric. 12:641-647 (1937).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 364 (1956).)

61 Němec, A.

The effect of a one-sided phosphate fertilization on the nutrition of spruce plants in forest nurseries. II. The effect on the uptake of phosphoric acid. III. The effect on the uptake of potash and calcium. IV. The effect on the uptake of magnesia.

Ann. Acad. tchécosl. Agric. 13:48-57, 101-109, 109-116 (1938).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 369 (1956).)

62 Němec, A.

The influence of liming on the growth of spruce in forest nurseries.

Lesn. Práce 17:209-234 (1938).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 367 (1956).)

63 Němec, A.

The effect of a one-sided fertilization with potash and kainite on the nutrition of spruce plants in forest nurseries. I. The effect on the uptake of potassium and phosphoric acid.

Ann. Acad. tchécosl. Agric. 14:270-277 (1939).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 380 (1956).)

64 Němec, A.

The effect of a one-sided fertilization with potash and kainite on the nutrition of spruce plants in forest nurseries. II. The effect on the uptake of nitrogen, calcium and magnesium.

Ann. Acad. tchécosl. Agric. 14:324-331 (1939).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 381 (1956).)

65 Ohmasa, M., and Tsutsumi, T.

Some experiments on water culture of seedlings.

J. Jap. For. Soc. 32:305-310 (1950).

(As abstracted in World Forestry Series, Bull. No. 2, ref. 431 (1956).)

66 Ovington, J.D., and Madgwick, H.A.I.

Distribution of organic matter and plant nutrients in a plantation of Scots pine.

For. Sci. 5:344-355 (1959).

67 Peech, M., Alexander, L.T., Dean, L.A., and Reed, J.F.

Methods of soil analysis for soil-fertility investigations.

Cir. 757 U.S.D.A. (1947).

68 Piper, C.S.

Soil and plant analysis.

Published by Interscience Publishers, Inc., New York, N.Y. (1944).

69 Pritchett, W.L., and Robertson, W.K.

Problems relating to research in forest fertilization with southern pines.

Proc. Soil Sci. Soc. Amer. 24:510-512 (1960).

70 Reitz, L.L., Smith, W.H., and Plumlee, M.P.

A simple wet oxidation procedure for biological materials.

Anal. Chem. 32:1728 (1960).

71 Rennie, P.J.

The uptake of nutrients by mature forest growth.

Plant and Soil 7:49-95 (1955).

72 Reuther, W., and Boynton, D.

Variations in potassium content of the foliage from certain New York orchards.

Proc. Amer. Soc. Hort. Sci. 37:32-38 (1939).

73 Scarseth, G.D.

Plant-tissue testing in diagnosis of the nutritional status of growing plants.

Soil Sci. 55:112-120 (1943).

74 Schuffelen, A.C., Muller, A., and van Schouwenburg, J.Ch.
Quick tests for soil and plant analysis used by small laboratories.
Neth. J. agric. Sci. 9:2-16 (1961).

75 Shear, C.B., Barrows, H.L., Neff, M.S., Sitton, B.G., and Kilby, W.W.
Determining critical ranges in leaf contents of nutrient elements from changes in gradients along the axis of one-year-old tung trees.
Proc. Amer. Soc. Hort. Sci. 76:310-322 (1960).

76 Shirley, H.L., and Meuli, L.J.
The influence of soil nutrients on drought resistance of two-year-old red pine.
Amer. J. Bot. 26:355-360 (1939).

77 Sowden, F.J., and Ivarson, K.C.
Decomposition of forest litter. II. Changes in the nitrogenous constituents.
Plant and Soil 11:349-261 (1959).

78 Steenbjerg, F.
Yield curves and chemical plant analysis.
Plant and Soil 3:97-109 (1951).

79 Steinbrenner, E.C., Duffield, J.W., and Campbell, R.K.
Increased cone production of young Douglas fir following nitrogen and phosphorus fertilization.
Jour. For. 58:105-110 (1960).

80 Stoeckler, J.H.

Soil and water management for increased forest and range production.

Proc. Soil Sci. Soc. Amer. 25:446-451 (1961).

81 Stoeckler, J.H., and Arneman, H.F.

Fertilizers in forestry.

Advanc. in Agron. 12:127-195 (1960).

82 Stone, E.L.

Magnesium deficiency of some northeastern pines.

Proc. Soil Sci. Soc. Amer. 17:297-300 (1953).

83 Swan, H.S.D.

The mineral nutrition of Canadian pulpwood species. Phase II. Fertilizer pellet field trials.

Res. Note No. 34, Woodlands Res. Dept. Pulp and Pap. Res. Inst. of Can. (1962).

