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# THE EFFECT OF ACID MINE WATER ON FLOODPLAIN SOILS IN THE WESTERN KENTUCKY COALFIELDS

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Large areas of land in the United States have been strip mined during the last 40 years. Even larger areas have been influenced indirectly by the acid mine wash originating from the mined land. The Clear Creek Floodplain, in Hopkins County, Kentucky, is an example of the way in which strip mining within the watershed has produced enough acid water to significantly pollute the streams and groundwater and produce extremely acid soil conditions. Fig. 1 shows an example of the devastation wrought by acid mine wash contamination on the Clear Creek Floodplain. Swampy areas, resulting from sedimentation in this watershed, covered about 700 acres in 1942 and about 8,000 acres in 1965.

The problems confronting the strip mine industry are of two distinct kinds—aesthetic and physical. The aesthetic problems stem largely from public resentment of marring natural scenic beauty. The physical problems, on the other hand deal with the complexities associated with (a) soil erosion, (b) stream sedimentation, and (c) adverse stream chemistry. Erosion removes soil, which results in stream sedimentation. It is also responsible for uncovering some of the acid-producing materials which contribute to the stream pollution problems.

In some areas the effects of strip mining are relatively temporary and are sometimes limited to the boundaries of the area mined. In other cases the undesirable effects extend far beyond the mined areas. These effects include land slides, mud flows, polluted streams, destruction of fish and wildlife, and damage to downstream lands and structures. According to a special report by the U.S. Department of Interior (8) over 7,000 miles of stream channels in the United States have had their normal storm-carrying capacities significantly reduced by sedimentation. Surface mines are generally considered to be one of the prime sources of sedimentary material in many places. The adverse stream chemistry associated with this mining is due largely to sulfide-bearing compounds such as pyrite, pyritic shales, and marcasite. These compounds are commonly found in close association with coal seams and they are frequently exposed to the atmosphere as a result of the mining processes. They are not found on the surface of the soil alone but are generally mixed with the overburden as the coal is removed and may be later exposed by uncontrolled erosion.

Oxidation of iron sulfide compounds in the absence of calcium carbonate results in the formation of ferric sulfate and sulfuric acid as follows:

$$FeS_2 + H_2O + 7.5\ O_2 \rightarrow Fe_2(SO_4)_3 + H_2SO_4$$

The acid produced may reach the streams by the way of groundwater and/or surface runoff. Iron sulfate and aluminum sulfate also are carried into streams during periods of runoff. Except in the most extreme cases acidity itself according to Arnon and Johnson (1) and Limstrom (3) is not directly a serious problem as it relates to plant and animal life. However, high hydrogen-ion concentrations favor the increased solubility of elements such as Fe, Al, Mn, Zn, Pb, and As that can be toxic to plants and animals. In less than lethal amounts these elements tend to suppress normal plant and animal growth.

The objectives of the study reported herein were: (a) to determine the degree of soil contamination produced by the acid water, (b) to determine whether contaminants are present in the soil in significant quantities to adversely affect plant growth and, (c) to ascertain whether these soils can be successfully

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FIG. 1. Area of Clear Creek Floodplain, Hopkins County, Kentucky, contaminated by acid mine wash.

reclaimed for agricultural use by management methods that have a practical application for the landowners.

### EXPERIMENTAL METHODS

Studies were carried out on five soil profiles representing three soils series (Alligator, Bonnie and Collins) occurring on the mine-wash contaminated floodplain of Clear Creek, Hopkins County, Kentucky. Sampling sites were selected to include profiles from the upper one-third of the floodplain near the stream origin, middle third and the lower one-third near its confluence with the Tradewater River. Two additional sites (Bonnie and Collins series) were selected outside of the mine-wash contaminated area to be used as a reference or check.

Routine characterization samples were collected by genetic horizons from specially dug pits. Soils most nearly fit the criteria for the series indicated. Additional bulk samples of the surface horizons were collected from four sites for greenhouse studies.

The methods of Peech, *et al.* (5) were followed in the determination of cation exchange properties of whole soils with CEC being determined by ammonia distillation and titration. An atomic absorption spectrophotometer was used for Mg and Na determinations, and a flame photometer was used for Ca and K determinations.

Soil pH was determined for 1:1 soil:water and 1:1 soil:$N$ KCl suspensions. In addition, soluble phosphorus and per cent organic matter were determined. Soluble salts were determined on the extract from a saturation paste according to a method described by Richards (6) modified to include 150 g. soil sample instead of 400.

The exchangeable acidity was determined by titration as described by Yuan (9), with the following modifications in the extraction procedure. Twenty-five ml. of $N$ KCl were added to 25 g. of whole soil, the suspension thoroughly stirred and decanted into a Buchner funnel fitted with No. 42 filter paper. An additional 175 ml. of $N$ KCl was added, in small aliquots, to transfer all soil to the Buchner funnel. The combined filtrate was then titrated.

