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

Soil Replacement for Reclamation of Stripmined Lands in North Dakota

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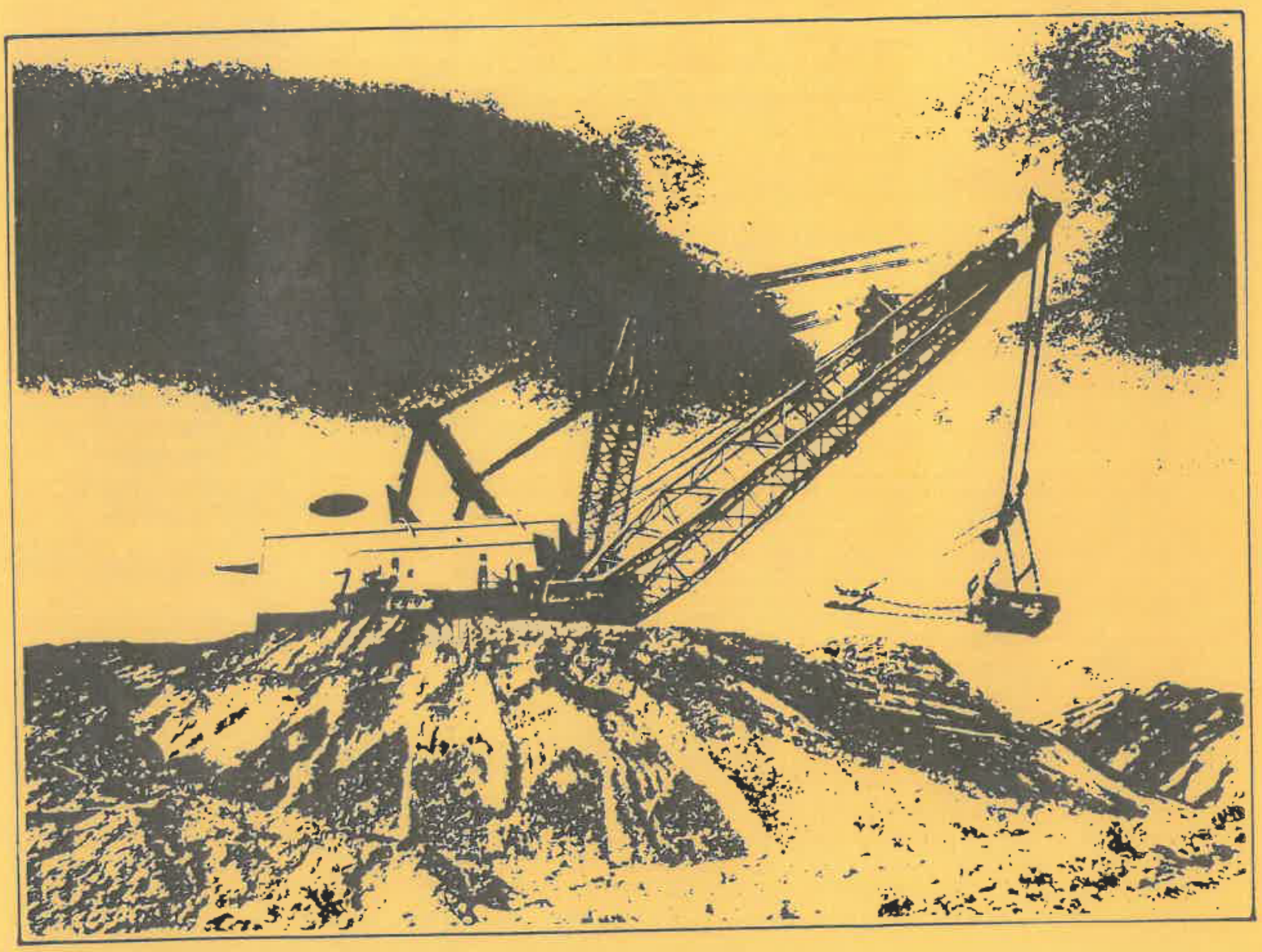

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FOREWORD

The research discussed in this report is from published and unpublished data of the reclamation research staffs of the North Dakota Agricultural Experiment Station and the Agricultural Research Service of the United States Department of Agriculture, most of whom are, or were, located at the Northern Great Plains Research Center in Mandan. Prior to July 1, 1981, NDSU reclamation research was administered by the Soil Science Department in Fargo, and after that date by the Land Reclamation Research Center in Mandan.

Published and unpublished results of the following USDA/ARS researchers were used in this report: J.J. Bond, E.J. Doering, L. Hofmann, S.D. Merrill, J.F. Power, G.A. Reichman, R.E. Ries, F.M. Sandoval, and W.O. Willis.

Published and unpublished research from the following NDSU researchers were used in this report: A. Bauer, E.C. Doll, G.W. Gee, J.E. Gilley, G.A. Halvorson, S.W. Melsted, H. Omodt, D.D. Patterson, M.W. Pole, J.L. Richardson, S.A. Schroeder, F.W. Schroer, C.M. Smith, and N.C. Wollenhaupt.

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INTRODUCTION

Commercial mining of lignite in North Dakota began to increase in the early 1960s in response to the increased demand for energy and the declining supply and increased costs of other sources of fossil fuels. The Fort Union formation, located in Montana, North Dakota, South Dakota and Wyoming, has been estimated to contain more than 40 percent of the total United States coal reserves. Much of western North Dakota, more than 28,000 square miles, is underlain by lignite. Strippable lignite reserve estimates refer to coal seams 5 feet or thicker overlain by 100 feet or less of overburden. Strippable reserves in western North Dakota are estimated to underlie as much as 2 million acres. A general discussion of North Dakota lignite reserves and development potential has been given by Dalsted and Leistritz (1974).