84 Swan, H.S.D.

The mineral nutrition of the Grand'mere plantations.

Tech. Report No. 276, Woodlands Res. Index 131. Pulp and Pap. Res. Inst. of Can. (1962).

85 Swindale, L.D., and Fieldes, M.

Rapid semimicro method for cation exchange capacities of clays and soils with the flame photometer.

Soil Sci. 74:287-290 (1952).

86 Taylor, G.A., and Smith, C.B.

Nutrition studies with sweet corn in Blair county, Pennsylvania.

Proc. Amer. Soc. Hort. Sci. 74:454-464 (1959).

87 Tucker, B.B., and Kurtz, L.T.

Calcium and magnesium determinations by EDTA titrations.

Proc. Soil Sci. Soc. Amer. 25:27-29 (1961).

88 Ulrich, A.

Plant analysis as a diagnostic procedure.

Soil Sci. 55:101-112 (1943).

89 Walker, L.C.

Foliar analysis as a method of indicating potassium-deficient soils for reforestation.

Proc. Soil Sci. Soc. Amer. 19:233-236 (1955).

90 Walker, L.C.

Foliage symptoms as indicators of potassium deficient soils.

For. Sci. 2:113-120 (1956).

91 Ward, G.M., and Johnston, F.B.

Chemical methods of plant analysis.

Pub. 1064. Res. Branch, Can. Dept. Agr. (1960).

92 Weetman, G.F.

Nitrogen relations in a black spruce stand subject to various fertilizer and soil treatments.

Woodlands Res. Index No. 129, Pulp and Pap. Res. Inst. of Can. (1962).

93 Wells, C.G., and Corey, R.B.
Elimination of interference by phosphorus and other elements in the flame photometric determination of calcium and magnesium in plant tissue.
Proc. Soil Sci. Soc. Amer. 24:189-191 (1960).

94 White, D.P.
Variations in the nitrogen, phosphorus and potassium contents of pine needles with season, crown position and sample treatment.
Proc. Soil Sci. Soc. Amer. 18:326-330 (1954).

95 White, T.L.
Petiole analysis as a guide to the manuring of sugar beet.
Plant and Soil 11:78-86 (1959).

96 Wilde, S.A.
Soil fertility standards for growing northern conifers in forest nurseries.
J. Agric. Res. 57:945-952 (1938).

97 Wilde, S.A.
Comments on tree nutrition and use of fertilizers in forestry practice.
J. For. 59:346-348 (1961).

98 Wilde, S.A., Trenk, F.B., and Albert, A.R.
Effect of mineral fertilizers, peat and compost on the growth of red pine plantations.
J. For. 40:481-484 (1942).

99 Wilde, S.A., and Voigt, G.K.

Determination of colour of nursery stock by means of Munsell colour charts.

J. For. 50:622-623 (1952).

100 Wolf, B.

Rapid photometric determination of total nitrogen, phosphorus and potassium in plant material.

Ind. and Eng. Chem. (Anal. Ed.) 16:121-123 (1944).

101 Wright, T.W., and Will, G.M.

The nutrient content of Scots and Corsican pine growing on sand dunes.

Forestry 31:13-25 (1958).

APPENDIX

APPENDIX TABLE A1: Mean Fresh Weight (g) of Red Pine Seedlings Grown in Magnesium Series Experiment

Replicate	I						2					
Growth Time	T_1			T_2			T_1			T_2		
Treatment and Level	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2
Soil A	.190	.158	.132	.408	.681	.313	.188	.220	.174	.339	.351	.277
Soil B	.320	.388	.306	.804	.736	.770	.436	.460	.425	.823	.597	.873
Soil C	.404	.689	.532	.890	.801	.881	.518	.686	.515	.782	.542	1.104
Soil D	.248	.227	.400	.474	.400	.385	.185	.203	.180	.716	.492	.585

APPENDIX TABLE A2: Mean Length (cm) of Red Pine Seedlings Grown in Magnesium Series Experiment

Replicate	I						2					
Growth Time	T_1			T_2			T_1			T_2		
Treatment and Level	Mg_o	Mg_1	Mg_2	Mg_o	Mg_1	Mg_2	Mg_o	Mg_1	Mg_2	Mg_o	Mg_1	Mg_2
Soil A	3.75	3.55	3.24	4.36	4.13	3.73	3.43	3.83	3.72	3.89	3.53	3.80
Soil B	3.93	3.59	4.17	4.37	4.24	4.20	4.16	4.63	4.06	4.36	4.36	4.74
Soil C	3.95	4.24	3.79	4.23	4.20	3.90	3.64	3.72	4.24	4.37	4.19	4.64
Soil D	4.02	4.03	4.12	4.08	4.16	3.55	4.16	3.98	4.17	4.38	4.26	4.49

