Casey and Julie Voigt v. Coyote Creek Mining Company, LLC
Case No. RC-23-348

Restoration of Productivity to Disturbed Land in the Northern Great Plains

Voigt Exhibit 45

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Exhibit 45 – Article – Restoration of Productivity to Disturbed Land in the Northern Great Plains
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Restoration of Productivity to Disturbed Land in the Northern Great Plains

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SUMMARY

This paper presents a review of current information on the potential for restoring agricultural productivity to land disturbed by strip mining in the Northern Great Plains. The discussion focuses on the nature of the available natural resources, and information is presented to show how these natural resources can be recombined to return the land to productive uses.

INTRODUCTION

The use of fossil energy is rapidly increasing throughout the world. In the United States, this increase has averaged about 4 percent annually over the past several decades. During this period, much of the rising demand has been met by increased use of petroleum products. However, U.S. crude oil reserves are rapidly being depleted, necessitating the importation of foreign oil. Imported oil will soon account for 50 percent of the oil consumed in the United States. Consequently, there is a growing recognition of the need to maintain a favorable balance of foreign trade, to lessen dependence of the U.S. economy on actions by foreign governments, and to conserve the remaining domestic oil supplies.

Recently, considerable interest and economic stimulation have been given to the substitution of coal for oil. Known U.S. coal reserves are sufficient to meet anticipated energy requirements for several centuries (Averitt 1975). Many of these reserves are located in the Western United States, especially in the Northern Great Plains. These coal fields, containing lignitic and subbituminous coal, have remained essentially undeveloped until the last decade.

The development of coal fields in the Northern Great Plains is not, however, without social, economic, and environmental problems. The area is sparsely populated (Table 3.1), and has an adequate but widely dispersed transportation system. The region is dependent primarily on an agricultural economy and lacks an industrial labor market. However, the coal deposits are vast (Table 3.2), with coal seams commonly 1 to 10 meters (m) thick—and some exceeding 30 m. The deposits are located in a landscape well suited to surface mining. This coal is relatively low in sulfur (S) content, reducing or eliminating the need for sulfur dioxide (SO_2) scrubbers when the coal is burned. The cost per calorie of burning surface-mined Western coal is frequently 30–50 percent less than that of Eastern U.S.–mined coal (National Coal Association 1975). Thus, these coal fields are rapidly being developed, with the coal either burned in large electrical-power-generating plants near the mine sites or transported by 10,000-ton unit trains to industrial centers in the central states. Also, permits have been granted to construct the first of potentially many coal gasification plants that will convert coal to a pipeline-quality gas (methane).

These factors are resulting in the development of extremely large mining operations. Most mines presently operating in the Northern Great Plains produce near or over 1 million tons of coal annually, and those

Table 3.1 Area and Population of Coal-Producing States in the Western United States (Source: 1970 census)

State	Area	Population	Population density
	thousand km^2	thousand	no./km^2
North Dakota	183	618	3.4
Montana	381	694	1.8
Wyoming	254	332	1.4
Colorado	270	2,207	8.2
Utah	220	1,059	4.8
New Mexico	315	1,016	3.2

State	Total estimated	Recoverable Surface Mines	 Underground	 Total
	- - - - - - - - -	-million tons - - -	- - - - - -	- - - - - -
North Dakota	560,630	16,003	0	16,003
Montana	378,675	42,562	65,165	107,727
Wyoming	545,656	23,674	27,554	51,228
Colorado	371,659	870	14,000	14,870
Utah	79,721	262	3,780	4,042
New Mexico	109,427	2,258	2,136	4,394

Table 3.2 Coal Reserves in Several of the Western United States (Source: National Coal Association 1975)

presently being developed will produce 5–20 million tons annually. Because of the scale of these operations and the economics involved, almost all mining is now done using surface-mining techniques. Collectively, these factors have resulted in rapid acceleration in coal production in the Northern Plains (Table 3.3), and an increase in the area disturbed annually by surface mining.