Water samples were collected from each portion of the floodplain. These samples were taken from adjacent streams, the water table within the sampling pits and from nearby surface ponding. The water samples were analyzed spectrographically for Ca, Mg, Mn, Fe and Al.

### *Greenhouse Methods*

A greenhouse study was conducted to determine the effects of lime, phosphorus and combinations of these on dry matter yield of corn. These experiments were performed on four surface horizons representing two soil series, Bonnie and Collins. A contaminated and an uncontaminated site were included for each series.

Equilibration studies were conducted to determine the lime requirement of each soil used in the greenhouse study. $Ca(OH)_2$ was applied to each soil receiving lime treatment in quantities required to adjust the soil pH to 6.5. All soils received 50 ppm. N and 42 ppm. K except the control treatment. Phosphorus (P) at the rate of 26 ppm. was applied to treatments LNPK and NPK. All treatments were replicated four times in a randomized block design.

## RESULTS AND DISCUSSION

The chemical data for an acid-wash contaminated Bonnie and Collins soil along with an uncontaminated (check) profile of each series are summarized in table 1, as representative of the soil conditions in the area.

The acid-wash-contaminated Bonnie and Collins profiles showed significantly lower pH values, with the surface horizons being ex-

TABLE 1

*Chemical properties of representative, contaminated and non-contaminated, Bonnie and Collins soils*

| Horizon | Depth Cm. | pH 1:1 ($H_2O$) | Soluble Salts *mhos.* | Exchangeable Acidity: $Al^{+3}$ | Exchangeable Acidity: Total | Exchangeable Bases: Ca | Exchangeable Bases: Mg | Exchangeable Bases: K | Exchangeable Bases: Na | CEC | Base Saturation | Organic Matter | Soluble P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *meq.*/100 g. of Soil | | | | | | | % | % | *ppm.* |
| Bonnie silt loam (acid-contaminated) | | | | | | | | | | | | | |
| A1 | 0–15 | 3.9 | 4.02 | 5.02 | 5.08 | 2.92 | 0.24 | 0.18 | 0.12 | 8.67 | 39.90 | 3.4 | 3.5 |
| B1g | 15–31 | 3.9 | 1.30 | 4.94 | 4.98 | 1.10 | 0.08 | 0.13 | 0.04 | 9.26 | 14.57 | 2.1 | 4.5 |
| B21g | 31–66 | 4.1 | 1.38 | 3.98 | 4.20 | 1.14 | 0.10 | 0.10 | 0.02 | 5.50 | 24.73 | 0.5 | 3.0 |
| B22g | 66–97 | 4.2 | 1.72 | 4.08 | 4.18 | 0.60 | 0.09 | 0.08 | 0.04 | 7.24 | 11.18 | 0.5 | 7.0 |
| Cg | 97–135 | 4.0 | 2.36 | 5.38 | 5.70 | 1.13 | 0.16 | 0.09 | 0.06 | 7.48 | 19.25 | 0.2 | 2.5 |
| Bonnie silt loam (non-contaminated) | | | | | | | | | | | | | |
| Ap | 0–20 | 5.0 | 0.36 | 1.30 | 1.42 | 3.20 | 0.17 | 0.15 | 0.02 | 10.23 | 34.60 | 1.8 | 3.5 |
| B2g | 20–43 | 5.2 | 0.28 | 0.98 | 1.11 | 3.50 | 0.20 | 0.13 | 0.02 | 10.14 | 37.97 | 1.2 | 2.5 |
| C1g | 43–89 | 5.0 | 0.26 | 1.62 | 1.72 | 3.00 | 0.18 | 0.12 | 0.05 | 10.02 | 33.43 | 1.1 | 3.0 |
| C2g | 89–127 | 5.0 | 0.20 | 2.84 | 2.85 | 2.25 | 0.17 | 0.12 | 0.04 | 10.36 | 24.90 | 0.6 | 3.0 |
| Collins silt loam (acid-contaminated) | | | | | | | | | | | | | |
| A1 | 0–10 | 3.1 | 4.84 | 3.24 | 5.00 | 1.82 | 0.20 | 0.09 | 0.04 | 7.35 | 29.25 | 3.0 | 1.5 |
| A2 | 10–36 | 3.9 | 2.64 | 4.22 | 4.24 | 1.25 | 0.16 | 0.04 | 0.06 | 6.25 | 24.16 | 1.0 | 1.5 |
| B2 | 36–71 | 3.3 | 2.98 | 2.86 | 3.56 | 1.10 | 0.13 | 0.05 | 0.03 | 5.12 | 25.59 | 0.8 | 1.5 |
| C1g | 71–107 | 3.6 | 2.04 | 2.95 | 3.49 | 1.20 | 0.14 | 0.04 | 0.03 | 6.98 | 20.20 | 0.6 | 1.5 |
| C2g | 107–142 | 4.0 | 2.98 | 2.42 | 2.71 | 1.19 | 0.14 | 0.06 | 0.04 | 4.84 | 29.55 | 0.5 | 2.0 |
| Collins silt loam (non-contaminated) | | | | | | | | | | | | | |
| Ap | 0–23 | 6.4 | 1.64 | 0.00 | 0.02 | 6.90 | 0.08 | 0.05 | 0.01 | 7.04 | 99.15 | 1.6 | 6.5 |
| B2 | 23–71 | 5.4 | 0.36 | 0.46 | 0.55 | 3.02 | 0.08 | 0.05 | 0.00 | 6.35 | 49.16 | 1.2 | 2.5 |
| Cg | 71–107 | 5.0 | 0.24 | 2.73 | 2.83 | 1.40 | 0.10 | 0.06 | 0.01 | 7.60 | 20.66 | 0.8 | 4.0 |

