1974/011
SOU
1974

TS-1974/011

EVALUATION OF THE ROLE OF DIFFERENT SOIL HORIZONS IN PRODUCING GROWTH OF *Picea glauca* (Moench) Voss., SEEDLINGS

BIBLIOTECA
BELEM - PARÁ

EVALUATION OF THE ROLE OF DIFFERENT SOIL HORIZONS IN PRODUCING GROWTH OF *Picea glauca*, (Moench) Voss., seedlings

by Gladys F. de Sousa

An abstract of the Thesis Presented in Partial
Fulfillment of the Requirements for the Degree
of Master of Science (in Agronomy).
May, 1974

An experiment was designed to determine the effect of 5 forest soil horizons on the growth of *Picea glauca* (Moench) Voss and to evaluate the contribution of each horizon and two levels of lime in the rate of organic matter decomposition and availability of nutrients.

The growth of spruce measured by the fresh and dry weight was affected considerably by the percent organic matter in the soil. The concentration of nutrients in tops and roots was closely related to the concentration of nutrients in the soil with the exception of Ca and Mg concentration. These two elements showed concentrations that were higher in tops and roots of white spruce grown in low horizons. This, however, was associated with a decrease in growth. The organic matter was probably the most significant factor for growth of *Picea glauca* and the increase in mineral composition of the soil profile (9, 17).

11/74
SOU

The concentration of all elements analysed for, except P, decreased as the organic matter concentration decreased. The amount of organic matter in the individual horizons decreased with profile depth. A linear correlation was obtained between organic matter and plant growth.

Linear correlations were also obtained between soil organic matter and cation exchange capacity, and organic matter and N. This showed organic matter to be the main source of N. The N present in the horizon correlated with plant growth.

An effect of lime was observed only in the O horizon. In the pots with no plants there was an increase in mineral concentration which was associated with an increase of the organic debris decomposition. In the pots with plants there was no effect or a decrease in mineral composition for the O horizon which was related with absorption by the plants. An effect of lime in the mineral soil was observed only for the concentration of Ca and Mg which increased with the application of 4000 kg of lime per hectare.

The N concentration in the tops and the roots decreased significantly for the O horizon with the application of lime.

EMBRAPA - IPEAN
BIBLIOTECA
BELEM - PARÁ

EVALUATION OF THE ROLE OF DIFFERENT SOIL HORIZONS IN PRODUCING GROWTH OF *Picea glauca*, (Moench) Voss. SEEDLINGS

by

GLADYS F. de SOUSA

A THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
(Agronomy)

The Graduate School
University of Maine at Orono
May, 1974

ACKNOWLEDGMENTS

The author would like to express her gratitude to Dr. Roland A. Struchtemeyer for his patience, guidance, advice and encouragement throughout the course of this project.

Special thanks go to the committee members Dr. Eric Lotse, Professor of Soils, and Dr. George Cooper, Professor of Plant Physiology, for their help and friendship.

The author is indebted to the Instituto de Pesquisas e Experimentacao Agropecuarias do Norte (IPEAN) for granting a leave-of-absence and financial support.

She is grateful to Dr. Struchtemeyer and to the Department of Plant and Soil Sciences of the University of Maine for the Research Assistantship and laboratory facilities which made these graduate studies possible.

Special gratitude goes also to Eduardo Alonso, a colleague and fellow graduate student, for his continuous help during the time of her work. The friendship and cooperation of the staff of the Department of Plant and Soil Science is also appreciated.

The author is also deeply indebted to her family for their confidence and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The maintenance of soil fertility is an important problem in agricultural and forest soil management. This is particularly true in areas with a humid climate.

In the case of agricultural soils where nutrients are removed each year by the harvesting of crops, the application of fertilizer is of importance in maintaining soil productivity. In forest soils, where a large quantity of organic debris is returned to the soil each year through leaf fall, fertility is also a factor which should be of concern to forest soil researchers. To date, the use of fertilizer on forest lands has not given the consistent response that has been recorded for agricultural lands.

The organic debris on the surface of forest soils has a great influence on the elemental composition of the soil. This organic matter decomposes and releases nutrients which presumably enrich the other horizons.

From a nutritional point of view, the understanding of the mineral composition of the different soil horizons is of great importance since it is here that the forest trees get the nutrients necessary for growth.

In warm climates with high precipitation, the rate of organic matter decomposition from forest soils is high. This should mean that the lower horizons are relatively well supplied with plant nutrients.

Although many experiments have been conducted on forest soils, few have attempted an evaluation of the importance of the different soil horizons to the growth of plants.

In view of the preceeding statements, this experiment was set up to determine the contribution of the different forest soil horizons to the nutrition of *Picea glauca* (Moench) Voss seedlings. The effect of lime on the rate of organic matter decomposition and the availability of nutrients was also considered.

LITERATURE REVIEW

Organic Matter

The development of soils has been shown to be a function of weathering of soil minerals and of organic matter accumulation (6, 8, 25, 38, 62). The characteristics contributed by the organic matter to a soil are dependent on the addition of residues principally from plants, and on the decay of these residues by soil organisms. On a typical forest floor the accumulation of plant debris contributes to the formation of an O horizon which contains a vast store of plant nutrients (52).

The organic matter fraction of a soil has a profound effect on structure, the absorption and retention of water, the reserve of exchangeable bases, and the capacity to supply N, P and some of the minor elements to growing plants. The adequacy of aeration and other physical properties of soils necessary for plant growth are also dependent to some extent upon the organic fraction of the soil (12).

The quantity and nature of the organic matter found at various depths in soil were shown to be dependent upon a number of environmental factors. A number of investigators have shown that with the annual addition of organic matter to the surface of the soil under a forest stand there was a rapid decrease below the O horizon which indicated that the downward movement of organic matter was slight and that it did not accumulate to any extent within the profile (8, 11, 26, 40, 52, 62).

Rieger and Dement (49) found that soils formed where a relatively large amount of precipitation occurred had a distinct accumulation of organic matter in the upper B horizon. Soils developed in areas with a small amount of precipitation had an accumulation of iron in the B horizon.

A number of investigations have shown that hardwood litter improved the soil by hastening decomposition of organic debris, reducing soil acidity and stimulating nitrification (38, 62, 67). This was because hardwood residues returned approximately twice as much calcium, magnesium, potassium and phosphorus to the soil annually as did coniferous residues.

The organic matter in forest soils derived mainly from the deposition of softwood needles and leaves had an acid reaction. The pH varied over a wide range but was as low as 3.7 (26). The acidity of organic litter was reported to be an important factor in the ability of unincorporated humus layers to cause intensive leaching of bases and sesquioxides from the uppermost mineral soil horizon (42).

McFee (40) studied the distribution and variability of organic matter in podzol soils and found an appreciable variation in the amount of organic matter in the different parts of the profile. The amount on the forest floor of undisturbed sites was greater than that incorporated within the mineral soil.

Tarrant and Miller (62) also found that the content of organic matter and nitrogen in the mineral soil was highest to a depth of 12 inches. The organic matter as well as nitrogen was highest in the O horizon and decreased with depth.

The organic matter in the soil is destroyed mainly by the transformations of the substrate through biological, physical and chemical means. As a result of the changes that take place a vast array of organic compounds was found to be present. Common among the compounds were carbohydrates and related compounds, proteins and their derivatives, lignins, fats, tannins, and their decomposition products (8).

Most of the organic nitrogen is derived from proteins but part of it is also present in the carbohydrate fraction (8, 11, 12, 38). The amount of nitrogen in the organic matter amounts to approximately 5 percent (12). Nitrogen in the surface layers of the mineral soils varies between 0.02 and 0.4 percent and practically 92 to 96 percent of that nitrogen is found in organic combinations derived from the organic matter in the soil (11, 12).

Huntjens (27) found that in turf soils the inorganic nitrogen was derived largely from the mineralization of soil organic matter. This was true even though the nitrogen of the soil organic matter was less easily mineralized than the nitrogen recently immobilized after application of nitrogen fertilizers.

It is known that the organic soils and organic matter from mineral soils possess exchange capacities which on a weight basis are very high relative to those of clay (23, 70). The organic matter contributes appreciably to the total cation exchange capacity of the soil and it has been demonstrated that the destruction of the organic fraction with hydrogen peroxide decreases the exchange capacity of the soil (23, 43).