Most land in the Northern Great Plains is used primarily for the production of domestic livestock (cattle and sheep) or is cultivated for dryland cropping, especially wheat and barley. Secondary uses include wildlife habitat and recreation. Because it is likely that the same land uses will be desired after mining, the rapid growth of mining is accompanied by the need to develop technology to restore to the land permanently the capacity to produce useful vegetation for the benefit of present and future generations. The harvest of coal is a one-time operation, while the harvest of agricultural produce and wildlife from this same land is an annual event.

Historically, surface mining for coal in the Northern Great Plains began 50 to 70 years ago at scattered locations to provide fuel for locomotives and for domestic consumption by pioneer homesteaders. Because only a few hundred hectares were mined annually, and because a frontier of new land existed, there was little concern for reclamation. Since the development of Western coal for electrical power generation and other industrial uses within the last decade, however, thousands of hectares are disturbed annually. This area will soon increase to tens of thousands of hectares. At the same time, concern over food production and awareness of aesthetic values and of the need for environmental protection have increased.

State	Production in: 1962	1966	1970	1973	1980[1/]	2000[1/]
	thousand tons					
North Dakota	2,733	3,543	5,639	7,400	19,000	119,000
Montana	382	419	3,447	9,950	41,000	133,000
Wyoming	2,569	3,670	7,222	13,600	47,000	110,000

[1/] At projected intermediate rate of development (Northern Great Plains Resource Program, 1974).

Table 3.3 Recent and Projected Annual Coal Production in the Northern Great Plains

Consequently, most Northern Great Plains states involved with mining have recently enacted reclamation laws, with the intent of restoring the landscape to a condition of equal or greater potential productivity for agriculturally important plant species than existed before mining.

Because of the recency of the awareness of the need for reclamation, present reclamation technology is actually in its infancy. Extensive research in most major mining regions has defined the primary problems involved and has suggested potential solutions for these problems. New practices that require a change in mining methods or equipment are sometimes slow and difficult to implement, however, because of the huge scale of major mining operations. Frequently, at these mines, over 30 million tons of earth and coal are moved annually. Huge, costly equipment is required for the operations. Fabrication and replacement of equipment to enable new practices usually requires several years and is extremely expensive.

RESOURCES

Most major coal mining regions in the Northern Great Plains have a continental climate. Table 3.4 summarizes several parameters of climate at several recording stations located in or near some major Western coal fields. Generally, annual precipitation is in the 20-to-40-centimeter (cm) range, with highest rainfall occurring between April and August. Most coal fields are located either in northern latitudes or at elevations greater than 1,000 m—areas with relatively short growing seasons, cold winters, and often hot summers.

Perennial grasses are adapted to almost all regions, but because of

Location	Annual precipitation	Month highest precipitation	Mean July temperature	Frost-free season 0°C
	mm		°C	days
Dunn Center, ND	399	June	21.0	115
Circle, MT	287	June	21.2	99
Colstrip, MT	384	June	22.6	127
Gillette, WY	363	June	22.4	129
Evanston, WY	269	May	17.1	49
Hayden, CO	391	April	18.1	76
Escalante, UT	310	August	21.4	138
Bloomfield, NM	208	August	23.3	147

Table 3.4 Mean Values of Selected Parameters of Climate near Several Major Coal Fields in the Western United States

climatic limitations, production of cultivated crops is limited to the areas with more favorable water supplies. Some shrubs and forbs are also adapted to the regions, while trees are confined to sandy areas or protected sites. Various wheatgrass species (*Agropyron*) are adapted throughout these areas, with crested wheatgrass (*A. desertorum* [Fisch] Schult.) being the species most commonly seeded. Other wheatgrass species found include slender (*A. trachycaulum*), western (*A. smithii* [Aybd.]), and intermediate (*A. intermedium*) wheatgrass. Grama species (*Bouteloua gracilis* [H.B.K.] Lag. and *B. curtipendula* [Michx] Torr.) are frequently found in native vegetation. In addition to many of the above, species of *Stipa, Poa, Bromus, Panicum, Sporobolus,* and other genera are often seeded on reclaimed mined lands. Legumes, such as alfalfa (*Medicago sativa* L.) and sweetclover (*Melitotus officinalis* L.), are frequently grown. Annual crops commonly grown include hard red wheats (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.).

