SOIL DEVELOPMENT UNDER 22-YEAR-OLD MIXED HARDWOOD, PINE, AND BLACK LOCUST PLANTATIONS ON A SURFACE MINE

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Abstract.--A study of soil development under three forest vegetation types showed development of O, A, and B horizons after 22 years. O horizon thickness was significantly greatest under pine (3.5 cm) and least under mixed hardwoods (2.4 cm). O horizon concentrations of N, P, Ca, Mg, Cu, Zn, Si, and Ni had significant differences attributable to vegetation type. A horizon development was quite variable with a mean thickness of 2.3 cm. There were significant differences between the A and B horizons for organic matter content, conductivity, exchangeable acidity, and concentrations of available N, P, K, Ca, Mg, Mn, Cu, Zn, B, Na, Pb, Ti, and Cr. The differences for A and B horizons were not significant for pH, Fe, Si, Al, exchangeable Al, Co, or Ni. There were significant differences among vegetation types for the ratio of A to B horizon means for pH, exchangeable acidity, conductivity, N, Zn, B, Na, and Ni.

INTRODUCTION

Surface mining for coal in the Eastern United States causes disruption of soil horizon organization, as well as dispersal and sometimes loss of the original soil materials. Overburden materials which often were the parent materials for the original soils are frequently mixed and left at the surface of the reformed topography where they become the parent materials of future soils. Soils that develop on the mined site are a function of the climate, vegetation and other organisms, topography, parent material, and time (Jenny 1941). Of these variables, time is the only one that is independent of man's influence. Methods of mining, spoil movement, and placement determine the future soils' parent material. Topography influences soil hydrology and somewhat modifies effects of climate. The pioneer vegetation can have an influence lasting decades. In this paper we will examine the development of soils and the influence of vegetation under 22-year-old tree plantations on a surface mine in southeastern Kentucky.

METHODS

The Site

The study site is located near the community of Fonde in southwestern Bell County in southeastern Kentucky. The area was mined in 1959 and remined in 1963. The mine was a bench cut at 564 m elevation with highwall, bench, and outslope spoil deposits that were common at that time. The Kentucky Strip Mine Research Coordinating Committee[2] established an 18-acre

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[2]The Kentucky Strip Mine Research Coordinating Committee was made up of the following organizations: Kentucky Coal Association; Kentucky Department of Natural Resources; Kentucky Reclamation Association; University of Kentucky; Northeastern Forest Experiment Station, U. S. Forest Service; and Tennessee Valley Authority.

Proceedings America Society of Mining and Reclamation, 1988 pp 54-62

DOI: 10.21000/JASMR88020054

https://doi.org/10.21000/JASMR88020054

demonstration area on the site in 1965 to show effects of some of the then-accepted methods of water control and revegetation. The bench was graded to direct surface waters toward the highwall, and two settling ponds with spillways were constructed. Acid-forming coal wastes and shales were buried where possible. Trees, shrubs, and grasses were planted on parts of the area. The USDA Soil Conservation Service designed and supervised construction of water control structures; American Association Limited supplied earth-moving equipment; the State-Federal Welfare, Education, and Training Program provided laborers; and different agencies on the committee provided technical planning, fertilizers, and plant materials. Tree planting and revegetation were supervised by the U. S. Forest Service. Mixed hardwoods were planted on sites subjectively judged "better." Virginia and pitch pine were planted on poorer sites, and black locust was planted on soils judged to be of the poorest, but plantable quality (W. G. Vogel, personal communication). Grasses and fertilization were limited to small areas of the mine which were avoided in this study.

Forest productivity of the mined site was studied in 1983 and the results were published by Wade et al. (1985).

Sampling

Three types of vegetation were chosen for this study: mixed hardwoods, pine, and black locust. Each vegetation type was repeated in plantations in the east, center, and west regions of the mine. Mixed hardwoods consisted of yellow-poplar, sycamore, red oak, white oak, sugar maple, red maple, and green ash in the center plantation, and yellow-poplar, sycamore, and red maple in the east and west plantations. Pine consisted of Virginia and pitch pine in the east and Virginia pine only elsewhere. Black locust was planted as a monoculture, but the stands are breaking up and red maple is now an important codominant.

