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Coal Spoil-Bank Materials as a Medium for Plant Growth[1]

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The use of draglines and mechanical shovels to uncover and remove coal from surface mines has greatly increased in importance in the last 20 years. Strip mining, as this is called, has resulted in a greater per man day coal production and a greater percentage recovery of coal. Along with this increased production and increased efficiency in the use of one resource there occurs a change in the use capability of land mined for coal.

Limstrom (1948) reported that by 1946-47 there were in the Central States area from Ohio to Kansas approximately 190,000 acres of strip-mined land. In Iowa, like other parts of this region, strip mining has increased quite rapidly and by 1950 there were 63 strip-mine operators with a production of 1,298,000 tons. This tonnage made up 67.2 percent of the state's total coal production. Iowa strip-mined areas totaled 2,499 acres in 1947 and by 1952 had increased to an estimated 5,000 acres.

Interest in the possibility of reclamation of strip-mined areas is shared by the mine operators and the people of the state of Iowa. This mutual interest in the restoration of strip-mined areas led to the signing of a memorandum of understanding in April, 1952 between the Iowa Coal Research Association and the Iowa Agricultural Experiment Station. Under the provisions of this memorandum the Experiment Station received a research grant from the Association to study the vegetative reclamation of coal strip mines.

Basic information on the chemical and physical properties of various kinds of spoil-bank materials was urgently needed. Information concerning the effect of these properties upon plant growth and the adaptability of various tree and forage species to the different spoil materials was also lacking. This paper reports the results of certain preliminary studies and other investigations designed to delineate the problem and characterize coal spoil materials as a medium for plant growth.

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[3]The authors wish to acknowledge the leadership and assistance rendered on this project by Jesse M. Scholl, Assoc. Prof. of Farm Crops and Leo A. Thomas, Assoc. Prof. of Geology.

PRELIMINARY INVESTIGATIONS

Geology and highwall studies[1]

Iowa coal-bearing rocks are of Pennsylvanian age and are part of the northern end of the Western Interior coal field. As Figure 1 illustrates, coal is mined in three districts within this field. Most strip mining activity is confined to the Des Moines River district.

Averitt (1949) and others reported the coal beds in the Des Moines River district were in the Cherokee group and at the base of the coal measures. These basal beds were said to have been deposited in restricted marshy areas which were low places on the Mississippian surface. The coal, as a result, forms discontinuous lenses usually thick at the center and thinning laterally. The lenses usually are small and rarely contain over 300 to 400 acres of coal of mineable thickness (2-3½ feet).

The overburden of .the coal beds in the Des Moines River district consists principally of Pennsylvanian shales, Wisconsin loess, and Kansan glacial till. The thickness and character of the overburden has an important influence upon the type of spoil banks produced by strip-mining operations.

Thirty two highwall sections were described and ten highwalls were sampled. The highwall descriptions, made with the help of Dr. L. A. Thomas of the Iowa State College Geology Department were located throughout the range of the Des Moines River district. The overburden in the studied highwalls generally consisted (from top to bottom) of loess, glacial till, buff colored shale and sandstone, gray shale and dark gray shale. Figure 2 pictures a more or less typical highwall in Marion County, Iowa. Table 1 summarizes by counties the highwall descriptions. Results indicated that loess, glacial till and bluff shale tend to be thicker in the highwalls of the northwest section of the district. As one proceeds southeast along the Des Moines River the percentage of acid-forming gray and dark gray shales increases. The only exception to this trend occurs in Davis and Van Buren Counties where, in a limited area several mines have a greater thickness of glacial till.

Survey of spoil-bank conditions

A survey of the location and character of Iowa strip-mine lands was made in 1952. Aerial photopraphs served to locate the areas and tracings made from these photographs were used as base maps. The areas selected represented about one-half of the state's strip-mine lands and were scattered uniformly throughout the district. Surface acidity (pH), texture and kind of parent materials

[1]The highwall is the steep wall which is exposed by the dragline when uncovering the coal. See Figure 2.