tremely acid. The contaminated profiles also showed evidence of clay accumulation on the surface horizon, apparently from recent flooding. The low pH values extended to the lowest horizons sampled in the contaminated soils.

Soluble salts were present in sufficient quantities to limit plant growth of salt-sensitive plants, but not enough to be considered harmful to most agronomic species (6). These salts showed the greatest accumulation in the surface horizons of the contaminated soils. The soluble salt content also decreased with distance from the stream channel and with distance from the stream origin. The soluble salt content was not directly related to soil series, exchangeable bases or pH.

Ca represented more than 75 per cent of the total exchangeable bases occupying sites in both contaminated and check soils. Mg, K, and Na occupied not more than 8 per cent of the exchange sites. The Na did not exceed 0.06 meq. per 100 g. of soil in any horizon in any profile, except the surface of the contaminated Bonnie profile shown in table 1 with 0.12.

The uncontaminated Bonnie and Collins soil profiles present no abnormalities since the pH, cation exchange capacity, per cent base saturation, total exchangeable bases and soluble salts are all relatively constant or decrease slightly with depth. The uncontaminated Collins profile (check) had been cropped and limed, recently accounting for the higher pH and per cent base saturation in the surface.

The exchangeable acidity in the uncontaminated soils shows an increase with depth in a relatively regular fashion, as is true of other similar soils of the region. The contaminated soils on the other hand showed the highest exchangeable acidity at the surface and gradually decreased with depth. Exchangeable Al constitutes most of the total exchangeable acidity in all soils, except in the relatively high organic surface horizon of the Alligator profile where hydrogen and Fe dominated.

Exchangeable Al concentrations in the surface of these contaminated soils were 5.0 and 3.2 meq./100 g. of soil for the Bonnie and Collins soils respectively. These concentrations far exceed the levels reported to restrict plant growth. Coleman, *et al.* (2) reported that Al contents of one meq. and a pH of 5.5 or less would inhibit root growth.

The organic matter content of all profiles followed a pattern common to many alluvial soils. The presence of organic matter at depths within a given profile is attributed to accumulation and subsequent burying as new alluvial deposits are added.

Soluble P was low in all soils and in all horizons. Variability in P concentrations generally can be attributed to past cropping and fertilization practices.

Water analyses (table 2) indicated that the acid conditions tend to decrease with distance downstream from stream origin, and laterally from the stream channel. This suggests a greater contamination threat on the upper portion of the floodplain near the source of the acid producing materials.

## PLANT GROWTH STUDIES

The equilibration studies to determine the lime requirement for soils used in the greenhouse studies were used as the basis for lime applications. The contaminated Bonnie soil required approximately 18,000 kg./ha. of agricultural lime ($CaCO_3$ equivalent of 100 per cent) to raise its pH from 3.9 to 6.5. Somewhat higher rates would be necessary under field conditions.

The treatments and dry yield of corn are presented for the contaminated and uncontaminated Bonnie soils (fig. 2) and Collins soils (fig. 3). Both soils gave similar re-

TABLE 2

*Analyses of water samples collected along Clear Creek Floodplain*

| Sample No. | Source of Sample and Position Along Floodplain | pH | Ca | Mg | Mn | Fe | Al |
|---|---|---|---|---|---|---|---|
| | | | | | *ppm.* | | |
| 1 | Stream channel; upper third | 3.7 | 152 | 56 | 5 | 1 | 22 |
| 2 | Soil water table; upper third | 3.7 | 104 | 32 | 26 | 137 | 11 |
| 3 | Surface ponding; middle third | 3.8 | 156 | 88 | 21 | 1 | 17 |
| 4 | Surface ponding; lower third | 4.9 | 52 | 20 | 3 | 9 | 1 |

sponses to the various combinations of treatments. Following lime applications, the Collins soil gave a greater response to phosphorus than did the Bonnie.