In each plantation, four sample points were randomly chosen with the constraint that each point would be located on a nearly level surface so as to minimize microtopographic effects. At each sample point, a 500-cm^2 quadrat was placed on the surface of the O horizon and the inside litter was cut free of outside materials. The litter and all organic materials down to the mineral soil surface were collected, bagged, and returned to the laboratory. Thickness of the O horizon was measured at four points on the perimeter of the quadrat and the mean was recorded. A soil pit was dug to approximately 30 cm, and thickness of the developing A horizon was measured. Percent stone content of each horizon was estimated, parent material was noted, and soil structure described. Representative soils in each planting were photographed. Soil samples were taken from the entire thickness of the A horizon. B horizon soils were sampled from the top of the B horizon to 10 cm below the A B interface. Obvious presence of soil fungi, millipedes, and earthworms was noted when they occurred.

Laboratory

Upon return to the laboratory, O horizon samples were oven dried at 65°C and weighed to determine forest floor biomass, ground in a Wiley mill to pass a 0.5-mm screen, then pulverized in a tungsten carbide shatterbox. Mineral soil samples were air-dried, stone was removed, and the remaining soil ground and passed through a 2-mm sieve.

Total nitrogen (Kjeldahl) was determined on subsamples of the O, A, and B horizons (Tecator Inc. 1979). Subsamples of the O horizon were ashed at 500°C and dissolved in 10 percent HCl; and P, K, Ca, Mg, Mn, Fe, Cu, Zn, B, Na, Al, Si, Co, Ti, Ni, Cr, and Pb were determined by DC arc plasma emission spectroscopy. Mineral soils were leached with a double acid extract and P, K, Ca, Mg, Mn, Fe, Cu, Zn, B, Na, Al, Si, Co, Ti, Ni, Cr, and Pb in the extracts were determined by DC arc plasma emission spectroscopy. Organic matter was determined by loss on ignition (Page 1982), and soil pH was determined in 1:1 soil: water (Page 1982). Exchangeable acidity and exchangeable aluminum were determined by the KCl extract method, and conductivity was determined by conductivity meter (Page 1982).

Statistical Analysis

The intent of the statistical analysis was to investigate differences among the soil horizons as well as among vegetation type for the measured soil physical and chemical characteristics. Three types of means were calculated: (1) the mean of each variable for each horizon, (2) the mean of the difference between the A and B horizon for each variable, and (3) the mean of the ratio of the A horizon to the B horizon value for each variable. The A to B horizon ratios were used to investigate vegetation effects on soil development because the original choice of plantation types was not random; mixed hardwood stands had been established on the best planting sites. The ratios express degree of differentiation of soil horizons in spoils of differing quality. One way analysis of variance (ANOVA) was used to determine statistical differences among the means due to vegetation. Variation among locations is included in the error for these tests. Vegetation effects were tested for O horizon values, differences between A and B horizon values, and ratios of A to B horizon values. Paired t-tests were used to test overall differences between A and B horizon values ignoring vegetation type and location. The level of significance for all tests was set at $\alpha = 0.05$ unless otherwise indicated in tables. Data were analyzed using the MINITAB package (Ryan et al. 1982) and SAS (SAS Institute Inc. 1985).

RESULTS

Forest Floor

Distinctive differences in the forest floor O horizon due to forest vegetation type were immediately noticeable. The pine plantations had a thick carpet (overall mean of 3.5 cm) of nearly undecomposed pine needles (table 1). The mixed hardwoods O horizons were significantly ($\alpha = 0.05$) thinner (mean 2.4 cm). The mixed hardwoods and black locust appeared to have better decomposition at the litter: soil interface than did the pine plantations. Fungal mycelia were visible in the lower parts of the O horizon in 67 percent of the pine samples, 42 percent of the hardwoods, and 25 percent of the black locust.