In 1966 Youngberg (74) studying the humus layers of second growth Douglas fir found that in the majority of the soils studied, the highest content of exchangeable cation was in the surface horizons 01 and A2 and decreased with depth.

Wells and Davey (70) found that the percent nitrogen and cation exchange capacity increased during decomposition of the organic matter and there was a high correlation between the cation exchange capacity and nitrogen content of the forest floor material.

Several studies of soils in the United States showed that the organic matter was the only variable that contributed significantly to the cation exchange capacity in the A horizon while in the B horizon, the total clay and fine clay gave better correlation with cation exchange capacity (72). Hutcheson and others (7, 29) showed that the cation exchange capacity was correlated mainly with clay in the soil profile instead of organic matter.

Wright and Foss (73) concluded that for the Maryland soils studied, approximately 50 percent of the variability in cation exchange capacity could be attributed to the organic matter content. McLean _et al_ (41) showed that a pronounced increase in cation exchange capacity occurred as the pH of the soil increased.

Plant Nutrition

Steenbjerg (57) has presented a valuable discussion of the factors that affect nutrient concentration in plants. One of the important aspects of nutrient uptake was that with the continued addition of a limiting nutrient to the supporting medium, its uptake unlike its concentration continuously increased over that part of its range where plant yield increased.

Research done on the influence of nitrogen on phosphorus uptake showed that an increase in nitrogen status of maize and _Pinus radiata_ seedlings caused an increase in the respiration rate and thus created a demand for phosphorus (36, 59).

Cheng and Kurtz (16) employing the N^{15} tracer technique observed that over 90 percent of the added nitrogen in the soils studied was found in the hydrolytic products of soil organic matter.

Reid (48) found that K fertilization had relatively little effect on the plant yields of nitrogen from the A and C horizons of the two soils studied. The application of lime depressed the nitrogen yields from the A horizon in which the clay content was lower than 16 percent. On the other hand, lime tended to increase the yield of nitrogen from the A horizon of the other soil which had a clay content of over 20 percent. The addition of fertilizer containing nitrogen increased the dry weight of plants (31, 66). Voight (67) pointed out that nitrogen losses as gaseous nitrogen or conversion to refractory compounds were stimulated by the presence of Ca. Nitrogen losses were also found to be a function of the level of nitrogen present.

Heilman and Gessel (26) found a decrease in phosphorus and potassium concentration with nitrogen fertilization. This was attributed to a dilution effect which resulted from an increased foliage production by the nitrogen treatments (65). Tamm (61) and later Leyton (37) attributed the severe phosphorus reduction to an antagonism between nitrogen and phosphorus. Nitrogen alone or in combination with phosphorus increased the basal area growth of some forest trees (13, 14, 20).

In addition to the amount of nitrogen and organic matter on the forest floor, considerable quantities of calcium, phosphorus and potassium are held in the organic form (38). Research done on calcium absorption by plants showed that the fastest rate of growth was obtained with an increase in both pH and available calcium (3, 39, 71). A general increase in soil pH increased leaf calcium, magnesium and phosphorus and decreased leaf K.

Kalra _et al_ (34), studying the calcium concentration in potato plants, found that its concentration in plants was affected by potassium, since a high percentage of potassium was observed at the lowest level of calcium in tops and roots. The tubers had a small percentage of calcium irrespective of its concentration in the tops. This fact was explained by some other researchers who showed that calcium was immobile and was fixed in the tissue as a cell wall material, and thus was difficult to translocate to the tubers (10, 34, 50).

Allaway and later Stanford (1, 55) concluded that the poor growth of corn was mainly related to low absorption of potassium by the plants which was due to an unfavorable balance between cation within the plants as well as in the soil.

MATERIALS AND METHODS

The soil used in this experiment was obtained from a pit in Northern Washington County, Maine. The site has not been surveyed by the Soil Conservation Service. However, based on profile characteristics, it was found to be similar to the Plaisted gravelly loam soil described in the Penobscot County Soil Survey Manual (64).

After close examination of the profile, it was concluded that even though O1, O2, A1, A2, B21, B22, B3 and C horizons could be identified, some of the horizons were present in amounts insufficient for sampling. This being the case, the decision was made that samples for this study would be taken from the O, B21, B22, B3 and C horizons.

The O horizon was made up of the undecomposed and partially decomposed organic matter overlying the mineral part of the profile. At this location it was about 5 cm thick.

The B21 horizon was 17 cm thick, strong brown in color, gravelly loam in texture and very friable. There was evidence of considerable root development in this horizon.

The B22 horizon was 30 cm thick, yellowish brown in color, gravelly sandy loam in texture and very friable. There was some evidence of roots but not to the extent noted in the B21 horizon.

The B3 horizon was about 50 cm thick, light olive brown in color, gravelly sandy loam in texture and very firm in place (fragipan). There were no roots growing in this horizon.

The C horizon was more than 50 cm thick, light gray in color, gravelly loamy sand in texture and very friable. Due to the firm layer (B3), no roots were found in this horizon.

Bulk soil samples were taken from each horizon, brought to the greenhouse, air dried, and screened through a 5 mm screen. The screened soil was placed in 6 inch plastic pots with holes which in turn were supported by 6 inch standard pots without holes.

The amount of soil that was placed in each pot was measured on a volume basis and was equivalent to 2280 ml of soil. The use of volume rather than weight was necessitated by the low density of the O horizon when compared to the other horizons. The pots were divided into two large blocks: one with white spruce seedlings and the other without seedlings.

In each of the large blocks, the 5 horizons made up the five main treatments. Each main treatment was subdivided by lime and no lime treatments. The lime was applied at a rate equivalent to 4000 kg per hectare which resulted in the mixing of 4.56 g of lime per pot. The lime was mixed thoroughly with the total amount of soil in the individual pots.

The 10 treatments (5 horizon x lime and no lime) were set up in a randomized complete block design with six replications.

Fifty pregerminated seeds of white spruce, Picea glauca (Moench) Voss, were planted in each pot of one large block. One week after planting the seedlings, the survival was checked and dead seedlings were replaced.

Water was added to all pots when needed. Need was determined visually. When water was added, the amount exceeded field capacity and the excess water drained into the pots without holes. This water was used in subsequent waterings. By following this procedure, no material was lost by leaching but instead was continually recycled.

All of the pots in the experiment were exposed to temperatures that ranged from 22° to 28° C. Day length was held constant at 16 hours during the six months of the study.

At the start of the experiment a composite soil sample was taken from each horizon. These samples were air dried and stored for analysis.

The soil in the pots with no plants was sampled at the end of 12 weeks to measure the breakdown of organic matter and the difference in elemental composition of each horizon. The samples were kept frozen to avoid any changes during the storage period. The soil in these pots was also sampled at the end of 24 weeks.

The soil in the pots with plants was sampled only at the end of 24 weeks which was the termination date of the experiment. All of the samples were placed in plastic bottles and immediately taken to a freezer where they were kept until the analyses were done. The soil for each analysis was weighed out just prior to testing and the remaining soil was immediately brought back to the freezer to be stored for subsequent analyses.

The plants were harvested at the end of 24 weeks and the fresh and dry weight of roots and tops recorded separately. To dry the plant material, it was placed in a drying room with a temperature of approximately 75° C. The dried material was weighed, grounded and stored for analysis.

The plant material was analysed for total N by the micro Kjeldahl procedure (44); phosphorus by acid soluble method (33); potassium, calcium and magnesium by atomic absorption (32).

The soil samples were analysed for total N (44) and exchangeable K, Ca and Mg (32). Phosphorus in the soil was determined by the dilute hydrochloric acid and sulfuric acid method (45). The percent organic matter was determined by ignition and Walkley-Black methods (68). In the ignition method the soil samples were burned in a furnace at 550° C during an 8-hour period. For the O horizon a modification was made in the Walkley-Black procedure; i.e., a 500 mg sample was used with 20 ml of potassium dicromate solution.

The amount of concentrated sulfuric acid added to complete the oxidation process was the same for all samples - 25 ml.

Other analyses made on the soil samples were pH and cation exchange capacity (32). The pH was determined in a 2:1 water to soil mixture and was measured after standing for 12 hours. The pH was also determined in 1 normal KCl.

All the soil and plant analyses were expressed on a dry weight basis.

The data collected were submitted to statistical analysis. Significance was measured by Duncan's New Multiple Range Test (56).

