

CHEMICAL WEATHERING OF STRIP-MINE SPOILS

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The aim of strip-mine reclamation has been defined as returning the disturbed land to a useful and productive condition as soon as possible. Fundamental to this is the natural process of soil formation. Sometimes we tend to forget that soil formation is natural and would proceed even if man suddenly ceased to exist. On strip-mine spoils, however, without our help new spoil would not necessarily be formed in the location or with the speed we desire. Nor would the new topography always be what we want. It is in these areas that man can work with nature, by grading and revegetating strip-mine spoils, to stimulate and direct the physical, chemical, and biological forces of soil formation.

We have been unaware, also, of the intensity with which these forces act. When we hear that it takes a thousand years to form an inch of topsoil, we are lulled into thinking of very gradual changes. Actually, the changes are slow only as the maturity of a soil is approached. In spoil banks, the quick development of acidity illustrates that very rapid chemical reactions occur as the exposed rock begins to come into equilibrium with its new environment.

In order to obtain quantitative information about the changes which take place during the weathering of fresh strip-mine spoil materials, an experiment was initiated on January 1, 1959, at the Ohio Agricultural Experiment Station. One of the objectives was to investigate the chemical changes in spoil samples subjected to natural weathering processes. These changes were assessed by periodically analyzing the drainage waters for the resulting soluble salts.

At the outset, it may be well to review briefly some of the concepts involved. Acidity in strip-mine spoils originates from iron disulfide particles in the rock, which oxidize when exposed to air and moisture, forming acid iron sulfate and sulfuric acid. The acids in turn attack other rock fragments, forming soluble salts. If enough limestone and other basic materials are present in the rock, the acid is neutralized, and mostly neutral salts are formed. Without sufficient lime, the acid sulfate salts of iron and aluminum are produced, causing the acidity often encountered in spoil banks. (This is quite different from soil acidity caused by exchangeable or adsorbed ions, in which salts are not involved.) Rain water that soaks into spoil banks hastens spoil improvement by leaching the salts from the surface layers. Flowing surface water, on the other hand, actually retards soil formation by eroding away the already leached and weathered spoil material and continually exposing new raw rock to be oxidized.

THE EXPERIMENTAL ARRANGEMENT

Nineteen spoil samples were placed in the ground in plastic lysimeters one foot in diameter and four feet deep (fig. 1). One soil sample (Wooster silt loam) was also included for comparative purposes. The spoil samples were obtained during active strip-mining operations and represent a mixture of the rock strata being removed at the time of sampling. A diversity of spoil types was obtained, including ten calcareous and nine acidic samples with a wide range of physical characteristics. Of the acid samples, five proved to be toxic and one marginal with respect to plant survival. Table 1 shows the source and description of each sample.

The spoil samples were exposed to natural weather conditions continually from the beginning of the experiment. Natural precipitation furnished the moisture

TABLE I
Sample description and source

Description	Coal seam strip mined	County
Calcareous	Meigs Creek No. 9	Belmont
Calcareous clay shale	Meigs Creek No. 9	Morgan
Toxic shale, fine sandstone	Meigs Creek No. 9	Noble
Toxic silty clay shale	Meigs Creek No. 9	Guernsey
Calcareous clay shale	Pittsburgh No. 8	Harrison
Calcareous shale, coarse sandstone	Pittsburgh No. 8	Harrison
Calcareous clay shale	Pittsburgh No. 8	Jefferson
Calcareous hard shale, limestone	Upper Freeport No. 7	Columbiana
Acid silty clay shale	Middle Kittanning No. 6	Coshocton
Acid shale, coarse sandstone	Middle Kittanning No. 6	Coshocton
Acid silty clay shale	Middle Kittanning No. 6	Perry
Marginal (very acid) shale, sandstone	Middle Kittanning No. 6	Perry
Toxic silty clay shale	Middle Kittanning No. 6	Perry
Calcareous silty clay shale	Middle Kittanning No. 6	Vinton
Calcareous silty clay shale	Middle Kittanning No. 6	Vinton
Toxic shale, sandstone	Lower Kittanning No. 5	Mahoning
Toxic soft clay shale	Lower Kittanning No. 5	Stark
Calcareous soft clay shale	Clarion No. 4a	Vinton
Calcareous shale, limestone	Brookville No. 4	Stark
Acid soil, Wooster silt loam		Wayne

which percolated through the samples, the leachate draining freely into collection flasks at the bottom. The liquid leachates, some colored brown with iron salts, were collected at about monthly intervals during the first year, and less often subsequently. The immediate objective was to measure the amounts of salts produced, and to note changes as time passed. Since most sulfate salts form crystals containing water, all were dried at 610 F before weighing.

