THE EFFECT OF SEVERAL CONIFEROUS SPECIES ON THE NITROGEN AND ORGANIC MATTER CONTENT OF THE SOIL

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THESIS

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INTRODUCTION

Forest soil management practices are becoming an increasingly important part of the forester's silvicultural program. During recent years much attention has been given to studying the influence of vegetation upon the development and nutrient content of the soil. In fact, climate and vegetation are considered the two most important soil forming factors, which essentially govern soil development. Climate for any given locality, of course, is relatively constant and not subject to significant change by man. Vegetation, however, can be controlled by the forester. Regulation of soil conditions through control of the forest cover type is apparently the way by which the forester can achieve the best results in forest soil management.

Vegetation influences soil development by adding to the soil organic materials, that during the process of decaying, support a complex chain of soil flora and fauna. Nutrient content, chemical composition, physical condition, and biological properties of soil are there by modified by the type of vegetation. Stand development, yield, and deterioration or improvement of site conditions may depend upon the particular forest type occupying the site. To determine the influence of forest cover types on nitrogen and organic content of a soil is the object of this study.

If there occurred a naturally uniform soil, bearing pure stands of various species, it would be a relatively simple procedure to sample and compare the effects of the various species upon the soil. Due to the usual mixture of species and to the great variations in soil characteristics, few such samples, however, can be found under natural conditions, even within what may appear to be a uniform environment.

The ideal situation for studying the effect of different tree species on soil conditions would be a uniform soil environment upon which pure stands of the different species had been planted. Such a situation is very closely approximated in what is known as the Sandhill Plantation at Michigan State College, East Lansing, Michigan. The Sandhill Plantation, of relatively uniform soil environment, was planted in 1914 to five different species of conifers.

SANDHILL PLANTATION

In 1913 Michigan State College purchased the Woodbury farm which contained what is now known as the Sandhill Plantation. The land originally was cultivated, but because of the sandy character of the soil there was considerable wind movement of the soil particles. A ridge of windblown sand, approximately 125 feet wide and 1000 feet long, was formed. This ridge extends in an east-west direction just south of Demonstration Hall. The sand, having blown from the south to form the ridge, is deepest on the south side, the crest of the ridge being close to that side of the plantation. There is a gradual slope to the north, the sand ranging in depth from about fifteen feet at the crest to about three feet on the north side. Throughout the length of the sandy ridge there are only minor differences in elevation.

In 1914, for the purpose of preventing wind erosion of the sand area, planting was begun. Straw mulch was used at that time to stabilize the soil, and there has been little movement of soil particles since. Through formation of a good canopy and litter development, the plantation has effectively stabilized the soil.

SOIL

The soil of the Sandhill Plantation is classified as medium sand. A mechanical analysis of the soil gives the following composition:

Soil Particle Size	Per Cent Composition
sand	95.0
silt	2.8
clay	2.2

The moisture equivalent of this soil is 66%; the wilting point is 3.1%; and the maximum water holding capacity is 30.8%.

The sand soil is relatively uniform in composition throughout the plantation and is underlain by a gravelly silt loam soil. The sand is not compact, nevertheless, there is little evidence of earthworms, burrowing rodents, or insect larvae, but in the organic surface layers conditions are more favorable for their presence. Throughout the litter and to considerable soil depth, mycelial threads of fungus were interwoven. Several of the fungus species formed mycorrhizae on the tree roots.

PLANTATIONS

The Sandhill Plantation is composed of stands of five species. Beginning at the east end of the plantation, there are stands of ponderosa pine (Pinus ponderosa Laws), Norway spruce (Picea excelsa L.), white pine (Pinus strobus L.), red pine (Pinus resinosa Ait), and Douglas fir (Pseudotsuga taxifolia (Lamarck) Britt). All species were set out as transplant stock in 1914 and were spaced 4x4 feet. Survival was almost complete and growth rapid. Thus, at an early date, an effective canopy was formed and litter began to accumulate on the forest floor. Thinnings were made in 1933, 1936, and 1937, under the direction of the Forestry Department of Michigan State College. Approximately 40% of the total number of trees were removed by thinning from below.

The stands, in all cases, are well stocked allowing only very small openings. Canopy density, competition, and litter accumulation have been sufficient to prevent most herbaceous growth. Occasional annual weeds are the only plants which form living ground cover.

Limited sunlight on the forest floor, prior to the thinnings, aided in the accumulation of litter.

COLLECTION AND COMPILATION OF DATA

There are two types of habitat represented by the Sandhill Plantation, namely; the ridge and slope types. The ridge type is the more exposed, drier site. The slope type is the sheltered, moist, north facing site. Hence aspect is one of the environmental factors that causes variation in vegetation growing on an otherwise uniform area.

Two species, Douglas fir and red pine, which occur at the west end of the plantation, have only the ridge type represented. Study plots for these two species, therefore, were taken only in the ridge type. For ponderosa pine, Norway spruce and white pine, data were taken for both the ridge and slope types.

METHODS OF COLLECTION

For the slope type, soil samples were taken at the midpoint of the slope and for the ridge type on the crest of the ridge, thirty feet from the south border of the plantation.

In collecting samples, soil profiles were made by digging trenches to depths of maximum root penetration. Representative samples of the various horizons were obtained by sampling each entire horizon and mixing thoroughly the soil for each sample. Two such sampling areas were taken for each slope and ridge type to be later combined, by horizons, for analysis.

Variation in depth of surface organic layers was very apparent. For that reason five measurements were taken in such type.

Root distribution and penetration were determined from the profiles made for each type. The number of roots occurring in the various horizons was noted.

Growth of trees on ridge and slope types was determined from plots of twenty trees, each containing two adjacent rows of ten trees for each type. The growth plots and the soil samples were taken from the same area. Diameters were measured with a diameter tape, and heights with a Forest Service hypsometer, checked by measurement of felled trees. Standard volume tables were used to determine volumes.

METHODS OF ANALYSIS

Total nitrogen was determined by the Kjeldahl-Gunning method as outlined in Methods of Analysis (2).

Organic matter was determined by the ignition method. According to Griffith, Hartwell, and Shaw (11), this method gave accurate results in New England soils with low carbonate content.

Waksman (34) refers to Mulder who stated that the loss in weight on ignition includes also a considerable amount of chemically combined water not driven off during the preliminary drying of the soil. Criticism of this method is given by Waksman in the following quotation: "The loss in weight on ignition includes also a considerable amount of chemically combined water not driven off during the preliminary drying of the soil. It is now well established that the water present in the soil colloids and in clay minerals (water of constitution) as well as water of hydrated minerals (water of crystallization) of the zeolite type are included in the loss on ignition".