APPENDIX TABLE A3: Mean Diameter (mm) of Red Pine Seedlings Grown in Magnesium Series Experiment

Replicate	1						2					
Growth Time	T_1			T_2			T_1			T_2		
Treatment and Level	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2	Mg_0	Mg_1	Mg_2
Soil A	0.97	0.83	0.72	0.95	1.21	0.93	0.82	0.82	0.97	0.79	0.80	0.74
Soil B	0.96	1.07	1.06	1.10	1.00	1.14	0.90	1.06	0.99	1.29	1.12	1.26
Soil C	0.92	1.13	0.98	1.20	1.15	1.20	1.03	1.15	1.01	1.23	1.18	1.40
Soil D	0.79	0.80	0.96	0.89	0.91	1.02	0.75	0.75	0.70	1.25	1.04	1.03

APPENDIX TABLE A4: Mean Fresh Weight (g) of Red Pine Seedlings Grown in NPK Series Experiment.

Treatment	N		P		K			
Level	0	1	0	1	0	1	None	All Max.
Replicate:Growth Time	Replicate I : Growth Time T_1							
Soil A	.222	.309	.151	.190	.173	.147	.281	.138
Soil B	.456	.279	.277	.365	.269	.711	.206	.383
Soil C	.255	.503	.215	.508	.526	.631	.362	.543
Soil D	.301	.348	.213	.111	.231	.140	.211	.182
Replicate:Growth Time	Replicate I : Growth Time T_2							
Soil A	.308	.507	.471	.472	.438	.497	.339	.406
Soil B	.821	.595	.664	.602	.445	.604	.252	.647
Soil C	.874	.878	.214	.736	.579	.752	.451	1.025
Soil D	.677	.385	.171	.455	.117	.468	.249	.255
Replicate:Growth Time	Replicate 2 : Growth Time T_1							
Soil A	.171	.265	.128	.140	.187	.151	.245	.159
Soil B	.415	.408	.255	.292	.358	.319	.320	.563
Soil C	.678	.631	.186	.313	.664	.565	.533	.546
Soil D	.256	.272	.153	.282	.152	.340	.290	.362
Replicate:Growth Time	Replicate 2 : Growth Time T_2							
Soil A	.202	.459	.445	.366	.284	.509	.318	.372
Soil B	.584	.732	.571	.617	.434	.654	.342	.661
Soil C	.688	.692	.364	.635	.842	1.209	.424	.775
Soil D	.229	.432	.146	.260	.245	.426	.258	.296

APPENDIX TABLE A5: Mean Length (cm) of Red Pine Seedlings

Grown in NPK Series Experiment

Treatment	N		P		K			
Level	0	1	0	1	0	1	None	All Max.
Replicate:Growth Time	Replicate I : Growth Time T_1							
Soil A	4.14	4.33	3.94	3.90	4.33	3.38	3.85	3.43
Soil B	4.43	4.98	4.19	3.94	3.39	3.67	3.71	4.19
Soil C	4.21	4.00	4.24	4.29	4.16	4.37	3.76	3.80
Soil D	3.94	3.89	4.46	3.75	3.61	3.11	3.80	4.00
Replicate:Growth Time	Replicate I : Growth Time T_2							
Soil A	4.29	4.45	4.90	3.59	4.25	4.53	4.24	3.92
Soil B	4.83	4.36	4.43	4.20	3.98	4.83	3.49	4.51
Soil C	4.33	4.57	3.99	4.44	3.78	4.26	3.71	4.27
Soil D	4.78	3.85	3.83	4.49	3.55	4.37	3.49	3.91
Replicate:Growth Time	Replicate 2 : Growth Time T_1							
Soil A	4.31	4.33	3.70	3.98	3.88	4.05	4.07	3.39
Soil B	4.44	4.17	3.69	4.35	3.97	4.36	3.54	3.91
Soil C	4.39	4.20	3.60	3.29	4.45	4.10	4.06	3.91
Soil D	4.50	3.98	3.90	3.83	3.30	3.98	4.23	3.90
Replicate:Growth Time	Replicate 2 : Growth Time T_2							
Soil A	4.59	4.26	4.17	3.99	4.15	4.00	3.76	3.98
Soil B	4.23	4.50	3.80	3.83	3.78	3.71	3.44	4.16
Soil C	4.31	3.90	3.90	3.83	4.46	4.68	3.33	3.71
Soil D	4.53	4.18	3.89	4.26	4.22	3.57	3.96	4.25