RESULTS

The results obtained in this study are presented in two parts:

I. Study of the soil profile

II. Influence of different soil horizons on the growth of white spruce seedlings

I. Study of the soil profile.

As a point of reference for the various analyses made on the soil samples collected during the experiment, the data on the composite sample taken from each soil horizon at the start of the project is presented in Table 1.

The percentage of organic matter, as determined by the Walkley-Black method, was greatest in the O horizon which corresponded to a depth of 5 cm. The amount of organic matter decreased rapidly with increased depth beyond this point.

Data in Tables 2 and 3 summarizes the concentration of the organic matter in the 5 horizons studied at the end of the study. From the data it is evident that the O horizon contained significantly more organic matter than any of the other horizons when measured by either the ignition or Walkley-Black method. The concentration of organic matter in the B21 horizon was significantly

Table 1. Composition of the soil at the beginning of the experiment.

Horizons	pH		OM	CEC	Ca	Mg	K	Na	P	B.S
	H_2O	KCl	(%)	(me/100g)	(me/100g)	(me/100g)	(me/100g)	(me/100g)	ppm	(%)
O	4.0	3.9	61.14	56.50	11.46	2.367	1.445	0.565	33.26	28.01
B21	5.7	4.5	7.09	17.60	0.23	0.068	0.069	0.406	6.22	4.37
B22	6.0	4.5	1.31	5.58	0.12	0.033	0.068	0.274	38.38	8.88
B3	5.7	4.5	0.93	4.28	0.10	0.029	0.036	0.236	75.96	9.37
C	5.8	4.6	0.27	2.51	0.15	0.033	0.026	0.262	52.96	18.74

w = Each observation represents a single determination on a combined sample.

higher than the B22, B3 and C horizons, which were at a par with each other.

The effect of applying lime to the various horizons is also shown in Tables 2 and 3. A significant effect of lime was observed mainly on the total organic matter concentration of the O horizon. There was a significant increase in the total organic matter concentration of the O horizon with plants and without plants when comparing the application of 4000 kg of lime per hectare with no lime. The readily oxidizable organic matter showed a significant increase with the application of lime to the O horizon of the soil without plants, while no effect was observed on the O horizon of the soil with plants.

Table 2. Relationship of soil horizons and two levels of lime to the concentration of readily oxidizable organic matter.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Organic matter in soil without plants		Organic matter in soil with plants	
		%		
O	53.67 b[w]	64.11 a	61.98 a	62.84 a
B21	6.93 c	6.36 c	6.24 c	7.09 c
B22	2.28 d	2.25 d	2.39 d	2.44 d
B3	1.00 d	0.87 d	0.93 d	1.12 d
C	0.54 d	0.59 d	0.76 d	0.69 d

w = Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's New Multiple Range Test.

Likewise, no effect of the lime treatment was observed in the mineral horizons for either readily oxidizable or total organic matter.

Table 3. Relationship of soil horizons and two levels of lime to the concentration of total organic matter.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Organic matter in soil without plants		Organic matter in soil with plants	
	%			
O	59.01 c[w]	62.40 b	63.78 b	67.40 a
B21	7.89 d	7.87 d	8.26 d	8.40 d
B22	3.22 e	3.21 e	3.31 e	3.42 e
B3	1.66 e	1.60 e	1.58 e	1.81 e
C	0.74 e	0.82 e	0.88 e	0.95 e

w = Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's New Multiple Range Test.

The readily oxidizable organic matter when expressed as a percentage of the total organic matter was highest in the O horizon. The percent was as high as 97.17 in this horizon with plants and as low as 90.95 without plants, when lime was not considered. For the mineral soil the percentage of the total organic matter which was readily oxidizable varied from a high of 87.83 percent in the B21 horizon of the soil without plants to a low of 58.86 percent in the B3 horizon of the soil with plants.

The data summarized in Tables 4 and 5 shows the total-N and dilute acid soluble P concentration in each of the horizons studied. It shows that the total-N unlike the P is dependent upon the amount of organic matter present.

The total-N was found to be higher in the O and B21 horizons which were significantly different from each other and from the lower mineral soil horizons. The B22, B3 and C horizons did not show any significant difference among themselves.

Table 4. Effect of soil horizons and two levels of lime on total nitrogen concentration.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Total N in soil without plants		Total N in soil with plants	
	mg/100g			
O	944.96 c[w]	1084.87 a	1013.54 b	974.00 bc
B21	134.93 d	132.19 d	124.43 d	119.73 d
B22	38.20 e	38.64 e	37.04 e	38.62 e
B3	27.32 e	22.74 e	23.56 e	21.29 e
C	11.00 e	8.37 e	6.36 e	6.96 ce

w = Means followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The concentration of acid soluble P as shown in Table 5 was significantly greater in the O horizon of the experiment without plants than in any other horizon.

For the mineral horizons there was a remarkable increase in P concentration with an increase in depth. In this soil situation the C horizon showed the highest P concentration which was significantly different from the other mineral horizons. The P concentration in the B21 and B22 horizons were at a par in the experiment without plants. For the experiment with plants the B3 horizon showed the highest P concentration which was significantly different from the other horizons. The B22 and O horizons were at a par but were significantly different from the C horizon. The B21 horizon showed the lowest P concentration of all the horizons.

Table 5. Effect of soil horizons and two levels of lime on dilute acid soluble phosphorus concentration.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	P concentration of soil without plants		P concentration of soil with plants	
	ppm			
O	101.48 b[w]	130.30 a	43.21 e	47.12 de
B21	8.03 g	7.54 g	6.85 g	5.70 g
B2	5.80 g	4.30 g	50.39 de	46.28 de
B3	53.31 d	49.00 de	80.19 c	74.32 c
C	73.58 c	72.45 c	27.53 f	20.91 f

w = Means followed by the same letters are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The effect of lime on total-N and dilute acid soluble P concentration is also shown in Tables 4 and 5. It appears that there was a significant increase in concentration of the two elements in the O horizon of the experiment without plants when 4000 kg of lime per hectare was added. In the experiment with plants no effect of lime was observed on the concentration of N and P in any of the horizons studied.

Tables 6, 7, 8 and 9 summarize the concentration of exchangeable bases in the 5 horizons studied without and with plants and with two levels of lime.

Table 6. Effect of soil horizons and two levels of lime on exchangeable potassium concentration.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Exchangeable K in soil without plants		Exchangeable K in soil with plants	
	me/100g			
O	1.039 a[w]	1.006 a	0.821 b	0.712 c
B21	0.105 d	0.100 d	0.091 d	0.092 d
B22	0.081 d	0.079 d	0.071 d	0.074 d
B3	0.046 d	0.056 d	0.045 d	0.054 d
C	0.042 d	0.054 d	0.035 d	0.050 d

w = Means followed by the same letters are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

Table 7. Effect of soil horizons and two levels of lime on exchangeable calcium concentration.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Exchangeable Ca in soil without plants		Exchangeable Ca in soil with plants	
	me/100g			
0	14.809 c[w]	27.565 a	13.555 d	24.538 b
B21	0.246 hi	2.744 ef	0.217 hi	3.005 e
B22	0.126 i	1.604 fg	0.112 i	1.832 efg
B3	0.077 i	1.461 fgh	0.076 i	1.521 fgh
C	0.069 i	1.003 ghi	0.066 i	1.042 ghi

w = Means followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The potassium concentration (Table 6) was significantly greater in the O horizon and decreased with soil depth. The statistical analysis, however, did not show any significant difference in K concentration among the mineral soil horizons. The soil with plants showed a significant decrease in K concentration in the O horizon as compared to the soil without plants.

The concentration of Ca, Mg and Na (Tables 7, 8 and 9) followed almost the same pattern as that noted for K, showing the highest value in O horizon which differed significantly from the mineral soil horizons. The Ca concentration of the B21 horizon was at a par with that of the B22, B3 and C horizons for either experiment without an with plants at zero level of lime. When 4000 kg of lime per hectare were added, the B21 was different from the C horizon while the B22, B3 and C horizons did not differ statistically. The data for Mg concentration showed no significant differences among the mineral soil horizons at zero level of lime for the soil without plants and with plants. The concentration of Na did not show any significant difference among the mineral soil horizons studied.

Considering the effect of growing plants in the different soil horizons on the concentration of K, Ca, Mg and Na, it was observed that a significant decrease occurred in the concentration of K, Ca and Na in the O horizon as a result of growing spruce seedlings. No difference was observed in the Mg concentration.