OBSERVATIONS AND RESULTS

As the study progressed, wide variation in rainfall caused fluctuations in the effluent leachate and salt yields. Figure 2 shows the pattern of rain distribution during different seasons and years, together with leachate and salt production from the marginal spoil sample. The first year was wetter than normal, with enough rain to leach out the salts as they formed. The salt yields from the samples were much greater than expected. In the first 11.5 months the five toxic samples yielded an average of 60 tons of salts per acre, one producing more than 130 tons. The marginal spoil yielded 10.3 tons per acre in the same period, the other spoil samples yielding lesser amounts down to 0.45 tons. By comparison only 320 pounds of salts per acre were leached from the soil sample.

In contrast with the first year, the second was very dry; rainfall was 27 per cent below the annual average of 38 inches. Late in the year, for periods lasting up to six months, some samples yielded no leachate at all until flushed by rains during the following spring. Consequently, the salt yields for the second calendar year were inordinately low, and could not properly be compared with first-year yields. When a similar pattern was noted the third year, however, a basis for valid comparisons became apparent: annual increments of salt yield could best be measured after spring rains from one year to the next, rather than on a calendar-year basis. Fortunately for the experiment, the first year with its unusually high rainfall proved to be exceptional and could be included with no loss of initial data for the first spring.

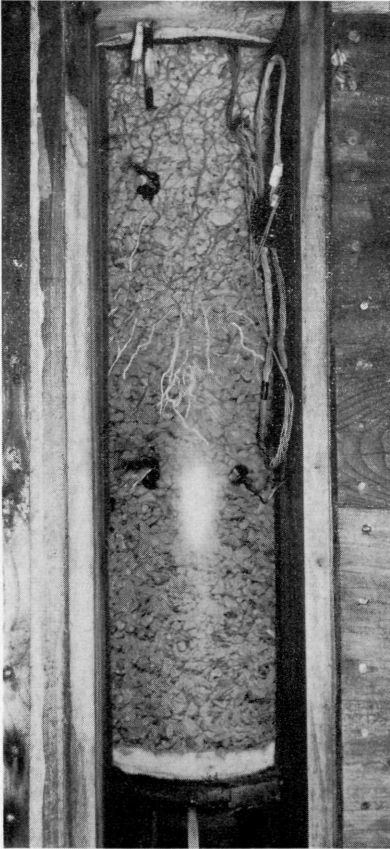


FIGURE 1. Lower part of plastic lysimeter containing marginal No. 6 spoil. Roots of alder (*Alnus glutinosa*) nearing 3-ft depth by midsummer.

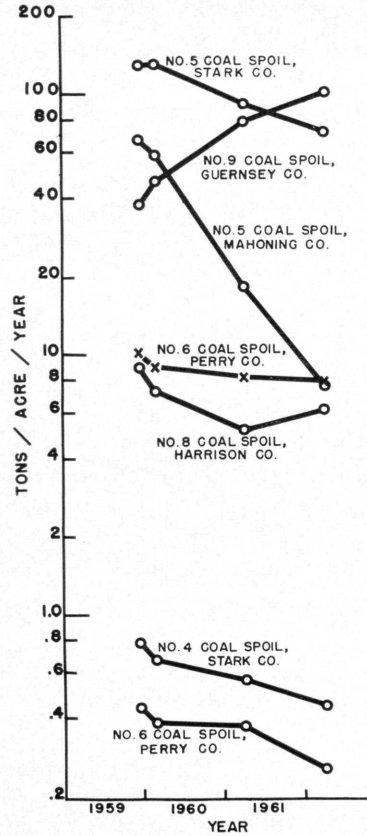


FIGURE 3. Annual salt yields from four ft of spoil materials, showing changes with duration of weathering. Points marked X identify the marginal sample.