In addition to climate and adapted vegetation, another basic resource involved in reclamation of mined land is the soil and overburden. Sandoval et al. (1973) and others provided information on various physical and chemical properties of coal mine spoils and overburden in the Northern Great Plains. Typical data on characteristics of spoils at several mine sites are given in Table 3.5. It is evident that many characteristics are site-specific, varying from mine to mine—or within a mine. However, most overburden and spoils in the Northern Great Plains have certain character-

Location	pH	$CaCO_3$ Equiv- alent	Clay	Saturation Extract:					
				EC	Ca	Mg	Na	SO_4	SAR[1]
		%	%	mmhos/cm^2	- - - - - - - - - - - -	- -	meq/l	- - - - - - - -	- - - - - - -
Beulah, ND	8.4	12	37	3	< 1	< 1	34	30	41
Center, ND	7.6	10	26	4	14	29	7	48	2
Stanton, ND	8.3	12	52	2	1	1	20	16	19
Zap, ND	8.8	10	54	2	< 1	< 1	19	7	48
Colstrip, MT	7.2	-	-	3	15	19	3	-	1
Sheridan, WY	6.1	-	-	7	29	28	45	-	8
Gillette, WY	7.4	-	-	8	25	73	31	-	5

[1] SAR = Sodium adsorption ratio = $Na/\sqrt{Ca + Mg/2}$, and is highly correlated with exchangeable sodium percentage (ESP).

Table 3.5 Properties of Surface Mine Spoils at Several Northern Great Plains Mine Sites
(Source: Sandoval et al. 1973)

istics in common—they are neutral or alkaline in reaction (pH), contain appreciable calcium (Ca) salts (especially calcium carbonate [$CaCO_3$]), and contain variable quantities of soluble salts (mainly comprising varying ratios of Ca, magnesium [Mg], and sodium [Na] sulfates). They are almost universally deficient in plant-available phosphorus (P) and biologically active forms of organic nitrogen (N), but may contain appreciable amounts of inorganic N (Power et al. 1974). Texture (particle size distribution) varies widely from location to location, ranging from clays to sands. Pyrite-bearing minerals and subsequent problems of acidity are almost entirely absent from these spoils and overburden. Most of these coal fields are located in the Fort Union geologic group.

The nature of the soil resources in the Northern Great Plains also varies widely, and includes various borolls and aridisols, as well as badlands. Natric (sodic) and saline soils are not uncommon in the region. Parent materials are typically the sandstones, siltstones, and shales that characterize the Fort Union geologic group. However, in localized areas, this formation may be covered with more recent alluvium, glacial drift, loess, or other materials.

With knowledge of plant growth requirements, a logical approach to the reclamation of strip-mined land is to: (1) inventory, sample, and map the original soils, and determine the physical and chemical properties of the overburden before mining; (2) relate the properties of the original soils and overburden, and their distribution over the area, to potential productivity of plant species that are of major significance when grown under the prevailing climate; and (3) devise a mining plan that will economically extract the coal resources and leave the landscape in a condition that permits the later development of the full productivity potential of the disturbed area. The decision of whether or not to develop fully this productivity potential can be left to the landowner, just as he now makes this decision on unmined land. Potentially irrigable land, for example, would be restored to a condition that would permit this potential use. However, present and future landowners would have the option of deciding whether or when to make the investment needed to develop irrigated agriculture. This approach provides the maximum potential for utilization of the available natural resources, and allows present and future generations the flexibility to make decisions in regard to land use.

WATER

Throughout the arid and semiarid regions of the Western United States, reclamation of land disturbed by strip mining depends primarily on the conservation and efficient utilization of the limited precipitation received.

On unmined land in the Northern Great Plains, it is usually lack of water that ultimately limits plant growth. Practices and techniques designed for the proper conservation and efficient use of water by productive vegetation are needed to restore adequate productivity to mined land. Reclamation technology must: enhance infiltration; reduce runoff, soil water evaporation, and leaching; and increase root absorption of soil water and dry matter production per unit of water used.

