Chemical and Physical Characterization of Coal Overburden

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The purpose of this study was to obtain information about the chemical and physical properties of coal overburden that will be needed to develop methods for reclaiming spoilbanks for future agricultural use.

Introduction

Coal has been mined in North Dakota since before statehood. U.S. Department of Interior, Bureau of Mines estimates of strippable lignite coal reserves in this state range from about four to more than seven billion tons (1, 4). This coal reserve occurs under about 28,000 square miles of western North Dakota in the Tongue River, Sentinel Butte and Ludlow formations of the Fort Union Group (7).

Production figures have been kept since 1884. Tonnage figures of coal mined are shown in Table 1.

Table 1. Coal production in tons, selected years (6).

Year	Production (tons)[1]	Estimated acres mined per year
1884	35,000	2
1923	1,435,605	96
1952	3,280,845	218
1961	2,557,498	104
1972	6,300,000	420

[1]*Calculated, using USDI Bureau of Mines average figure for N.D. of 15,000 tons/acre.*

Until about 1960, the lignite was used mostly as fuel for heating purposes. The large increase in tonnage since then has been used mainly to generate electric power.

In fiscal 1972, 95 per cent of the tonnage (6.3 million tons) was surface mined by four companies: Consolidation Coal Company at Stanton and Velva; Knife River Coal Company at Gascoyne and Beulah; Baukol Noonan, Inc. at Center and Larson, and North American Coal Company at Zap (6). Mining operations in 1972 created about 420 acres of spoilbank. Projections based on tonnage trends in years 1965 to 1971 forecast annual production of about 45 million tons by 1990 (5). Mining of this tonnage will create about 3,000 acres of new spoilbank per year. More recent projections that anticipate requirements for gasification plants are as high as 80 million tons per year, which would create 5,000 acres of spoilbank annually (5). As of January, 1974, the North Dakota Geological Survey[1] estimated that there were about 9,500 acres of mine spoilbank in North Dakota.

Previous Work

Since 1954, many of the more extensively occurring soils in potential strip mine areas of North Dakota have been characterized by chemical and physical analyses. This work was done by North Dakota State University (NDSU) and Soil Conservation Service (SCS) soils laboratories. These analyses and accompanying field site descriptions, for the 0 to 5-foot depth commonly examined, aid in soil classification and mapping and in making interpretations for various uses. Since the data are based on defined kinds of soils, they are as significant and as relevant to the problems of reclamation as if they were obtained especially for this purpose (3).

Very little chemical and physical data were available on the geologic materials at depths below five feet. In 1971, NDSU soils laboratory analyzed 27 samples from old spoilbank and reclaimed areas at nine mine sites. The samples were all alkaline (pH 7.5 to 9.7) and salinity was low in most samples (ECE 3 to 5). Sodium was high in most samples from Beulah south, Stanton and Noonan mines, where sodium adsorption ratios (SAR) ranged from 11 to 30. Sodium was low in samples from Wilton, Garrison, Underwood, Sawyer, Center and Beulah north where SAR was 0.1 to 5. Nitrate-N test values were mostly low, P values were very low to low, and K values were high to very high.

Sandoval and others (5) analyzed 10 samples of spoilbank material from five mine sites in North Dakota. They found the material to be mostly fine-textured, with low to moderate salinity, alkaline reaction (pH 7.6 to 8.8), and sodium the dominant water soluble cation (SAR 2 to 48). They also analyzed three complete profiles of mine overburden at two sites, to 100 and 500 feet deep, respectively. These materials were all alkaline, calcareous and mostly low in salinity. Sodium was the dominant water soluble cation (SAR 15 to 50), except in the upper 20 feet where SAR was 1 to 7.

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Thanks are expressed to Linda Thomas, Margaret Norman and Darrell Vanderbusch for many hours of laboratory work.

[1]*Carlson, C. G., personal communication.*

Table 2. Detailed analytical data for Chama silt loam.