Alexander and Byers (1) have stated that soil when heated by the ignition method showed loss of water due to dehydrated minerals of the mica and zeolite type, as well as "water of constitution" or water present in colloids and clay materials. However, since the plantation soils contained practically no carbonate or colloidal material, the ignition method gave sufficiently accurate results for the purpose of this study.

All soil samples for laboratory work were put through a forty mesh sieve to pulverize the small roots and other organic material. To obtain the desired accuracy in results, it was found necessary to use 20-30 gram samples instead of the 5-10 gram samples recommended in Official and Tentative Methods of Analysis (2).

RELIABILITY OF DATA

In the total nitrogen determinations an attempt was made to keep the average deviation below ± .005 per cent. By using the larger triplicate samples, this accuracy was obtained. The larger samples were desirable, also, in view of the very low nitrogen content of some of the soil samples. Results, varying by more than ± .005 per cent, were checked by duplicating the determinations.

The average mean deviation of organic matter determinations is ± .023 per cent. This is within the accepted limits of error due to sampling and weighing. The standard deviation of ± .037 per cent is higher because of the greater amount of organic matter in the surface soil layers, thus increasing the error in sampling.

REVIEW OF LITERATURE

The decay and deterioration of vegetation, when it falls on the ground, gives soil characteristics that are comparable with the chemical constituents of the cover type. Jenny (17) has found that, of the soil forming factors, vegetation is second only to climate in its importance in influencing the nitrogen content of soils. Biological activity and leaching mix organic matter into the soil, forming a relationship between vegetation and soil organic matter.

It has been found that (30, 29, 20, 19, 17) a ratio exists between organic matter and nitrogen in the soil.

Russell and McRuer (29) found a definite ratio between organic matter and nitrogen content in virgin grassland soils. Their organic mattern-nitrogen ratio for 0-6 inch and 7-12 inch samples was 20.8 and 19.3, respectively. They implied that the same general conclusions could be reached whether organic matter or nitrogen was determined. Further study by Waksman (34), Leighty and Shorey (19), and others has shown that multiplying the nitrogen content by a factor of twenty is not reliable for the purpose of calculating organic matter content.

While not all of the investigators have found that the organic matter and carbon-nitrogen ratios are represented by a constant value, the work of Morgan and Lunt (26) and Lunt (20, 21) showed that there was a carbon-nitrogen ratio which varied considerably between individual horizons. Jenny (17) states that under low temperatures the composition of the organic matter of soil approaches that of the undecayed materials. In temperate regions, the carbon-nitrogen ratio tends toward a constant value of ten to twelve; while in the original plant materials, the ratio varies between sixteen and two hundred. One would not expect the carbon-nitrogen ratio to be absolutely constant, in that it becomes wider as one goes from south to north.

Recently some studies have been made on the relation of total soil nitrogen content to site productivity. Hicock, et al. (16), found that the total nitrogen content of the A_{1}-2 horizons showed a better correlation with site index than other factors analyzed. In reviewing various studies of site quality, he found that Von Flackenstein showed a striking positive correlation between nitrogen content of the topsoil and "quality class", or yield capacity, in forests on sandy soils in northern Germany. A method of site evaluation for yellow poplar has been developed by Auten (3) and is based on the depth of organic matter incorporation or what is called depth of the undisturbed A_1 soil horizon. The many factors under consideration are so interrelated and complex that it is difficult to attribute a good site index to any one factor.

The formation of soil horizons, each varying in chemical characteristics and physical composition is influenced by organic surface layers (34) that supplys substances essential for the process of eluviation with resulting illuviation in the B horizon.

According to Marbut (24) there is a rapid decrease in organic matter content of the gray-brown podsolic forest soils with increasing depth, and the percentage of organic matter is very low at shallow depth.

Information on the nitrogen content of the leaves of various tree species is very limited in this country. However, Coile (9), Alway and Zon (7), Alway, Kittredge, and Methley (4), and a few others have made leaf analyses of a number of species. They have found that the amount of nitrogen in leaves varies between species and, in litter, is affected by the amount of weathering as well as by the species concerned. The decomposition of leaves making up the litter determines, in a large part, the nitrogen found in the soil and the humus. The nature and rate of decomposition, according to Waksman (32), Melin (25), and Tenny and Waksman (30), depends upon the environmental conditions, micro-organisms present, chemical composition of plant material, age of plant, and nature and amount of available nitrogen, phosphorus, and other nutrients in the soil.

LABORATORY ANALYSES

The purpose of laboratory analyses is to aid in determining the extent to which soil conditions are modified by the influence of vegetation. While field observations and measurements serve as an indication of conditions under different forest cover types, the determination of actual nitrogen and organic matter content is necessary for accurate definition of soil differences under various stands of trees.

NITROGEN CONTENT

Table I gives the nitrogen content at various depths on ridge and slope soil types for the five tree species considered in this study. Soil nitrogen values in general are very low; values for litter, however, are normal. It was found that white pine litter had the highest nitrogen content, 1.848±.005 per cent, followed, in decreasing order, by Norway spruce, Douglas fir, ponderosa pine, and red pine. Red pine litter has a nitrogen content of only .922±.023 per cent, which is distinctly lower than for the other species and less than half the value for white pine litter. Alway, Kittredge, and Methley (4) also found a large difference between nitrogen of litter under red and white pine cover types.

It is known that leaves of different tree species vary in mineral and nitrogen content. Studies by McHargue and Roy (23) and Alway, et. al. (5) show that before leaves fall the nitrogen content decreases. Leaching of leaves after