Public concern about the degradation of land by strip-mining increased concurrently with increases in production. Beginning in 1970, North Dakota passed legislation requiring reclamation of strip-mined lands. The state reclamation laws were strengthened by each succeeding legislative assembly until the current 1979 North Dakota law was passed to bring the state into compliance with the 1977 Federal Stripmining Act. The 1979 law requires that strip-mined lands be restored to productive levels which are equal or better than before mining.

Initial attempts to revegetate leveled spoils were generally successful only on nonsodic spoils (Power **et al.,** 1974). This led to experiments on highly sodic spoils in which various chemical treatments, mulches and topsoil replacement were compared. It soon became apparent that even 2 inches of topsoil markedly increased vegetative establishment and dry matter production. These experiments showed that reclamation success would be directly related to chemical and physical characteristics of the underlying spoil materials and the amount and quality of soil materials available for replacement. Further studies were initiated to 1) characterize overburden materials in the potential stripmining areas of North Dakota, 2) evaluate soil materials available for use in reclamation, and 3) develop reclamation technology to assist in meeting legal requirements for land restoration. The purpose of this review is to evaluate published and unpublished North Dakota research relating to the depth and quality of topsoil and subsoil (first and second lift) needed for successful reclamation of North Dakota strip-mined lands and to identify areas where further research may be needed.

OVERBURDEN CHARACTERISTICS

Most of the lignite reserves in North Dakota are located in the Bullion Creek and Sentinel Butte formations of the Fort Union Group and consist of alternating layers of lignite, soft shales, silts and some sands (Sandoval **et al.,** 1973). Soils in the area are derived from these Fort Union geologic materials, from overlying glacial till or from alluvial or aeolian deposits.

Studies of the characteristics of the lignite stripmine spoils in North Dakota as related to reclamation potential have been reported by Gee **et al.** (1978); Sandoval **et al.** (1973); Schroer (1976 and 1978) and in ARS-NDSU Progress Report 20 (1975) and the succeeding Update (1977) and Supplement to the 1977 Update (1979). No attempt will be made in this discussion to summarize all the results of these studies; instead, the variability in the properties of these spoil materials which relate to soil replacement depths will be emphasized.

Schroer (1976 and 1978) analyzed several hundred overburden samples for various physical and chemical properties and noted that these properties varied widely with depth both within and between mine areas. Because of this wide variation, he stated that site sampling will be needed at each mine or permit location to assess pertinent properties so that the appropriate reclamation procedure can be developed. He also sampled and analyzed reshaped spoils at four mine sites and noted that the resulting properties of the reshaped spoils could have been predicted from pre-mine overburden sampling.

Sandoval **et al.** (1973) reported that minespoils derived from the Fort Union geologic materials are frequently fine-textured, with clay contents as high as 40 percent. Smectite is the predominate clay mineral, with appreciable quantities of vermiculite and illite, with traces or low amounts of chlorite and kaolinite (Bauer **et al.,** 1976; Klages and Hopper, 1982). Sandoval **et al.** (1973) and Schroer (1976 and 1978) reported that these overburden materials tend to be nonsaline to moderately saline (EC below 8) but are often sodic (SAR above 20). However, the sodium content is variable with SAR values varying from 2 to 70. In some areas, the Fort Union stratified materials are overlain by glacial drift and/or aeolian materials. These materials are generally low in soluble salts and sodium but are occasionally coarse-textured with a low water-holding capacity.

When the sodium content increases in a clay high in expanding-lattice clay minerals (such as smectite), the particles disperse, the surface becomes sealed, and water intake may be reduced to nearly zero. Gee **et al.** (1976) reported that when topsoil was spread over sodic spoil and excess water was applied, the moisture content of the topsoil was still above field capacity after 30 days.

The results cited above and those to be discussed later show the importance of spoil properties in determining the optimum depth of topsoil and subsoil to be replaced. The most important spoil properties are sodium content, salinity, clay content and kinds of minerals. The water-holding capacity is dependent upon these properties.

INITIAL EXPERIMENTS COMPARING TOPSOIL WITH CHEMICAL AMENDMENTS AND STRAW MULCH

When the first reclamation law was passed in North Dakota in 1970, initial efforts were focused on the reestablishment of vegetation on reshaped spoils. Sandoval **et al.** (1973) noted that the severity of revegetation problems increased as the clay content and exchangeable sodium percentage (ESP) of the spoils increased. They observed that while spoil properties varied widely within and between mine areas, the severity of the problems associated with high clay and high sodium contents also tended to increase with overburden depth at each site.

The earliest work on vegetative reestablishment in North Dakota compared replacement of topsoil with applications of chemical amendments and straw mulch (Sandoval **et al.**, 1973; Power **et al.**, 1974; and Power **et al.**, 1975). Typical results from one experiment are given in Table 1; the spoil at this location has an ESP of about 25. These results indicate that while gypsum applied to sodic spoil increased production, much higher yields were obtained when 2 inches of topsoil was applied. Straw mulching increased vegetative production both on topsoiled and nontopsoiled plots.

Table 1. Slender wheatgrass yields as affected by chemical amendments, straw mulch, and topsoil application on highly sodic spoil (Power et al., 1974).