SOIL SURVEY LABORATORY: NORTH DAKOTA STATE UNIVERSITY, FARGO, NORTH DAKOTA

SOIL TYPE: Chama silt loam LOCATION: 525' N, 213' E of W ¼ corner of Sec. 31-145-92

SOIL NUMBERS: SU75ND-25-11 LABORATORY NUMBERS: 825-829 DATE: Dec. 10/75

Depth (in)	Horizon	Size Class and Particle Diameter (mm) (percent): very coarse sand 2-1	coarse sand 1-0.5	medium sand 0.5-0.25	fine sand 0.25-0.10	very fine sand 0.10-0.05	total sand 2-0.05	silt 0.05-0.002	clay <0.002	>2	0.020-0.002	0.020-0.050	Textural Class
0-4	A1						33.5	45.9	20.6		17.5	28.4	1
4-10	B2						39.1	38.1	22.8		15.5	22.6	1
10-35	C1ca						9.8	66.2	24.1		36.2	30.0	sil
35-62	IIC2r						3.6	61.8	34.6		40.8	21.0	sicl
62-110	IIC3r						25.4	60.0	14.6		21.9	38.1	sil

Depth (in)	pH (paste)	CO_3 Clay (%)	Organic Carbon (%)	N (%)	C/N (%)	Gypsum (meq/100g)	$CaCO_3$ Equivalent (%)	Bulk Density[a]: oven dry (g/cc)	Bulk Density[a]: 1/3 bar (g/cc)	Water Content[b]: 1/10 bar (%)	Water Content[b]: 1/3 bar (%)	Water Content[b]: 15 bar (%)	COLE[c]
0-4	6.6		2.91	0.254	11.5		---	1.25	1.17		33.5	13.1	.02
4-10	7.3		1.47	0.138	10.7		---	1.40	1.33		21.1	10.4	.02
10-35	8.5	3.8	0.81				25.8	1.45	1.36		23.1	9.5	.02
35-62	8.7	1.3	0.50				13.5	1.63	1.45		25.5	14.3	.04
62-110	8.3		0.32				---					7.9	

Depth (in)	Saturation Extract Soluble Ions (meq/1): Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	ECE 25°C (mmhos/cm)	SAR	Water At Sat'n (%)
0-4	2.4	1.1	0.1	0.7		2.6	0.1	1.6	0.38	0.1	49
4-10	3.1	1.2	0.1	0.5		3.7	0.1	1.1	0.41	0.1	38
10-35	1.6	4.0	3.2	0.2		2.9	0.4	5.7	0.84	1.9	45
35-62	23.5	127.0	74.0	0.5		1.4	4.5	219.1	11.50	8.5	55
62-110	6.5	71.0	59.0	0.5		1.5	4.4	131.1	8.30	9.5	43

Depth (in)	CEC (meq/100g)	Exchangeable Cations[de] (meq/100g): Ca	Mg	H	Na	K	Exchangeable Na (%)
0-4	25.8	16.0	3.6	3.5	0.1	1.3	0.2
4-10	22.6	15.6	3.5	2.0	0.1	0.8	0.3
10-35	15.5	12.0	8.8	---	0.4	0.3	2.7
35-62	28.3	7.7	18.2	---	4.5	0.3	16.0
62-110	13.1	1.7	10.0	0.3	2.1	0.2	16.3

[a] 1/3 bar: saran coating

[b] 15 bar: loose samples

[c] Saran coating

[d] Exchangeable cations: $BaCl_2$ TEA extracted minus saturation extract soluble cations

[e] Exchangeable hydrogen: $BaCl_2$ TEA procedure

---Zero or negligible amount

Procedure

The work was conducted in three phases:

1. *Sampling and detailed analyses of soils in potential coal-producing areas.*

This work was done in cooperation with SCS personnel in Mercer and Dunn counties where county soil surveys are in progress. Nineteen soils were described and sampled from pit walls by genetic horizons to 5-foot depth. Auger samples were taken to 10-foot depth at 10 of the sites.

Samples were analyzed for pH, salinity (saturation extract), SAR, exchangeable cations and cation exchange capacity, organic carbon, total nitrogen, particle size distribution, water held at 1/3 and 15 bars tension, coefficient of linear extensibility (COLE) and bulk density. This information contributes to our bank of base line soils data and can be interpreted for many uses.