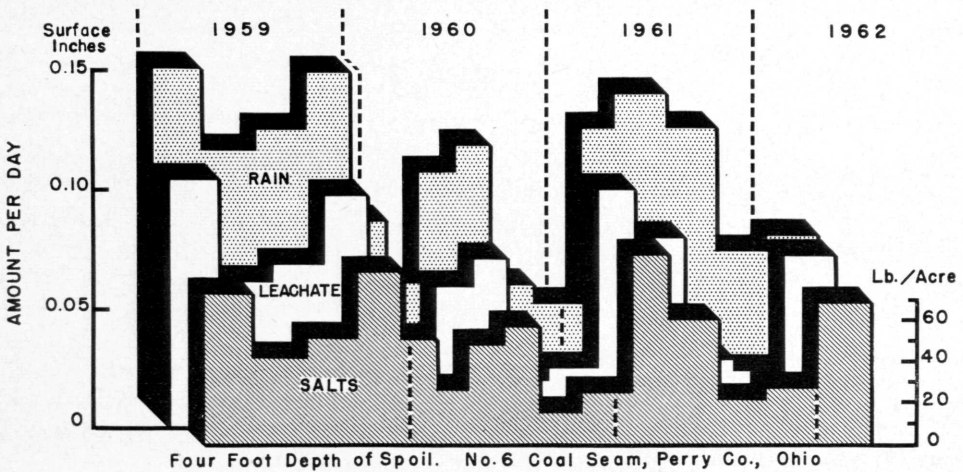


FIGURE 2. Daily rainfall rates and corresponding drainage and salt-yield rates for marginal No. 6 spoil.

TRENDS IN SALT YIELD

Having established the basis for observing changes with time, definite trends could be observed in salt yields from the different spoil samples. Figure 3 shows the results plotted for several samples which were selected to illustrate the wide range in yields observed, and the different trends noted. Data for three toxic spoils are shown at the top of the figure. Curves for the two No. 6 coal spoils from different sites in Perry County exemplify the variability which may occur in overburden from the same coal seam. Data for the marginal spoil sample are designated with points marked X; these points represent decreasing yields of 10.3, 9.1, 8.3 and 8.17 tons of salt per acre per year. Only the last three quantities are additive, however, since the first two represent overlapping increments. In each curve the first point represents salt yield for the initial 11.5 months, and subsequent points are for annual increments ending about March, after the spring flush of drainage. In the foregoing case, the cumulative salt yield amounted to 28.3 tons per acre in three and one-quarter years.

Variations in slope of the long lines in the graphs indicate different rates of salt production with the passage of time. Most spoil samples showed progressively decreasing salt yields. The dip in the curve for the No. 8 coal spoil is probably an exaggerated effect of the low rainfall during the second year, rather than an indication of a reversal in the rate of salt production. The real exception to the general trend is the increasing salt yields from the toxic No. 9 coal spoil, shown near the top of the graph. In three years, the annual increment per acre rose from 38 to 105 tons. However the rate of salt yield is gradually decreasing, and a decrease in the quantity of salt will follow after a few more years.

These results corroborate field observations that most spoil banks improve with time, but some appear to become more and more toxic the first few years after being formed. An increase in toxicity develops when there is considerable excess potential acid relative to the basic minerals in overburden material, with the result that the rock minerals—including more polysulfides—are attacked by increasingly stronger acid products.

The toxic samples all had higher salt yields and lower pH levels (below 3.0) than the nontoxic spoils. However, no relationship was found within either group between amount of salts produced and the spoil reaction or pH. This was true even when comparing alkaline and acid samples. The highest and lowest yields among the nontoxic samples were both from acid samples, shown by curves for the two No. 6 spoils. Respectively adjacent curves for the calcareous No. 8 and No. 4 spoils indicate almost equally high and low salt production from samples having alkaline reactions.

COMPOSITION OF SALTS

In addition to a measure of the total salts leached from spoils, the composition of the salts was also determined. Chemical analyses showed considerable variation in the mixture of salts from the different samples. Summarized results of first-year analyses of four samples are shown in figure 4, the relative weights being indicated cubically. A similarity in both array and relative amounts of the metal ions can be noted between the soil sample at the top and the next two spoil samples. In all of these, calcium was the major metal component of the salt, exceeding magnesium and other cations, while aluminum, manganese, and iron were relatively minor constituents. Plants were found to grow successfully in all three of these materials.

The fourth illustration in the figure, however, showing results for a toxic sample, presents an entirely different picture. The total salt was much greater; among the cations, calcium was exceeded by magnesium, and potassium was relatively low. Iron, aluminum, and manganese formed a considerable portion

of the metal ions. These findings appear to be generally characteristic of toxic spoils.