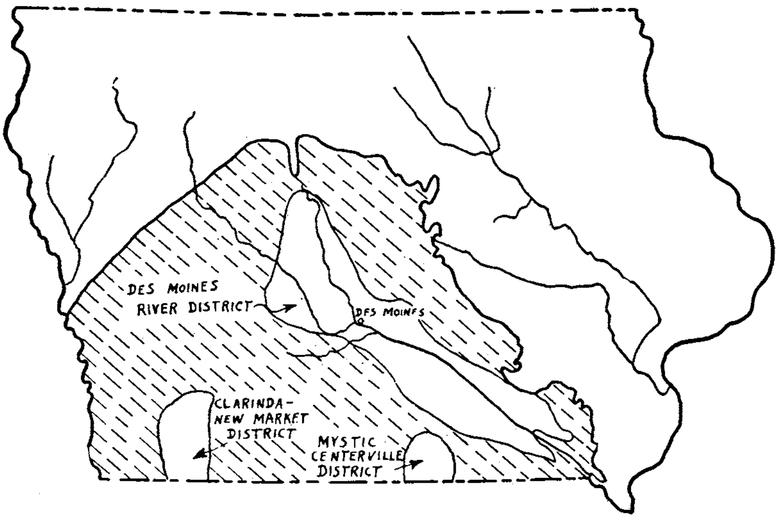

Figure 1. Map of Iowa coal fields showing chief coal-producing districts. The shaded area pictures the northern end of the Western Interior coal field. Map from Averitt (1949, p. 2).

were the criteria used for making the area separations which were mapped directly on the tracings.

Survey results showed that 93 percent of the spoil areas were located within 10 miles of the Des Moines River where the topography was rolling, naturally developed soils were shallow and relatively unproductive and the coal overburden was generally thin. The northernmost mine was located near Runnells and the area extended southeast along the river to Farmington.

Table 1.

Average thickness of highwall materials by counties in the Des Moines River coal district

Geological formation	Marion	Mahaska	Wapello	Van Buren-Davis
	Average thickness of strata in feet			
Loess	3.8	3.2	.9	2.0
Glacial till	5.5	4.8	3.0	10.0
Buff shale[a]	8.0	5.0	5.7	3.1
Gray shale[b]	9.9	11.6	13.2	12.3
Dark gray shale	13.8	12.0	12.7	9.1
Black calc. shale	—	1.5	—	—
Coal	3.6	3.4	3.7	3.2
Percent acid forming material	58	62	73	59
Number highwalls	12	7	5	7

[a]Buff shale includes very light gray shale and sandstone.
[b]Gray shale includes gray shales with brownstone partings.

Toxic spoil materials (pH less than 4.0) are the major revegetation problem in Iowa. Figure 3 pictures a toxic area in Mahaska County, Iowa. Results of the survey (Table 2) indicated that spoil banks in the northwestern part of the Des Moines River district were the best suited to plant growth while in the southeastern part the banks were poorer.

The textures of Iowa spoil-bank materials are quite uniform and offer no insurmountable problem in revegetation. Most materials have loam, silt loam or clay textures. Large rocks are little or no problem. Greenhouse and nursery weathering studies indicated newly exposed, consolidated shales disintergrated very rapidly during the first year.

