MINERAL ANALYSES OF SOILS AND FOLIAGE COMPARED TO THE GROWTH OF PINUS RESINOSA AND BETULA PENDULA

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The levels of available soil nutrients and levels of the same ions in the foliage of the plants are determined through atomic absorption spectrophotometry. These analyses are compared and related to growth of Pinus resinosa and Betula pendula. B. pendula contains higher levels of potassium, calcium, and magnesium than P. resinosa. Manganese also occurs in greater abundance in the former, but leaches quickly from the litter formed by leaf drop from this species. Iron does not appear to be limiting in either species and may favorably affect the growth of both.

Additional key words: Mine soils; litter production; Pennsylvania

Introduction

Reclamation practices devoted to amending the condition of the land and renewing vegetation growth, on essentially infertile mineral soil, have been developed through years of research and trial application. Following World War II, trees were used as the predominant means of restoring the land to productivity. This proved quite feasible, especially in retaining a reasonable amount of stability at a low cost. Species were selected for their tolerance to low pH and ability to survive without soil amendment. For these reasons, early plantings consisted largely of pine. Pinus resinosa, Ait., (red pine), the object of this study, was widely planted by the Pennsylvania Department of Forests and Waters and the Civilian Conservation Corps in the late 1940's and 1950's, and grew well as an exotic in Clarion County. In addition, pines furnished cover, browse, seed for wildlife, and screens for highwalls. Few other species were found to exhibit reasonable growth under the conditions provided by strip-mine spoil.

Within a few decades of the early plantings, it was realized that the stabilization of the soil was not achieved by the trees, and erosion and runoff continued to occur. Unable to provide substantial benefits, certain species, viz. pines were practically eliminated as routine practice, and were superceded by various herbaceous species that furnished favorable cover and quick stabilization. Herbaceous vegetation combats erosion and eventual sedimentation that may arise from steep slopes. The deemphasis of tree planting was to such an extent that, with the passage of the 1971 Surface Mining and Reclamation Act, trees were not required unless the slopes generated were in excess of 20°. With such conditions, both grass and tree treatments were required; however, many tree seedlings could not compete with the grass and other herbaceous plants (Pitsenbarger, 1980).

An abundance of research has been directed toward evaluating modes of reclaiming land, primarily as trial-and-error attempts. Minimal attention has been given to the study of conditions of mine spoil as integrated systems. One objective of this study is to evaluate the growth of a species--considering the soil components-and derive information regarding the quality of the soil, most beneficial to a particular species, when given conditions of mine spoil.

The scope and intent of this study is to consider the growth of Pinus resinosa on reclaimed mine spoil, relative to the nutrients and supposed toxicants in the soil and foliage of the trees. Also determined are the nutrients in the litter fall and the effect these have on the growth of the tree, and particularly, their contribution to the soil. Data provide a generalized site condition that describes all factors that may contribute to the productivity of the soil and growth of the trees.

The ecosystem dynamics exhibited by this growth will be reflected in the amount of litter accumulated, and the nutrient composition of the litter. The present study involves all of these in order to view the reclaimed land as a biological system, and not as an unnatural, contrived situation.

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The direct effect of surface mining on soil is a drastic alteration of the various components that form a normal soil profile. A once-distinct delineation of horizons is disrupted into a heterogeneous conglomeration of broken strata and mineral spoil of inferior quality. The spoil material is composed of stones of various sizes, shale fragments, and some silt, sand, or clay particles. With no ordinary channels for water percolation, runoff is a commmon problem. Analyses of spoil banks usually indicate limited quantities of major nutrients, especially nitrogen and phosphorus. The main factors associated with establishment and growth have been identified as chemical and physical properties and topographical factors; any of these, or a combination of all can serve to inhibit vegetation (Thompson and Troeh, 1973).

The physical properties are most adverse when the spoil is a mixture of the overburden, and is course in texture, stony, and unable to retain water at the surface. Texture, defined as the particle distribution of sand, silt, and clay affects moisture, aeration, and compaction. It is dependent on the structure of aggregates, and hence, affects plant growth by interfering with water potential.

The assessment of soil fertility is ultimately expressed in growth of the plant it supports, and is reflected by the nutrients in the plant and soil. It seems reasonable to suppose that analysis of mineral content of soil would be an indicator of the nutrient supply available for tree growth.

Pioneer foresters in late nineteenth century Europe developed the idea that measurement of the chemical constituents of vegetation would provide information about nutrient removal from a forest, and that the relative fertilities of soils could be established when the species growing on different soils were compared. It is now recognized that determination of the amount of nutrients in a forest biomass is necessary, but does not always reflect the level of soil fertility (Armson, 1977).