2. *Chemical and physical properties of overburden.*

For this phase, coal overburden was sampled in 5-foot increments to the mined (or mineable) coal seam at the principal operating mines and in three proposed mine areas. Drilling usually was done by drillers under contract to the coal companies. Samples were drilled using air circulation when possible and collected in a kitchen-utensil-type strainer. Water-mist circulation was needed to recover samples taken in glaciated areas of McLean and Mercer counties. Samples from 76 drill holes were analyzed.

Core samples were taken from 11 drill holes in Dunn county in cooperation with University of North Dakota (UND) Engineering Experiment Station personnel. The outer 1/8-inch was peeled from the cores to eliminate (or reduce) contamination caused by the drilling water. High wall samples were analyzed from 28 measured sections. Twenty-four of these sections were sampled by UND geologists and four by NDSU Department of Soils personnel. The drilled and highwall samples were analyzed for constituents considered to be important in assessing their value as suitable plant growth material.

All samples were textured by hand. Particle size analyses were made on selected samples to check the hand texture evaluation. Chemical analyses included pH, salinity (by electrical conductivity), saturation extract soluble carbonate, bicarbonate, chloride, calcium, magnesium, sodium and potassium. Soil test values for N, P and K were obtained on some of the samples.

3. *Analyses of reshaped mine spoil.*

Reshaped materials were sampled in seven reclaimed fields at four mine sites. Samples were taken at 1-foot intervals to the 5-foot depth with a soil coring machine. Five to 10 sites were sampled in each field and data analyzed separately to get a measure of the variability within and between fields. From 1 to 10 inches of "topsoil" had been added on two of the fields. The fields had been reshaped before the present regulations governing the addition of "topsoil" were in effect. Analyses on these samples were the same as for the overburden samples. In addition, bulk densities were determined from core volumes at about half of the locations.

Laboratory methods used for all analyses were essentially as outlined in USDA Handbook No. 60 (8). Calcium carbonate equivalent was determined by the method of Williams (9). Coefficient of linear extensibility was run by the method of Brasher, and others (2).

Results and Discussion

Sampling and detailed analyses of soils in potential coal-producing areas.

The following narrative description for Chama silt loam is an example of the site and soil profile descriptions recorded. Analytical data in Table 2, from samples taken at the Chama site, indicate the kinds of chemical and physical information obtained. Space does not permit inclusion of all analytical data from the 19 sites.

Soil type: Chama silt loam
Sample no.: SU75ND25-11 (FIPS)
Date: October 7, 1975
Sampled by: F. Schroer, D. D. Patterson, M. R. Wright, L. E. Edland, and S. R. Base
Area: about 1 1/2 miles south of Werner, Dunn county, North Dakota
Location: 525 feet north and 213 feet east of the W 1/4 corner Sec. 31, T 145 N., R. 92 W.
Classification: fine-silty, mixed Typic Haploborolls
Vegetation: prairie junegrass, western wheatgrass, and green needlegrass
Parent material: residuum from siltstone
Physiography: sedimentary upland
Relief: simple smooth
Slope: 1 per cent
Permeability: moderate
Drainage: well
Ground water: deep
Erosion: slight
Pedon description: Chama silt loam (Colors are for dry soil unless otherwise stated)

A1 — 0 to 4 inches; dark grayish brown (10YR 4/2) silt loam; very dark grayish brown (10YR 3/2) moist; weak medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; many very fine roots; clear wavy boundary.

B2 — 4 to 10 inches: brown (10YR 4/3) silt loam; dark brown (10YR 3/3) moist; weak medium prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; common very fine roots; many very fine tubular pores; clear wavy boundary.

Clca — 10 to 35 inches; light gray (2.5Y 7/2) silt loam; brown (10YR 5/3) moist; weak coarse prismatic structure parting to weak medium subangular blocky; sticky, plastic; common very fine roots; many very fine and fine tubular pores; violent effervescence; abrupt wavy boundary.