Water Storage

The storage of water received as precipitation is controlled by those properties of mine spoils that affect infiltration, runoff, erosion, and sedimentation. Included are texture, extent of fragmentation of sedimentary rocks in the overburden, exchangeable Na content, bulk density, and slope and slope length. As mentioned, texture of spoils varies widely from mine to mine, and even within a mine. Infiltration generally decreases as clay content increases, but closely packed fine sand fractions, even with relatively low clay contents, can also be relatively impermeable. Most spoils are derived from sedimentary rock—sandstones, siltstones, and shales. However, the degree of fragmentation and fracturing of these materials during the mining process may affect infiltration. Shales may fracture into pieces ranging from a pulverized, almost single-grain arrangement to segments several centimeters in diameter, depending on their properties and on the mining technique. Consequently, differential packing of these fragments results in variable porosity and infiltration rates. The larger fragments frequently are not wetted by infiltrating water—the water merely moves through the spaces between fragments.

Exchangeable sodium percentage (ESP) is highly important in regulating infiltration rate and water storage of mine spoils in the Northern Great Plains. As ESP (the percentage of the cation exchange capacity occupied by Na) increases above about 12, spoils become dispersed and water entry is restricted. Runoff and erosion consequently increase, leaving less water stored in the soil for use by vegetation. The effects of sodic conditions are somewhat less pronounced in materials containing a high percentage of sand or appreciable amounts of biologically active organic matter. Restricted infiltration resulting from sodic conditions can be improved by replacing the exchangeable Na with Ca. This replacement can be done by adding gypsum (calcium sulfate or $CaSO_4 \cdot 2H_2O$) to the spoil material. Under the climate prevailing in most mine areas in the Northern Great Plains, gypsum additions reduce exchangeable Na content 30–50 percent in the upper 30 cm of material within a few years after treatment (Fig. 3.1). The Na replaced must be leached below the root zone, and this process can be accomplished by the use of mulches and fallow in