	Dry matter yield			
	No topsoil		Two inches topsoil	
Amendment	No straw	Straw	No straw	Straw
	pounds/acre			
None	0	63	605	1283
Gypsum	227	316	921	746
Sulfur	47	62	930	1587

Identical experiments were initiated in 1973 at four mine sites (Merrill **et al.**, 1983b) in which each of two topsoil applications (none or 12 inches) was combined with each of two gypsum treatments (none or 10 tons per acre). On topsoil treatments, gypsum was incorporated into the spoil prior to application of topsoil. Crested wheatgrass was seeded on all except selected plots which were summerfallowed for three years before seeding. The purpose of summerfallowing was to increase moisture content in the soil and spoil and promote the downward leaching of sodium displaced by calcium from applied gypsum. Summerfallowing proved ineffective in increasing gypsum effectiveness. Average yields for the four-year period 1975-78 and yields for 198 are given in Table 2. At the highly sodic Zap site average yields from 1975 to 1978 without topsoi were less than half of yields when topsoil was applied. Gypsum had little effect on yields at Zap or either the no topsoil or topsoiled treatments. On the moderately sodic Beulah and Stanton sites, gypsum did not affect yields on the topsoil plots in the 1975-78 period; however, when gypsum was applied to the plots which were not topsoiled, yields approached those on the topsoiled plots. On the nonsodic Center site, average yields from 1975-78 were not affected by gypsum, but yields tended to be higher when topsoil was applied. In 1983, yields at each location were much lower than yields for the 1975-78 period, partly because of climatic and stand differences and partly because nitrogen fertilizer was not applied after 1978. No consistent yield differences due to gypsum were apparent in 1983 at any site except possibly at Stanton. However, 1983 yields obtained 10 years after topsoil was applied tended to be two or three times as large as when no topsoil was applied. These results emphasize the need for respreading topsoil, since neither stands or yields were maintained when only gypsum was applied.

Table 2. Average crested wheatgrass yields from 1975-78 and yields for 1983 at four mines as affected by topsoil and gypsum.

Mine	SAR of Spoil	Year	No topsoil		Topsoil[1]		Average relative yield w/o topsoil
			No Gypsum	Gypsum[2]	No Gypsum	Gypsum[2]	
			tons/acre				%
Center	1	1975-78	1.6	1.3	1.7	1.8	84
		1983	0.4	0.2	0.7	0.8	37
Beulah	11	1975-78	0.9	1.1	1.1	1.1	90
		1983	0.3	0.3	0.6	0.6	55
Stanton	12	1975-78	0.9	1.1	1.1	1.2	84
		1983	0.1	0.2	0.5	0.7	27
Zap	27	1975-78	0.4	0.3	0.7	0.8	47
		1983	--[3]	--[3]	0.6	0.8	--

[1] 12 inches of topsoil applied

[2] 10 tons per acre of gypsum applied to spoil before topsoiling

[3] no yields obtained due to loss of stand

These initial experiments demonstrated that topsoil depths needed for optimum yields would be related to the quality of the underlying spoil, with greater depths of good quality soil needed to restore productivity on poor quality spoil. This is illustrated by results given in Figure 1 from treatments without gypsum as reported by Merrill **et al.** (1981). On adequately fertilized plots on nonsodic spoil, yields were 8 percent higher on topsoiled plots than on nontopsoiled plots, 29 percent higher on moderately sodic spoil and 84 percent higher on highly sodic spoil. The lower yields obtained with topsoil as the sodicity level in the spoils increased indicated that 12 inches of topsoil was not enough to restore optimum productivity.

Doering and Willis (1975) conducted a laboratory and field study of chemical reclamation for highly sodic strip-mine spoil (SAR 25) using gypsum and

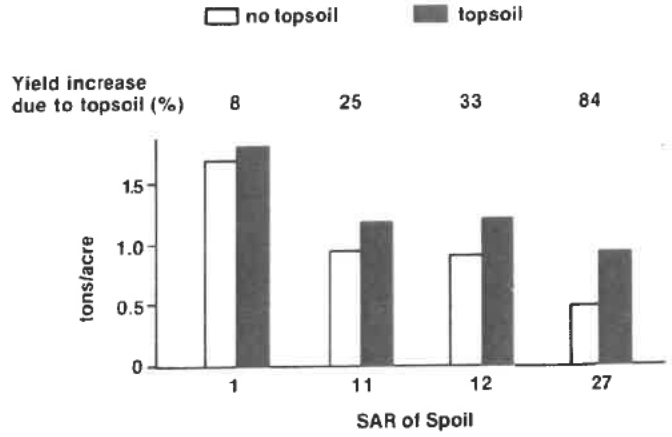

Figure 1. Yields of crested wheatgrass with and without 12 inches of topsoil at four sites with different SAR values (Merrill et al., 1981).

calcium chloride. Gypsum, because of its low solubility, was not an effective reclamation agent. Calcium chloride (0.25 Molar) was sufficiently soluble to increase the hydraulic conductivity of the spoil so that the replaced sodium was leached downward. Their results indicated that chemical reclamation of sodic spoils was feasible but not practical due to the high cost of calcium chloride. Their results and the results of other North Dakota experiments led Merrill **et al.** (1981) to conclude that the use of chemical amendments was feasible only when an adequate supply of suitable plant growth material is not available.

TOPSOIL DEPTH EXPERIMENTS

Since the earlier experiments indicated that 1 foot of soil replacement was inadequate to restore premine productivity, further research was conducted to compare the effects of different soil depths.

Yield and Establishment of Forage Grasses:

The first experiment in North Dakota comparing different depths of topsoil was initiated in 1972 at Stanton (Ries **et al.**, 1978). The spoil at this site was highly dispersed (SAR 25) and moderately high in clay (silty clay loam). Topsoil was applied at depths of 0, 2, 6, and 12 inches. Two fertilizer treatments were applied at each topsoil depth — no fertilizer or fertilized with 100 pounds per acre of phosphate initially (and none thereafter) plus 50 pounds per acre of nitrogen each year for the first three years (and none thereafter). The experiment was conducted for nine years, but yields were obtained only the first three and the last two years. Yield trends for crested wheatgrass and native grasses were similar, so only crested wheatgrass yields are given (Table 3).