TABLE I

PER CENT NITROGEN AT VARIOUS DEPTHS

Species	Aspect	Litter	DEPTH OF SOIL SAMPLE				
			0-1 inch ($\frac{1}{2}$")	$2\frac{1}{2}$-$5\frac{1}{2}$ inches (4")	10-14 inches (12")	22-28 inches (25")	35-40 inches (37.5")
Ponderosa Pine	Ridge	1.216±.033	.0432±.0043	.0411±.0010	.0376±.0066	.0182±.0046	.0102±.0020
	Slope		.0510±.0072	.0411±.0086	.0424±.0036	.0225±.0025	.0182±.0029
Norway Spruce	Ridge	1.611±.021	.0844±.0018	.0350±.0027	.0239±.0032	.0109±.0023	.0071±.0000
	Slope		.0610±.0028	.0299±.0031	.0367±.0010	.0136±.0006	.0073±.0010
White Pine	Ridge	1.848±.005	.0498±.0032	.0430±.0019	.0262±.0045	.0170±.0017	.0165±.0011
	Slope		.0649±.0033	.0527±.0000	.0556±.0106	.0303±.0016	.0236±.0046
Red Pine		.922±.023	.0669±.0006	.0396±.0033	.0251±.0024	.0119±.0000	.0086±.0000
Douglas Fir		1.354±.002	.0493±.0013	.0434±.0013	.0153±.0007	.0109±.0015	.0112±.0005
Average All Samples		1.390	.06006	.04073	.03285	.01689	.01290

falling, removes water soluble materials, leaving organic matter that is more resistant to decomposition. In this study the litter was collected for analysis in early summer, after being subjected to weathering over winter. Since all litter was subject to the same conditions, the results should be comparable. They are in agreement with data obtained by Alway, Methley, and Younge (6) who found, in their study of forest floors, that by using the nitrogen of maple-basswood litter as 100, white pine litter would have a nitrogen content of 75, and red and jack pine litter a nitrogen content of 22 to 45.

Nitrogen content of the mineral soil is shown to decrease rapidly with depth. Maximum nitrogen content of mineral soil occurs in all cases in the 0-1 inch depth class, decreasing in the 35-40 inch depth class to values from 10 to 35 per cent. There are marked differences in nitrogen content. This is evident in ridge and slope samples of the same type and, also, distinct in ridge and slope samples of different species. In general, the slope type shows higher nitrogen content than the ridge type. The highest value is found in the 0-1 inch horizon on the ridge type under Norway spruce. Norway spruce has the second highest nitrogen content of the litter, white pine having the higher value. The decrease of nitrogen content is very rapid in the case of Norway spruce, however, and the lowest value obtained is in the 35-40 inch horizon under this species, in which the nitrogen content is only .0071 per cent.

The important variations in nitrogen content appear to be due mainly to species forming the cover type, although the significance can probably be attributed to the quantity and quality of the litter.

In comparing the slope types, the white pine soil has distinctly the highest average nitrogen content, followed by ponderosa pine and Norway spruce. Nitrogen content is better maintained in the deeper layers in white pine and ponderosa pine than in Norway spruce, which shows a rapid decrease in nitrogen content with increased depth. This may be due to the relatively thin layer of surface organic material under Norway spruce which would result in smaller yields of nitrogen.

Falconer, Wright and Beal (10), in their study of decomposition of certain types of forest litter, found that an increase in lignin content decreases the rate of decomposition. It was determined that jack pine wood had a higher lignin content than white pine. They concluded, also, that white pine twigs decayed twice as rapidly as red pine and four times as rapidly as jack pine; therefore, the rate of decomposition is a factor that will influence the amount and rate of nitrogen additions to the soil.

It may further be noted from Table I, that although there is a decrease in average nitrogen content with depth of layer, the third layer, at 10-14 inches, shows an increase in nitrogen content of the slope samples. For instance, in white pine the nitrogen content increases from .0527 to .0556 per cent from the second to the third depth layer, from .0299 to .0367 per cent in Norway spruce, and from .0411 to .0424 per cent in ponderosa pine. This would indicate that the slope soils are somewhat podsolized. The third layer, corresponding to the B_1 horizon of illuviation, would be expected to have a higher nitrogen and nutrient content than the leached horizon, or horizon of eluviation, above it.

Table II, giving the average nitrogen content of slope and ridge soil samples, further brings out the increase which occurs from the 2½-5½ inch layer to the 10-14 inch layer. Averages of ridge and slope soil samples, however, show a steady decrease with increased depth of layer.

TABLE II

AVERAGE NITROGEN CONTENT OF SLOPE AND RIDGE SOIL SAMPLES

	Nitrogen		
Depth inches	Ridge per cent	Slope per cent	Average per cent
0-1	.05908	.05897	.05902
2½-5½	.03970	.04123	.04046
10-14	.02923	.04490	.03706
22-28	.01537	.02213	.01875
35-40	.01160	.01653	.01406

Figures I and II present graphically the nitrogen content of the ridge and slope soils at the different depths. Figure I gives values under each species and Figure II gives