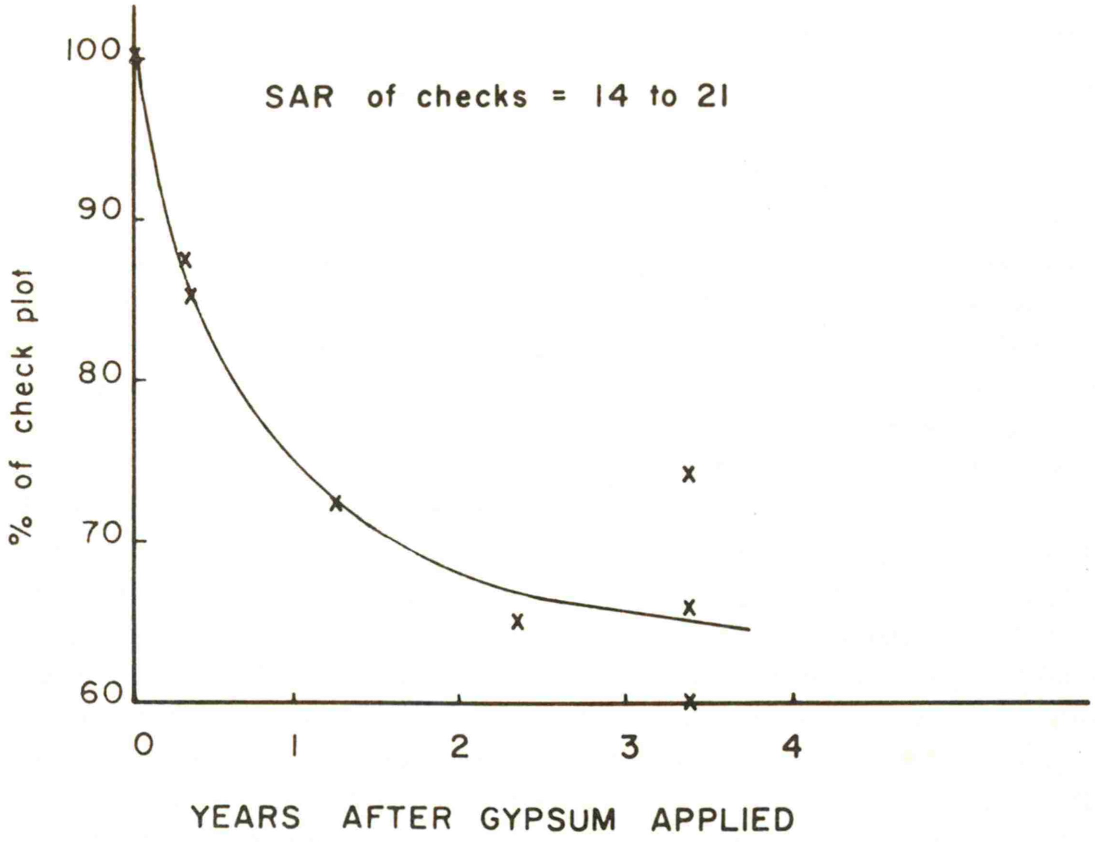

Figure 3.1 Reduction in Sodium Adsorption Ratio of North Dakota Mine Spoils Following Gypsum Treatment (for the range of values listed, SAR was found to be approximately numerically equivalent to ESP)

combination with gypsum. In more arid regions, natural precipitation may be too meager to accomplish this exchange and leaching of Na after gypsum treatment.

Sodium can be almost completely replaced within a few days by leaching with about 0.75 N calcium chloride ($CaCl_2$) (Doering and Willis 1975). This technique is known as high-salt leaching. But, because of the high concentration of soluble salts introduced, this treatment must be followed by leaching with 50–100 cm or more of irrigation water before plant growth is possible. Thus, this technique is expensive and requires good drainage and considerable supplemental water. Limestone or calcite ($CaCO_3$) is too low in solubility under alkaline conditions to be of use in replacing exchangeable Na.

Water infiltration and movement through spoils decreases as bulk density increases. However, water storage per unit depth increases with increased bulk density. Generally, bulk density of spoils is 10–30 percent lower than that of the original overburden. Typical bulk density values of overburden are 1.4–1.7 grams per cubic centimenter, whereas spoils are usually 1.1–1.4 gm/cm^3. Most spoils in the northern Great Plains are relatively dry at time of mining; therefore, use of heavy machinery seldom causes severe compaction. Sandy spoils may be an exception, and ripping or other surface disturbances of these spoils before seeding may be beneficial (Jensen and Hodder 1975). Overburden is commonly removed and piled with a dragline, and spoil piles are usually smoothed with a bulldozer. Both operations result in packing of spoils near the center axis of the piles, with lesser packing on the outslopes where materials are pushed or slide down slopes. Bulk density of smoothed spoils thus varies widely, with the higher densities usually found along the center line of the original spoil piles. This distribution may result in uneven subsidence and differences in surface drainage.

The steeper the slope of smoothed spoils, the greater the likelihood of runoff and erosion (Gilley et al. 1976). Many smoothed spoils have slope lengths over 100 m, permitting concentration of runoff water and subsequent erosion. On sodic spoils, however, sediment losses are often relatively low because of the surface seal, resulting in a pavementlike surface. However, loose sodic spoils are initially very erosive. Most states require that usable topsoil be saved and returned to smoothed spoils, but this topsoil readily erodes from long steep slopes, especially on areas devoid of vegetation (Table 3.6). The amount by which slopes can be reduced depends somewhat on the original topography of the mined area. If original slopes were steep and the topographic gradient of primary water courses was also steep, after mining smoothed spoils may have steep slopes or will need to be properly terraced. If the area was originally relatively level, postmining slopes can easily be reduced to grades of 5 percent or less.

Water Use

As important as improving infiltration and water storage in mined areas is enhancing the efficiency with which the stored water is used by productive vegetation. Under semiarid and arid conditions, essentially all of the available water within the root zone of a crop is used up by harvest time, regardless of the crop yield. Practices that increase plant growth and yield generally increase water-use efficiency under dryland conditions (Viets 1962). Soil fertility status, salinity level, thickness, compaction, and the presence of toxic materials all affect water-use efficiency.