Litter weights (g/m^2) also varied significantly ($\alpha = 0.05$) among vegetation types (table 1). Litter weight was greatest under pine and least under mixed hardwoods.

Soil Weathering

Stone content of A and B horizons was not significantly related to vegetation type, but significant differences were noted in different areas. Stone content of the B horizon did not differ significantly, but there were significant differences in the A horizon. A:B stone values suggest that surface stone in the eastern area has undergone significant decomposition into soil size particles (table 2).

Soil Structure

Soil structure in the A horizon was predominantly weak fine granular under pine and the mixed hardwoods. Black locust stands had mostly weak very fine granular structure in the A horizon.

B horizon structure was predominantly weak, fine, or medium angular blocky to massive under pine. Structure under black locust was more commonly weak, very fine granular to moderate fine granular. The hardwood stands were intermediate to the other stands in B horizon structure.

Horizon Differentiation

Differences in A horizon thickness were not significant among vegetation types ($\alpha = 0.05$) due to the larger amount of variation among sample locations. Site variables other than vegetation were obviously also influencing rate of A horizon formation.

Of the 23 soil chemical variables covered in this study, 15 showed significant differentiation of A and B horizons (table 3).

Soil organic matter analysis was confounded by coal fines and carbon in dark shales (table 3). Organic matter content was high as a result, but this is mostly relatively inert fossil carbon, not the more active humic materials formed from recent biotic activity. Nevertheless, there was an overall significantly greater amount of organic matter in the A horizon, which is consistent with the observed A horizon formation.

Soil reaction differences between horizons has not developed although pH has generally risen since plantation establishment (Wade et al. 1985). There were no

Table 1.--Soil horizon thickness and stone content by vegetation type. (Means are given over standard deviations in parentheses. Means followed by the same letter are not significantly different, ANOVA followed by Tukey's-w, $\alpha = 0.05$. Means not followed by letters indicate no differences due to vegetation effects, ANOVA, $\alpha = 0.05$).

	O horizon thickness (cm)	O horizon mass (g/m^2)	A horizon thickness (cm)	A stone content (%)	B stone content (%)
Mixed pine	3.50 a (0.73)	525 a (144)	1.71 (1.01)	24 (19)	36 (24)
Mixed hardwoods	2.48 b (0.94)	317 b (125)	2.24 (1.07)	20 (19)	24 (17)
Black locust	3.18 ab (0.87)	412 ab (180)	3.06 (2.42)	26 (23)	25 (16)

Table 2.--A:B stone ratios by vegetation type and location. (Upper values are means; lower values are standard deviations.)

Vegetation	Location East	Center	West	All
Mixed hardwood	0.29	1.00	1.00	0.76
	0.48	0.00	0.00	0.43
Mixed pine	0.30	1.25	0.64	0.78
	0.15	0.29	0.31	0.48
Black locust	0.38	1.00	1.34	0.91
	0.43	0.00	0.47	0.53
All	0.33	1.08	1.03	0.82
	0.36	0.19	0.41	0.47

significant differences between horizons in pH, or exchangeable aluminum (table 3). However, the A horizons had significantly greater conductivity and lower exchangeable acidity than the B horizons. This indicates that salts had increased in the A horizons relative to the B horizon, and total acidity due to both H and Al had decreased in the A horizon.

The major plant nutrients nitrogen, phosphorus, potassium, and calcium showed significant accumulation in the A horizon (table 3). Of the minor plant nutrients, magnesium, manganese, zinc, and boron showed significant accumulation in the A horizon. Copper was more abundant in the B horizon. Sodium was significantly higher in the A horizon. Extractable aluminum, silicon, and iron did not show differences between soil horizons. The non-nutritive heavy metals lead, titanium, and chromium showed significant accumulation in the A horizon, but nickel and cobalt did not.