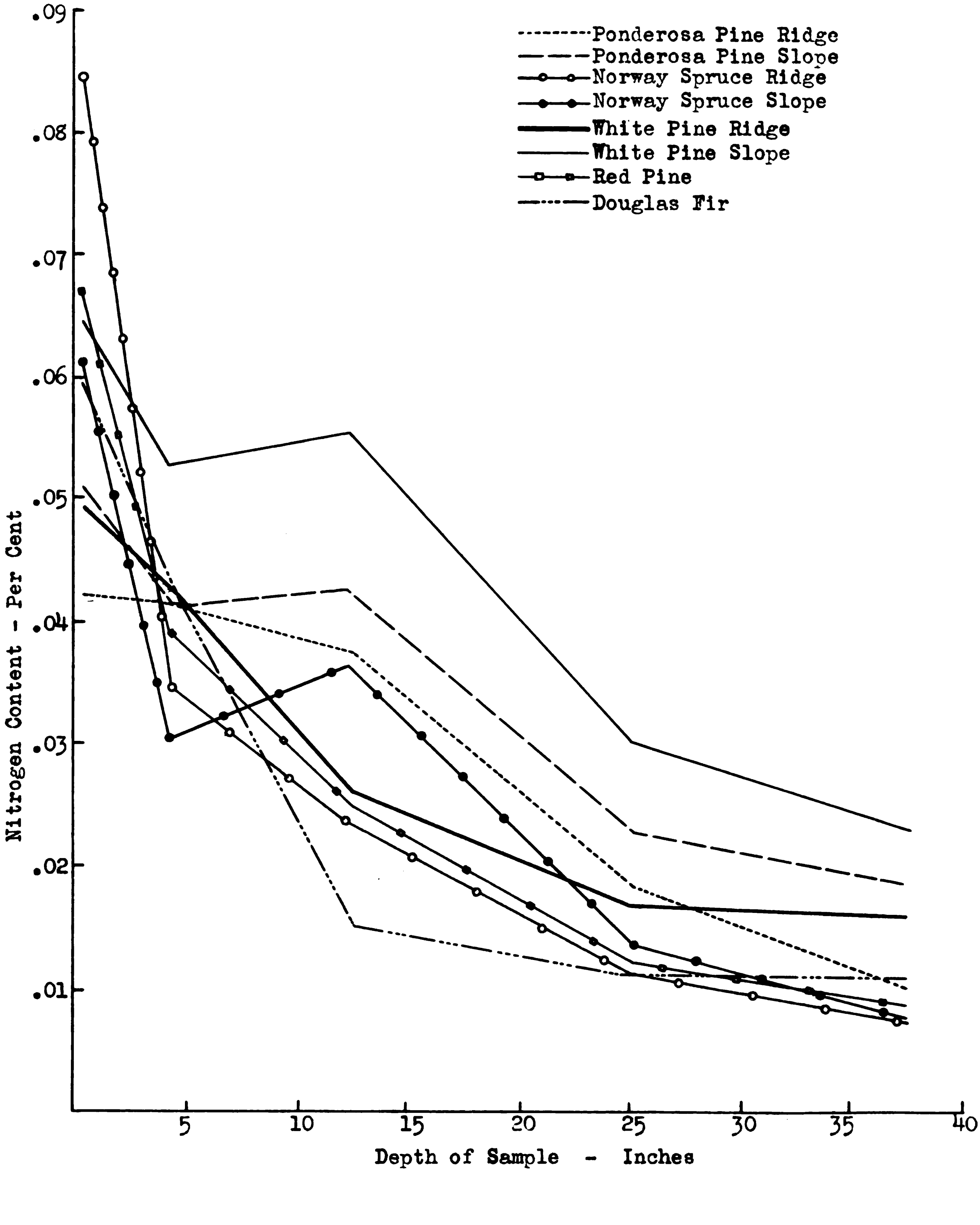

Fig. 1 - The Relation of total Nitrogen to Soil Depth under several Coniferous Species.

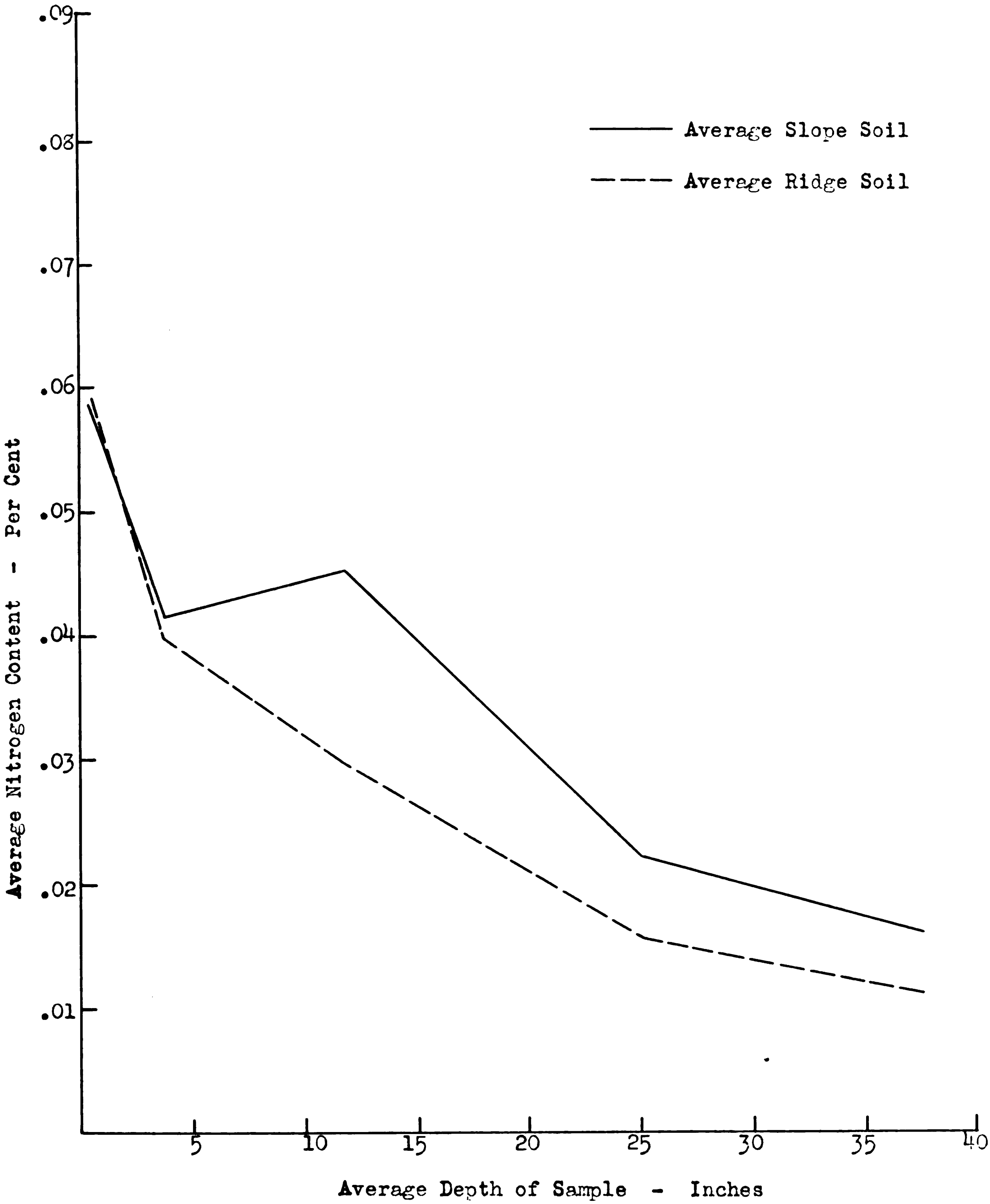

Fig. 2 - Average Nitrogen Content in relation to depth in Ridge and Slope Soils.

average values for ridge and slope types. The trends are clearly shown by the graphs, particularly the increase in nitrogen content in the 10-14 inch layer on the slope type and the great amount of nitrogen in the white pine type.

ORGANIC MATTER CONTENT

The percentage of organic matter, found in the litter and in the soil at various depths, is shown in Table III, and graphically illustrated in Figure III. White pine litter has significantly the lowest organic matter content with 85.29 per cent, and ponderosa pine highest with 94.34 per cent. Red pine has the second highest organic matter content, 93.03 per cent. Norway spruce and Douglas fir have about the same content, 91.97 and 91.46 per cent. The higher nitrogen and organic matter content of soil under the white pine is in agreement with the lower organic matter content, a factor favoring organic decomposition. The high nitrogen content of the white pine litter would be an additional factor favoring decomposition, since Tenny and Waksman (31) state, that when the nitrogen content is about 1.7 per cent, it is just sufficient to cover the requirements of the micro-organisms active in decomposition of plant materials.