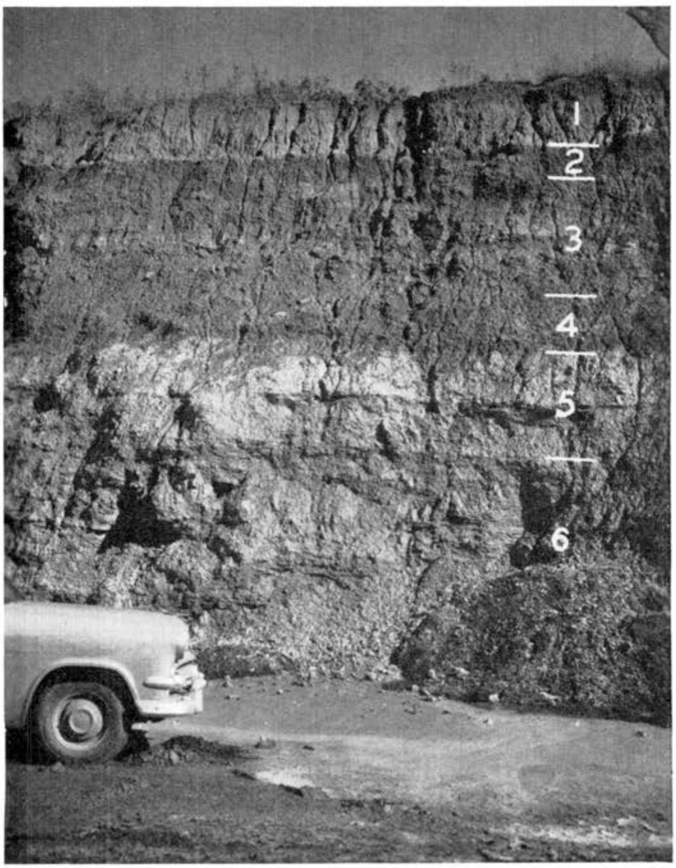

Figure 2. Typical sequence of coal overburden materials in a Marion County, Iowa highwall. From top to bottom are: (1) Wisconsin loess, (2) Kansan glacial till, (3) buff colored Pennsylvanian shale, (4) dark gray Pennsylvanian shale, (5) light gray Pennsylvanian shale and (6) gray Pennsylvanian shale grading into dark gray shale. The automobile is parked on the exposed 3 foot vein of coal.

Figure 3. A toxic strip-mine area in Mahaska County, Iowa which resulted from the placing of dark gray shales, originating in the lower part of the highwall, upon the surface of the spoil-bank.

Development of acidity in spoil-bank materials

The chemical and physical characteristics of spoil-bank areas depend upon the types of coal overburden and the method of strip mining used. The high acidity of spoil banks is the most important chemical characteristic influencing plant growth. Measurement of the pH of freshly exposed highwall material, however, is not a good indicator of the acidity that may later develop in the spoil banks. Often the pH of fresh unweathered highwall material is high enough for good plant growth but when this same material is placed upon the spoil banks it becomes very acid or toxic. The development of acidity is due to the oxidation of sulfur from certain sulfur compounds (pyrite, markasite and poly-sulfides) and the production of sulfuric acid.

A series of experiments was set up in 1952 to measure the changes which occur during the weathering of highwall materials.

Table 2.

Percentage of surface area of spoil materials by acidity classes and counties.

County	Toxic[a] (pH 4.0 or less)	Very acid (pH 4-5)	Acid (pH 5-7)	Neutral to alkaline (pH 7.0 and higher)
Marion	29	13	27	31
Mahaska	38	7	23	32
Warren	36	4	42	18
Davis	44	12	15	29
Van Buren	72	2	14	12
Wapello	78	3	14	5
State of Iowa	38	10	25	27

[a]Toxic materials usually will not support plant growth.

Samples from newly exposed highwalls were ground to a uniform size and placed in large jars. These jars were placed in the greenhouse and received 1 inch of water every 8 to 10 days. Similar samples were placed outdoors to weather. Measurements of pH were made periodically and samples of the water leaching from the greenhouse materials were also collected. Figure 4 presents the pH changes which occurred. The total sulfur content of the original samples were: acid buff shale 0.04%, acid gray brown shale 0.07%, toxic gray shale 0.34% and the toxic black shale 2.41%.

These results indicate that most shales exposed to the air will develop maximum acidity in about 6 months. After 6 months there was little change and no noticeable improvement took place within the two year duration of the experiment. The rate of development and the extent of acidity is likely related to the amount, type and fineness of the sulfur compounds and the presence of other modifying materials.