Table 8. Effect of soil horizons and two levels of lime on exchangeable magnesium concentration.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Exchangeable Mg in soil without plants		Exchangeable Mg in soil with plants	
	me/100g			
O	2.177 b[w]	11.212 a	2.419 b	11.428 a
B21	0.044 e	1.444 cd	0.038 e	1.867 bc
B22	0.047 e	0.661 de	0.050 e	0.914 d
B3	0.019 e	0.377 de	0.024 e	0.463 de
C	0.016 e	0.162 de	0.017 e	0.189 e

w = Means followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

Table 9. Effect of soil horizons and two levels of lime on exchangeable sodium concentration.

Horizons	Lime (kg/ha) 0	4000	0	4000
	Exchangeable Na in soil without plants		Exchangeable Na in soil with plants	
	me/100g			
0	1.02 a[w]	1.03 a	0.89 b	0.90 b
B21	0.27 cd	0.26 cd	0.21 cde	0.23 cde
B22	0.25 cde	0.24 cde	0.22 cde	0.22 cde
B3	0.22 cde	0.22 cde	0.21 cde	0.18 e
C	0.21 cde	0.21 cde	0.19 de	0.18 e

w = Means followed by the same letter are not significantly different at 5% of probability according to Duncan's New Multiple Range Test.

The effect of lime on exchangeable bases K, Ca, Mg and Na is shown also in Tables 6, 7, 8 and 9. There was a significant increase in the amount of Ca and Mg when lime was added. Only the C horizon failed to show a significant change with the application of lime in the concentration of Ca. In the soil without plants, the lime effect on the Mg concentration was significantly different in 0 and B21 horizons while no significant difference was observed in the B22, B3 and C horizons. No lime effect was observed on the concentration of K in the experiment without plants. However, a significant decrease in the concentration of K was observed in the 0 horizon with the application of lime in the experiment with plants. No significant effect on the concentration of Na was observed as a result of the lime application.

The cation exchange capacity seemed dependent on the amount of organic matter in the soil horizon. The highest value as shown in Table 10 was found in the O horizon with a significant decrease in the lower horizons as the organic matter decreased. In the mineral soil horizons, the B21 had a significantly higher cation exchange capacity than the B22, B3 and C horizons.

Table 10. Effect of soil horizons and two levels of lime on cation exchange capacity.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	CEC of soil without plants		CEC of soil with plants	
	me/100g			
O	84.70 c[w]	103.01 a	91.99 b	98.64 a
B21	14.90 d	15.28 d	13.90 d	15.03 d
B22	6.47 e	7.23 e	6.45 e	6.68 e
B3	4.65 e	4.83 e	5.24 e	4.67 e
C	3.04 e	2.94 e	3.04 e	3.49 e

w = Means followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The effect of lime on the cation exchange capacity is shown in Table 10. It shows difference only in the O horizon of the experiments conducted.

Data summarized in Table 11 show the pH values of the various soil horizons. They indicate that there was a significant increase in pH with increasing depth. The highest pH in H_2O was usually obtained in the C and B3 horizons. A low pH value was obtained in the organic matter layer regardless of the method used for the pH determination. The highest pH value was obtained in the C horizon which was significantly different from the other horizons in either soil without plants and with plants at any level of lime application. From Table 11 it is also possible to observe the effect of the addition of 4000 kg of lime on the pH values of the soil horizons studied. The lime treatment increased the pH values.

The time of sampling showed practically no effect on the composition of the different soil horizons studied. Only the O horizon showed significant increases in the concentration of P and K at the second time of sampling. No difference was observed in the N concentration and the cation exchange capacity at either of the sampling dates. The Na concentration showed a significant decrease in all the horizons studied at the second sampling date while the concentration of organic matter, Ca and Mg decreased significantly only in the O horizon.

Table 11. Effect of soil horizons and two levels of lime on the pH of the soil.

Horizons	pH (H$_2$O) Soil without plants, Lime 0 (kg/ha)	pH (H$_2$O) Soil without plants, Lime 4000 (kg/ha)	pH (H$_2$O) Soil with plants, Lime 0 (kg/ha)	pH (H$_2$O) Soil with plants, Lime 4000 (kg/ha)	pH (KCl) Soil without plants, Lime 0 (kg/ha)	pH (KCl) Soil without plants, Lime 4000 (kg/ha)	pH (KCl) Soil with plants, Lime 0 (kg/ha)	pH (KCl) Soil with plants, Lime 4000 (kg/ha)
O	4.7 e[w]	4.7 e	4.6 e	4.7 e	4.1 i	4.5 f	4.1 i	4.3 h
B21	5.6 cd	5.6 cd	5.4 d	5.7 cd	4.4 fgh	5.1 d	4.3 gh	5.1 d
B22	5.7 cd	5.8 cd	5.6 cd	5.9 bc	4.4 fgh	5.3 c	4.4 fgh	5.2 c
B3	5.8 c	6.1 ab	5.5 d	6.3 a	4.5 f	5.7 b	4.4 fg	5.6 b
C	5.7 cd	6.3 a	5.6 cd	6.3 a	4.7 e	5.9 a	4.6 e	5.9 a

w = Means within four columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

EMBRAPA – IPEAN
BIBLIOTECA
BELEM – PARÁ

II. Influence of different soil horizons on the growth of white spruce seedlings.

The data for fresh and dry weights of tops and roots are summarized in Tables 12 and 13. The data show significant differences in fresh and dry weight of tops and roots between the horizons. The O horizon produced the most growth and was significantly greater than any of the other horizons. In the mineral soil the amount of growth produced in B21 differed from B22, B3 and C horizons which were the same (Table 13).

Table 12. Effect of soil horizons and two levels of lime on the fresh weight of roots and tops of white spruce.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Fresh weight of roots		Fresh weight of tops	
	g/50 plants			
O	6.73 b[w]	9.94 a	6.21 b	8.85 a
B21	4.36 c	3.36 cd	1.39 c	1.62 c
B22	1.54 e	1.74 e	0.94 c	0.86 c
B3	1.32 e	1.39 e	0.93 c	0.82 c
C	2.42 de	2.16 e	1.03 c	0.95 c

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

Table 13. Effect of soil horizons and two levels of lime on the dry weight of roots and tops of white spruce.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Dry weight of roots		Dry weight of tops	
	g/50 plants			
0	1.437 b^{w}	1.869 a	2.397 b	3.332 a
B21	0.965 c	0.643 d	0.584 cd	0.692 c
B22	0.479 e	0.402 e	0.431 d	0.370 d
B3	0.363 e	0.334 e	0.362 d	0.351 d
C	0.461 e	0.476 e	0.412 d	0.396 d

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

Lime increased the fresh and dry weight of tops and roots in the O horizon as is shown in Tables 12 and 13. No signifncant effect was observed on growth of tops or roots of the white spruce grown in any of the other horizons as a result of the application of lime.

The results of the chemical analyses of roots and tops of white spruce are summarized in Tables 14, 15, 16 and 17. These tables show the composition of the plants in terms of N, P, K, Ca and Mg.

The total N in tops and roots was considerably higher for the O horizon and was significantly different from the B21 horizon. The B21 horizon showed a significant difference from B22, B3 and C horizons. The C horizon showed the lowest N concentration in tops and roots when 4000 kg of lime per hectare was applied (Tables 14 and 15).

It is also apparent in Tables 14 and 15 that the concentration of P in both the tops and the roots reached its highest value in the O horizon. The P concentration of the plants growing in the B3 was significantly greater than in B21 and B22 horizons and statistically equal to C horizon when lime was not applied.

The K concentration, as with N and P, showed its highest concentration in the plants grown in the O horizon (Tables 14 and 15). The B22 and B3 horizons produced the lowest K concentration in tops and roots. These values were significantly different from the ones obtained for the other horizons.

The concentration of Ca in the tops and roots (Tables 16 and 17) were inversely related to the amount of organic matter present in the soil. There was a considerable decrease of Ca in the plants as the percent of organic matter increased in the soil. The C horizon showed the highest value for Ca in tops and roots and differed significantly from the other horizons, when lime was applied. The Ca concentrations of roots in the B3 horizon were significantly different from those in the B22 which were in turn significantly different from those in B21 and O horizons, the latter being statistically the same with lime treatment. For the tops there was a statistical equality between B3 and B22 which differed significantly from B21.

Table 14. Effect of soil horizons and two levels of lime on N, P and K concentration of tops of white spruce.