When dealing with mined-land reclamation, it is important to assess the long-term results and future potential of the land. Following mining procedures, there is a re-establishment of organisms and secondary succession ensues. Krzysik et al., (1981) determined that the major critera in evaluating a suitable reclamation process should be that which insures the development of wildlife habitats. This includes providing conditions suitable for invasion or colonization by desirable species. Successional development follows and this necessitates creation of litter and development of a nutrient-enriched soil.

Results and Discussion

The initial portion of the study reported here was completed in 1971 as part of the doctoral research of the senior author, at the University of Pittsburgh. Later in 1980, Muzika completed the second part of the study while a graduate student at Clarion University and reported that information in her master's thesis.

Mineral analyses of some spoils planted from 1946 to 1952 were made with a Lamotte-Purdue soil testing kit prior to planting. This information was made available to the authors by Dan Dunmire of Rimersburg, now deceased. These data show a wide range of nitrate nitrogen, potassium, and phosphorus, with a surprising number of sites of relatively high nutrient content (Table 1). Approximately 50% of the sites, on Clarion coal spoils, exhibited a nitrate level in excess of 8 pounds per acre. Phosphorus occurred in 67% of these sites at levels above 160 pounds per acre, while potassium exceeded 400 pounds per acre in over half the sites.

In more than a third of the soil samples (35%), phosphorus was present in very small quantities (less than 1 microcrogarm per gram of soil). One Clarion site contained an abundance of phosphorus (over 20 micrograms per gram of soil), but relatively few of the Kittanning samples showed sufficient quantities (over 5 micrograms per gram of soil), with most having less than 0.5 micrograms per gram of soil. The analytical procedure of phosphorus analysis is open to question and one might well doubt both the data of the earlier study and the present one. Much of the literature, however, seems to support the results of Dunmire's analyses.

The potassium values in the present study corroborate the 1950 data. Potassium content, in all Clarion County spoils tested, appears well above the minimum requirements (25 ppm). The potassium is present in larger amounts in the Kittanning spoils, wile the Clarion coal spoils contain larger quantities of phosphorus (Table 2).

Significant differences also exist between the two spoil types considering magnesium and sodium. All of these occur in larger quantities in the Kittanning spoils than in the Clarion. Results of the analysis for calcium do not show significant difference between the two spoil types (Table 3).

The toxic elements iron, manganese, and aluminum are present in quite large quantities. Iron does not appear to be as readily available as in the spoils studied by other authors. In only two cases does extractable iron exceed 50 ppm. It is unlikely that iron is toxic to the trees on these spoils. There is no significant difference in the mean extractable iron of the two spoil types (Table 4). Presumably, the iron is in an insoluble form, and upon oxidation, is immediately leached and is not readily available to plants. The iron in the leacheate is, however, reprecipitated in streams throughout the mining area, causing the red color so characteristic of Clarion County streams. One soil sample collected from a recently stripped area, contained such a high iron content, as to transmit considerable color to the extracting solution. This may indicate why iron is often reported in greater concentrations from mining wastes.

Aluminum may well be toxic for it is present in larger quantities than iron. The Clarion #3 site does not have an abundance of aluminum. In some of the samples from other Clarion sites, available aluminum exceeds 20 ppm, while at least 10 ppm occur in about half the samples. Kittanning sites exhibit even higher aluminum values. In both, large standard deviations from the mean occur.

Manganese occurred in quantities over 5 ppm in 88% of our Clarion spoil samples and in all the Kittanning spoils. In most of these samples, manganese exceeded 10 ppm. The Kittanning spoils are significantly higher in manganese than those of the Clarion coal.

Comparison of the two spoil types by foliar analyses shows only aluminum content to differ significantly at the one percent level. The trees on the Kittanning spoil have a larger mean aluminum content than those of the Clarion spoil. Foliar calcium and sodium differ by amounts which are significant at the five percent level. Trees grown on the Clarion spoils have a higher calcium and sodium content. Results of the other analyses do not exhibit any significant differences in the means (Table 4).

Regression analyses were run for growth parameters and mineral analyses. Iron proved to have a positive regression coefficient on height growth, suggesting that iron was not toxic, but likely beneficial to the growth of the pines on these spoils. Manganese, on the other hand, gave a negative regression coefficient. We are suggesting that manganese may be partially responsible for the difference in height growth between the Clarion and Kittanning spoils. Manganese showed a similar correlation with DBH as with height.

It is interesting to note that a far larger array of soil and foliar parameters have a significant effect on the diameter of trees. There appeared to be a positive and significant relationship between aluminum and DHB. We had been expecting a negative regression coefficient as aluminum was suspected of being toxic to the pines. Calcium also surprised by showing a negative coefficient with DBH.

There exists in the literature reference to an excess of magnesium causing a deficiency of calcium by inhibited absorption. One might expect, therefore, a negative relationship between growth parameters and magnesium. This was indeed true in this case. We have assumed that this may account for some of the apparent negative affect of calcium.