A comparison of first- and second-year results are shown by linear bar graph in figure 5. Only cations contributing 1 per cent or more to the salts are included. Considerable changes took place in salt composition as the samples continued to weather. Calcium, being the most active cation, showed evidence of steady progress toward depletion under acid conditions. Less was leached the second year than the first, the greatest reduction occurring in the toxic No. 9 spoil. Magnesium yield also decreased the second year in the toxic sample, but increased in the marginal No. 6 spoil. A marked increase in the production of

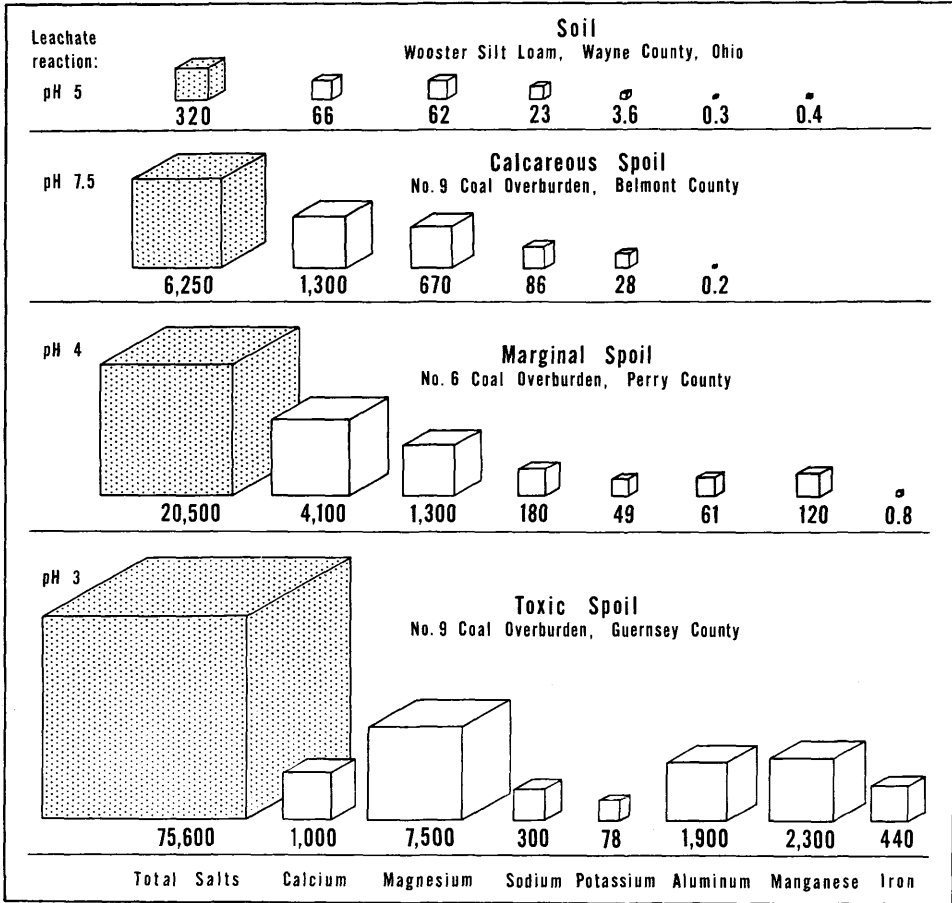


FIGURE 4. First-year yields of leached salts and metal ion components, in pounds, from four acre-ft of soil and spoil materials.

iron and aluminum occurred in toxic spoils as the basic minerals neared depletion. This constituted a characteristic difference between toxic and nontoxic spoils.

The different percentage ranges, shown by the lengths of the bars in the graph, are probably indicative of somewhat different anion composition in the salts. Although most strip-mine salts are sulfates, nontoxic spoils no doubt also contribute appreciable amounts of carbonates and bicarbonates to their leachate solutions,

thus tending to increase the basic cation percentage. On the other hand, toxic spoils may yield some free sulfuric acid along with the salts, thus decreasing the cation concentration. These anionic influences varied with changes in cation composition upon continued exposure to weathering.