Liming toxic gray shale

Prior to setting up experiments to investigate nutritional deficiencies of spoil materials, the lime requirements of toxic gray shales were studied. Lime, as precipitated calcium carbonate, in amounts equivalent to 21.0, 17.6 and 10.0 tons per acre was added to a series of pots of shale which had an original pH of 2.5. The results of this study are summarized in Figure 5 and clearly demonstrate the

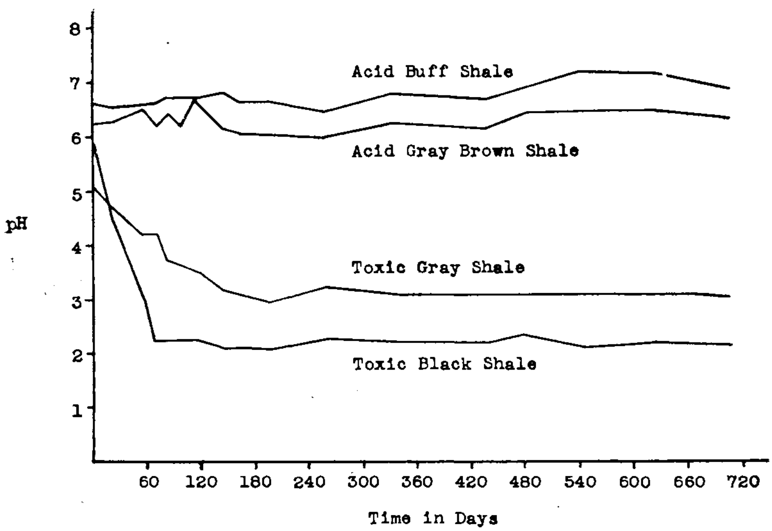

Figure 4. Weathering of coal-overburden materials.

difficulties involved in reclaiming toxic areas. The application of 21.0 tons of lime per acre increased the pH from 2.5 to 7.4 after a period of 30 days. This pH, however, did not remain constant and after 8 months had dropped from 7.4 to 5.2. Similar trends occurred in the pots receiving 17.6 and 10.0 tons of lime per acre.

It is interesting to note that a gray shale which contains 2 percent oxidizable sulfur would require approximately 62 tons of calcium carbonate per acre to neutralize all the sulfuric acid formed in the surface 6⅔ inches. This assumes all the sulfur is in a form which will be oxidized to sulfuric acid and does not allow for leaching losses. The gradual pH drift, even after liming, may be explained by the continued oxidation of the residual sulfur.

Chemical and Physical Properties of the Principal Coal Spoil Materials

Large scale strip mining is relatively new and most spoil materials have been exposed to weathering for only a short time. Little is known of the soil forming properties of these materials in Iowa and how they compare with normally developed soils as media for plant growth. In order to correctly recommend uses and species for planting on these materials, chemical and physical analyses need to be made. Based upon data obtained from the survey of spoil-bank areas in Iowa, seven types of coal spoil materials which represent the principal materials types present were selected for detailed study and analysis. The seven types were sampled throughout their geographic range in the area studied as indicated in Figure 1. The

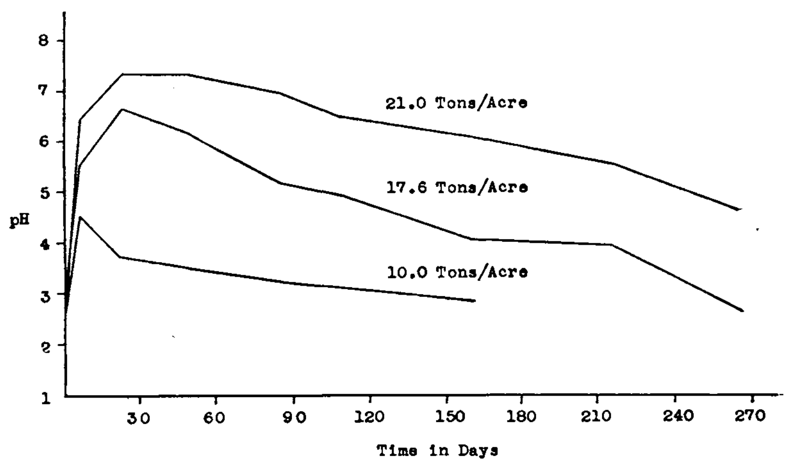

Figure 5. Effect of lime on the pH of toxic coal-spoil materials.

number of samples taken varied depending upon the importance, availability and variability of the materials in question.