Horizons	Lime (kg/ha)					
	0	4000	0	4000	0	4000
	Nitrogen		Phosphorus		Potassium	
	mg/100g					
O	3486.1 a^{w}	2888.3 b	223.7 a	227.5 a	1016.6 b	1270.8 a
B21	1640.8 d	2119.7 c	47.2 e	102.7 c	970.8 b	837.5 c
B22	710.6 f	1055.2 e	38.0 e	124.8 b	537.5 d	550.0 d
B3	780.7 f	1088.8 e	86.0 cd	215.2 a	612.5 d	616.6 d
C	713.6 f	750.2 f	71.9 d	80.2 cd	791.6 c	841.6 c

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

Table 15. Effect of soil horizons and two levels of lime on the N, P and K concentration of roots of white spruce.

Horizons	Lime (kg/ha) 0	4000	0	4000	0	4000
	Nitrogen		Phosphorus		Potassium	
	mg/100g					
O	3120.1 a[w]	2818.1 b	188.3 b	203.5 a	1087.5 b	1325.0 a
B21	975.9 d	1521.9 c	14.8 f	49.8 de	875.0 cd	1200.0 ab
B22	570.3 f	695.3 ef	21.1 f	55.4 d	558.3 e	733.3 ce
B3	597.7 f	753.3 e	43.0 de	87.7 c	608.3 e	737.5 ce
C	561.1 f	573.3 f	38.3 e	49.1 de	883.3 c	675.0 de

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The O horizon showed the lowest value which was significantly different from the values obtained for the mineral soil. The statistical analyses did not show any difference in concentration of Ca in roots among the horizons at zero level of lime.

Table 16. Effect of soil horizons and two levels of lime on the Ca and Mg concentration on tops of white spruce.

Horizons	Lime (kg/ha) 0	4000	0	4000
	Calcium		Magnesium	
	mg/100g			
O	441.6 f[w]	595.8 e	279.1 gh	416.6 d
B21	716.6 e	1575.0 c	244.1 h	716.6 a
B22	937.5 d	1879.1 b	354.1 ef	583.3 c
B3	983.3 d	1987.5 b	387.5 de	662.5 b
C	700.0 e	3200.0 a	325.0 fg	404.1 de

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The Mg concentration in the roots was highest for the B3 horizon which was at a par with B22 but different from the other horizons (Table 17). The B22 and C horizons produced equal Mg concentrations in the roots and significantly different from B21. The Mg concentration in the tops showed that the B21 horizon was equal to O horizon for the zero level of lime.

Table 17. Effect of soil horizons and two levels of lime on Ca and Mg concentration on roots of white spruce.

	Lime (kg/ha)			
	0	4000	0	4000
Horizons	Calcium		Magnesium	
	mg/100g			
0	268.3 de[w]	375.0 d	87.5 f	210.0 de
B21	208.3 e	489.1 d	95.8 f	280.8 c
B22	246.6 de	644.9 c	218.3 de	391.6 ab
B3	211.6 e	1033.3 b	257.5 cd	437.5 a
C	274.1 de	1626.6 a	200.0 e	354.1 b

w = Means within two columns followed by the same letter are not significantly different at 5% level of probability according to Duncan's New Multiple Range Test.

The effect of lime was found to be significant on the concentration of N, P, Ca and Mg in the tops and roots of white spruce seedlings. The data summarized in Tables 14, 15, 16 and 17 show the effect of lime on the concentration of those nutrients determined in the tops and roots of white spruce. It shows a significant increase in N concentration of tops and roots of plants growing in the mineral soil horizons when lime was applied. An exception was noted for the C horizon which did not show any effect on the N concentration and the O horizon showed a decrease in N concentration.

The concentration of P in the tops and roots was significantly increased by the application of 4000 kg of lime per hectare to the B21, B22 and B3 horizons. The C and O horizons did not show any effect of lime on the P concentration of tops of white spruce. The Ca and Mg concentration increased in tops and roots with the application of lime in all of the horizons studied.

The K concentration did not seem to have been affected by the lime treatment since the O horizon was the only one that showed a significant increase in K concentration of tops and roots. The data for the rest of the soil horizon showed only a significant decrease in tops produced on the B21. The roots showed a significant increase in K concentration.

DISCUSSION

The results of the analyses for the 5 soil horizons studied showed that the concentration of organic matter decreased rapidly with depth as was expected (6, 7, 11, 12, 38, 40, 42, 54, 58, 62, 74). The conditions under which this soil was formed, forest vegetation and a humid climate, usually results in an appreciable organic matter accumulation as 01 and 02 horizons.

Since tree growth is largely dependent on the nutrients native to the site, the organic matter becomes one of the primary sources of plant nutrients. Actually in this study, the organic matter proved to be the main source of nutrients in the soil and the main factor responsible for growth since the concentration of N and exchangeable bases in each of the horizons decreased with the decrease in the organic matter content (9, 17).

The relatively high concentration of N and bases in the horizon immediately below the O horizon could be attributed to the recycling of these elements through leaf fall, decay and reabsorption before effective removal by leaching (38).

The organic litter that accumulates under softwood trees produces a strongly acid reaction (25, 38, 62). This characteristic was confirmed by the results obtained in this study which showed the pH (KCl) of the

O horizon to range from 4.1 to a maximum of 4.5 when treated with 4000 kg of lime per hectare (Table 11). The absence of a continuous A2 horizon resulted in the development of a B21 horizon immediately below the organic horizon. This horizon also showed strong acid reaction ranging in pH (KCl) from a low of 4.3 on the unlimed soil with plants to a maximum of 5.1 on a limed soil without plants. The acidity in the B21 can be explained by the fact that some of the acid organic matter filtered into the B21 from the O horizon.

Studies have been reported that prove the rate of decomposition of organic matter to be greatly limited by low N and an inadequate supply of Ca in acid soils (17, 19, 25, 38, 53, 62). Many workers have pointed out that organic debris decomposed more rapidly in soils rich in lime than in those poor in lime (38). The lime application favoring the conditions of microorganisms activity decomposed the organic debris, increasing the N and available nutrients in the organic layer (28). The organic matter as an N source was also indicated by the linear correlation ($r = 0.92$ at $P > 0.01$) as shown in Fig 1.

Research done on the cation exchange capacity of soil profiles has shown a high relationship of the cation exchange capacity with clay content (19, 35, 41). Others have pointed out that the organic matter was the main factor that contributed to the variation in the total cation exchange capacity within the profile (63, 71, 72,

