CHEMICAL PROPERTIES OF TOXIC STRIP-MINE SPOIL BANKS IN PENNSYLVANIA

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Strip mining is a relatively safe and efficient method of mining bituminous coal. Nevertheless, many problems are created when the overburden is removed to get at the coal. The stripped area may be subject to runoff and erosion if not backfilled properly and revegetated. In addition to the silt from eroded areas, chemical substances leached from the spoil banks may further pollute the streams.

In 1945, the Pennsylvania Legislature passed the Conservation Act, which required reclamation of stripped areas. With consequent amendments the act now states that all stripped areas must be backfilled, graded, planted, and inspected by a Land Reclamation Board. For most of the strip-mined areas, revegetation has been satisfactory. Decades of research and experience have resulted in improved planting practices and the selection of the best performing species (Research Committee 1965). Yet, there are a substantial number of strip-mined areas which cannot be revegetated successfully by present methods. These spoils are characterized by being highly acid. However, it is possible that the revegetation failures are a result of toxic substances or lack of essential nutrients rather than acidity *per se*. For example, aluminum and manganese become soluble under conditions of high acidity and could possibly reach toxic concentrations (Berg 1965).

There have been few reports on either the actual chemical concentrations or the concentrations which limit plant growth on the highly acid spoils. Therefore, selected toxic spoils were analyzed to provide basic information for subsequent plant growth studies.

In Pennsylvania, four major coal seams, the Lower Kittanning, Middle Kittanning, Clarion, and Brookville, produce the most troublesome spoils. All are generally highly acid although there may be considerable variation in conditions from one area to another within the same bank. From each of these spoils five samples were collected from the surface layers of typically toxic portions. Five samples were also collected from a non-toxic spoil on the Lower Freeport coal seam. Since only one bank from each seam was sampled, no estimate of the variation between banks within the individual seams could be made. Each of the spoil samples was analyzed for pH, soil texture class, lime requirement, nitrogen, phosphorus, soluble salts, and exchangeable calcium, magnesium, potassium, iron, manganese, and aluminum. Since we were interested in the spoils primarily as a plant growth medium, agronomical analyses were made.

Among the first analyses made were pH determinations, since the majority of revegetation failures occur on spoils with a pH value below 4.0 (Wheeler 1965) and the availability of ions to plants in the soil is profoundly affected by the hydrogen ion concentration. The pH's were measured using a glass electrode pH meter with a 1:1 soil:water ratio (Jackson 1958). According to this technique, the pH values of most soils lie in the range between pH 4.0 and pH 8.5. The pH's of the toxic spoils were all well below pH 4.0 -- Brookville 3.3, Lower Kittanning 3.1, Middle Kittanning 2.9, and Clarion 3.1. In contrast, the non-toxic Lower Freeport spoil had a pH value of 5.2.

Also of major importance in soil chemistry are the exchange properties of soils which are dependent on the nature of the soil colloids. Since clay soils possess high surface areas per unit volume, they have higher cation exchange capacities (Slabaugh 1952) as well as different physical properties than those of coarse-textured soils. Hence, a mechanical analysis was made of the spoil material.

The material was first dry-sieved to determine the percentage by weight of soil-size particles (diam < 2mm). The percentages were as follows: Lower Freeport, 55; Brookville, 66; Lower Kittanning, 65; Middle Kittanning, 54; and Clarion, 55. Using the hydrometer method of separation (Bouyoucos 1928), the soil was fractionated into various groups of separates, and a textural designation based on the relative distribution of the soil separates was determined (Table 1). On the spoils studied, texture is evidently not a limiting factor since at least half the particles were of soil size and had a particle distribution in a loam class.

Table 1. Mechanical analyses of selected strip-mine spoils in Pennsylvania.

Seam	Sand	Silt	Clay	Texture Class
	percent	percent	percent	
Brookville	50	25	25	Sandy clay loam
Lower Kittanning	46	28	26	Loam
Middle Kittanning	33	32	35	Clay loam
Clarion	30	29	41	Clay loam
Lower Freeport	32	42	26	Loam

Both clay content and pH influence the cation exchange capacity (CEC) of the soil. This term refers to the capacity of a soil to absorb and hold the cationic nutrient elements that are used by plants. More precisely, it is a measure of the total quantity of negative charges per unit weight of soil and is equal to the sum of the exchangeable hydrogen and the exchangeable bases. The measured CEC varies somewhat according to the nature of the cation employed, the concentration of the salt, and the equilibrium pH. Hence it is not a highly exact but rather an equilibrium measurement under chosen conditions.