APPENDIX TABLE A6: Mean Diameter (mm) of Red Pine Seedlings

Grown in NPK Series Experiment

Treatment	N		P		K			
Level	0	1	0	1	0	1	None	All Max
Replicate:Growth Time	Replicate I : Growth Time T_1							
Soil A	.89	1.05	.88	.91	.83	.81	.98	.78
Soil B	1.07	1.00	1.06	.99	.99	1.08	.87	1.11
Soil C	1.03	1.09	.99	.84	.89	1.07	.94	1.05
Soil D	.80	.87	.86	.68	.84	.68	.78	.81
Replicate:Growth Time	Replicate I : Growth Time T_2							
Soil A	.87	1.05	1.01	.99	.96	1.03	.86	1.01
Soil B	1.37	1.12	1.26	1.09	1.00	1.10	.83	1.18
Soil C	1.30	1.31	.83	1.19	1.08	1.24	.98	1.36
Soil D	1.16	.93	.74	1.02	.67	1.03	.85	.76
Replicate:Growth Time	Replicate 2 : Growth Time T_1							
Soil A	.91	1.04	.84	.84	.87	.88	.96	.82
Soil B	1.09	1.11	.81	1.01	.88	.99	.93	1.12
Soil C	1.08	1.07	.83	.83	1.11	1.05	1.04	1.03
Soil D	.82	.79	.72	.80	.77	.85	.92	.89
Replicate:Growth Time	Replicate 2 : Growth Time T_2							
Soil A	.82	1.00	.94	.94	.93	1.05	.95	.99
Soil B	1.17	1.22	1.30	1.12	1.00	1.15	.93	1.19
Soil C	1.20	1.37	.94	1.14	1.30	1.52	.99	1.31
Soil D	.77	.96	.76	.83	.85	.98	.85	.92

APPENDIX TABLE A7: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Arundel Plantation.

Nutrient Element

Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	93.38	4.87	9.11	22.14	6.41
	88.31	5.05	9.13	23.68	6.73
	87.60	4.50	8.24	25.86	9.33
Slope	-2.89	-0.19	-0.44	1.86	1.46
2	101.02	5.10	6.72	15.98	5.97
	87.60	4.59	4.50	24.01	11.42
	100.59	4.97	6.24	22.62	7.95
Slope	-0.22	-0.07	-0.24	3.32	0.98
3	94.16	4.93	9.43	17.92	6.55
	99.37	5.05	8.45	19.38	7.23
	89.67	4.05	7.47	23.45	6.64
Slope	-2.25	-0.44	-0.98	2.76	0.05
4	94.73	4.97	5.78	18.33	6.95
	101.52	4.62	5.90	19.77	6.63
	91.95	1.87	3.49	22.00	3.08
Slope	-1.52	-1.55	-1.15	1.83	-1.93
Mean Slope	-1.72	-0.56	-0.70	2.44	0.14

APPENDIX TABLE A8: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for C.I.P. Plantation.

	Nutrient Element				
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	95.02	4.58	10.36	13.00	8.22
	96.09	4.56	8.61	14.49	7.80
	85.74	3.95	6.91	24.99	7.56
	85.10	3.63	4.89	29.59	8.69
Slope	-4.01	-0.35	-1.81	6.03	0.12
2	93.95	4.32	11.04	12.69	7.90
	94.31	4.28	11.60	13.11	7.16
	92.16	4.00	10.00	16.18	7.84
	90.95	3.95	8.44	26.04	7.03
Slope	-1.12	-0.14	-1.44	4.32	-0.19
3	86.67	4.30	12.15	13.05	7.02
	90.67	4.32	10.02	12.79	8.73
	92.09	4.26	9.16	19.13	7.39
	84.74	4.01	7.32	24.07	8.24
Slope	-0.44	-0.09	-1.55	3.94	0.23
4	95.73	4.87	12.61	12.79	5.53
	86.24	4.70	10.08	13.81	6.99
	87.60	4.14	7.50	19.80	7.31
	84.88	3.92	8.15	21.24	8.03
Slope	-3.12	-0.34	-1.60	3.14	0.78
5	94.81	4.20	12.51	14.17	4.59
	86.88	4.37	12.04	13.82	13.08
	83.53	3.97	9.59	19.01	8.47
	84.67	3.87	8.79	27.87	6.34
Slope	-3.38	-0.20	-1.36	4.63	0.07
6	89.38	4.62	12.98	12.80	8.24
	91.52	4.49	11.74	14.17	7.34
	83.74	3.97	8.57	26.05	8.42
	78.74	3.56	8.47	28.38	7.92
Slope	-3.97	-0.37	-1.67	5.86	0.01
Mean Slope	-2.67	-0.25	-1.57	4.65	0.17

APPENDIX TABLE A9: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, Control Row, Plantation.