Organic matter contents have about the same trend as nitrogen contents and, likewise, values are greater on the slope than on the ridge. They decrease with depth, except for the increase from the second to the third layer on the slope. Considerable variation occurs among the species.

TABLE III

PER CENT ORGANIC MATTER AT VARIOUS DEPTHS

	Aspect	Litter	DEPTH OF SOIL SAMPLE				
			0-1 inch ($\frac{1}{2}$)	$2\frac{1}{2}$-$5\frac{1}{2}$ inches (4")	10-14 inches (12")	22-28 inches (25")	35-40 inbhes (37.5")
Western Yellow Pine	Ridge	94.345±.545	1.346±.031	1.004±.018	.662±.010	.518±.005	.378±.001
	Slope		1.541±.030	1.028±.009	1.336±.013	.651±.008	.528±.022
Norway Spruce	Ridge	91.968±.008	2.038±.116	1.370±.014	.698±.010	.405±.016	.402±.010
	Slope		2.438±.168	1.034±.000	1.212±.024	.528±.013	.390±.000
White Pine	Ridge	85.283±3.211	1.503±.028	1.293±.028	.622±.016	.487±.003	.356±.013
	Slope		1.769±.084	.9205±.006	.943±.012	.710±.007	.538±.001
Red Pine		93.030±.490	2.060±.022	1.314±.041	.930±.038	.672±.001	.398±.002
Douglas Fir		91.457±.082	1.763±.080	1.382±.008	.660±.0005	.524±.007	.498±.006
Average All Samples		91.218	1.8073	1.1689	.8828	.5618	.4359

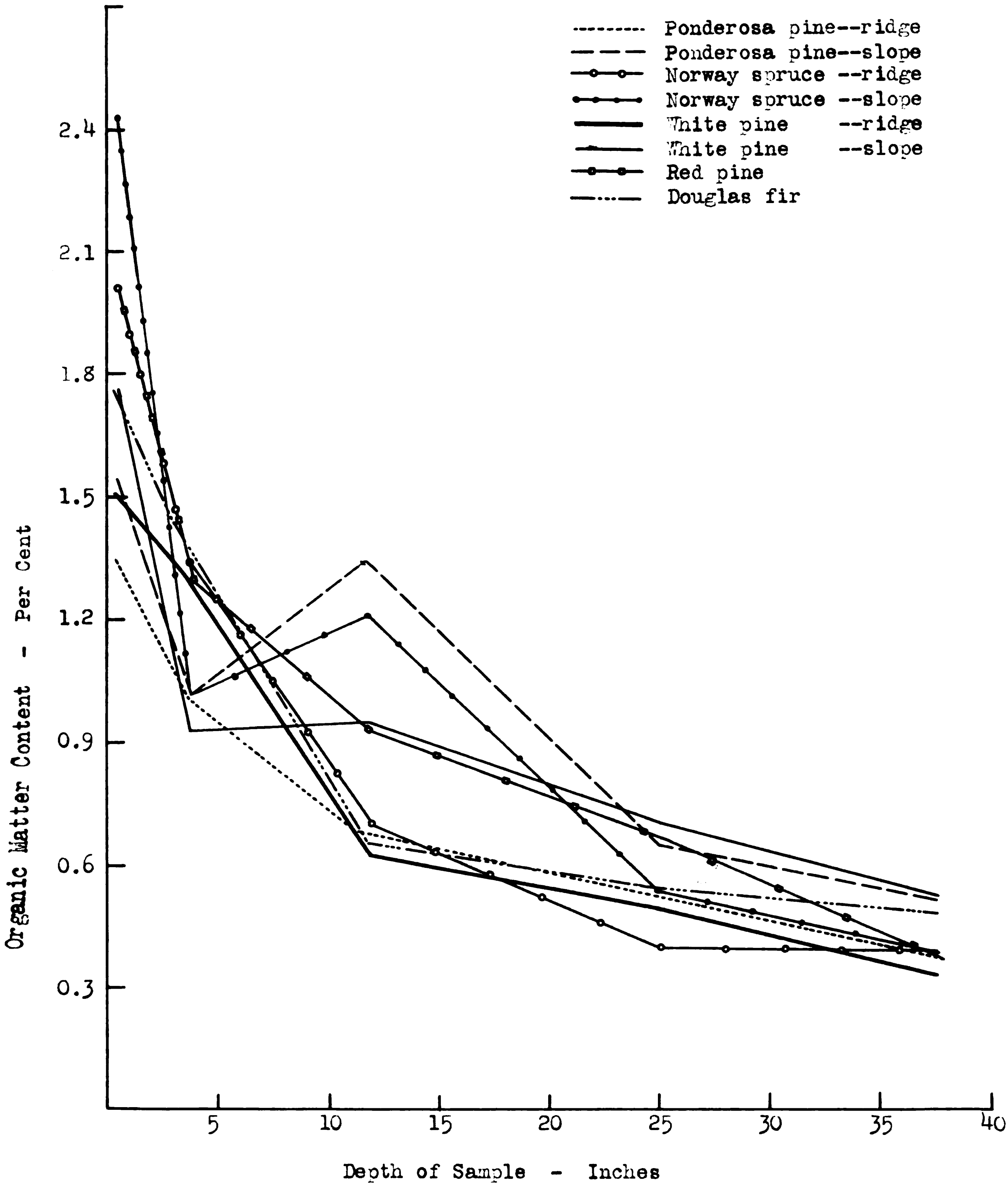

Fig. 3. The Relation of Organic Matter to Soil Depth under Several Coniferous Species