Exchangeable hydrogen was determined according to the method of Woodruff (1947) employing a buffered solution and glass electrode. The exchangeable bases were leached from the sample materials according to the method of McLean et al. (1965), and their concentrations were determined by atomic absorption spectroscopy. The results are presented as milliequivalents per 100 grams of soil in Table 2 and parts per million in Table 3.

Table 2. Exchangeable concentrations of cations and CEC in milliequivalents per 100 grams of soil on selected strip-mine spoils of Pennsylvania.

Cation	Brookville	Lower Kittanning	Middle Kittanning	Clarion	Lower Freeport
	me/100g	me/100g	me/100g	me/100g	me/100g
Ca	0.51	0.20	0.22	0.28	3.20
Mg	1.06	0.42	0.53	0.47	1.12
K	0.51	0.39	0.44	0.38	0.35
Fe	0.13	0.10	0.26	0.25	0.09
Mn	0.05	0.01	0.01	0.02	0.21
Al	1.00	1.60	2.01	2.18	0.05
H	12.00	16.00	16.00	16.00	6.00
CEC	15.26	18.72	19.47	19.58	11.02

Table 3. Exchangeable concentrations of cations in parts per million on selected strip-mine spoils of Pennsylvania.

Cation	Brookville	Lower Kittanning	Middle Kittanning	Clarion	Lower Freeport
	ppm	ppm	ppm	ppm	ppm
Ca	102	41	44	56	640
Mg	126	50	64	56	135
K	199	154	172	149	136
Fe	37	28	72	71	26
Mn	13	2	2	4	58
Al	90	144	186	197	5
H	120	160	160	160	60

A comparison of the spoils reveals that the toxic spoils as a group differed from the non-toxic spoil in the cation exchange capacity and in the concentrations of hydrogen, calcium, manganese, and aluminum. Although the four toxic spoils had higher exchange capacities than the non-toxic spoil, this was mainly a result of their much higher hydrogen concentrations. The essential nutrient calcium was very low on the toxic spoils in comparison to the non-toxic spoil. Since the potentially toxic manganese was considerably higher on the non-toxic spoil, it could be eliminated as a potential cause of the toxicity on the other spoils. However, another potentially toxic element, aluminum, was considerably higher on all of the toxic spoils. On three of the spoils, Lower Kittanning, Middle Kittanning, and Clarion, the low concentrations of magnesium could contribute to the revegetation failures. Neither potassium nor iron differ sufficiently among the spoils to be probable limiting factors.

Because of the high concentration of hydrogen ions and the low calcium content, the lime requirements of the toxic spoils are quite high. Based on the Woodruff (1947) method, it would take 6 tons of lime per acre on the Brookville, 8 tons on the Lower Kittanning, 8 tons on the Middle Kittanning, and 8 tons on the Clarion to neutralize the exchangeable hydrogen.

Concentrations of two additional essential growth elements, nitrogen and phosphorus, were also quite low on the toxic spoils (Table 4). Total nitrogen was determined by the Kjeldahl method (Bremner 1960), and phosphorus, by the extraction method developed by Bray and Kurtz (1945). Although the concentration of nitrogen on the Lower Freeport spoil exceeded that of the toxic spoils by an order of magnitude, it is still low in comparison to average cultivated soils.

The soluble salt content was determined by measuring the electrical conductivity with a Solu Bridge (Beckman Instruments Inc. 1967). As used in soils, this term refers to the inorganic constituents that are appreciably soluble in water. A well fertilized field soil optimum for plant growth would be between 1.0 and 2.0 millimhos/cm. The soluble salt content was thus quite low for all the spoils including the non-toxic Lower Freeport (Table 4).

Based upon the results of these analyses, it seems likely that the chemical properties of the spoil banks associated with the Brookville, Lower Kittanning, Middle Kittanning, and Clarion coal seams in Pennsylvania contribute to the revegetation failures. The two chemical properties which seem to be most serious are the low pH's and the high concentrations of exchangeable aluminum. We are currently conducting studies designed to evaluate the effects of various combinations of pH and aluminum concentration on the growth of selected species. The low concentrations of the essential nutrients, calcium, nitrogen, phosphorus, and magnesium, suggest the possibility of improving growing conditions through liming and fertilizing.

Table 4. Total nitrogen, extractable phosphorus, and soluble salt content on selected mine spoils of Pennsylvania.

Seam	Nitrogen	Phosphorus	Soluble Salt
	percent	ppm	millimhos/cm
Brookville	0.003	3	0.30
Lower Kittanning	0.004	1	0.26
Middle Kittanning	0.002	6	0.53
Clarion	0.009	5	0.11
Lower Freeport	0.070	25	0.20

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