	Nutrient Element				
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	102.60	4.32	11.69	13.09	6.69
	102.00	4.32	11.87	12.69	7.29
	89.09	3.86	8.39	13.13	7.27
	77.46	3.29	7.06	17.75	8.66
Slope	-8.83	-0.35	-1.74	1.44	0.59
2	82.17	3.04	7.01	12.83	6.73
	82.24	3.42	7.96	13.72	6.60
	76.53	2.87	5.70	20.93	5.58
	73.10	2.61	5.37	24.84	7.39
Slope	-3.29	-0.19	-0.72	4.32	0.10
3	95.73	3.74	9.44	13.57	6.96
	90.38	3.72	9.00	15.68	8.43
	90.38	3.82	8.90	19.24	8.17
	90.95	3.60	8.26	24.45	6.81
Slope	-1.43	-0.33	-0.36	3.62	-0.07
4	89.02	3.90	7.73	14.73	5.86
	87.74	3.80	7.01	16.33	6.62
	86.67	3.91	4.96	16.81	5.55
	83.03	3.50	4.58	18.50	5.95
Slope	-1.90	-0.11	-1.15	1.18	-0.08
5	88.52	3.85	5.01	14.67	5.18
	89.81	3.66	5.96	17.38	3.85
	80.46	3.38	4.30	19.98	5.77
	76.24	3.24	3.48	19.31	6.31
Slope	-4.62	-0.21	-0.63	1.65	0.53
6	94.45	3.79	5.21	12.22	7.54
	96.88	3.64	4.71	12.10	7.77
	87.24	3.61	4.20	18.96	8.78
	80.74	3.38	3.68	16.21	7.69
Slope	-5.08	-0.31	-0.51	1.88	0.15
Mean Slope	-4.19	-0.25	-0.85	2.35	0.20

APPENDIX TABLE A10: Nutrient Contents (me/100g tissue) Listed From Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, K-Fertilized Row, Plantation.

			Nutrient Element		
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	80.10	3.33	6.84	11.64	8.08
	78.74	3.42	6.24	14.39	8.91
	86.45	3.50	5.68	18.73	8.65
	82.81	3.42	6.19	19.25	7.20
Slope	1.59	0.04	-0.25	2.72	-0.29
2	82.67	3.58	6.93	13.39	6.70
	82.38	3.13	5.65	14.09	6.68
	75.74	2.60	4.64	17.56	5.72
	68.25	2.89	4.55	26.98	6.23
Slope	-4.99	-0.27	-0.82	4.24	-0.59
3	96.66	3.45	6.22	8.41	6.44
	91.81	2.86	5.51	11.14	6.23
	74.82	2.91	4.02	20.55	6.64
	77.74	3.04	4.26	25.65	7.88
Slope	-7.38	-0.12	-0.74	6.11	0.47
4	84.67	3.35	4.86	11.26	7.48
	80.96	2.62	3.57	13.76	7.46
	80.53	3.47	2.60	19.09	7.27
	80.17	3.55	5.45	21.53	7.65
Slope	-1.39	0.15	0.08	3.61	0.03
5	93.31	4.29	7.85	11.09	7.80
	87.81	3.91	7.75	10.90	9.24
	93.09	3.84	6.22	16.48	9.44
	85.17	3.32	5.61	21.09	8.27
Slope	-1.91	-0.30	-0.83	3.56	0.16
Mean Slope	-2.82	-0.20	-0.51	4.09	-0.04

APPENDIX TABLE A11: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, P-Fertilized Row, Plantation.

Nutrient Element

Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	100.60	3.21	5.19	11.87	3.69
	93.45	3.25	5.31	15.43	3.82
	90.95	3.65	6.56	11.95	7.42
	89.38	3.42	5.77	17.10	8.26
Slope	-3.62	0.10	-0.30	1.22	1.73
2	92.02	3.82	7.44	10.91	7.70
	90.74	4.85	7.34	12.19	7.73
	96.52	4.37	6.51	16.56	6.92
	80.17	4.16	5.88	17.86	7.71
Slope	-2.98	0.06	-0.55	2.52	-0.08
3	89.45	4.73	7.97	8.32	9.55
	86.60	5.07	7.42	11.82	12.28
	83.67	4.14	7.34	14.48	9.06
	86.02	4.13	5.56	13.62	8.09
Slope	-1.32	-0.27	-0.73	1.86	-0.76
4	105.66	4.37	6.74	13.63	7.25
	104.30	4.37	6.14	13.68	6.06
	90.02	4.16	5.45	21.10	6.82
	80.03	6.03	4.68	18.41	7.24
Slope	-9.12	0.48	-0.69	2.18	0.07
5	88.67	5.71	5.70	17.15	6.33
	86.24	6.03	4.75	17.12	6.41
	83.74	5.04	3.93	21.95	5.62
	82.74	5.39	2.62	25.64	5.84
Slope	-2.03	-0.20	-0.99	3.03	-0.23
6	91.66	6.23	5.90	11.63	6.48
	85.88	5.84	5.17	15.19	6.69
	82.17	5.61	4.94	18.22	6.14
	82.03	5.89	2.86	22.78	7.35
Slope	-3.26	-0.12	-0.94	3.65	0.21
Mean Slope	-3.72	0.01	-0.60	2.41	0.16