Table 3. Yields of crested wheatgrass in selected years from 1974 to 1982 with (w) and without (w/o) fertilizer as affected by topsoil depth (Ries, et al., 1978 and unpublished USDA/ARS data).

	Yield									
Topsoil	1974		1975		1976		1981		1982	
depth	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
inches	tons/acre									
0	0	0	--	--	0.1	0	0.1	0	0	0
2	1.8	0.4	1.1	0.6	0.6	0.4	0.4	0.3	0.7	0.4
6	1.7	0.6	1.2	0.8	0.7	0.4	0.5	0.4	0.8	0.6
12	2.0	1.1	1.7	1.3	0.8	0.7	0.6	0.6	1.0	0.9

Each year, yields were higher when 12 inches of topsoil was applied, but the rate of yield increase indicates that maximum yields were not attained at the 12-inch depth even with adequate fertilization. The application of fertilizer increased yields at each topsoil depth every year. The persistence of this increase through the ninth year suggests that part of this fertilizer increase was due to phosphorus application, but the relatively greater increases in the first three years indicate that yields were also increased by nitrogen fertilizer. The relative response to fertilizer decreased as the depth of topsoil was increased; this decrease can be attributed to the available nutrient content of the replaced topsoil. These results also suggest that the optimum depth of soil replacement is not reduced by fertilization.

The effect of topsoil thickness on stand establishment (plants per unit area, not yield) was measured in 1974 and 1976, two and four years after crested wheatgrass was seeded. When no topsoil was applied, stands were much lower than when topsoil was applied (Figure 2), but stands did not increase as the depth of soil increased. Since these measurements were made in 1974 and 1976, they do not reflect any long-term effects of topsoil thickness upon stand retention. Stands were subsequently observed to decline even further on plots to which no topsoil was applied.

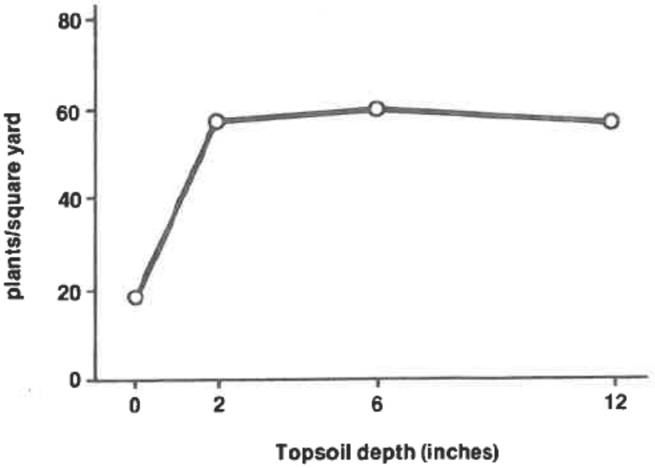

Figure 2. Effect of topsoil depth over sodic minespoil on stand density of crested wheatgrass (Ries et al., 1978).

Even though yields for the first year (1974) were satisfactory (but less than optimum) when 12 inches of topsoil was applied, yields declined as the experiment progressed. Part of this decline can be attributed to drought in 1976, but soil analyses indicated that part of the yield depression was due to upward movement of sodium from the spoil into the overlying topsoil (Sandoval and Gould, 1978). Merrill **et al.** (1980a and 1983a) have shown that upward movement of sodium into overlying soil materials tends to increase with the degree of dispersion of the spoil; dispersion in turn increases as adsorbed sodium increases. These initial experiments indicated that even though 12 inches of topsoil was initially adequate to reestablish grass cover on highly sodic spoils, productivity could not be maintained.

Yields of Wheat and Corn Silage:

An experiment (Pole **et al.**, 1979) was initiated in 1974 at the Knife River Mine in which 2, 6, 12, and 24 inches of sandy loam topsoil were placed over moderately sodic spoil material (SAR 12). Corn and wheat were rotated on two series of plots so that each crop was grown each year. Yields of all crops for the first cropping year (1975) were extremely low due to the dryness of the recently-applied topsoil, and were low in 1977 and 1980 because of drought. Wheat yields were not obtained in 1977.

Yields of wheat (Table 4) indicate that highest yields for the first two years were obtained when 24 inches of topsoil was applied, but highest yields in 1979 and 1980 were obtained on plots to which 12 inches of topsoil was applied. Yields in 1978 and 1979 were similar on plots which received either 12 or 24 inches of topsoil.

Table 4. Wheat yields at Knife River Mine as affected by depth of topsoil applied over moderately sodic spoil (SAR 12, Pole et al., 1979, and unpublished data).

Topsoil	Wheat Yield					
depth	1975	1976	1978	1979	1980	Average
inches			bushels/acre			
2	1.7	11.2	17.3	16.2	3.0	9.9
6	2.1	13.7	19.4	18.9	4.8	11.8
12	3.1	14.1	21.1	20.0	6.1	12.9
24	3.6	15.3	22.4	20.0	5.1	13.3

Corn silage yields (Table 5) followed the same general trends as the wheat yields, except that after two years, yields from plots which received 12 inches of topsoil were equal to or higher than yields from plots which received 24 inches.

Soil samples taken in 1978 did not indicate any significant upward movement of sodium, but sodium movement 3 to 6 inches above the soil/spoil interface was detected by intensive resampling in 1981.