Methods

Chemical analyses included cation exchange capacity, exchangeable calcium and total exchangeable bases using the ammonium acetate method (Black, 1954). Available phosphorus after dilute acid extraction (Forest Soil Committee, Douglas Fir Region, 1953) and available potassium (Russel, 1950) were determined colorimetrically. Soluble salts were determined from a 1:2 soil-water extract by use of a direct indicating bridge (solubridge) described by the U.S. Salinity Laboratory (1954). The percent sand, silt and clay were determined using a modified Bouyoucos (1936) method. Spoil material pH measurements were made with a glass electrode meter and a 1:1 soil-water mixture. Quick tests for active iron and aluminum were made by the methods described by Lunt *et al.* (1950).

Results

Table 3 summarizes results of some of the analyses made on the various types of spoil materials. Results indicate that Wisconsin loess, Kansan glacial till, acid buff shale, calcareous black shale and Pleistocene sands have reasonably favorable physical properties for plant growth. These materials also have moderately high levels of plant nutrients (except nitrogen) and favorable pH. In general these materials are suitable for plant growth. The acid and toxic gray shales and brownstone shales were found to be poorly suited for plant growth. Poor growth on these two abundant spoil materials appeared to be associated with low pH, high soluble salts and high levels of active iron and aluminum.

Calcareous black shales are of minor importance but are of interest because of the good growth found on many of these areas. These materials are also unusual in that they contain high amounts of total nitrogen (1800-4700 pounds per acre). Investigations indicate that this material when properly handled could become one of the better producing spoil materials.

Studies of Shale-Derived Soils

Gosport and Bauer soil series are shallow soils developed on materials of Pennsylvanian age in southeastern Iowa. The parent materials for these soils are the same shales which are found in strip-mine spoil banks. Prediction of the future potentialities of spoil banks for plant growth is difficult because of the relatively young age of the areas. The study of the highly weathered clays and shales which occur as part of the Gosport and Bauer soil profiles, appears to be the best method of predicting the potentialities of shale spoil-bank materials.

Table 3

Chemical and physical properties of the principal coal-spoil materials[a]

Type spoil Material	pH	Soluble salts p.p.m.	Cation Exchange Capacity[b]	Base Saturation %	Exch-ang'le Ca[b]	Available P p.p.m.	Available K p.p.m.	Particles < 2 mm. %	Textural class material < 2 mm.
Wisconsin loess	5.5-7.5	50-80	22-25	90	10	35	140	95	silt loam to clay loam
Kansan glacial till	6.0-8.0	50-110	12-30	95-100	12[d]	12	97	90-95	loam to clay loam
Acid buff shale[c]	5.0-7.0	50-500	11-18	80	7	10	75	60-90	loam to clay
Acid & toxic gray shale	2.5-4.5	3000-13000	11-20	20	4[d]	7	75	60-90	silty clay loam
Brownstone shales[c]	2.5-7.5	200-2000	8-12	65	4	90	150	60-80	silty clay
Calcareous blk. shale[c]	7.0-7.8	3000	12-18	100	16[d]	13	160	70-80	loam to clay loam
Pleistocene sands	5.5-7.0	30-80	6-11	90-100	4	20	66	60-90	loam to loamy sand

[a]Data represent the dominant conditions found in weathered coal spoil-materials based on 6-10 samples in each type of material.
[b]Me. per 100 grams.
[c]Material of Pennsylvanian age.
[d]Soluble plus exchangeable.