Vegetation Effects on Soil Development

The mixed pine, mixed hardwoods, and black locust stands had significant differences in element concentrations in the O horizon (table 4). Nitrogen concentrations were significantly higher under the black locust stand, probably due to nitrogen fixation. Phosphorus was significantly higher in mixed hardwoods litter than in the black locust litter. Calcium and magnesium concentrations were significantly higher in the mixed hardwood litter than in the other two stand types. Copper, zinc, and nickel were significantly more concentrated in mixed hardwoods and black locust litter than in the pine litter. Silicon was significantly higher in mixed hardwoods litter than in the pine litter.

Vegetation showed significant effects on mineral soil horizon differentiation (A:B horizon ratios) for 8 of the 23 soil chemistry variables (table 5). The mixed hardwoods showed the greatest differentiation in pH values between the A and B horizons. Exchangeable acidity (which includes acidity due to aluminum) tended to be lower in the A horizon soils than in the B horizon, and the differentiation was greatest under mixed hardwoods. The greatest differences in conductivity were under mixed hardwoods. Among the plant nutrients, nitrogen, zinc, and boron enrichment of the A horizon was significantly greater under mixed hardwoods. Sodium enrichment was greatest under hardwoods and least under pine. Of the heavy metals, only nickel showed differential effects of vegetation on A horizon enrichment; it was greatest under the mixed hardwoods.

Soil Fauna

Millipedes, and less commonly earthworms, were noted in half of the pine samples. None were noted in the other two vegetation types.

DISCUSSION

Residual soil development is normally a process that occurs over geologic time periods (Buol et al. 1973). At mined sites, mechanical disruption of consolidated subsurface layers and mixing of materials provides an atypical parent material with much more surface area exposed to weathering. Apart from this, it is expected that soil formation has for the most part followed generally accepted processes on this mine.

Soil development normally proceeds with accumulation of an organic layer over mineral soil and the development of a discernable A horizon. Plant nutrients generally accumulate in mine soils of low initial fertility (Vogel 1987). Other important chemical properties include modification of soil reaction and the liberation and leaching or concentration of potentially toxic materials such as aluminum.

At Fonde, three different criteria, visual evidence of soil horizon differentiation, O horizon chemistry, and mineral soil chemistry all suggested that rapid soil development is taking place.

Visual examination showed obvious differences in the soil profile. The profile had changed from an initially more or less homogeneous mass to a series of three horizontal layers. An O horizon was present on the surface and an A horizon had developed in the upper few centimeters of mineral soil.

The lower part of the profile showed some weathering of parent material although it still resembled the parent mine spoils. For the study, this was termed a B horizon (Wade et al. 1985). Whether or

Table 3.--Chemistry of developing soil horizons arranged in order of strength of differentiation based on T value from paired t-tests of A and B horizon values. A horizon mean value and standard deviation are given above those of the B horizon.

Variable	Unit	Mean	s.d.	T	α
Pb	ppm	2.51 1.53	0.92 0.73	9.45	.001
Conductivity	Mmho	0.151 0.088	0.041 0.032	8.90	.001
B	ppm	0.368 0.152	0.155 0.080	7.52	.001
Organic matter	%	9.82 7.21	3.22 3.42	6.79	.001
P	ppm	12.7 6.1	10.6 7.7	5.81	.001
K	meq/100g	0.255 0.188	0.082 0.040	5.30	.001
N	%	0.340 0.226	0.186 0.139	5.08	.001
Ti	ppm	1.54 1.18	0.43 0.36	4.85	.001
Mn	ppm	133 41	150 37	4.24	.001
Mg	meq/100g	1.94 1.20	1.74 1.02	4.14	.001
Cu	ppm	2.98 4.06	1.64 1.44	-3.67	.001
Exchangeable acidity	meq/100g	4.17 5.05	3.16 3.31	-3.58	.001
Cr	ppm	0.154 0.104	0.101 0.056	3.56	.01
Ca	meq/100g	2.64 0.71	3.52 0.71	3.40	.01
Na	meq/100g	0.044 0.034	0.015 0.010	3.30	.01
Zn	ppm	11.5 7.1	11.7 5.5	2.81	.01
Ni	ppm	4.72 2.70	8.46 1.85	1.61	ns
Co	ppm	1.96 1.60	1.40 0.94	1.92	ns
pH	pH	4.62 4.50	0.67 0.52	1.93	ns
Fe	ppm	138 131	87 77	0.77	ns
Al	ppm	462 444	337 369	0.53	ns
Exchangeable Al	meq/100g	4.70 4.07	10.4 3.0	0.41	ns
Si	ppm	19.5 20.2	15.3 10.6	-0.29	ns