Negative regression coefficients for both sodium and potassium are produced by the regression of DBH on these parameters. One must question how sodium, and more particularly, potassium may come to affect plant growth in a negative fashion (a matter to be discussed below).

It is interesting to note that some factors that are not related to height can be related to site index, which is based on a five-year height increment (the five-year intercept). Site index is positively related to magnesium. Sodium content, which could not be related to height, can be related to site index. As they were with DBH, sodium and potassium are negatively correlated to site index. Reference has been made to sodium toxicity on alkaline soils and with mention of unfavorable soil structures. This may hint at the underlying problem, when total salts appear to be a measure of soil toxicity.

When we formed regression analyses with foliar nutrients on growth parameters, we found that foliar nitrogen was related to DBH, but had no effect on height. Foliar aluminum, on the other hand, was found to be negatively correlated with DBH. The reader will recall a positive relationship between soil aluminum and DBH.

It was this relationship with the foliar nutrients that led to the question of cause-and-effect relationship between soil nutrients and foliar nutrients. When we compared these parameters in the more recent study, we suspect that the litter produced by the trees may be responsible for the available nutrients in the surface soil beneath the trees. In this study, birch (Betula pendula) was compared to pine (Pinus resinosa).

Soils beneath the birch appeared to have greater concentrations of manganese, while the soils beneath pines seemed to contain more calcium. In general, the soils were far less variable than either the foliage or the litter.

The litter of the birch trees bears greater amounts of the essential macronutrients than the litter from the pine. In this study, there was significantly more calcium and manganese in the birch litter. The difference in potassium concentration did not prove to be significant. Pine litter does appear to have a greater concentration of iron.

Nutrients in vegetation and soils can be strongly affected by species, and hence, forest tree species exert an important effect on fertility of soil. Soil changes caused by vegetation occur primarily in the surface soil, of the forest floor and are frequently the direct result of nutrient uptake by the forest vegetation. Generally, hardwoods absorb more nutrients from the soil and return a higher percentage of these in leaf fall than do the conifers. This study tends to support this statement.

The soil characteristics depend on the rate at which these nutrients are made available, primarily by decomposition. Decomposition is the result of microbial degradation and interactions of soil invertebrates and occurs with a varying time factor in different situations. The physical components of the soil also play an important role in determining the amount of an element that is retained or made available to the plant.

Of the three, foliage, litter, and soil, the soil tends to be the least variable, as indicated by the lack of difference in magnesium and iron concentrations of soil under the pine and birch. Birch soils contained more manganese and potassium, while pine soils accumulated calcium. The latter is peculiar in that hardwoods usually favor accumulation of this element in the surface soil. The higher calcium content should favor decomposition, but apparently, the higher concentration of calcium in the litter itself allow for birch decomposition to exceed that the pines.

Alban (1974) reports the largest mineral differences under different species tend to be attributable to calcium. A greater amount of calcium was evident in soils beneath Pinus, than other genera, such as Poplus and Picea, in that study. The present study indicates that calcium was the element that occurred in greater quantity in soils under pines than under birches. The calcium "missing" from the birch soils may be that in the foliage.

The calcium in the soil of pines may, in part, represent unavailable calcium brought into solution by the extracting process, and hence, it may not be an indication of the calcium uptake by the tree. This quantity could represent an immobile pool of nutrients, as opposed to that calcium in the components of birch, which is translocated from the soil to the foliage, and eventually, to the litter. The possibility exists that the spoil on which the pines grow may have been treated with excess lime, which could remain bound in the soil. Also, sampling error is difficult to avoid when dealing with reclaimed land. A primary reason being that spoil amendments are applied in a clumped manner and are not randomly dispersed throughout the area.

The soil analyses indicate that the spoil possesses less manganese and iron than other elements. Berg and Vogel (1968) report that manganese may be toxic at low pH in quantities ranging from 1 to 50 ppm. The range on the pine site of the present study, from 3.4 to 9.6 ppm (Table 5), and for birch of 4.4 to 44 ppm (Table 5), were all in excess of toxic levels. The general rule is that sufficient concentrations of iron and manganese in solution may be toxic to plants when the pH falls below 5 (Brady, 1974). The growth of the trees, on our sites, is probably extremely less than optimum.

Product-moment correlations of soil minerals with those of litter and foliage illustrate the equality of the relationships of the concentrations, or even if such relationships exist. An inverse correlation of soil and litter indicates that the mineral material is not being transported to the root zone as rapidly as translocation by the tree occurs. Since the foliage eventually becomes litter, the correlation of soil minerals with either should also indicate a correlation with the other.