11C2r — 35 to 62 inches; light brownish gray (2.5Y 6/2) soft weathered siltstone that parts to silt loam; dark grayish brown (2.5Y 4/2) moist; moderate medium platy structure; sticky, plastic; common very fine roots; many very fine tubular pores; few small salt crystals at 39 to 62 inches; strong effervescence; common medium irregular shaped soft masses of lime; abrupt wavy boundary.

11C3r — 62 to 110 inches; soft weathered siltstone that crushes to silt loam; light olive brown (2.5Y 5/6) moist; massive; nonsticky, nonplastic; few very fine tubular pores.

Table 3 shows the soils sampled and some selected properties derived from the data that are of interest in evaluating the soils as reclamation material. These series illustrate the range in soil material that occurs in the coal-bearing areas of Mercer, Oliver and Dunn counties. Interpretations in Table 3 are made from the soil profiles analyzed. They may not represent the modal concept for the series.

Depth of suitable plant growth material is based on North Dakota Public Service Commission (PSC) standards. These standards are: electrical conductivity (ECE) as a measure of salinity, less than 4 millimhos per centimeter; sodium adsorption ratio (SAR) less than 10, or exchangeable sodium percentage (ESP) less than 12.

PSC standards for soil material best suited for top dressing are: minimum organic matter content of 1.5 per cent (equal to organic carbon content of about 0.8) where available; calcium carbonate equivalent less than 10 per cent (for medium to fine-textured soils); ECE less than 2 millimhos per centimeter; SAR less than 4, or ESP less than 5.

Permeability classes are SCS estimates for these textural classes. Available water in inches per 5-foot profile was calculated from water content at 1/3 bar (field capacity) minus water at 15 bar (wilting point) data.

Chemical and physical properties of overburden.

Figures 1, 2 and 3 show graphically, with depth, some properties of overburden that are significant in reclamation.

Salinity of saturation (water) extracts is shown as electrical conductivity of the extracts, $ECE \times 10^3$ (mmhos). Conductivity values above 4 millimhos are considered to restrict plant growth and only very salt-tolerant species survive at values above 15 millimhos. As noted above, a maximum of 4 millimhos has been set for reclamation material suitable for plant growth.

The sodium adsorption ratio (SAR), which closely approximates exchangeable sodium percentage, indicates the tendency of soil material to develop poor physical condition when the material is exposed to sun and rain. SAR values above 10 or exchangeable sodium percentages above 12 are taken as maxima for suitable growth material. At high SAR values, soil colloids disperse, the surface seals and infiltration of water is reduced to near

Table 3. Selected properties and interpretations of soils sampled.

Soil series	Classification: Textural family	Slope (%)	Available water capacity (inches/5 ft.)	Permeability (least permeable layer)	Depth of suitable plant growth material (inches)	Depth of soil material best suited for top dressing (inches)
Amor	fine-loamy	4	12	moderate	60	13
Arnegard	fine-loamy	4	8	moderate	>168	33
Chama	fine-silty	1	11	moderate	35	10
Daglum	fine	3	11	very slow	7	4
Farland	fine-silty	1	10	moderately slow	70	17
Flaxton	fine-loamy	2	8	moderately slow	>60	16
Grail	fine	1	7	slow	48	26
Harriet	fine-silty	1	7	slow	0	0
Krem	sandy/loamy	2	10	moderately slow	>60	0
Lefor	fine-loamy	5	7	moderate	54	10
Lihen	sandy	2	8	rapid	>60	17
Livona	fine-loamy	2	9	moderately slow	>60	9
Parshall	coarse-loamy	1	8	moderately rapid	>129	15
Straw	fine-loamy	1	8	moderate	>60	52
Tally	coarse-loamy	7	8	moderately rapid	>162	11
Vebar	coarse-loamy	7	7	moderately rapid	>108	24
Werner (like)	loamy	20	5[1]	moderate	15	5
Williams	fine-loamy	1	7	moderately-slow	>108	16