Table 4.--Element concentrations in the O horizon under different vegetation types. (Mean values are given above standard deviations in parentheses. Means followed by the same letter are not significantly different; Tukey's-w following ANOVA, α = .05).

	N	P	K	Ca	Mg	Mn
	%	ppm				
M. pine	1.59 b (0.55)	944 ab (182)	831 (305)	2432 c (1327)	678 b (1113)	2333 (856)
M. hardwood	1.53 b (0.28)	1069 a (214)	1108 (299)	5093 a (1173)	2576 a (1327)	1944 (963)
B. locust	2.20 a (0.52	875 b (155)	881 (881)	3853 b (1634)	854 b (812)	1793 (996)

	Fe	Cu	Zn	B	Si	Na
	ppm					
M. pine	7123 (5242)	9.9 b (2.7)	66.0 b (24.7)	31.6 (9.1)	3972 b (1013)	95 (35)
M. hardwood	9294 (6865)	16.2 a (4.8)	128.9 a (90.5)	37.1 (5.3)	5151 a (716)	114 (22)
B. locust	5616 (3254)	15.8 a (4.2)	176.9 a (59.4)	36.4 (5.6)	4544 ab (1081)	105 (32)

	Al	Co	Ni	Ti	Cr	Pb
	ppm					
M. pine	4721 (2274)	8.3 (3.3)	21.9 b (6.8)	62.8 (17.2)	9.2 (3.1)	41.4 (17.4)
M. hardwood	4166 (3467)	15.2 (10.9)	39.1 a (17.6)	78.1 (19.9)	11.1 (3.0)	37.9 (3.2)
B. locust	4571 (2805)	12.2 (5.0)	34.8 a (11.8)	69.9 (20.4)	9.1 (2.8)	41.1 (10.6)

not significant weathering of primary minerals in the B horizon has occurred, there has been some structure formation and an obvious "uncementing" of particles of sedimentary rocks. (The mining process that shattered this parent material could be called the primary "weathering" process.) Time required for rock weathering is not necessarily long. Hilger (1897 cited in Jenny 1941) exposed rock particles 10-20 mm in diameter to the atmosphere for 17 years. Stuben sandstone became 90 percent soil size particles (< 0.5 mm) in that time. Jenny (1941) gives several other examples of rapid physical weathering as well as examples of rocks with high stability. Differences in A:B stone ratios in the different areas of the mine indicate that local site differences such as parent materials and microclimate might be affecting rock weathering. Geyer and Rogers (1972) and Schafer et al. (1980) noted rapid weathering of spoil rock into soil-sized particles.

Differentiation of A and B horizons occurred in less than 22 years. Expected differences in the rate of A horizon development under different vegetation types could not be proved due to the high amount of variation within plantations and between different areas under the same vegetation type. We suspect that microclimate, parent material differences, and erosional removal rates at least are confounding factors. The mean A horizon thickness for all sample points was 2.3 cm. Davidson (1981) studied soil development on 45- to 60-year-old surface mines in Pennsylvania. He found A and B horizon mean thicknesses of 5.3 cm and 21.2 cm developed under pine and spruce plantations that were being invaded by hardwoods. Thomas and Jansen (1985) found 10 cm A horizons in 50- to 64-year-old mine spoils. A spoil composed of loess in Iowa developed a 31 cm A

Table 5.--Vegetation effects on soil horizon differentiation expressed as means and standard deviations (in parentheses) of A horizon:B horizon ratios. (Means followed by the same letters are not significantly different: ANOVA followed by Tukey's-w, α = 0.05. Means not followed by letters did not show significant differences due to vegetation: ANOVA, α = 0.05).