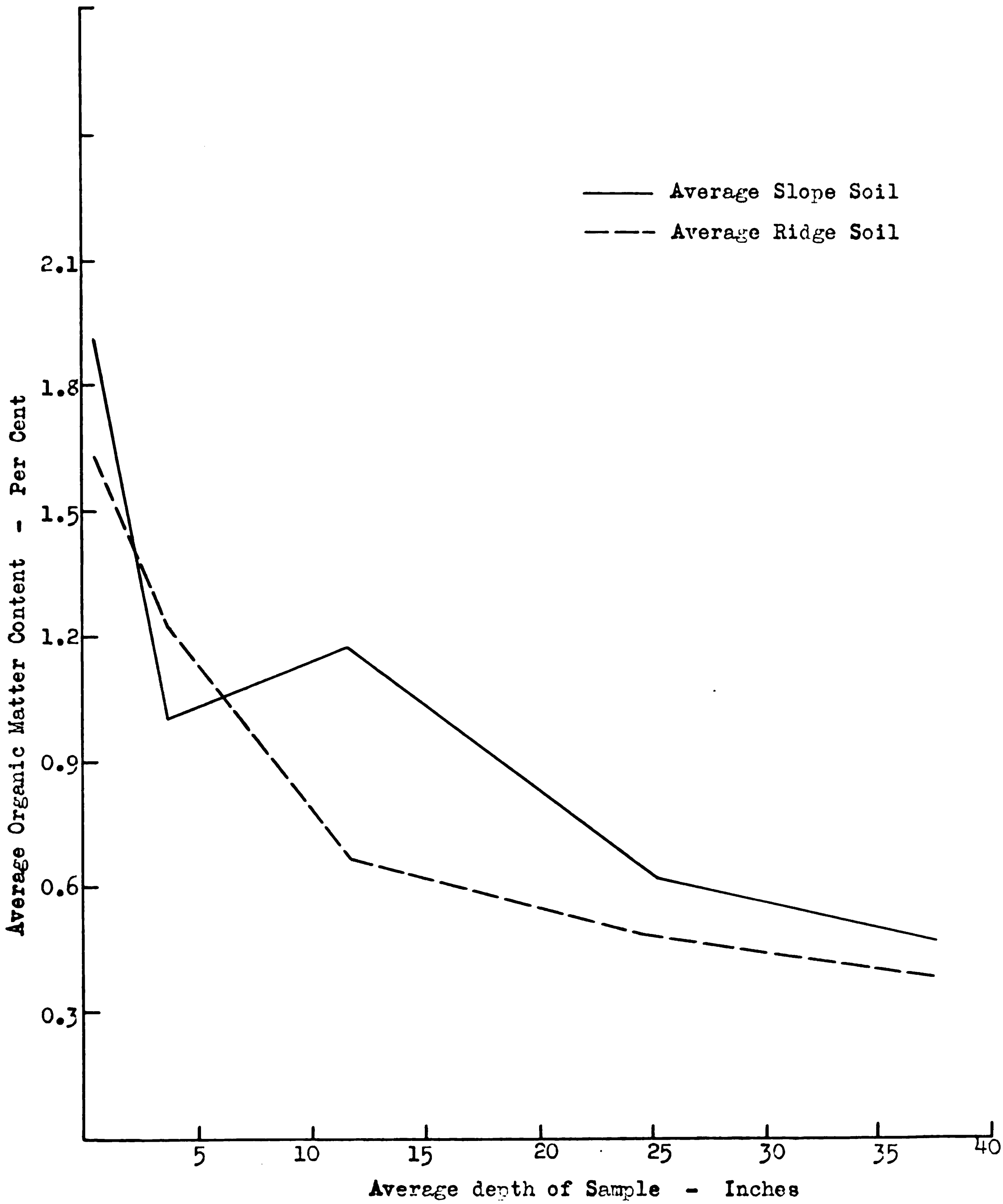

Fig. 4 - Average Organic Matter content in relation to depth in Ridge and Slope soils.

The more rapid decomposition of the Norway spruce litter is shown by the high organic matter content in the first layer, 0-1 inch, of mineral soil and in the complete profile. The thinness of the layer may here be a factor favoring rapid decomposition of the litter of this species.

The rather uniform decrease in organic matter content and the concentration zone in the B horizon of the slope soils are better shown in Table IV and Figure IV, which give the average organic matter content of slope and ridge soils. The ridge soils and the average of ridge and slope soils show decreasing organic matter content with increased depth. The slope soils, however, show the higher content at 10-14 inch depths. This soil characteristic, also, is in agreement with results of Griffith, et. al. (11) and Lunt (21) who found a similar concentration of organic matter in the B_1 horizon of podsol soils.

ORGANIC MATTER-NITROGEN RATIOS

There is considerable variation in the organic matter-nitrogen ratios in the soils on the Sandhill Plantation. This may be noted from Table V which gives the organic matter nitrogen ratios for the various conditions. Values vary from 17 to 56.5, although for all conditions they average close to 30. Lowest ratios appear in the 10-14 inch horizon where concentration of nitrogen and organic compounds have accumulated as a result of soil forming processes.

TABLE IV

AVERAGE ORGANIC MATTER CONTENT OF SLOPE AND RIDGE SOIL SAMPLES

Soil sample	Organic matter content		
Depth inches	Ridge per cent	Slope per cent	Average per cent
0-1	1.6290	1.9160	1.7725
2½-5½	1.2243	.9942	1.1092
10-14	.6607	1.1637	.9122
22-28	.4700	.6629	.5664
35-40	.3787	.4250	.4019

TABLE V

ORGANIC MATTER-NITROGEN RATIOS

Species		DEPTH OF SOIL SAMPLES				
	Aspect	0-1 inch	2½-5½ inches	10-14 inches	22-28 inches	35-40 inches
Ponderosa Pine	Ridge	31.1	24.4	17.6	28.5	37.0
	Slope	30.2	25.0	31.5	28.9	29.0
Norway Spruce	Ridge	24.1	39.1	29.2	37.1	55.6
	Slope	39.9	34.6	33.0	38.8	50.0
White Pine	Ridge	30.2	30.2	23.7	28.6	21.6
	Slope	27.3	17.5	17.0	23.4	22.8
Red Pine		29.3	33.1	37.1	56.5	46.2
Douglas Fir		29.7	31.9	43.1	48.0	44.4
Average All Samples		30.1	28.7	26.9	33.2	33.7

Lunt (29), Morgan and Lunt (26) and Leighty and Shorey (19) found similar variations in organic matter-nitrogen ratios, expressed as C:N ratios, in podsol soil types of New England. Ratios, however, are much higher than those found by Russell and McRuer (27). A possible cause for higher ratios may be due to use of the ignition method which increases loss of water by dehydration of inorganic soil constitutents. The loss of water by this method would be computed as organic matter.