[1]*For 2.5-foot depth*

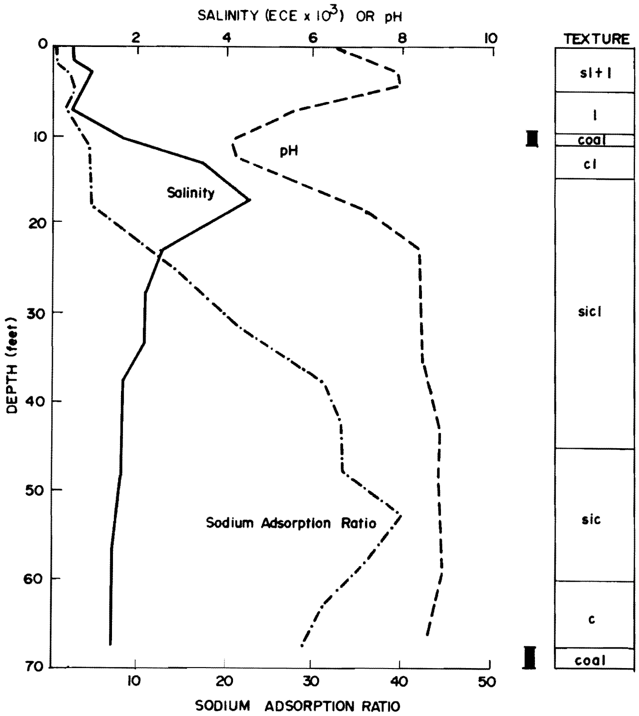

Figure 1. ECE, SAR, Texture and pH of Overburden in Mercer County.

zero. Dispersive effects are more severe as clay content increases.

Texture (or relative proportion of sand, silt and clay) is indicated by the textural class abbreviation in box charts at the right of the figures. A key to textural class abbreviations is:

s, fs - sand	sil - silt loam
ls, lfs - loamy sand	sicl - silty clay loam
fsl, sl - sandy loam	sic - silty clay
l - loam	c - clay

pH is also shown on the figures. The materials are mostly moderately alkaline in reaction with pH values around 8. Lower pH values (5 to 6) may occur in or close to the coal seam.

The soil is Flaxton fine sandy loam, developed in aeolian sandy loam deposited over glacial till which overlies a thin coal seam at 10 feet. The coal and material below it are of Fort Union age. Suitable plant growth material occurs to about 25 feet at the site. Below this depth, high SAR makes the material unsuitable for plant growth.

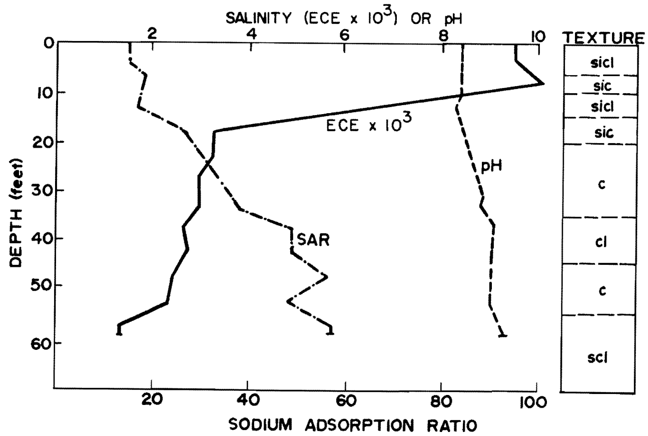

Figure 2. ECE, SAR, Texture and pH of Overburden in Mercer County.

The overburden characterized by Figure 2 is from a drill hole in a Rhoades soil area. The Rhoades soil is high in sodium and moderately fine-textured. There is no suitable plant growth material at this site because of high salinity (ECE values of 4 to 9.5 in the upper 20 feet), and SAR in excess of 15 to the coal at about 60 feet. This situation usually occurs in soil associations where Rhoades and Daglum are part of the mapping unit.

About 30 feet of suitable plant growth material, low in salinity and sodium, occurs at this site. Some of the fine sandy loam to loamy sand in the 30-70-foot section is also suitable. Soil blowing and low water holding capacity will be problems in reclamation of the sandy loam to loamy sand material. Poor stability of the banks during mining operations is also a problem in coarser-textured material. The high SAR clay to clay loam below 70 feet is unsuitable plant growth material.