Soil fertility is of major importance in regulating plant growth on mined lands. Proper control of soil fertility can greatly increase the efficiency with which water is used (Smika et al. 1965). Almost all mine spoils in the Northern Great Plains are deficient in plant-available P. Because most spoil materials in the West are calcareous, this deficiency is readily corrected, however, by applying 50–100 kilograms (kg) of fertilizer P per hectare (ha) before seeding the first crop. This quantity meets the requirements of grass for several years. Spoil materials are usually devoid of biologically active organic N materials, but many shales contain 10–50

Land Use	Runnoff	Soil Loss
	mm	MT/ha
Rangeland	10	0.2
Spoil	51	7.8
Spoil covered with topsoil (25 cm)	41	36.0

[1/] 9-10% slope, 100 mm water added in 4 hours to initially wet soil material.

Table 3.6 Runoff and Soil Loss from Rangeland Mine Spoils, and Spoils Covered with Topsoil, Using the Purdue Rainulator (Source: Gilley et al. 1976)

parts per million (ppm) exchangeable ammonium (NH_4) (Power et al. 1974). This substance is readily nitrified to NO_3-N within a few months after exposure to the atmosphere by the mining process. These shaley materials are frequently poorly drained, and the NO_3-N formed is often lost from the surface 25-50 cm, presumably by denitrification, within about two years (Table 3.7). Thus, available N in freshly exposed shale spoils is variable, but is usually low in older spoils. Until a pool of mineralizable organic N is built up, either annual fertilization or N-fixing legumes are required to sustain a supply of plant-available N in such spoils.

Potassium (K) has not been found to be deficient in mine spoils in the Northern Great Plains, just as it is seldom deficient for most dryland crops produced on unmined land. Predominant clay minerals are montmorillonites and illites, which hold considerable adsorbed K. Also, the sedimentary rock may contain some primary K-bearing minerals.

Seldom have deficiencies of other essential plant nutrients been recognized in mined spoils in the Northern Great Plains, although the amount of research on this subject to date is very limited. In some areas, exchangeable Mg levels are high enough to have the potential to restrict Ca uptake even from materials containing 10 percent free $CaCO_3$. Also, a few reports have indicated that molybdenum (Mo) levels in plants may occasionally be high enough to interfere with copper (Cu) nutrition of livestock. No selenium (Se) deficiencies or toxicities have been detected. Materials that contain appreciable biologically inert organic carbon (C),

Date[1]	NH_4-N	NO_3-N
	ppm	ppm
May, 1971	17.1	21.4
August, 1971	2.1	28.7
August, 1975	1.6	10.5

[1] Spoils exposed by mining in March, 1971.

Table 3.7 Changes in Inorganic Nitrogen Content in Upper 30 cm of Unvegetated Mine Spoils Exposed to Normal Weathering

such as carbonaceous shales, leonardite, or coal slack, may sometimes contain toxic levels of boron (B), however.

High salinity reduces water-use efficiency by increasing the osmotic potential of the soil water. Consequently, the plant must expend more energy to extract water from the saline soil and the result is less growth per unit of water used. Only at a few locations in the Northern Great Plains is the level of total soluble salts high enough to interfere seriously with water uptake. Besides the osmotic effects of dissolved salts, individual salts may accumulate to toxic levels. For example, Mg may accumulate to the point that it interferes with Ca nutrition (Ries et al. 1976). The effects of Na accumulations were discussed earlier. At most locations, SO_4 is the predominate anion and Ca, Mg, and Na are the predominate cations in spoils (Sandoval et al. 1973). Salinity problems are commonly alleviated by leaching the soluble salts below the root zone, by means of either natural precipitation or supplemental irrigation. If leaching is not practical, then only salt-tolerant species can be grown on saline spoils.

As indicated, in dryland regions most plant species use essentially all the water available within the root zone by the end of the season. Therefore, efficient use of this water is enhanced not only by fertilization or other practices that stimulate growth, but also by proper selection of plant species. In the Northern Great Plains, perennial grasses are especially well adapted to the climate and soil resources that prevail. The proper selection of species for reclaimed land for optimum water utilization and for best support of domesticated livestock is critical.