APPENDIX TABLE A12: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, K-Fertilized Row, Plantation.

Nutrient Element

Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	91.24	6.23	9.40	12.51	6.35	5	92.24	3.86	12.07	17.59	7.55
	83.24	3.82	8.21	18.31	5.36		72.03	3.23	9.71	11.57	5.30
	80.24	3.68	6.46	22.15	5.99		71.32	3.18	9.12	14.53	5.87
	78.03	3.62	5.55	25.56	6.67		71.39	3.08	7.03	16.75	6.92
Slope	-4.26	-0.80	-1.33	4.30	0.16	Slope	-7.72	-0.24	-1.57	0.04	-0.13
2	83.03	3.79	11.61	11.95	5.04	6	92.59	3.74	10.48	17.75	7.83
	73.89	3.36	10.44	11.46	5.32		97.02	3.84	9.64	17.72	7.01
	72.46	3.56	8.34	24.37	5.65		92.81	3.76	8.75	20.77	6.04
	69.82	3.03	5.58	33.41	4.49		73.53	3.12	6.88	23.99	7.61
Slope	-4.11	-0.21	-2.02	7.73	-0.13	Slope	-6.14	-0.20	-1.17	2.18	-0.16
3	91.66	3.87	11.15	17.59	3.56	7	81.31	3.39	9.27	22.20	6.74
	85.88	3.70	10.23	16.02	3.97		72.03	3.08	7.44	21.62	7.44
	72.03	3.45	7.87	24.00	5.04		78.74	3.35	6.88	27.15	8.34
	82.53	3.16	6.83	19.27	6.45		69.82	2.95	6.93	34.60	7.48
Slope	-5.62	-0.24	-1.53	1.30	0.97	Slope	-2.78	-0.11	-0.76	4.27	0.31
4	86.45	3.43	11.40	18.13	6.06	8	96.45	4.11	10.48	17.48	6.35
	83.88	3.42	10.23	17.25	6.60		93.66	3.59	9.32	16.95	6.49
	80.67	3.01	8.63	18.80	6.74		92.45	3.48	8.57	22.38	7.24
	77.24	2.82	7.48	19.65	6.60		81.96	3.16	6.54	30.69	7.07
Slope	-3.08	-0.22	-1.34	0.61	0.18	Slope	-4.47	-0.24	-1.26	4.51	0.29

	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Mean Slope	-4.77	-0.28	-1.37	3.12	0.19

APPENDIX TABLE A13: Nutrient Contents (me/100g tissue) Listed From Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, Mg-Fertilized Row, Plantation.

Nutrient Element

Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	91.88	3.30	8.63	11.32	5.43
	85.38	3.31	7.41	13.85	4.86
	81.67	3.08	6.06	25.38	5.23
	70.32	2.75	5.30	32.64	8.07
Slope	-6.84	-0.19	-1.13	7.55	0.83
2	94.38	3.31	6.86	19.69	8.22
	92.59	3.30	6.05	11.91	6.45
	82.24	3.24	5.60	17.06	8.07
	78.39	3.11	5.08	22.37	8.22
Slope	-5.83	-0.07	-0.58	1.32	0.16
3	99.80	3.61	6.77	12.10	6.39
	99.45	3.42	6.14	14.29	7.39
	90.88	3.26	5.51	18.45	5.82
	88.38	3.08	4.53	21.25	6.83
Slope	-4.28	-0.17	-0.74	3.16	-0.03
4	88.52	3.47	5.93	9.42	7.76
	88.59	3.33	5.41	11.44	6.55
	89.17	3.28	4.81	14.21	7.63
	79.89	2.99	3.93	16.27	7.75
Slope	-2.53	-0.15	-0.66	2.33	0.11
5	101.52	3.71	6.00	10.22	6.98
	96.38	3.54	5.06	12.04	6.01
	97.73	3.62	5.06	13.13	6.24
	88.74	3.33	4.95	14.52	7.18
Slope	-3.70	-0.11	-0.32	1.40	0.08
Mean Slope	-4.64	-0.14	-0.69	3.15	0.23

APPENDIX TABLE A14: Nutrient Contents (me/100g tissue) Listed From Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, NPK-Fertilized Row, Plantation.