Figures 1 through 3 illustrate some of the variation in overburden from Fort Union materials. Because of their variability in thickness, depth and area, onsite sampling will be needed at future mine sites to assess overburden properties.

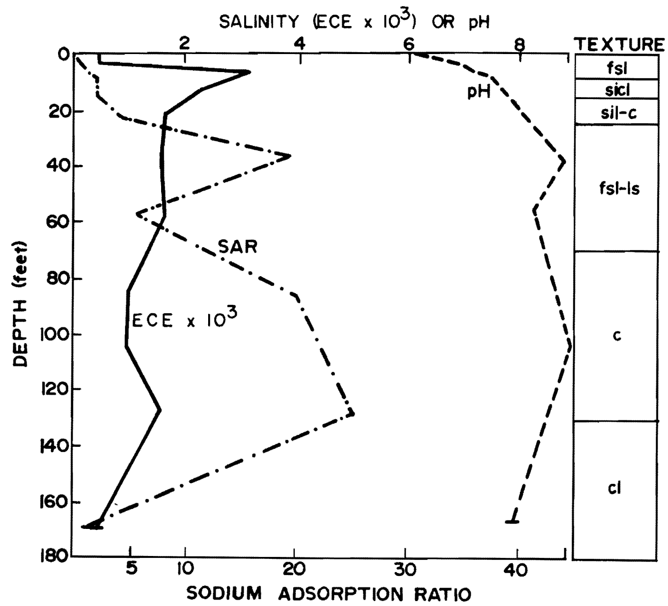

Figure 3. ECE, SAR, Texture and pH in a Telfer soil area in Dunn County.

About 40 feet of glacial till overlies soft Fort Union bedrock at this site. The glacial till is suitable plant growth material, except for the 10 to 15-foot depth where salinity (ECE) is over 4 millimhos. Sodium (SAR) values are low, even in the Fort Union silty clay from 40 to 110 feet.

The Fort Union silty clay is suitable chemically as plant growth material, but because of its fine texture it is difficult to spread and pack without voids. It is, therefore, less desirable as reclamation material than glacial till.

All of the nine drill holes sampled in glacial till had similar material except for one site in an area of Niobell soils. At this site, the SAR and ECE were too high in the upper 10 feet for suitable plant growth material.