Table 4

Some chemical and physical characteristics of profiles G-2 and G-4

Profile No.	Layer thickness	Type parent material	Particle size distr. Sand %	Clay %	pH	Cation exchange capacity	Total exchangeable bases	Base saturation %	Exchangeable C[a]	Available P lb/A	K lb/A
G-2	0-3″	Loess-till	35.2	15.1	5.4	18.2	13.1	72.0	8.2	5	308
	3-6″	Loess-till	34.7	21.2	5.6	14.1	9.2	65.2	6.7	1	296
	6-9″	Till-shale	32.2	32.2	4.5	13.7	8.7	63.5	3.2	1	84
	9-15″	Br. shale	31.3	36.4	4.5	15.5	8.3	53.5	15.5	1	88
	19-22″	Br. to gr. shale	......	......	4.3	14.6	7.4	50.6	1.2	2	88
	22-28″	Dk. gr. shale	25.1	47.0	4.2	16.0	7.8	38.7	2.0	8	84
	28-36″	Dk. gr. shale	......	......	4.5	17.5	9.3	53.1	3.0	31	108
G-4	0-4″	Loess-till	28.8	22.9	5.5	21.6	18.0	83.3	12.1	10	320
	4-6″	Loess-gr. shale	30.4	39.2	4.4	20.9	16.7	82.8	14.2	25	70
	6-16″	V. dk. gr. shale	28.6	43.8	2.8	22.2	4.1	18.5	9.2	16	108

[a]Me. per 100 grams.

Four shale-derived soils were investigated in Marion County, Iowa. Soil profiles were described and samples were collected from each horizon. The laboratory analyses made on these materials included particle size, available phosphorus, available potassium, exchangeable calcium, cation exchange capacity, total exchangeable bases and pH. Methods used were the same as those used on spoil-bank samples.

Data relating to the chemical and physical properties of two of these profiles, G-2 and G-4, are presented in Table 4. Profile G-1 was similar to profile G-2 with the exception that G-1 was less acid and had a higher percent base saturation. The parent material of profile G-2 developed from pale brown and brown shale while the lower horizons were derived from dark gray and very dark gray shales. Profile G-3 was very sandy and was characterized by low pH (4.3 to 4.5), low base exchange capacity (5.1 - 13.6), low base saturation (37-42%) and low amounts of available and/or exchangeable calcium, potassium and phosphorus. Profile G-4 developed from dark gray shale.

Several conclusions are apparent from the work with these shale-derived soils. A comparison of the properties of coal spoil materials (Table 3) with the properties of the studied shale-derived soils (Table 4) indicates soils developing from Pennsylvania shales and sandstones very probably will have a moderate to low base exchange capacity, low pH, low base saturation and will have moderate to low levels of available calcium, phosphorus and potassium. Such soils will be of limited use for cultivated crops but when not excessively acid will be suitable for trees and forage. Soils developing from loess and glacial till spoil materials should be better suited for plant growth than the shale-derived soils and well adapted to a wide variety of plant species.

An interesting feature of profiles derived from gray shales is the low pH values (2.8 to 4.5) which occur even after hundreds of years of weathering. This suggests that the decrease of the acidity in toxic spoil-bank materials may be a much slower process than proposed by other workers in this field.

Nutrient Deficiencies of Spoil-Bank Materials

Coal spoil-bank materials differ greatly from naturally occurring soils, especially the soils formed under prairie vegetation, in that they lack the A_1 horizon rich in organic matter and nitrogen, and frequently are much more acid. Little was known about the availability, in these spoil materials, of certain elements essential for plant growth or of the reasons for poor growth on acid areas and the failure of plants on toxic areas in Iowa. To obtain information on these questions a series of greenhouse experiments was set up.

Table 5
Tomato yields on coal-spoil materials

Type matr.	Lime added	pH or pH[a] drift	Average green weight in grams[b]								
			Check	N	P	K	NP	NK	PK	NPK	X
Toxic shale	19.4 T/A	6.4 to 5.8	.53	.57	1.12	.55	1.27	.45	1.20	2.42	1.01
Toxic shale	15.8 T/A	5.0 to 4.8	.33	.50	.63	.52	1.79	.47	.75	1.89	.86
Toxic shale	12.2 T/A	4.7 to 4.6	.25	.25	.71	.41	1.13	.47	.70	1.94	.73
Neutral shale	None	7.2	.72	1.36	.81	.62	5.67	1.37	.98	5.06	2.07
Buff shale	None	6.0	.24	.20	.92	.31	3.40	.22	.90	6.35	1.57
Glacial till	None	7.8	.40	.43	.50	.58	3.51	.63	.52	4.12	1.34

[a]First pH is at start, second is after 45 days.

[b]Average green weight of tomato plants based upon three replicates.