	pH	Cond.	Exch. Acid	Exch. Al	O.M.	N	P	K
M. pine	1.02 b	1.47 b	0.84 a	1.24	1.44	1.30 b	2.38	1.29
	(0.04)	(0.31)	(0.17)	(1.47)	(0.78)	(0.58)	(0.96)	(0.36)
M. hardwood	1.09 a	2.42 a	0.50 b	0.38	1.94	2.50 a	3.00	1.59
	(0.09)	(0.83)	(0.47)	(0.44)	(0.78)	(1.15)	(2.25)	(0.44)
B. locust	0.97 c	1.68 b	1.00	0.93	1.37	1.57 b	2.87	1.29
	(0.04)	(0.58)	(0.22) a	(0.24)	(0.46)	(0.48)	(2.23)	(0.51)
	Ca	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**	**B**	**Si**
M. pine	3.79	1.66	5.80	1.40	0.76	1.31 b	1.72 b	0.89
	(2.27)	(0.57)	(2.73)	(0.76)	(0.26)	(0.63)	(0.70)	(0.35)
M. hardwood	4.84	2.54	3.89	0.84	0.79	3.17 a	4.18 a	0.83
	(4.09)	(1.61)	(2.81)	(0.57)	(0.53)	(2.57)	(1.87)	(0.17)
B. locust	6.28	1.54	3.18	1.30	0.76	1.36 b	1.87 b	1.82
	(10.81)	(0.64)	(2.32)	(1.01)	(0.28)	(0.66)	(0.66)	(3.09)
	Na	**Al**	**Co**	**Ni**	**Ti**	**Cr**	**Pb**	
M. pine	1.10 b	0.96	0.94	1.29 b	1.21	1.44	1.74	
	(0.46)	(0.32)	(0.27)	(0.71)	(0.35)	(0.50)	(0.55)	
M. hardwood	1.76 a	1.23	1.75	2.71 a	1.56	1.78	1.98	
	(0.51)	(0.61)	(1.08)	(1.82)	(0.41)	(0.84)	(0.62)	
B. locust	1.32 ab	1.24	1.19	1.17 b	1.31	1.60	1.68	
	(0.73)	(0.42)	(0.84)	(0.63)	(0.45)	(1.15)	(0.69)	

horizon in 100 years (Hallberg et al. 1978).

A horizon thickness was determined visually from color differences in the sides of the soil pits. The A horizon organic matter content was significantly greater than that of the B horizon. Coal fines and carbon in dark shales caused great variability in the data so that more subtle vegetation effects could not be determined.

Soil reaction and salts content has decreased since vegetation establishment (Wade et al. 1985). There was no overall significant differentiation in soil reaction between mineral soil horizons, but testing for vegetation effects showed significant differences. A and B horizon ratios of pH, conductivity, and exchangeable acidity (which includes acidity due to aluminum) were greatest under mixed hardwoods; differentiation under other vegetation types was significantly less. Lack of overall differentiation may be due to opposite trends under hardwoods vs. pine.

Accumulation of major plant nutrients in the A horizon is probably due in part to a "pumping action" (Black 1968, Klopatek 1978) by vegetation. This differentiation of nutrients can be detected after only a short period, at least for K (Wade 1985). Another possible mechanism of surface concentration is by soil solution movement to and evaporation from the soil surface. This is probably the case for salt accumulation. A third mechanism is accelerated leaching of ions from the B horizon (Birkeland 1974). Because some differences can be related to vegetation type in this and other studies (Wade 1985), it is suspected that all three mechanisms are operable here. Hallberg et al. (1978) and Thomas and Jansen (1985) also found A horizon accumulation of P in spoils.

Potassium enrichment of developing A horizons in spoils has also been documented by Shafer et al. (1980) and Thomas and Jansen (1985).

Minor plant nutrients have followed the pattern of the major nutrients except for copper. It may be that copper levels in the soils were initially well above the requirements or usability of vegetation and that downward leaching has exceeded surface deposition by vegetation.