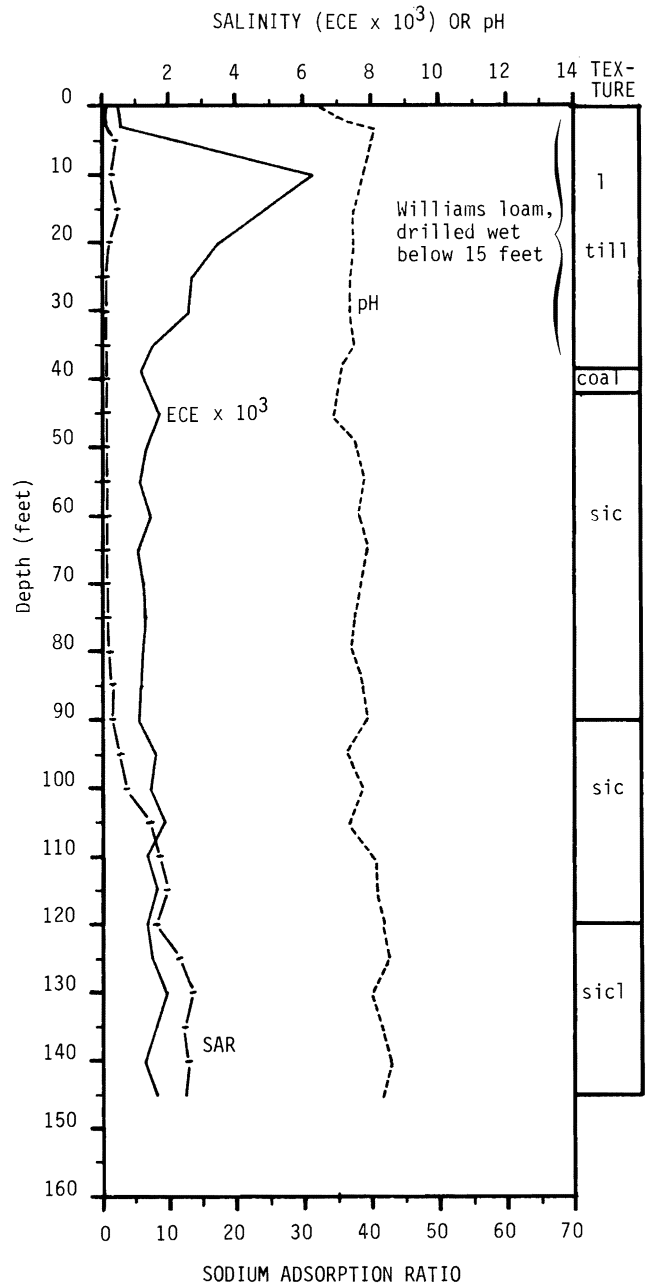

Figure 4. ECE, SAR, Texture and pH of overburden in a Williams soil area in McLean County.

Analyses of reshaped mine spoil.

Figures 5, 6 and 7 show ECE, SAR and pH data from the 0 to 60-inch depth in reshaped spoilbank areas at three mine sites. The data are averages of from 5 to 10 cores per area. Dominant textures are indicated on the figures.

The areas were selected to show different "soil" properties and associated problems and do not necessarily represent an entire mine. All spoilbanks were reshaped prior to the present regulations governing additions of "top dressing."

The data in Figure 5 are for an area of reshaped silt loam to silty clay loam spoil with moderate permeability. The material is nearly neutral in reaction, pH 7 ± 0.5. The ECE is less than 4 millimhos and SAR is less than 7, so the material is suitable for plant growth.

Thin lenses or pieces of unweathered sandstone and siltstone were found in the cores. Bulk densities ranged from 1.0 to 1.5 grams per cubic centimeter. These densities are no greater than those of the original soils.

Two to 10 inches of "topsoil" (A and B horizons mixed) had been spread on the surface. A fair stand of grasses, oats and alfalfa was present. Reclamation appears to be feasible on this field.

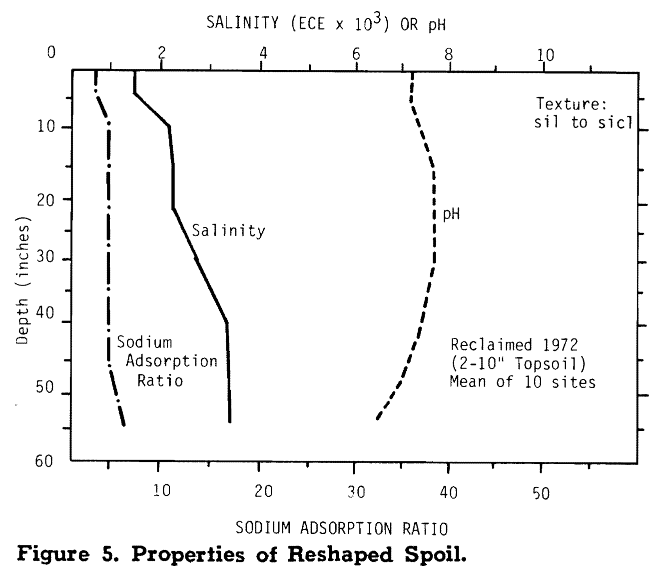

Figure 5. Properties of Reshaped Spoil.