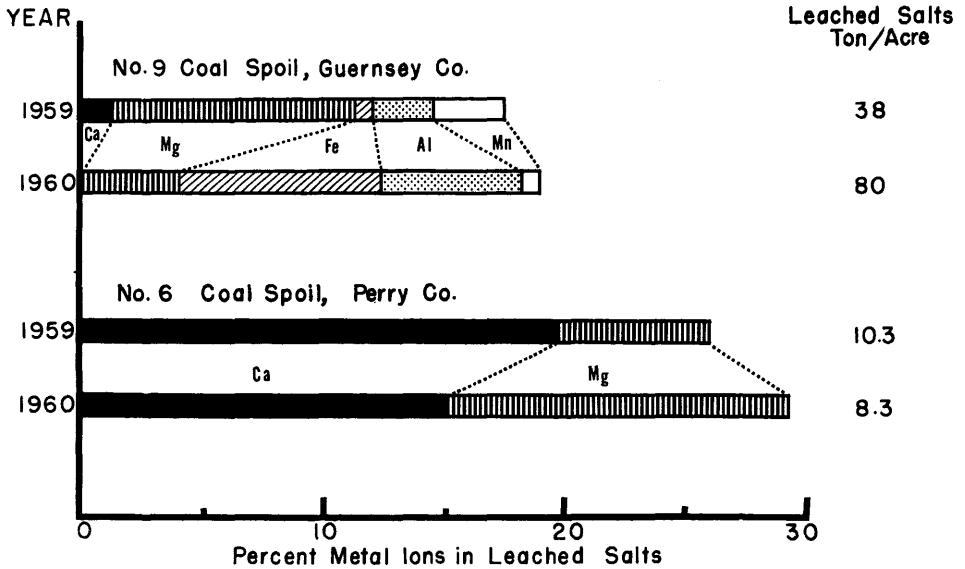


FIGURE 5. Changes in major components (over 1 per cent) of salts leached during consecutive years from toxic and marginal spoil samples.

SUMMARY

Quantitative analytical information has become available for the first time regarding the chemical weathering of coal strip-mine spoil materials, which can be summarized in the following observations:

1. Intensive chemical weathering of spoils began immediately upon exposure to air and moisture.
2. Large quantities of sulfate salts were produced in the top four feet of spoil materials the first year. Quantities measured varied from 900 pounds to more than 130 tons per acre.
3. Highest salt concentrations in spoils occurred in late summer and fall, lowest in early spring.
4. Soluble mineral plant nutrients were generally more abundant in spoils than in Ohio soils.
5. Salt production decreased in most spoils after the first year. The salt yield increased over a period of three years in one sample toxic to plants.
6. Salt production was not related to spoil reaction (pH) among either toxic or nontoxic samples.
7. Toxic spoils were characterized chemically as follows:
 - a. Very high acidity with pH levels below 3.0.
 - b. Very high salt content.
 - c. Limited and quickly depleted amounts of calcium and magnesium, with low Ca/Mg ratios.
 - d. High levels of soluble aluminum, iron and manganese salts.

The findings have practical significance in the reclamation of strip-mined land.

Plant establishment has been observed to be more successful in the spring than at other seasons; it is now evident that one of the reasons is the lower salt content of spoils after leaching by winter and early spring rains. Grading in a manner to encourage maximum rain infiltration and leaching throughout the year also assumes greater significance as a means to promote spoil amelioration and plant survival. After salt concentrations in toxic spoils have been reduced by chemical weathering and leaching, it appears probable that moderate applications of lime can restore the mineral balance and decrease the acidity to permit the establishment of plant cover.

Considering the great chemical reactivity in spoil banks, pride may well be taken in the progress and achievements which have been made in strip-mine reclamation.

QUESTIONS DIRECTED TO DR. STRUTHERS:

1. Why do you say grading is necessary when test plots indicate tree growth is better on ungraded areas?

Answer:

There are a number of considerations involved. Perhaps if growth were the only objective, grading might not be necessary. However, if the trees are to be harvested, or any other use made of the forested land, grading would certainly facilitate access to such areas. Also, other uses are sometimes made of strip-mined land, as for pasture and forage crops, in which case grading would certainly be an advantage. My main thought, however, was that proper grading can prevent excessive erosion, decrease water runoff, and increase leaching, thus leaving the surface in a condition for more rapid soil formation, and leading to even greater productivity.

2. In Pennsylvania a comparable pH reading (3.5 to 4.5) can be obtained from the same plots after ten years. Five of nine plots increased in acidity slightly and four decreased slightly. Do you have an explanation as to why these soils apparently stay the same?

Answer:

This situation is probably a common occurrence, and involves an important concept. The soil has been left acid because most of the basic minerals have been leached out; it will remain acid and unproductive until they are replaced, even after the formation of acid sulfates has virtually ceased. In this case, pH is not a good indicator of change.

One of the objectives of my study is to determine how long it takes to reach this nearly static situation in spoils. Once it has been reached or approached, the soil acidity can be quickly corrected by the addition of lime, and the productivity restored with fertilizers. If man does not do this, the same additions will occur naturally over a long period of time, with the gradual accumulation and decay of dead plant material such as leaves. Surface erosion, of course, would delay this slow process even further, which emphasizes the importance of properly grading our spoil banks.