Nutrient deficiencies were investigated by growing tomatoes (*Lycopersicum esculentum*) in the greenhouse. The tomatoes, used as indicator plants, were grown for 45 days on four types of spoil materials which ranged in original pH from 2.5 to 7.2. The toxic gray shale (original pH 2.5) was limed with precipitated calcium carbonate. No lime was added to the other three types of spoil materials. On all four materials nitrogen, phosphorus and potassium alone, and in all possible combinations, were investigated. Nutrient deficiency symptoms were noted and green weights were determined. The experiments were three replicate, completely randomized, 2x2x2 factorials. Nitrogen was applied as sodium nitrate at a rate of 100 pounds per acre. Phosphorus was added at a rate of 100 pounds per acre as monobasic sodium phosphate and potassium at a rate of 126 pounds per acre as potassium chloride.

The toxic gray shale that was used had an original pH of 2.5 and individual lots were treated with 19.4, 15.8 and 12.2 tons of lime per acre respectively. Lime treatments were applied 4 months before planting so that the potted material would have the desired pH and additional pH drift wood be at a minimum (see Figure 5).

Table 5 summarizes the data obtained in this study. All data were statistically analyzed. The results show that liming increased growth on toxic gray shales. Phosphorus was the plant nutrient first limiting growth on toxic (limed), very acid and acid spoil materials while nitrogen was first limiting on the neutral gray shale. The best yield on acid shales was obtained with the complete NPK treatment while on the neutral gray shale the NP treatment was best.

On calcareous Kansan glacial till nitrogen alone, phosphorus alone or potassium alone did not significantly increase yields. The NP treatment, as in the case of the neutral gray shale, gave the highest yield response.

The exact mechanism involved in the first response to phosphorus on acid shale materials is not evident from the data. The phosphorus applications may have improved growth by decreasing soluble aluminum, decreasing soluble iron and/or increasing available phosphorus. Very probably the obtained response was due to a combination of these actions.

Field Studies of Tree and Forage Species

The establishment of vegetation on coal spoil areas presents many problems. Steep slopes, erosion, lack of organic matter, poor physical character, low nitrogen and abnormal nutrient levels often are not conducive to the establishment and growth of plants. To further test the suitability of spoil bank materials as a medium for plant growth a series of field studies involving trees, grasses and legumes was made. A total of 13 tree experiments, 4 grass trials and 12 legume trials were established on the principal types of spoil materials. These results are not reported here in detail.

Figure 6. Five-year-old black locust and Virginia pine on a loess-buff shale spoil area. The Virginia pine are 4 to 8 feet tall and the black locust 16 to 20 feet.

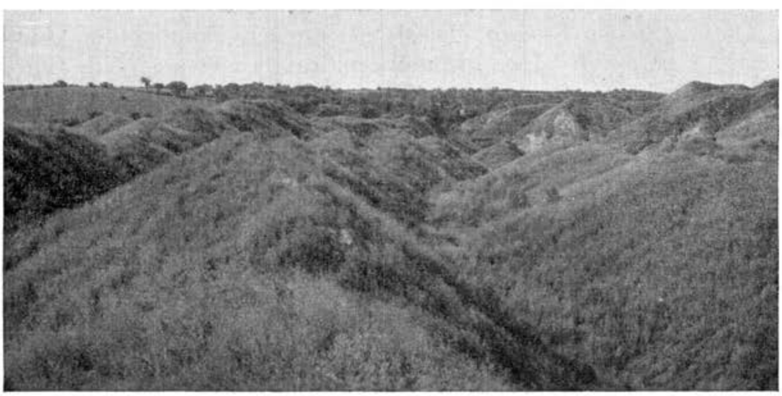

Figure 7. A stand of sweetclover obtained by early spring seeding of a new spoil-bank area in Marion County, Iowa.

Tree species showing promise include jack pine, red pine, Virginia pine (Figure 6), pitch pine, eastern red cedar, green ash, cottonwood, American elm, sycamore and black locust. Legume species which produced good stands included sweetclover (Figure 7), lespedeza, alfalfa and birdsfoot trefoil. Grasses that did well were smooth brome, orchardgrass, intermediate wheatgrass, Canada wild rye and timothy.