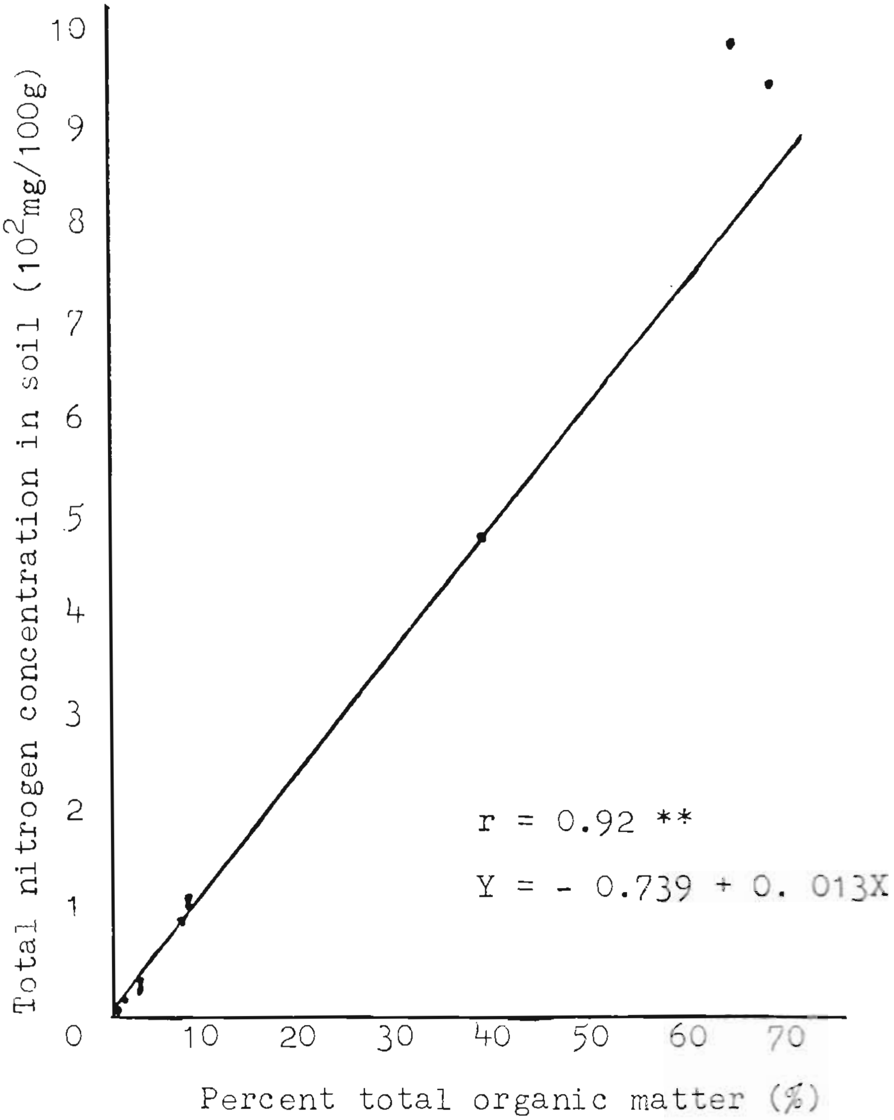

Fig. 1. Relationship of total nitrogen to the percent total organic matter in the soil horizons

73). The present work showed that the cation exchange capacity of the forest soil profile was almost totally dependent on the organic matter in each horizon. This was verified by a correlation coefficient of $r= 0.99$ $P>0.01$.

The percent base saturation of 22.33 percent found in the O horizon was relatively high in comparison to 12.8 percent, the highest obtained in the mineral soil horizons as shown in Table 18. A remarkable increase of percent base saturation was observed for the B21 downward to the C horizon. However, the percent base saturation is very low compared to the ones obtained in some earlier works with agricultural soils which showed increased growth of plants with the increase in base saturation from 20 to 40 or 75 percent depending on the clay mineral present (18, 22, 46).

Table 18. Effect of soil horizons and two levels of lime on the percentage base saturation.

Horizons	Lime (kg/ha)			
	0	4000	0	4000
	Base saturation of soil without plants		Base saturation of soil with plants	
	%			
O	22.33	43.39	19.22	38.10
B21	4.98	30.55	4.05	34.56
B22	8.61	38.23	7.08	45.50
B3	9.82	46.45	6.85	47.60
C	12.80	56.10	10.36	42.00

The lime treatment increased the percent base saturation which was associated with the increase of Ca and Mg concentrations since no increase was observed in K and Na concentrations (Tables 6, 7, 8 and 9).

Analyses show that the B21 and B22 horizons, without plants, contained the lowest concentrations of acid soluble phosphorus of the horizons studied. The low P concentrations can be explained by weathering and subsequent leaching and plant removal of P. The tendency for the P concentration to increase in the B3 and C horizons is due to lower intensity of weathering in these horizons.

The spruce seedlings in this experiment produced very little growth in the mineral soil. However, a significantly greater amount of dry matter was produced by the O horizon. The B21 horizon produced the highest amount of dry matter in the mineral soil horizons. This was expected since the chemical analyses of the O and B21 horizons showed a higher nutrient concentration and organic matter content than the other horizons.

The concentration of nutrients in the plant tissue of spruce seedlings, both tops and roots, showed a trend similar to the concentration of nutrients in the soil (Tables 14, 15, 16, 17). The exception to this generalization was for Ca and Mg concentration where the concentration increased in tops and roots as the amount of organic matter and consequently the N decreased in the soil horizons (Tables 16, 17).

Nitrogen was reported to increase the Ca level in the foliage of apple trees (13, 15, 69). Others have found a negative interaction between N and Ca in the foliage of apple trees (21). The results obtained in the present work showed an increase in Ca concentration in tops and roots with a decrease of N in the soil. However, this apparent negative interaction between Ca concentration in plants and N concentration in soil was not found when the total uptake of Ca and N was considered, since both Ca and N uptake decreased with an increase in soil depth (24, 51).

The difference in concentration of Ca between tops and roots could probably be explained by the work of Rinne and Langston (50). They indicated that the redistribution of Ca in the plant is in an upward direction. On the other hand, Biddulph _et_ _al_ (10), indicated that Ca is the most immobile of all the essential elements. Once delivered to a particular organ, it cannot circulate.

Ingestad (30) reported that the absolute requirement of Norway spruce with respect to the nutrients in the foliage for maximum growth is in the order of N>K>P>Mg>Ca and that a reduction of growth would occur if the N concentration of the foliage were not close to the optimum (1.50 - 2.30% N). For white spruce the levels of N, P and K in the foliage for optimum growth according to Armson (5) were 2.3 % N, 0.35 % P and 0.97 % K on a dry weight basis. In the present research only the O horizon filled the requirements of optimum concentration of N and K in the foliage (Table 14). Although the P level in plants was below the reported level of 0.35 % in the O horizon, the higher concentration of N, K and P could probably explain the greater growth in this horizon than in the mineral soil. The B21 horizon showed concentration of N and K closer to the reported levels required and the growth obtained was significantly higher than the growth produced by the B22, B3 and C horizons. In those horizons where the growth was practically nil, the N content in the plants was lower than the Ca and K contents in contrast with the higher N content of plants in O and B21 horizons. The results of the analyses for the mineral soil was also in agreement with the ones found by Armson, Alonso, Talli and others (2, 4, 47, 60).

From these results and the linear correlation between the soil N and growth of plants (Table 19, Fig 2), it is possible to conclude that the N was the main nutrient in promoting growth of the white spruce.

Growth was also dependent on the organic matter in the soil as shown by the correlation coefficients obtained as shown in Table 19.

Table 19. Correlation coefficients relating tree performance and nitrogen concentration and organic matter of the 5 soil horizons.

Tree performance	Organic matter	Nitrogen
	r	
Fresh weight		
tops	0.95 **	0.93 **
roots	0.80 **	0.78 **
Dry weight		
tops	0.91 **	0.90 **
roots	0.87 **	0.86 **

** P > 0.01

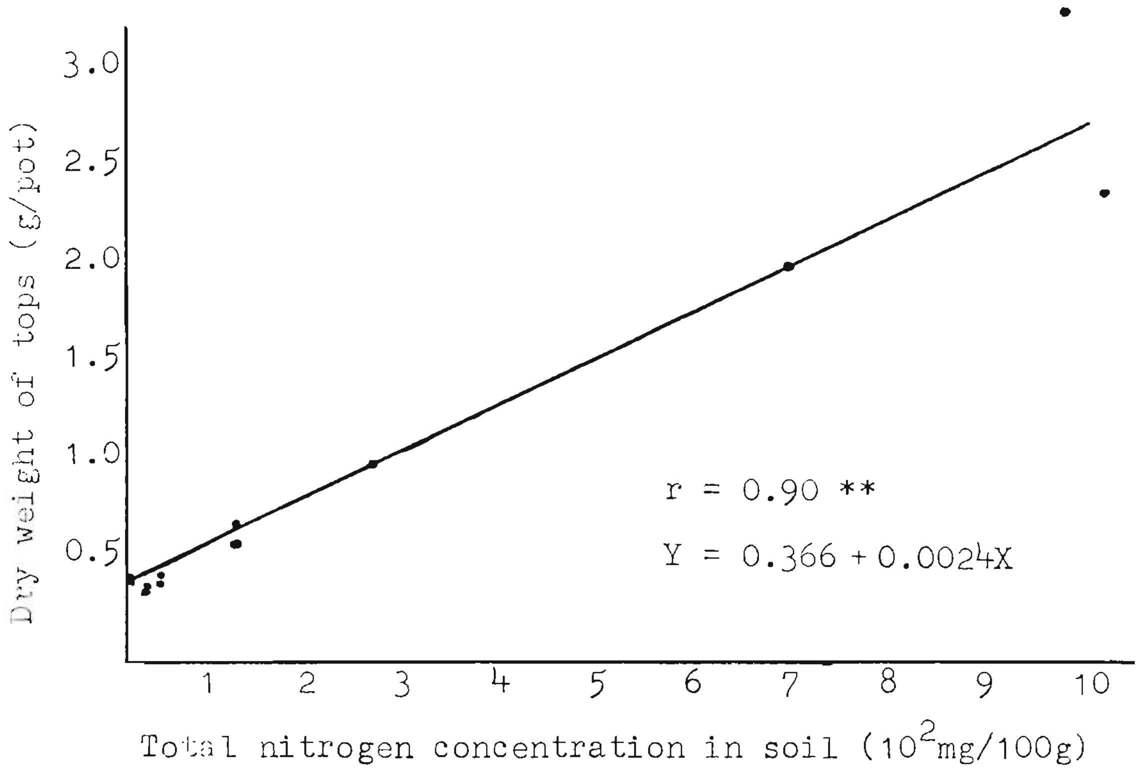

Fig. 2. Relationship of dry weight of tops of white spruce seedlings to the nitrogen concentration in the soil horizons

SUMMARY AND CONCLUSIONS

An experiment was designed to determine the effect of 5 forest soil horizons on the growth of *Picea glauca* (Moench) Voss and to evaluate the contribution of each horizon and two levels of lime in the rate of organic matter decomposition and availability of nutrients.