The extent of differentiation between soil horizons differs considerably between elements. Based upon magnitude of mean horizon differences and the consistency of that differentiation (ranked by T values from paired t-tests, table 3), lead, conductivity, boron, organic matter, phosphorus, potassium, and nitrogen best differentiated the mineral soil horizons. Elements such as iron, silicon, and aluminum, which tend to form insoluble hydroxides in soil environments were least differentiated between horizons.

Jenny (1941) cites many examples and mechanisms of vegetation effects on soil development. He shows how different vegetation types can have significant effects in a few decades. The results of this study follow what Jenny's examples predict, particularly in visible attributes of O and A horizon development. Vegetation has three possible mechanisms for causing differential soil horizon development: (1) Plant species differentially remove elements from the soils. These element use ratios are preserved in litterfall and can affect soil surface chemistry through litter leaching and decomposition. (2) Plant species with nitrogen-fixing symbionts increase nitrogen availability in the soils and alter the availability or mobility of other elements that are tied up in organic matter. This additional nitrogen also alters magnitudes of many biological processes. (3) Some plant species produce litter rich in organic acids or chelating agents that alter the weathering and leaching patterns of the surface soils.

The suspected better original fertility or more favorable soil reaction and parent material of the mixed hardwoods plantations <u>may</u> have been responsible for the greater degree of horizon differentiation seen there. However, the higher nitrogen fertility of the black locust did not lead to greater differentiation between horizons. So, initial fertility differences <u>per se</u> can't be used to explain away <u>significantly</u> greater differentiation of nitrogen, zinc, boron, sodium, and nickel under mixed hardwoods. Vegetation effects may well have been a major operative factor. More research is needed to settle the question of the relative influences of initial fertility vs. vegetation on soil development.

The thickest and heaviest O horizons developed under pine; the thinnest and lightest developed under mixed hardwoods. These O horizons may well differ in organic acid release, insulating properties, and absorption of water before it reaches the soil surface during precipitation events. It is expected that differences in concentrations of O horizon elements will emphasize differences in A horizon element concentrations and development as the decay of O horizon organic matter progresses. Nutritive and nonnutritive elements were generally more concentrated in the O horizon by a factor of 10 over the available amounts in the A horizon. Vegetation type showed significant influences on N, P, Ca, Mg, Cu, Zn, Si, and Ni concentrations in litter. The O horizon differences in nutrient capital sequestration will be examined in the near future.

There are now numerous reclaimed surface mines with diverse parent materials, topographic positions, surface treatments, and established vegetation types two or more decades in age. These should now be studied to determine the effects of different reclamation practices on soil development and site productivity.

SUMMARY AND CONCLUSIONS

This study of soil development under forest plantations on a surface mine showed that O and A horizons had developed over B horizons in 22 years or less. In that time, a large proportion of surface stone had weathered to soil-sized particles on some areas of the mine.

The O horizon was significantly thickest and heaviest under pine. The mean A horizon thickness was quite variable around a mean of 2.3 cm and was unaffected by vegetation type after 22 years. A horizon organic matter content was 2.6 percent greater than that of the B horizon. Soil structure has developed in the A horizon and also was visible in some of the B horizon samples.

Soil pH generally increased since plantation establishment. There were no overall pH differences between A and B horizons, but there were significant A:B pH differences among vegetation types. Soil conductivity was greater in the A horizon, and effects attributable to vegetation were evident.

Major and minor plant nutrients (except for Cu) are more concentrated in the A horizon than in the B horizon. Heavy metals Pb, Ti, and Cr were significantly more concentrated in the A horizon; Ni and Co were not. Iron, Si, and Al showed no horizon differentiation.

Vegetation type appeared to have significant effects on horizon A:B ratios in available N, Zn, B, Na, Ni, and pH, exchangeable acidity, and conductivity. O horizons had significant differences in concentrations of N, P, Ca, Mg, Cu, Zn, Si, and Ni attributable to vegetation type.

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