Table 5. Corn silage yields from 1975 to 1980 at Knife River as affected by depth of topsoil over moderately sodic spoil (SAR 12, Pole et al., 1979 and unpublished data).

Topsoil	Corn Silage Yields						
depth	1975	1976	1977	1978	1979	1980	Average
inches				tons/acre			
2	1.0	1.7	1.2	4.9	5.4	1.3	2.6
6	1.3	2.3	1.5	5.4	7.7	1.6	3.3
12	1.8	2.9	1.7	6.1	8.1	2.4	3.8
24	2.7	4.2	1.4	6.1	7.8	2.3	4.1

Results from another experiment adjacent to this site indicated that much of the sodium which moved upward into the topsoil was periodically leached downward into the spoil (Merrill **et al.**, 1983b).

TOPSOIL AND SUBSOIL DEPTH EXPERIMENTS

The results of the preceding experiments indicted that the depth of soil needed to restore optimum productivity would require more soil material than was available from the A horizon (topsoil or plow layer) of the premine soils. Subsoil (B and C horizon) materials, when available of suitable quantity and quality, would also need to be replaced. Therefore, additional experiments were initiated with thicker depths of soil replacement using both topsoil and subsoil materials.

Stanton Wedge Experiment:

The details of an experiment constructed in 1974 at the Glenharold Mine at Stanton have been reported by Power **et al.** (1981). Subsoil was shaped into a wedge varying in depth from 0 to 7 feet over sodic spoil. Topsoil depths of 0, 8, and 24 inches were spread over the subsoil wedge so that each topsoil treatment extended over every depth of subsoil. A fourth treatment consisted of subsoil and topsoil mixed in a 3:1 ratio during construction of the subsoil wedge. Construction details are shown diagrammatically in Figure 3. Topsoil was mostly from the A horizon and subsoil from the B and upper C horizons of an undisturbed Temvik-Williams silt loam. Properties of the topsoil, subsoil and spoil materials are given in Table 6. The spoil (SAR 25) was a poor medium for plant growth and exhibited severe surface sealing when exposed. The subsoil was slightly saline (EC 4) and somewhat sodic (SAR 6) but within the minimum suitability criteria for subsoil (second lift) material under current North Dakota stripmine reclamation regulations.

As reported by Power **et al.** (1981), alfalfa yields tended to increase as the subsoil depth increased to 28 or 36 inches (Table 7). Highest yields were obtained when topsoil was placed over subsoil, but no increases in yield were noted when depth of topsoil in-

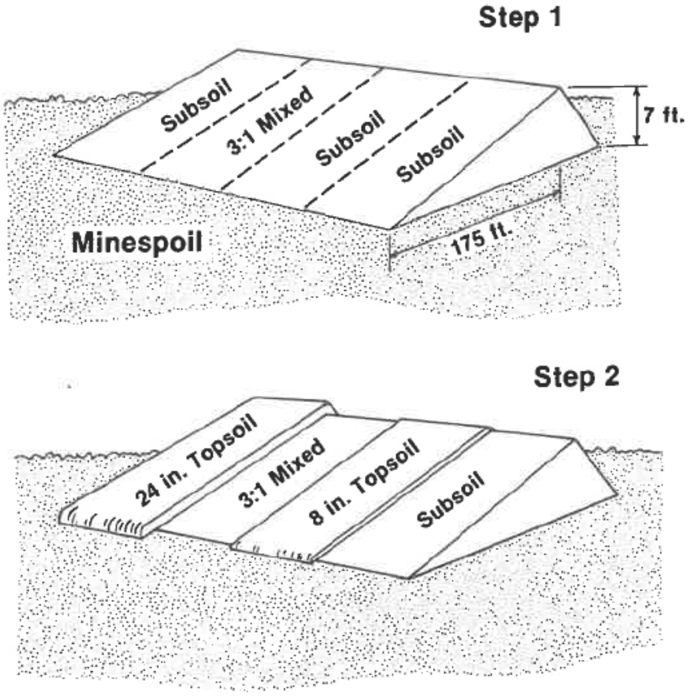

Figure 3. Schematic diagram illustrating the construction of the subsoil wedge (Step 1) and placement of topsoil over the wedge (Step 2) in the Stanton wedge experiment.

Table 6. Average properties of topsoil, subsoil, and minespoil in the Stanton wedge experiment (Power et al., 1981).

Material	SAR	EC	Clay
		mmho/cm	%
Topsoil	1	1	16
Subsoil	6	4	32
Minespoil	25	3	38

Table 7. Average alfalfa yields (1976-79) as affected by thickness of soil materials at the Stanton wedge experiment (Power et al., 1981).

Subsoil Depth	Topsoil Depth (inches) 0	8	24	Mixed Subsoil-topsoil
inches	-----	tons/acre	-----	-----
4	0.31	0.62	0.63	0.21
12	0.53	0.74	0.79	0.38
20	0.62	0.88	0.88	0.58
28	0.67	1.00	0.94	0.70
36	0.58	0.96	0.90	0.77
48	0.49	0.95	0.90	0.82
60	0.47	0.96	0.85	0.84
72	0.52	0.76	0.75	0.75

creased from 8 to 24 inches. Maximum yields were obtained when 8 inches of topsoil was placed over 28 inches of subsoil, giving a total soil replacement depth of 36 inches. When topsoil and subsoil were mixed, yields were similar to those obtained with subsoil alone, except at the 36 to 60 inch thicknesses. Yields on the other treatments generally tended to decrease at subsoil thicknesses above 28 inches.