The low ratios in the 10-14 inch horizon indicate that the soil forming processes are developing the soils in the Sandhill Plantation. The soils are weakly podsolized under the influence of coniferous stands. An explanation of the lower ratios in the B_1 horizon appears in the fact that nitrogen, being subject to rapid leaching, would be easily carried from the A horizon to the B_1 horizon. Waksman (34) states that limited evidence points to the probability that humus as a whole is not leached downward, but only certain constituents are susceptible to movement. This, he states, can be demonstrated by the fact that although the concentration of humus and nitrogen diminished with depth in the case of podsol soils, the nitrogen content of the humus becomes greater in the lower horizons. This is further substantiated by organic matter-nitrogen ratios in the Sandhill Plantation.

Table VI presenting the average organic matter-nitrogen ratios of slope and ridge samples, gives on the ridge a ratio of 30.8 at 4 inches and 22.6 at 12 inches. This indicates that nitrogen has penetrated more rapidly than organic matter. On the slope the average at four inches is 24.1, whereas, at 12 inches it is 26.6. On the ridge, organic matter has penetrated less than on the slope.

TABLE VI

AVERAGE ORGANIC MATTER-NITROGEN RATIOS OF SLOPE AND RIDGE SAMPLES

Depth in inches	Ridge	Slope	Average
0-1	27.5	32.5	30.0
2½-5½	30.8	24.1	27.4
10-14	22.6	26.6	24.6
22-28	30.5	29.7	30.1
35-40	32.6	24.0	28.6

These organic matter-nitrogen ratios do not compare with those found by Russell and McRuer (29) and indicate that soil forming processes, under conifer plantations, are quite different from grassland conditions in which the ratios were very close to 20 for all horizons. Supporting this fact

Waksman (34) states several factors that cause wider C:N ratios in forest soils than in field soils: 1) different composition of organic materials; 2) different microbiological populations (fungi predominate in forest soils while bacteria and actinomyces are most abundant in grassland soils); 3) different nutritive requirements of the forest vegetation, which frequently depends upon the activities of mycorrhiza fungi.

FIELD OBSERVATIONS

The extent to which soil conditions are modified by the influence of vegetation will depend upon species and stand characteristics. While much of this study pertains to the nitrogen and organic content of the soil under different forest cover type conditions, field observations and measurements were made of some of the conditions which determine nitrogen and organic matter content of the soil. These observations and measurements are of value in correlating the effects of different species upon nitrogen and organic matter content of the soil. They include: 1) depth measurements of surface organic layers on ridge and slope conditions, 2) depth measurements of darkened horizon and 3) root distribution of various species. These factors are considered as being most significant in their influence upon nitrogen and organic matter content of the soil. Basal area and height growth on ridge and slope conditions for two of the species gives an indication of the effectiveness of nitrogen and organic matter content in controlling growth.

Table VII gives the depth of surface organic layers. The surface organic material is considered as made up of two layers, the litter and duff. This is a well known classification based upon the degree of decomposition. Litter is the practically undecomposed organic debris, while duff is partially decomposed.

TABLE VII

DEPTH OF SURFACE ORGANIC LAYERS UNDER DIFFERENT SPECIES ON RIDGE AND SLOPE

Species		Litter	Duff	Total litter & Duff
		inches		
Ponderosa pine	ridge	.30	.75	1.05
	slope	.50	1.75	2.25
Norway spruce	ridge	.20	.30	.50
	slope	.25	.50	.75
White pine	ridge	.30	.75	1.05
	slope	.75	2.20	2.95
Red pine		.40	1.00	1.40
Douglas fir		.25	.70	.95

The depth of surface organic layers serves as a measure of the amount of organic material added to the soil under the different conditions. It can be seen from Table VII to vary with the species and from ridge to slope. Since surface organic layers in the Sandhill Plantation are made up almost entirely from needle fall, thickness of the surface organic layers is a measure of foliage production for the different species. It should express reasonably well general relatiohships which exist among the species considered in regard to the amounts of organic materials added to the soil.

White pine is shown to have the deepest layer of surface organic materials, followed by ponderosa pine, red pine, Douglas fir and Norway spruce.

Heyward and Barnette (15) found in longleaf pine, that surface organic layers increased in depth up to a point where equilibrium was established, in from 8 to 12 years following a fire. Atthis point decay balanced additions of organic materials, and depth of the surface layers remained about constant. It seems reasonable that if conditions for decomposition remain fairly constant this same principle would hold for all species. Since the Sandhill Plantation is twenty-four years old, the equilibrium probably has been attained, and surface organic layers have reached maximum depths.

Tree development on the slope is much better than on the ridge, therefore, surface organic layers receive a greater volume of annual needle fall. With increased needle fall on the moist slope, comes more complete incorporation by soil organisms which builds up the layers of topsoil in nutrient content. Furthermore, needles from trees on dry ridges have a tendency to collect on slopes and increase site improvement.

Decomposition is probably more rapid on the ridge due to the more open condition of the stand which allows oxidation of the carbonaceous portion of the duff rather than accumulation, as on humid slopes. Hansen (12) found decomposition of surface organic matter greatly hastened by thinnings which lowered crown density and increased the temperature of the forest floor. Thinner layers of organic matterial on the ridge type are, in all probability, caused by conditions favoring more rapid decomposition and less annual needle fall.

DEPTH MEASUREMENTS OF DARKENED HORIZON

Below the layer of soil humus is a layer pale rusty tan in color. This humus layer shows the depth to which organic matter has penetrated, since below that layer no gray color can be detected. The depth of this horizon varies with the species and with ridge and slope conditions. Table VIII shows the depth to which organic matter has been incorporated in the soil under different species and on ridge and slope conditions.

TABLE VIII

DEPTH TO WHICH ORGANIC MATTER HAS BEEN INCORPORATED IN SOIL UNDER DIFFERENT SPECIES ON RIDGE AND SLOPE

Species		Depth variation in inches	Average depth inches
Ponderosa pine	ridge	5 - 9	7.0
	slope	12 - 17	14.5
Norway spruce	ridge	6 - 10	8.0
	slope	13 - 16	14.5
White pine	ridge	3 - 9	6.0
	slope	14 - 24	19.0
Red pine		7 - 10	8.5
Douglas fir		6 - 9	7.5

It is apparent that organic matter has penetrated more deeply on the slope than on the ridge. There appear no great differences in the depth of penetration for different species on the ridge. Under slope conditions penetration is the same for ponderosa pine and Norway spruce (14.5 inches) but somewhat greater (19 inches) for white pine. Nevertheless, penetration is least with white pine on the ridge, 6.0 inches compared with a maximum of 8.5 inches for red pine and 7.0 to 8.0 inches for the other species.

By comparing Tables VII and VIII, a positive correlation is evident between thickness of surface organic material and depth of the darkened horizon. The depth of the horizon, except in Norway spruce, is more or less in proportion to the thickness of the surface organic layers.