The growth of spruce measured by the fresh and dry weight was affected considerably by the percent organic matter in the soil. The concentration of nutrients in tops and roots was closely related to the concentration of nutrients in the soil with the exception of Ca and Mg concentration. These two elements showed concentrations that were higher in tops and roots of white spruce grown in low horizons. This, however, was associated with a decrease in growth. The organic matter was probably the most significant factor for growth of *Picea glauca* and the increase in mineral composition of the soil profile (9, 17).

The concentration of all elements analysed for, except P, decreased as the organic matter concentration decreased. The amount of organic matter in the individual horizons decreased with profile depth. A linear correlation was obtained between organic matter and plant growth.

Linear correlations were also obtained between soil organic matter and cation exchange capacity, and organic matter and N. This showed organic matter to be the main source of N. The N present in the horizon correlated with plant growth.

An effect of lime was observed only in the O horizon. In the pots with no plants there was an increase in mineral concentration which was associated with an increase of the organic debris decomposition. In the pots with plants there was no effect or a decrease in mineral composition for the O horizon which was related with absorption by the plants. An effect of lime in the mineral soil was observed only for the concentration of Ca and Mg which increased with the application of 4000 kg of lime per hectare.

The N concentration in the tops and the roots decreased significantly for the O horizon with the application of lime.

LITERATURE CITED

1. Allaway, Hubert, and W. H. Pierre. 1939. Availability, fixation and liberation of potassium in high-lime soils. J. Amer. Soc. Agron. 31:940-953.

2. Alonso, E. S.. 1972. Effect of Nitrogen on growth of Picea glauca (Moench) Voss., and on the soil nitrogen composition. M.S. thesis. University of Maine at Orono, 51 pp..

3. Anderson, Carl A., and Frank G. Martin. 1969. Effects of soil pH and calcium on the growth and mineral uptake of young citrus trees. Biological abstracts, 51:abstract number 133031.

4. Armson, K. A.. 1963. The effects of levels and times of fertilizer application on the growth of white spruce seedlings. Soil Sci. Soc. Amer. Proc. 27: 596-597.

5. Armson, K. and Carman. 1961. A manual for Forest Nursery Soil Management Ontario Dept. of Lands and Forest. Toronto Original not seen. Cited by A. R. Talli in growth and nutrition of Picea glauca Ph.D. Thesis, 1966.

6. Bachtell, M. A., C. J. Willard and G. S. Taylor. 1956. Building fertility in exposed subsoils. Ohio Agricultural Experiment Station Bull. 782., 35 pp..

7. Bailey, H. H., and P. E. Avers. 1971. Classification and composition of soils from Mountain colluvium in Eastern Kentucky and their importance for forestry. Soil Sci. 111:244-251.

8. Bear, F. E..(Editor). 1964. Chemistry of the soil. 2nd ed. Van Nostrand Reinhold Company. New York, N.Y.. 515 pp..

9. Beckwith, R. S.. 1963. Chemical extraction of nutrients in soils and uptake by plants. Agrochimica VII. 4:296-313.

10. Biddulph, O., S. Biddulph, R. Cory, and H. Koontz. 1958. Circulation patterns for phosphorus. sulfur and calcium in the bean plants. Plant Physiol. 33:293-300.

11. Black, C. A.. 1957. Soil-Plant relationships. 2nd ed. John Wiley & Sons, Inc. New York, N. Y.. 792 pp..

12. Broadbent, F. E.. 1953. The soil organic fraction. In:Advances in Agronomy Vol V:153-183.

13. Cain, J. C.. 1953. The effect of nitrogen and potassium fertilizers on the performance and mineral composition of apple trees. Proc. Amer. Soc. Hort. Sci. 62:46-52.

14. __________. 1959. Plant tissue analysis. In:Mineral nutrition of trees. A symposium. Duke Univ. School of Forestry Bull. 15:55-62.

15. __________, and D. Boynton. 1948. Some effects of season, fruit crop and nitrogen fertilization on the mineral composition of McIntosh apple trees. Proc. Amer. Soc. Hort. Sci. 51:13-22.

16. Cheng, H. H., and L. T. Kurtz. 1963. Chemical distribution of added nitrogen in soils. Soil Sci. Soc. Amer. Proc. 27:312-316.

17. Chepil, W. S.. 1954. Factors that influence clod structure and erodibility of soil by wind: III. Calcium carbonate and decomposed organic matter. Soil Sci. 77:473-480.

18. Chu, T. S., and L. M. Turk. 1949. Growth and nutrition of plants as affected by degree of base saturation of different types of clay minerals. Michigan Agri. Exp. Sta. Techn. Bull. 214.. 47 pp..

19. Clark, J. S.. 1966. The lime potential and percent base saturation of some representative Podzolic and Brunisolic soils in Canada. Soil Sci. Soc. Amer. Proc. 30:93-97.

20. Curlin, J. W.. 1963. Response of natural stands of Shortleaf Pine to thinning and fertilization with nitrogen and phosphorus. Soil Sci. Soc. Amer. Proc. 27:234-236.

21. Eaves, C. A., and A. Kelsall. 1954. Chemical composition of Cortland apple leaves in relation to nutritional treatment. J. Hort. Sci. 29:59-71.

22. Gibbs, J. A., and H. F. Perkins. 1966. Properties and genesis of the Hayesville and Cecil series of Georgia. Soil Sci. Amer. Proc. 30:256-260.

23. Grunes, D. L.. 1959. Effect of nitrogen on the availability of soil and fertilizer phosphorus to plants. In:Advances in Agronomy XI:369-396.

24. Hansen, E. M.. 1972. Studies on the chemical composition of isolated soil solution and the cation absorption by plants. I. Relationship between form and amount of added nitrogen and absorption of N, K, Na, Ca and Mg by barley. Plant and Soil 37:589-607.

25. Hausenbuiller, R. L.. 1972. Soil Science principles and practices. Wm. C. Brown Company Publishers. Dubuque, Iowa. 504 pp..

26. Heilman, P. E., and S. P. Gessel. 1963. The effect of nitrogen fertilization on the concentration and weight of nitrogen, phosphorus and potassium in Douglas Fir trees. Soil Sci. Soc. Amer. Proc. 27: 102-105.

27. Huntjens, J. L. M.. 1971. Influence of living plants on immobilization of nitrogen in permanent pastures. Plant and Soil 34:393-404.

28. ________________. 1971. The influence of living plants on mineralization and immobilization of nitrogen. Plant and Soil. 35:77-94.

29. Hutcheson, T. B. Jr., and H. H. Bailey. 1965. Effect of underlying residua on chemical and mineralogical properties of soils developed in a uniform Loess overlay. Soil Sci. Soc. Amer. Proc. 29:427-432.

30. Ingestad, T. 1959. Studies on the nutrition of forest tree seedlings. II. Mineral nutrition of spruce. Physiol. Plant. 12:568-593.

31. ___________. 1970. A definition of optimum nutrient requirements in Birch seedlings. Physiol. Plant. 23:1127-1138.

32. Jackson, M. L.. 1958. Soil chemical analysis. Prentice Hall, Englewood Cliffs, N. J., 498 pp..

33. Johnson, M. C., and A. Ulrich. 1959. Plant analysis and analitical methods. Calif. Agr. Exp. Sta. Bull. 766, 78 pp..

34. Kalra, G. S. 1971. The influence of three levels of soil moisture and three levels of soil fertility on the uptake of nutrients and histological changes in potato plants. Ph.D. thesis. University of Maine at Orono, 148 pp..