When no topsoil was applied, crested wheatgrass yields were highest at subsoil depths of 28 to 36 inches (Table 8) but were always lower than when topsoil was applied. Yields obtained with 8 or 24 inches of topsoil were not different at similar subsoil depths above 20 inches. For subsoil depths below 20 inches, yields tended to be slightly higher (but not significantly) with 24 inches than with 8 inches of topsoil. When topsoil and subsoil were mixed, yields at thicknesses of 20 inches or more were about as high at similar depths of subsoil as when topsoil was applied over subsoil. As with alfalfa, yields tended to decrease at subsoil depths above 28 or 36 inches except when topsoil and subsoil were mixed.

Table 8. Average crested wheatgrass yields (1976-79) as affected by thickness of soil materials at the Stanton wedge experiment (Power et al., 1981).

Subsoil Depth	Topsoil Depth (inches) 0	8	24	Mixed Subsoil-topsoil
inches	-----	tons/acre	-----	-----
4	0.67	0.86	0.96	0.56
12	0.86	0.99	1.14	0.91
20	0.90	1.13	1.24	1.12
28	0.98	1.08	1.27	1.16
36	0.92	1.20	1.26	1.20
48	0.80	1.15	1.14	1.08
60	0.78	1.13	1.16	1.11
72	0.70	1.04	1.08	1.20

Highest yields of mixed native grasses (dominated by blue gramma and sideoats gramma) were obtained when topsoil was applied over 20 to 28 inches of subsoil, with no apparent difference between 8 and 24 inches of topsoil (Table 9). When no topsoil was applied or topsoil and subsoil were mixed, highest yields were obtained at soil depths of 28 to 36 inches, although these yields were lower than on the topsoiled treatments. When topsoil was applied, yields tended to decrease when the subsoil depths were greater than 36 inches.

Average wheat yields for 1975 and 1978 were highest when topsoil was applied over 28 to 36 inches of subsoil (Table 10). At each subsoil depth, no yield differences were apparent between 8 and 24 inches of topsoil. When no topsoil was applied, highest yields (but lower than with topsoil) were obtained when about 28 inches of subsoil was applied. When topsoil and subsoil were mixed, highest yields (lower than with topsoil) were obtained at the 20-inch depth. Yields when topsoil was applied tended to remain the same or decrease slightly when the subsoil depth exceeded 36 inches.

Table 9. Average native grass yields (1976-79) as affected by thickness of soil materials at Stanton wedge experiment (Power et al., 1981).

Subsoil Depth	Topsoil Depth (inches)			Mixed Subsoil-topsoil
	0	8	24	
inches	tons/acre			
4	0.04	0.31	0.26	0.01
12	0.20	0.42	0.30	0.07
20	0.30	0.47	0.39	0.29
28	0.33	0.48	0.47	0.38
36	0.36	0.41	0.45	0.37
48	0.35	0.41	0.40	0.43
60	0.32	0.39	0.42	0.40
72	0.33	0.37	0.35	0.41

Table 10. Average spring wheat yields for 1975 and 1978 as affected by thickness of soil materials at the Stanton wedge experiment (Power et al., 1981).

Subsoil Depth	Topsoil Depth (inches)			Mixed Subsoil-topsoil
	0	8	24	
inches	bushels/acre			
4	6.3	21.8	26.6	7.0
12	18.7	29.4	28.8	19.6
20	21.0	31.9	31.6	27.5
28	25.4	31.8	33.5	27.6
36	25.2	33.8	31.0	26.7
48	24.2	34.1	33.1	27.2
60	23.5	33.2	32.8	28.0
72	22.1	31.8	30.3	28.3

For each topsoil-subsoil treatment and crop, the three highest yields (as given in Tables 7 through 10) were averaged; for each crop, relative yields were determined as percentages of highest average yield (Table 11). Highest relative yields (100 percent) were always obtained for topsoiled treatments, and differences between the 8 and 24-inch depths were not significant. Yields for subsoil without topsoil were from 64 to 76 percent of maximum yields, and when subsoil and topsoil were mixed, yields were from 83 to 94 percent of maximum yields. This indicates that at least 8 inches of topsoil must be replaced to restore optimum yield levels with subsoils of the quality used in this experiment.

Table 11. Average relative yields for each of the four crops for the various topsoil and subsoil combinations at the Stanton wedge experiment (calculated from Power et al., 1981).

Crop	Topsoil Depth (inches)			Mixed Subsoil-topsoil
	0	8	24	
	percent			
Crested wheatgrass	74	92	100	94
Mixed native grasses	76	100	98	90
Alfalfa	64	100	94	84
Spring wheat grain	74	100	98	83

The yield data in Tables 7 through 10 indicate that yields obtained when 8 and 24 inches of topsoil were replaced did not differ greatly for the same subsoil depths. However, yields at both topsoil depths tended to increase as the subsoil depth increased to about 28 or 36 inches. This was true even when an additional 18 inches of topsoil was applied, and even though highest yields were always obtained on topsoiled treatments. However, yields obtained with 0, 8, or 24 inches of topsoil can be compared at equal total soil depths of 28 and 36 inches (Table 12). At equal total soil depths, yields were consistently higher with 8 inches of topsoil than with 24 inches except for crested wheatgrass at 36 inches. The topsoil was sandy loam in texture, with an available volumetric water-holding capacity of approximately 15 percent; the subsoil was clay loam with an available water-holding capacity of approximately 26 percent (Power et al., 1981). Thus, the available water-holding capacity of the subsoil was nearly twice that of the topsoil, and the higher yields obtained with 8 inches of topsoil are likely related to this high water-holding capacity.

Table 12. Average yields for topsoil depths of 0, 8, and 24 inches at total soil depths of 28 and 36 inches at the Stanton wedge experiment. Data calculated from Tables 7, 8, 9, and 10.