In greenhouse studies the uncontaminated (check) Bonnie soil responded to a complete fertility treatment of LNPK (lime, nitrogen, phosphorus and potassium) by producing more than a 100 per cent increase in dry matter over those with no lime or fertilizer. The contaminated and uncontaminated Bonnie soils produced almost equal yields for LNPK treatments. A comparison of treatment LNPK on the contaminated Bonnie soil (fig. 2) when compared with the control (no fertility addition) shows a twelve-fold increase.

These greenhouse studies indicate that liming of the extremely acid soils will alleviate much of the toxicity produced by acid mine wash water. The high levels of exchangeable $Al^{+3}$ are considered to be the major limitation for plant growth. Moschler, *et al.* (4) have reported that for very strongly acid soils, a rapid decrease in exchangeable $Al^{+3}$ is associated with the first additions of lime and progressively smaller decreases in exchangeable $Al^{+3}$ with succeeding increments of lime. Shoop, *et al.* (7) also reported increases in yield with additions of lime and the yield increase was coincident with a decrease in exchangeable $Al^{+3}$. In this study, measurements for exchangeable $Al^{+3}$ were made on contaminated soils after they were limed and cropped with corn. Since no exchangeable $Al^{+3}$ was found, the lime application apparently had neutralized the $Al^{+3}$.

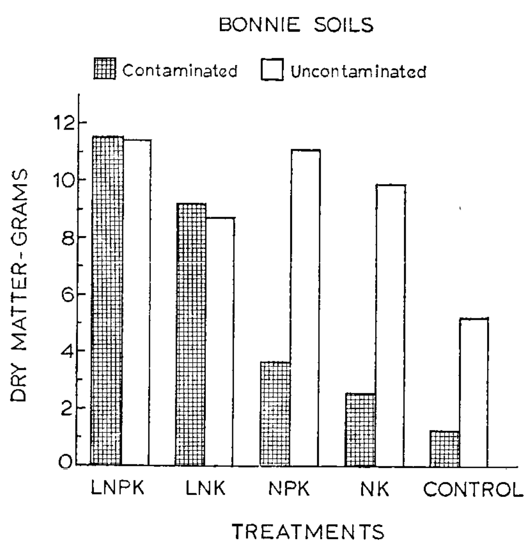


FIG. 2. Effect of lime and phosphorus applications on yield of corn grown on Bonnie soils in the greenhouse.

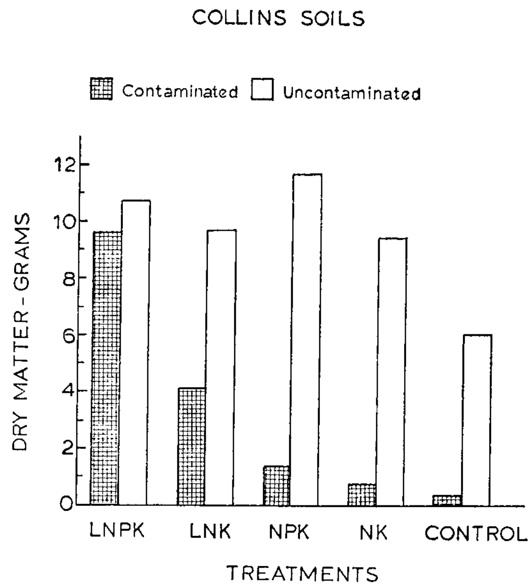


FIG. 3. Effect of lime and phosphorus applications on yield of corn grown on Collins soils in the greenhouse.

## SUMMARY AND CONCLUSIONS

A study of the effects of acid mine-wash contamination of soil on the Clear Creek Floodplain, Hopkins County, Kentucky, was conducted both in laboratory and the greenhouse. The acid levels of the contaminated soils were great enough to produce toxic conditions that were extremely detrimental to plant growth. High concentrations of $Al^{+3}$ account for much of this soil acidity and are considered to be the major limiting factor in plant growth. The acidity due to $Al^{+3}$ can be neutralized quickly at least in the surface layers, by additions of lime. Soluble salts, while approaching limiting levels in the surface horizons are not considered to be the major problem in these soils.

Results from these laboratory and greenhouse studies showed that phosphorus applied in the presence of lime to these acid-contaminated soils produced significantly higher yields of corn than when either lime or phosphorus was applied alone.

To reclaim these acid mine-wash-contaiminated soils, the following recommendations are presented for consideration: (a) install an adequate drainage system; (b) protect the area from further contamination by flood control measures and by careful planning of any future mining operations; (c) adjust the soil pH to 6.0–6.5 with lime applications; and (d) supply phosphorus and other fertility amendments on the basis of recommendation from soil tests.

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