Those factors that favor organic matter incorporation also improve site conditions and tree growth. In evaluating sites for yellow poplar, Auten (3) states that the depth of organic matter penetration, representing its production, decomposition and i corporation, is an index or integration of all the meteorologic, biotic and pedologic factors of site which influence tree occurrence and rate of growth.

ROOT DISTRIBUTION OF VARIOUS SPECIES

The depth and extent of root development varies primarily with the species, but also with soil conditions. Moisture supply and soil nutrients will influence root development and the occurrence of roots will, in turn, modify the soil by adding organic material, mainly by the decaying of roots or root parts. Differences in organic matter content of the soil, therefore, may well be due to distribution of roots in the various horizons and at various depths.

Table IX shows the distribution of roots of the five species at different depths. The data in the table show the number of roots exposed in a thirty inch profile at the depths given.

TABLE IX

DISTRIBUTION OF ROOTS IN DIFFERENT HORIZONS FOR VARIOUS SPECIES

Species	Depth in inches		
	0-8	8-24	24.50
	Number of roots		
Ponderosa pine	49	36	20
Norway spruce	39	10	2
White pine	34	20	5
Red pine	44	17	3
Douglas fir	41	14	4

Ponderosa pine is shown to have the most extensive and best developed root system of the five species. Roots of this species were found to depths of seventy inches. On the basis of number and depth of penetration of roots, red pine and douglas fir have the next best developed root systems, followed by white pine and Norway spruce. Norway spruce has an especially shallow root system, with sixty-five percent of the roots occurring in the upper eight inches of soil. Few roots extended to below depths of 50 inches although all species had roots below 24 inches. In all species, however, most of the roots occurred at relatively shallow depths.

There appears little or no correlation between either the depth or penetration of surface organic matter and the distribution of roots in different horizons.

DIAMETER AND HEIGHT GROWTH ON RIDGE AND SLOPE

Diameter and height growth or volume growth may be taken as a measure of site productivity of an area. Productivity will vary with different species, but this, in cases, might be because soil fertility is maintained or built up by additions of organic materials and nitrogen.

The average growth of white and ponderosa pine on ridge and slope is given in Table X. The data are averaged from samples of 20 trees of each condition.

TABLE X

AVERAGE GROWTH OF PONDEROSA AND WHITE PINE ON RIDGE AND SLOPE

Species		Average Basal Area in sq. ft.	Average Height	Average Total Volume cu. ft.
Ponderosa pine	(ridge)	.171	29.2	2.13
	(slope)	.203	32.3	2.73
White pine	(ridge)	.126	25.3	1.55
	(slope)	.153	30.8	2.27

The differences in growth of ponderosa and white pine between ridge and slope are clearly shown. It is interesting to note that these differences are in agreement with variations in depth and penetration of surface organic matter.

Site conditions, such as aspect and soil moisture are, undoubtedly, important factors in bringing about such variations. The total nitrogen content on slopes also is favorable to better growing conditions. It is significant, however, that thickness of surface organic matter and depth of penetration have a positive relationship with growth rate, and it is possible, that as soil development proceeds, the differences in growth rate may become even more evident.

SOIL PROFILE DEVELOPMENT

In its early stages the soil of the Sandhill Plantation was practically a pure, light-colored, medium sand. From a pedologist's standpoint, this type is classed as a very young soil and is included in the gray-brown podsolic soil group.

Observations by Griffith, Hartwell and Shaw (11) led them to believe that a leached horizon appeared under white pine after about 60 years. Their study was made from soils, thought to be of uniform origin, from which they measured stands of various ages.

Hunt (21) reviewed observations made in Sweden by Tamm, who found, that in a young soil under scotch pine, one to two cm. of leached soil are formed in about 100 years. In New England, Hunt, in his own observations, determined that podsols had not been formed by one generation of trees. These studies of podsolization indicate that after only 24 years there can be very little podsolization on this plantation.

The extent of this soil development process is aided by coarse soils that permit leaching and a coniferous growth of trees that develop acid soil conditions. In addition to movement of silt and clay, the main materials leached are iron, aluminum, ortanic matter, nitrogen and calcium. Studies of the slope soil samples indicated that at a depth of 12 inches there was an increase in nitrogen and organic matter over the 4 inch samples (Fig. 2 & 4). At this early stage of the eluviation process, no leached layer is apparent, although laboratory analyses show a zone of illuviation.

Joffe (18) states that the podsol process of soil formation sets in as soon as the forest cover is capable of keeping the surface horizon moist and thereby favoring the leaching reactions by the percolating rainwater. The thick mat of surface organic matter maintains constant moist soil surface layers in the Sandhill Plantation.

Under present vegetative, climatic, and environmental conditions of this soil; it can be expected that soil formation processes will continue and that relative effects of the various coniferous species, on the nitrogen and organic matter content of the soil, will be more evident.

SUMMARY

1. Measurements of nitrogen and organic matter content were made on a medium sand soil planted in 1914 to five different conifer species.

2. Surface layers or organic matter varied from thinnest to thickest in the following order: Norway spruce, Douglas fir, red pine, ponderosa pine, and white pine.

3. Comparison of slope and ridge soils under three species shows that more nitrogen and organic matter are found in slope than ridge soils. Factors that contribute to these differences appear to be: 1) depth of surface organic material, 2) depth of organic matter penetration, 3) character and composition of surface organic material according to tree cover type, 4) environmental differences between slope and ridge, and 5) environmental factors influencing soil development processes.

4. Organic matter is incorporated to greater depths on slope than on ridge soils and is greatest under white pine, followed by Norway spruce and ponderosa pine.

5. Organic matter and nitrogen content decrease with depth but show a concentration zone corresponding to the B_1 horizon in this lightly podsolized soil.

6. Ponderosa pine had the most extensive and deepest penetrating roots of the five species studied.

7. There is a wide organic matter-nitrogen ratio that varies considerably between species and soil depths of the same species. The lowest ratios appeared in the B_1 horizon at 10-14 inch depths.

8. The slope type, having better tree growth than the ridge type, also had higher organic matter and nitrogen content.

9. In all probability, the first stage of profile development is found in the slope types which have an accumulative zone at a twelve inch depth.

10. Under present vegetative, climatic, and environmental conditions of this soil; it can be expected that soil formation processes will continue and that relative effects of the various coniferous species, on the nitrogen and organic matter content of the soil, will be more evident.

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