		Nutrient Element			
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	94.52	3.97	9.09	11.72	5.41
	85.24	2.96	7.61	15.69	7.67
	78.10	3.60	5.05	18.31	3.38
	72.89	2.85	4.53	25.60	6.62
Slope	-7.20	-0.27	-1.62	4.43	-0.07
2	109.44	4.49	8.90	15.40	6.18
	103.30	4.31	7.65	16.00	6.66
	88.17	3.48	5.78	22.98	6.37
	72.25	2.71	4.63	31.67	6.83
Slope	-12.67	-0.62	-1.47	5.58	0.17
3	88.45	3.83	7.30	15.37	3.84
	86.02	4.04	7.24	14.83	4.02
	81.81	2.79	6.06	18.82	6.46
	81.74	3.30	4.95	24.61	7.06
Slope	-2.43	-0.28	-0.82	3.17	1.21
4	95.45	3.87	8.63	18.78	10.45
	89.74	3.37	7.43	22.62	12.29
	91.59	3.66	7.52	16.23	6.64
	85.88	3.35	5.81	24.21	6.46
Slope	-2.69	-0.13	-0.84	0.99	-1.76
5	92.66	3.63	8.62	14.49	5.74
	89.88	3.63	6.10	12.90	7.19
	76.53	3.07	5.37	24.27	3.80
	81.88	3.23	5.81	23.94	5.61
Slope	-4.57	-0.18	-0.92	3.97	-0.38
Mean Slope	-5.91	-0.30	-1.13	3.63	-0.17

APPENDIX TABLE A15: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Harrington, NPKMg-Fertilized Row, Plantation.

	Nutrient Element				
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	74.96	3.52	10.31	7.96	7.55
	77.46	4.04	8.30	11.21	7.10
	77.82	3.05	6.92	19.57	7.89
	74.53	2.80	6.51	23.36	9.93
Slope	-0.09	-0.31	-1.28	5.46	0.79
2	85.03	3.65	10.14	8.40	6.73
	87.88	3.60	8.67	10.63	6.69
	79.24	3.42	7.12	18.14	6.62
	78.53	2.96	6.75	23.67	8.00
Slope	-2.81	-0.22	-1.17	5.33	0.37
3	101.80	4.84	13.05	13.86	8.87
	99.52	4.94	7.47	12.52	8.35
	97.59	4.67	6.43	10.72	9.43
	91.45	4.34	5.93	15.54	8.32
Slope	-3.30	-0.20	-2.24	0.32	-0.06
4	95.09	3.60	8.54	9.88	5.93
	89.45	3.45	7.79	13.47	6.48
	84.31	3.37	6.69	16.73	6.46
	77.10	3.07	5.92	19.02	8.57
Slope	-5.91	-0.17	-0.90	3.07	0.79
5	96.95	3.66	9.53	11.70	8.37
	90.59	3.39	9.30	12.56	6.36
	84.38	3.05	7.98	16.66	6.55
	89.09	2.96	6.15	18.33	5.94
Slope	-2.98	-0.24	-1.15	2.40	-0.71
Mean Slope	-3.02	-0.23	-1.35	3.32	0.24

APPENDIX TABLE A16: Nutrient Contents (me/100g tissue) Listed from Top Lateral to Last Lateral Sampled; Concentration Gradients - Slopes - (me/100g tissue/Position) per Tree and Mean Concentration Gradients for Knowlton Plantation.

	Nutrient Element				
Tree	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1	84.88	3.82	6.73	10.59	7.24
	84.88	4.04	8.47	10.62	9.06
	75.89	3.66	6.56	13.57	7.93
	73.46	3.36	4.16	19.77	8.55
Slope	-4.33	-0.18	-0.96	3.05	0.28
2	97.66	4.39	9.64	11.95	6.80
	100.02	4.55	5.08	13.58	6.92
	91.95	3.94	6.55	17.43	6.41
	90.67	3.61	5.24	27.17	5.99
Slope	-2.90	-0.30	-1.18	4.95	-0.30
3	90.95	4.03	7.19	10.52	4.92
	85.88	3.92	7.58	13.39	6.26
	91.09	3.91	6.55	18.48	6.32
	79.86	3.66	4.95	23.84	5.87
Slope	-2.81	-0.11	-0.78	4.50	0.29
4	85.81	4.08	9.44	11.87	5.89
	88.59	3.93	7.99	16.17	6.17
	87.17	3.76	6.80	17.47	7.48
	85.17	3.61	5.56	29.32	6.02
Slope	-0.33	-0.16	-1.28	5.37	0.17
5	89.74	4.15	7.62	10.57	5.05
	88.45	4.12	6.72	10.28	5.68
	82.67	3.56	5.91	18.61	5.30
	89.67	3.45	4.09	27.63	6.65
Slope	-0.60	-0.27	-1.14	5.95	0.44
Mean Slope	-2.19	-0.20	-1.07	4.76	0.18