The reshaped spoil material represented by data shown in Figure 6 is fine sandy loam to silt loam of moderate permeability. It is slightly alkaline (pH about 7.5) through most of the 60-inch depth. The SAR is less than 5, so dispersion should not be a problem. Excess salinity is a problem as indicated by ECE values of more than 4 millimhos at about 9 inches, increasing to 10 millimhos at 60 inches. Leaching of salts and/or improved drainage will be needed to obtain good productivity of all but salt-tolerant crops. Because of excess salin-

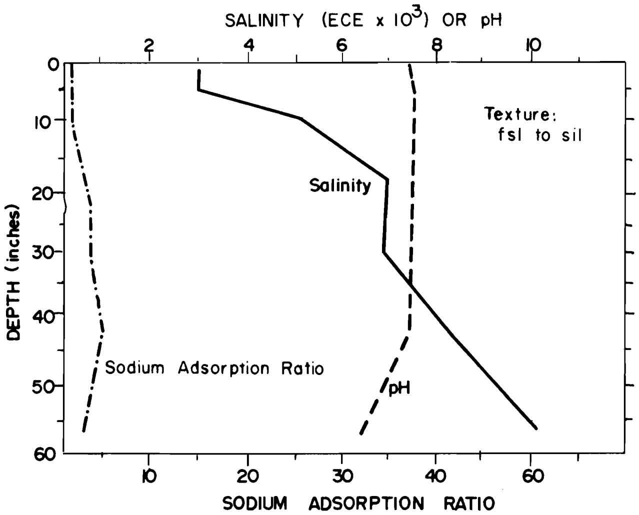

Figure 6. Properties of Reshaped Spoil.

ity, the material below 10 inches is not suitable for plant growth.

Numerous thin layers of oxidized coal and some pieces of siltstone and sandstone were in the cores. Bulk densities ranged from 0.5 in coal layers to 1.5 where hard pieces occurred. The average density of 1.1 is less than that of the original soil.

Figure 7 shows properties of reshaped spoil where moderately saline, high sodium, silty clay to clay is the dominant characteristic. The material is all moderately alkaline (pH 8), ECE values are 4 to 5 and SAR is more than 25. Because of the high sodium, the surfaces soon disperse and become impervious to water. All of this material is unsuitable for plant growth. Reclamation of such areas is impossible without a covering of suitable plant growth material. No "topsoil" had been spread at this site and only a few kochia weeds were growing. Bulk densities (data not shown) averaged 1.3.

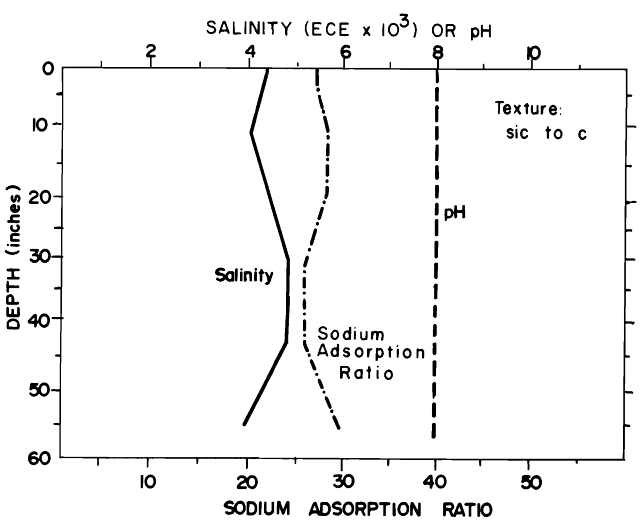

Figure 7. Properties of Reshaped Spoil.

Summary

Surface mining of coal will produce increasing acreages of spoilbank to be reclaimed for agriculture. Chemical and physical properties of native soils, coal overburden and overburden reshaped after mining were studied in this project.

The soils studied represented the range in properties found in the major coal producing area of North Dakota. Properties varied widely over small areas. Therefore, highly detailed soil maps will be needed to determine the amounts of suitable plant growth material and top dressing material within a projected mine area.

Chemical and physical properties of overburden varied greatly with depth and within or between mine areas. Therefore, reclamation problems will differ from area to area.

Properties of reshaped mine spoil are generally similar to those of the overburden in a mined area, but are usually "averaged" by the mixing process that accompanies reshaping of the spoil. There is generally less variation in properties within a 0 to 60-inch section of reshaped spoil than in a natural soil profile of that thickness.

Some interpretations are suggested based largely on present regulations of the North Dakota Public Service Commission.

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