Based upon field trials, greenhouse work with tomatoes and chemical and physical analyses, Wisconsin loess, Kansan glacial till, acid buff shales, calcareous black shales and Pleistocene and Pennsylvanian sands were found to be best suited for plant growth. Toxic and acid gray shales and brownstone shales were found to be unsuited.

Summary and Conclusions

Briefly summarized below are some of the more important conclusions resulting from the several preliminary investigations and the work on the characterization of the principal coal spoil materials.

1. A 1952 survey of Iowa strip-mine areas shows that 93 percent of the estimated total of 5,000 acres are located within 10 miles of the Des Moines River. The northernmost mine is located near Runnells and the strip-mining area extends south along the river to Farmington.

2. Spoil banks with toxic surfaces make up approximately 38 percent of the total spoil-bank area in Iowa and constitute a major problem in revegetation.

3. Iowa spoil materials consist of a high percentage of particles less than 2 mm. in size and the textures are predominantly in the silty clay loam and loam range.

4. Liming of toxic spoil areas is not practical from an economic viewpoint and the results of the treatment with moderate amounts of lime are temporary.

5. Studies of normally developed shale-derived soils in southeast Iowa show that many are of low productivity and indicate that soil derived from spoil bank shales will be of limited value for cultivated crops but will be suited for tree and forage crops. This study also suggests that the improvement of toxic and very acid spoils areas by leaching and weathering is a slow process.

6. Fertilizer experiments indicate phosphorus is the plant nutrient first limiting plant growth on toxic (limed), very acid and acid spoil materials. Best yields were obtained from the NP treatment on neutral light gray shale and glacial till while the NPK treatment gave the best yields on acid Pennsylvanian shales.

7. Iowa spoil-bank areas were divided into seven principal types of materials. Wisconsin loess, Kansan glacial till, acid buff shale, Pleistocene and Pennsylvanian sands and black calcareous shales were the spoil materials best suited for plant growth and toxic gray shales and brownstone shales were the least suited.

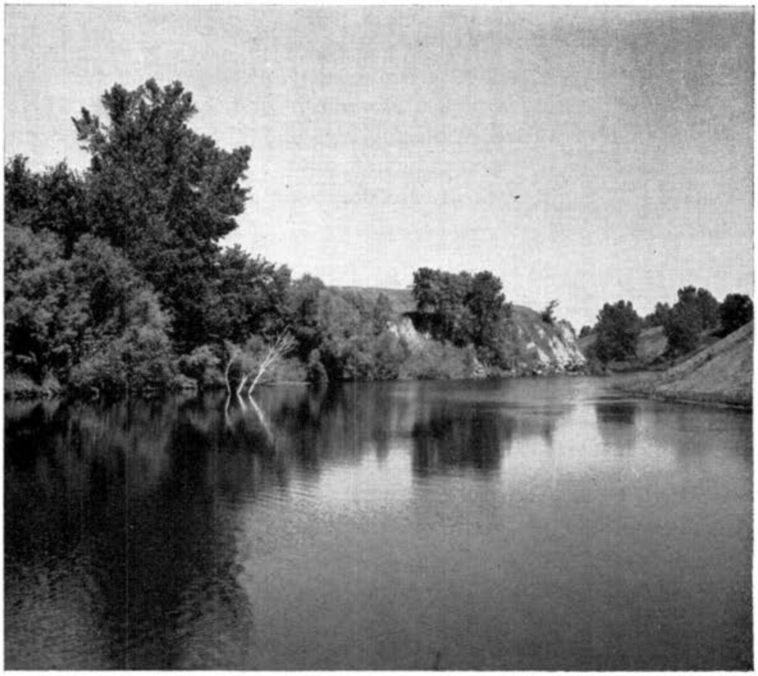

Figure 8. This strip-mine pond near Hartford, Iowa is a good example of an area where multiple use is being practiced. The spoil banks around the pond are being pastured while the pond itself is being used for fishing, swimming and boating.

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