Total Soil Depth	Topsoil Depth (inches)		
	0	8	24
inches			
		Alfalfa	
		tons/acre	
28	0.67	0.88	0.63
36	0.58	1.00	0.79
		Crested Wheatgrass	
		tons/acre	
28	0.98	1.13	0.96
36	0.92	1.08	1.14
		Native Grass	
		tons/acre	
28	0.33	0.47	0.26
36	0.36	0.48	0.30
		Wheat	
		bushels/acre	
28	25.4	31.9	26.6
36	25.2	31.8	28.8

As noted in the preceding discussion, yields for each subsoil-topsoil combination tended to reach a maximum at subsoil depths of 28 to 36 inches and then decline as the subsoil thickness increased. The slope of the completed wedge was about 5 percent, and higher yields at the midpoint of the slope are attributed to higher moisture levels due to accumulation of runoff water from the summit of the slope and to accumulation of snow at the midpoint of the south-facing slope.

The results of this experiment can be briefly summarized as follows:

1. Highest yields were always obtained when at least 8 inches of topsoil was applied.
2. At equal total soil depths of 28 and 36 inches, yields were higher when 8 inches of sandy loam topsoil was placed over clay loam subsoil than when 24 inches of topsoil was applied.
3. Higher yields at the midpoint of the slope as compared to the top of the slope (where total soil depth was greater) are attributed to moisture differences due to rainfall runoff and snow accumulation.
4. Highest yields of all crops were obtained at total soil depths of 36 to 52 inches.

Zap Double Wedge Experiment:

Another wedge experiment was initiated in 1975 at the Indianhead Mine near Zap (Merrill **et al.**, 1982b) in which 10 inches of topsoil was uniformly placed over three different subsoil materials which differed in salinity, sodium content and texture. The topsoil was a nonsaline, very slightly sodic loam (Table 13). The first subsoil material (listed as "A") was a moderately saline, somewhat sodic silty clay; the second subsoil (listed as "B") was a slightly saline, somewhat sodic loam; the third (listed as "C") was a nonsaline, very slightly sodic loam. The underlying spoil was a moderately saline, moderately sodic silty clay. The subsoil materials were placed in a double wedge which was 42 inches thick at the summit and which sloped to zero thickness at the north and south limits of the wedge. The south slope was 1 to 2 percent and the north slope was 5 to 6 percent (Figure 4). Four plots parallel to the slope were laid out over each of two blocks of subsoil materials and seeded to spring wheat, alfalfa, crested wheatgrass, and Russian wildrye. Yields for only spring wheat and crested wheatgrass are discussed here.

Average crested wheatgrass and spring wheat yields were related to topographic position, total soil thickness and subsoil properties (Figure 5). Maximum yields of both crops were obtained at midslope positions on both north and south slopes, but higher yields were obtained at the midpoint of the steeper north slopes than on the midpoint of the gentler south slopes (Figure 5). As total soil thickness decreased below the midslope position, yields