APPENDIX TABLE A17: Mean Nutrient Contents of Current Year's Needles (T.) and Soil Test Values - "Fine Earth" (F.E.) and Corrected to Field (F.) - in me/100g of Material.

Site and Soil		Nitrogen			Phosphorus			Potassium			Calcium			Magnesium		
		T.	F.E.	F.	T.	F.E.	F.	T.	F.E.	F.	T.	F.E.	F.	T.	F.E.	F.
						x10-3	x10-3									
C.I.P.	3	92.59	9.75	9.75	4.48	49.23	49.23	11.94	0.35	0.35	13.08	0.96	0.96	6.90	0.35	0.35
Knowlton	5	89.81	15.65	13.09	4.10	24.21	20.25	8.12	0.13	0.11	11.10	1.12	0.94	5.98	0.22	0.18
Arbuckle	8	110.62	22.17	19.43	4.02	15.33	13.44	8.82	0.20	0.17	13.01	3.20	2.80	7.34	0.61	0.54
Arbuckle	9	104.02	26.91	21.53	4.22	12.90	10.32	14.89	0.25	0.20	10.50	2.78	2.22	10.49	1.31	1.04
Syberg	10	101.27	23.13	19.02	4.05	17.75	14.60	5.44	0.20	0.17	14.57	2.46	2.02	6.15	0.15	0.13
Konrad	11	67.04	12.93	9.70	3.55	25.02	18.77	4.63	0.01	0.01	9.90	0.90	0.68	5.95	0.12	0.09
Arundel	-	95.82	19.33	14.86	4.97	70.37	47.04	7.76	0.18	0.12	18.59	3.55	2.37	6.47	0.28	0.19
Harrington Control	-	92.08	10.82	10.23	3.78	42.61	40.27	7.68	0.11	0.10	13.52	1.63	1.06	6.49	0.16	0.15
Knowlton	5	101.16	15.65	13.09	4.91	24.21	20.25	6.62	0.13	0.11	11.02	1.12	0.94	6.19	0.22	0.18

NOTE: Tissue and soil test results represent the mean of several values.

APPENDIX TABLE A18: Per Cent Fine Earth and Mechanical Analysis of Soils Listed in Appendix Table A17.

Site and Soil		Fine Earth %	Coarse Sand %	Fine Sand %	Silt %	Clay %
			Per Cent of Fine Earth.			
C.I.P.	3	100.00	1.5	80.2	3.3	11.8
Knowlton	5	83.66	20.0	33.6	21.7	13.0
Arbuckle	8	87.64	14.1	28.4	24.6	17.8
Arbuckle	9	80.00	11.0	21.0	41.0	12.4
Syberg	10	82.24	19.4	33.7	18.0	17.4
Konrad	11	75.02	29.7	41.0	10.4	13.2
Arundel	-	66.85	24.2	35.2	16.4	13.4
Harrington Control	-	94.51	34.7	43.4	5.4	12.5

NOTE: All results reported represent the means of at least three determinations; excluded from the sands, silt and clay are hydroscopic moisture, loss on ignition and sesquioxide content, thus total will be less than 100.0%.

APPENDIX TABLE A19: Mean Values of Nutrient Elements, Contained in Current Year's Needles from Topmost Lateral; Expressed as Per Cent of Oven-Dry Material for Sites and Fertilizer Treatments Listed.

Site and Soil		Elemental Nutrient Content - Per Cent				
		N	P	K	Ca	Mg
C.I.P.	3	1.30	0.14	0.47	0.26	0.084
Knowlton	5	1.26	0.13	0.32	0.22	0.073
Arbuckle	8	1.55	0.12	0.34	0.26	0.089
Arbuckle	9	1.46	0.12	0.58	0.21	0.128
Syberg	10	1.42	0.13	0.21	0.29	0.075
Konrad	11	0.94	0.11	0.18	0.19	0.072
Arundel	-	1.34	0.15	0.30	0.37	0.079
Harrington/ Control	-	1.29	0.12	0.30	0.27	0.079
Harrington/K	-	1.25	0.13	0.42	0.34	0.075