Manganese concentration of birch soil and litter were inversely related, but there was no significant correlation of soil and foliage manganese. Reasons for the inverse relationship may be the rapid leaching of manganese from the litter and through the soil to a point below which the soil sample was taken. The manganese (and other metals) displays increased solubility because of the low pH of the spoil, and is thus transported to the lower soil levels rapidly. Since the birch litter is more mobile in the wind than is pine litter, it may not directly effect the surface soil.

Possibly toxic concentrations of manganese occur in soil, foliage, and litter, in the pine community. The expected correlations exist there. Calcium concentrations in soil and foliage show a positive correlation, but there was corresponding correlation between litter and soil. Calcium may leach from the foliage to the soil, or it may be so readily mobile that it leaches from the litter immediately after litter fall.

The calcium concentration of the birch litter and foliage varies with the soil concentration. This the only situation that presents a somewhat uniform distribution. The tree that exhibited the highest amount of calcium in the litter also had the greatest amount in the soil and foliage.

Iron concentrations in the pine soil are inversely correlated with the iron in the foliage. This indicates that the trees with the highest concentration of iron in the litter and foliage have the least in the soil. Iron obviously remains bound in the foliage and litter. There may be some degree of leaching from the surface soil under the pines. The birch community does not yield any correlations with this element.

Conclusions

Confiers tend to be accumulator plants (Fortsque and Martin, 1970). This means that large quantities of elements, removed from the soil may be stored in the annual wood or bark of the tree, and remain unavailable for the remainder of the life of the tree. Foliage also remains on the tree longer and the litter is more slowly decomposed. Accumulator plants may remove elements from the soil to the xtent that a nutritional imbalance is created in the ecosystem.

Although pines have been used in reclamation practices for many years because of their tolerance to the adverse conditions and may be returning to favor because of their timber value, it would seem that their ameliorating effect is minimal, considering ecosystem function. The tree components, in this study, contain more manganese, which is transferred to the surface soil, causing toxic conditions for other vegetation.

The complexity of the ecosystem is obvious. Litter accumulation and decomposition, organic matter, mineral matter, and other abiotic factors, all act independently, yet, independent phenomena dictate the degree to which interactions occur.

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TABLES

Table 1. Macronutrient analyses of Clarion coal seam spoil. Data from Dan Dunmire, in the senior author's possession.

Nutrient Levels	Nitrate		Phosphorus		Potassium	
	Range	No. of Sites	Range	No. of Sites	Range	No. of Sites
Very High	12-16	10	200-	20	500-	16
High	8-12	10	160-200	6	400-500	6
Medium	6-8	8	80-160	6	200-400	8
Below Medium	4-6	6	*	*	*	*
Very Low	2-4	4	30-80	0	80-200	9
Extremely Low	0-2	5	0-30	11	0-80	4

Table 2. Soil analyses for potassium and phosphorus, 1970. Mean values recorded in units micrograms/gram of soil.

Site Number	Potassium	Phosphorus
C-1	1.6	39.5
C-2	0.5	44.1
C-3	24.0	89.4
K-1	7.6	84.8
K-2	0.5	94.2
K-3	18.0	79.2

Table 3. Soil analyses for sodium and magnesium, 1970. Mean values recorded in units micrograms/gram of soil.

Site Number	Sodium	Magnesium
C-1	24.4	10.3
C-2	15.3	15.6
C-3	29.0	30.2
K-1	29.0	31.6
K-2	29.0	31.2
K-3	27.4	31.4

Table 4. Comparison of spoils through mineral analyses.

	Clarion Spoil		Kittanning Spoil	
	Mean	Standard Error	Mean	Standard Error
Soil Fe	2.671	0.085	2.315	0.245
Soil Mn	15.243	1.876	25.949	1.903
Soil Mg	19.186	1.612	31.474	0.213
Soil Al	9.400	1.624	14.885	2.971
Soil Ca	510.712	80.146	589.169	44.837
Soil Na	23.600	1.168	28.731	0.269
Soil K	59.343	4.466	84.564	3.333
Soil P	0.960	0.238	0.331	0.974
Plant Mn	197.436	16.413	224.103	15.638
Plant Mg	932.820	29.089	943.589	26.561
Plant Al	226.667	14.082	324.865	16.716
Plant Ca	4767.179	140.156		
Plant Na	133.846	17.559	5376.615	7.397
Plant K	4526.666	72.627	4505.000	90.229
Plant P	1818.461	74.501	1877.368	54.807
Plant N	1.533	0.040	1.465	0.037

Table 5. Soil analyses under both birch and pine on Clarion spoil, 1980. Mean values in ppm.

	K	Ca	Mg	Mn	Fe
Pine Soil	80.0	205.96	26.67	5.777	1.064
Birch Soil	106.77	58.55	23.62	17.608	0.569