Until the last decade or two, the prevailing philosophy was that only plant species native to the region should be considered for permanent sustained production. More recently, many other species have proved much more productive and well adapted to Northern Great Plains livestock ranching systems. It has also become apparent that both native and introduced grass species growing in favorable moisture sites respond well to fertilization. However, the use of introduced species, monocultures, fertilizers, and such practices requires intelligent management of livestock grazing to maintain the natural resources. In earlier generations, the ranching operations in the Northern Great Plains generally have not shown this degree of livestock management. (The effects of man's activities on grassland ecosystems in the West have been thoroughly discussed by Lewis [1969].)

RECLAMATION TECHNOLOGY

In the preceding paragraphs, many of the properties of mine spoils that interfere with soil-water relationships, and consequently restrict plant growth, have been identified, and potential methods of alleviating the adverse effects of these properties have been indicated. Unfortunately, many of these solutions are inadequate or impractical. In particular, changing the properties of sodic spoils is extremely difficult because present technology is extremely expensive, of limited effectiveness, or creates other problems.

Many of the problems encountered in reclamation can be solved by covering undesirable spoils with good soil material. A cover of as few as 5 cm of topsoil over sodic spoils increases the infiltration rate severalfold, reduces runoff, and vastly improves plant survival and growth (Sandoval et al. 1973). A thin layer of soil material absorbs raindrop impact, reducing surface sealing of sodic spoils. However, a cover of only 5 cm is of little value in enhancing water-holding capacity or the fertility status of the root zone. These are best improved by covering spoils with a greater thickness of acceptable soil material. In one experiment, first-year growth of spring wheat, alfalfa, crested wheatgrass, and native grasses all increased as total thickness of replaced soil (topsoil plus subsoil) spread over sodic spoils (SAR = 26) increased to about 70 cm (Table 3.8). Further increase in soil thickness had no consistent effect on production.

When high-quality topsoil was spread over the subsoil, yields with 70 cm or more of soil material were comparable to those obtained on unmined land. Applying topsoil and subsoil in separate layers is superior to mixing the two materials. With better quality spoils, containing fewer restrictions to growth, soil thickness requirements for maximum productivity may be less. On the other hand, thickness requirements may need to be increased somewhat to allow for salt migration upward from spoil into the replaced soil, for surface erosion losses, temporary waterlogging, or for other reasons.

Gilley and coworkers (1977) found that water erosion from sodic spoils

Topsoil Thickness	Subsoil Thickness, cm							
	10	30	50	70	90	110	130	150
	A. Spring wheat grain yields, kg/ha							
0	800	1062	1196	1290	1263	1250	1317	1250
20	1606	1915	1956	1942	1982	1949	2029	1922
60	1962	2016	2050	2050	1935	2009	2076	2130
Mixed[1]	1055	1344	1472	1505	1559	1478	1512	1452
	B. Alfalfa (first cutting), kg/ha							
0	108	446	805	970	829	691	834	869
20	720	637	1244	1152	1344	1287	1161	1207
60	912	930	980	1044	927	1323	1212	1085
Mixed[1]	128	380	808	952	1233	1057	1144	1217
	C. Crested wheatgrass, kg/ha							
0	1956	2498	2897	3039	3368	2769	3465	3194
20	2827	3194	3252	3697	3311	3137	3465	3165
60	2768	2942	3155	3251	3059	3280	2826	3097
Mixed[1]	1587	2498	3349	3252	3524	2980	3291	3368
	D. "Native grass" mixture[2], kg/ha							
0	17	151	118	181	320	272	339	296
20	463	609	871	1026	1048	864	790	656
60	325	133	491	432	366	250	260	314
Mixed[1]	0	7	84	165	103	85	345	349

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[1] Topsoil and subsoil mixed 1:3 ratio; for other treatments topsoil spread over subsoil.

[2] Blue grama *(Bouteoua gracilis)* and side-oats grama (B. *curtipendula)*.