35. Kunze, G. W., and H. Oakes. 1957. Field and laboratories studies of the Lufkin soil, a Planosol. Soil Sci. Soc. Amer. Proc. 21:330-335.

36. Latkovics, G., and F. Mate. 1968. Investigation on the nitrogen and phosphorus uptake by young maize plants by means of P^{32} and N^{15} labelling. Biological Abstract, 51:abstract number 121143.

37. Leyton, L.. 1957. The relationship between the growth and mineral composition of the foliage of Japanese Larch. II Evidence from manurial trials. Plant and Soil IX:31-48

38. Lutz, H. J., and R. F. Chandler, Jr.. 1946. Forest soils. 11th ed. John Wiley & Sons, Inc. New York, N. Y.. 514 pp..

39. Martin, A., and S. Oliver. 1969. Diferencias entre gramineas (Helictotrichon y Koeleria) procedentes de suelos acidos y basicos. I. Relationes entre la composition mineral de las plantas, las caracteristicas de los suelos y el ano de recoleccion. Biological Abstract, 51:abstract number 138648.

40. McFee, W. W., and E. L. Stone. 1965. Quantity, distribution, and variability of organic matter and nutrients in a forest Podzol in New York. Soil Sci. Soc. Amer. Proc. 29:432-436.

41. McLean, E. O., and Eric J. Owen. 1970. Effects of pH on the contributions of organic matter and clay to soil cation exchange capacities. Soil Sci. Soc. Amer. Proc. 33:855-858.

42. Morgan, M. F., and H. A. Lunt. 1932. The role of organic matter in the classification of forest soils. J. Amer. Soc. Agri. 24:655-662.

43. Motoc, E. 1966. Effect of soil organic matter oxidation on the results of mechanical analysis. Biological Abstract, 49:abstract number 80562.

44. Muller, L.. 1961. Un aparato micro-Kjeldahl simple para analisis rutinarios rapidos de materiales vegetales. Turrialba Vol II:17-25.

45. Olsen, S. R., and L. A. Dean. 1965. Phosphorus. In: Methods of soil analysis. Agronomy 9:1035-1049.

46. Peech, M.. 1941. Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 51: 473-486.

47. Popovic, B.. 1973. Influence of lime and phosphorus fertilizers upon accumulation of mineral nitrogen in incubation experiment of forest soils. Symposium on forest soils. Academy of Science Sarajevo. Research notes. Dep. of Plant Ecology and Forest soils.

48. Reid, A. S. J., G. R. Webster, and H. R. Krouse. 1969. Nitrogen movement and transformation in soils. Plant and Soil XXXI. 2:224-237.

49. Rieger, S., and J. A. Dement. 1965. Cryorthods of the Cook Inlet-Susitna Lowland, Alaska. Soil Sci. Amer. Proc. 29:448-453.

50. Rinne, R. W., and R. G. Langston. 1960. Studies on lateral movement of phosphorus 32 in peppermint (*Mentha piperita* L.). Plant Physiol. 35:216-219.

51. Said, I. M.. 1959. Cation selectivity and cation-anion balance as factors governing the mineral composition of pasture herbage. Versl. Landbouuk. Onderz. Mededeling 94. 64 pp..

52. Salonius, P. O.. 1972. Microbiological response to fertilizer treatments in organic forest soils. Soil Sci. 114:12-19.

53. Shaw, W. M., and B. Robinson. 1960. Organic matter decomposition and plant nutrient release from incorporations of soybean hay and wheat straw in a Holston sandy loam in outdoor lysimeters. Soil Sci. Soc. Amer. Proc. 24:54-57.

54. Smith, R. M., D. O. Thompson, J. W. Collier, and R. J. Hervey. 1954. Soil organic matter, crop yields, and land use in the Texas Blackland. Soil Sci. 77:377-388.

55. Stanford, G., J. B. Kelly, and W. H. Pierre. 1941. Cation balance in corn grown on high-lime soils in relation to potassium deficiency. Proc. Soil Sci. Soc. Amer. 6:335-341.

56. Steel. R. G., and J. H. Torrie. 1960. Principles and procedures of Statistics. McGraw-Hill Book Company, Inc., New York.

57. Steenbjerg, F. 1954. Manuring, plant production and the chemical composition of the plant. Plant and Soil V, 3:226-241.

58. Stevenson, F. J.. 1957. Distribution of the forms of nitrogen in some soil profiles. Soil Sci. Soc. Amer. Proc. 21:283-287.

59. Taber, Henry G., and William W. McFee. 1972. Nitrogen influence of phosphorus uptake by <u>Pinus radiata</u> seedlings. For. Sci. 18:126-132.

60. Talli, A. R.. 1966. Growth and nutrition of <u>Picea glauca</u> (Moench) Voss seedlings. Ph.D. thesis. State University College of Forestry at Syracuse, 181 pp..

61. Tamm, C. O.. 1956. Studies on forest nutrition. III. The effect of supply of plant nutrients to a forest stand on a poor site. Medd. Statens Skogsforskn. 46:1-84. Original not seen. Cited by L. Leyton in Plant and Soil IX:31-48.

62. Tarrant, R. F., and R. E. Miller. 1963. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-Fir. Soil Sci. Soc. Amer. Proc. 27:231-234.

63. Tembhare, B. R., and M. M. Rai. 1967. Effects of pH, calcium carbonate, texture and organic matter on the availability of Mn. Biological Abstract, 49: abstract number 64632.

64. U. S. Department of Agriculture. Soil Conservation Service. 1963. Soil Survey Penobscot County, Maine. Series 1959, 28.

65. VanGoor, C. P.. 1953. The influence of nitrogen on the growth of Japanese larch (<u>Larix leptolepis</u>). Plant and Soil. 1:29-35.

66. VanLear, D. H., and W. H. Smith. 1972. Relationships between macro and nicronutrient nutrition of slash pine on three coastal plain soils. Plant and Soil. 36:331-347.

67. Voight, G. K.. 1965. Nitrogen recovery from decomposing tree leaf tissue and forest humus. Soil Sci. Soc. Amer. Proc. 29:756-759.

68. Walkley, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter titration method. Soil Sci. 37: 29-38.

69. Weeks, W. D., F. W. Southwick, and M. Drake. 1952. The effects of rates and sources of nitrogen, phosphorus and potassium on the mineral composition of McIntosh apple foliage and fruit color. Proc. Amer. Soc. Hort. Sci. 60:11-20.

70. Wells, C. G., and C. B. Davey. 1966. Cation-exchange characteristics of forest floor materials. Soil Sci. Soc. Amer. Proc. 30:399-402.

71. Wiklander, L., and A. Lax. 1967. Absorption of calcium, magnesium, potassium and sodium as influenced by liming. Biological Abstract, 50:abstract number 106091.

72. Wilding, L. P., and E. M. Rutledge. 1966. Cation exchange capacity as a function of organic matter, total clay, and various clay fractions in a soil toposequence. Soil Sci. Soc. Amer. Proc. 30: 782-785.

73. Wright, W. R., and J. E. Foss. 1972. Contributions of clay and organic matter to the cation exchange capacity of Maryland soils. Soil Sci. Soc. Amer. Proc. 36:115-118.

74. Youngberg, C. T.. 1966. Forest floors in Douglas-fir forests: I. Dry weight and chemical properties. Soil Sci. Soc. Amer. Proc. 30:406-409.

EMBRAPA - IPEAN
BIBLIOTECA
BELÉM - PARÁ

BIOGRAPHY

Gladys Ferreira de Sousa, was born in Pedreiras, State of Maranhão, Brazil in 1945. She received her early education in Pedreiras until 1959. She attended the Instituto de Educação e Cultura in Sao Luis, Maranhão, between 1960-1962, receiving the degree of Professor in Elementary Education. She continued her education at the Escola de Agronomia da Amazônia in Belém (1963-1966) receiving the degree of Engenheiro Agrônomo.

In 1967 she was appointed a Researcher in Soil Fertility by the Brazilian Department of Agriculture at the Instituto de Pesquisas e Experimentação Agropecuárias do Norte (IPEAN). She was granted a leave-of-absence in 1972 to pursue graduate studies at the University of Maine. At the University of Maine she was granted a Research Assistantship in the Department of Plant and Soil Sciences, under Professor R. A. Struchtemeyer.

She is a candidate for the degree of Master of Science (in Agronomy) from the University of Maine at Orono in May, 1974.