Table 3.8 Yield of First Harvest of Several Crops Indicating Effects of Thickness of Subsoil and Topsoil Spread over Sodic (SAR = 26) Mine Spoils in North Dakota covered with soil is much more severe than erosion from bare spoils. This condition arises from the fact that the pavementlike surface of sodic spoils is somewhat more resistant to the erosive action of water than is the loose replaced soil. For several reasons, most soil material is relatively dry when spread on spoils. Therefore, soil-covered spoils must be fallowed for several months to store sufficient water to insure germination and establishment of seedlings. During this time, these spoils are especially vulnerable to wind and water erosion. Research is in progress to determine the feasibility of adding a few centimeters of water after the soil material is spread, and seeding immediately afterward, with or without additional watering. Such an approach not only aids in solving the soil erosion problem, but also makes it possible to seed at almost any time during the growing season. The effects of supplemental watering on stand establishment, species competition, survival, and production are being investigated (Ries, Power, and Sandoval 1976). Information is also being acquired to determine water quality requirements and tolerances when only a few centimeters of water are applied to a seeding.

In recognition of the benefits of covering undesirable spoils with suitable soil material, legislation has been enacted in most major mining states requiring that suitable soil materials be saved and respread over graded spoils. In North Dakota, for example, before mining can begin, a soil survey of the permit area must be made, and overburden systematically sampled and analyzed. The topsoil (A horizon) is scraped off in accord with the soil survey, and is stockpiled. Next, the subsoil material (B and C horizons) is removed to a depth of 1.5 m, if present to that depth, and is also stockpiled. After mining and grading of spoils, the subsoil and then the topsoil materials are spread on the surface of the spoils. Thus practically all usable soil material is saved and returned, which, with proper fertilization and management, essentially ensures that potential productivity of the permit area will be equal to or greater than that before mining. If care is exercised in reduction of slopes of smoothed spoils, in some instances potential productivity after mining may be greater than that before mining. In areas where the supply of soil material is limited and spoils are sodic, application of gypsum before spreading the soil material may enhance water infiltration and root development into the soils.

CONCLUSIONS

Successful reclamation of surface-mined land in the Northern Great Plains is essentially the process of developing an environment conducive to the conservation and efficient utilization of precipitation by productive vegetation. Almost all potential types of postmining land use—agricultural production, grazing, wildlife, recreation, and so forth—are dependent upon successful revegetation. In the arid and semiarid regions concerned, successful revegetation is, therefore, essentially a problem of creating a plant-rooting medium that will effectively store precipitation where it falls, conserving the water in the plant root zone in a way that will enable productive plant species to use it most efficiently. If this objective is successfully accomplished, then the full productive potential determined by the available natural resources and local climate can be achieved on such land for this or future generations.

The conservation ethic dictates that the plant growth capability of the natural resources included in Northern Great Plains ecosystems not be diminished in the process of extracting the coal. It is not likely that mining activities will affect the resource of climate. Reclamation laws in most states now require that the soil resource be saved and returned to spoils after mining. As discussed earlier, preliminary research results have indicated that this could be done without appreciably diminishing the ability of the soil resource to produce vegetation. Disruption of both the groundwater and surface water resources will occur, but the latter can be restored and controlled by proper earth-moving activities during the mining process. The problem of restoring groundwater resources has not been solved. The vegetative resources can be duplicated and frequently improved in terms of potential use for man and animal, but we do not now have the technology to reproduce the native mixed prairie of the Northern Great Plains. Vegetation that can be established in its place will probably be more productive but will require more skillful management to maintain productivity.

The reclamation procedures currently required in most states appear adequate for restoration of plant growth potentials, but many problems that require additional research remain. Because these recently developed reclamation techniques have been used for only a few years, the long-term stability of the materials, of the landscapes and surface drainage, and of the perennial vegetation is largely unknown. Differential subsidence will probably continue for many years unless mining methods are changed to permit more uniform packing of spoil materials. Such subsidence will continually alter surface drainage. Problems relating to groundwater hydrology, which have not been addressed here, may be of major importance in some areas. Likewise, research is needed to restore wildlife habitats and other ecological niches. The need for or desirability of restoring native vegetation is another subject only briefly discussed here.

Much research remains to be done, but the outlook for restoring or enhancing the potential for producing vegetation useful to man appears promising, if the technology developed to date is properly utilized. Utilization of this technology can be achieved through proper enforcement of prudent legislation that recognizes the principles of the natural sciences involved.

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Edited by

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UNIVERSITY OF NEW MEXICO PRESS

Albuquerque

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