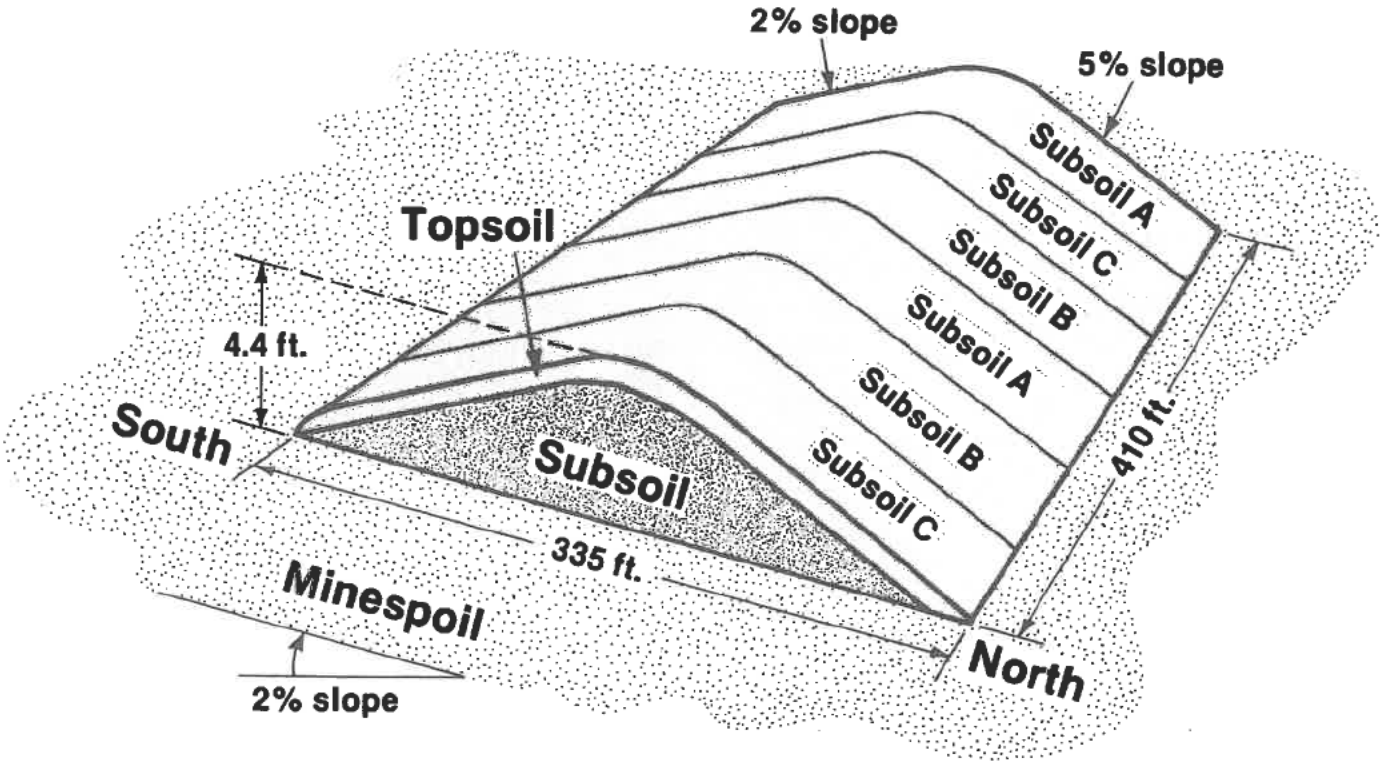

Figure 4. Schematic diagram illustrating the construction of the Zap double wedge experiment (Merrill et al., 1982b).

Table 13. Characteristics of topsoil, subsoils, and minespoil in the Zap wedge experiment.

Material	EC	SAR	Available Water[1]	Clay
	mmho/cm		%	%
Topsoil	1	3	9	24
Subsoils:				
"A"	7	6	12	45
"B"	4	5	14	34
"C"	1	2	6	13
Spoil	5	15	18	46

[1]Gravimetric water content

decreased. The effect of the topographic configuration and slope aspect on runoff and runon of rainfall and on the accumulation and melting of snow apparently had as great an effect on crop yields as did soil depth at thicknesses greater than 20 to 36 inches. Highest yields of crested wheatgrass were obtained at soil thicknesses of 20 to 32 inches and highest yields of spring wheat at thicknesses of 35 to 43 inches. Yield differences due to topographic position were less pronounced for spring wheat than for crested wheatgrass. Yield patterns of Russian wildrye (not given) were similar to those of crested wheatgrass.

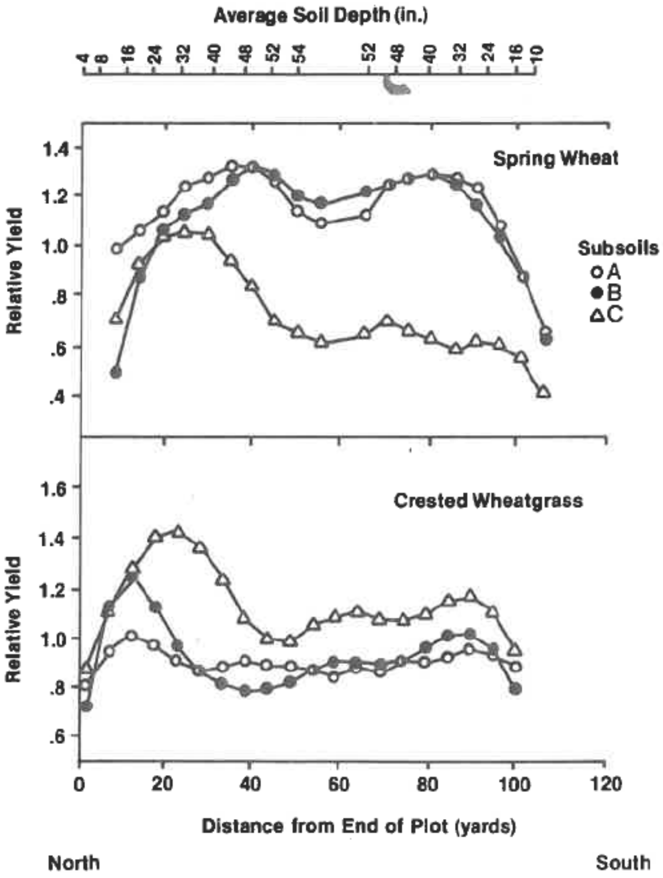

Figure 5. Average relative yields of spring wheat (1976 and 1978) and crested wheatgrass (1978, 1979, 1981) as affected by topographic location, total soil thickness and subsoil material at the Zap double wedge experiment. Average yield for each crop assigned relative yield 1.0.

Average yields at midslope positions (average of both north and south positions) and for the topographic summit (where soil thickness was greatest) are given in Table 14. Wheat yields were higher on plots with finer-textured moderately saline subsoil materials (A and B) than on plots with coarse-textured nonsaline subsoil (C) at both midpoint and summit. Wheat yields were not appreciably different between midslope and summit positions over finer-textured subsoils (A and B); yields over coarse-textured subsoil (C) were higher at the midslope position. Crested wheatgrass yields each year were somewhat higher at the midslope position than at the summit position and were higher over the coarse-textured nonsodic subsoil material (C) than over the finer-textured subsoils (A and B). In 1978, a higher rainfall year, crested wheatgrass yields were higher at the midslope position; greatest yield differences were noted over the coarse-textured subsoil (C).

Table 14. Average spring wheat yields for 1976 and 1978 and crested wheatgrass yields for 1978 and the average for 1979 and 1981 as affected by different subsoil materials and topographic location at the Zap wedge experiment.

Topographic position	Subsoil	Wheat (1976,78)	Crested Wheatgrass 1978	Crested Wheatgrass 1979,1981
		bu/A	-------------tons/acre	-------------
	A	15.1	1.39	0.60
Midslope	B	13.8	1.45	0.71
	C	10.4	1.74	0.86
	A	14.5	1.35	0.52
Summit	B	14.6	1.38	0.53
	C	7.7	1.16	0.75

Soil water storage in topsoil and subsoil in the spring was consistently greater at midslope positions than at summit positions for all crops (data not given). Soil water use (evapotranspiration) by spring wheat was generally later in the growing season than that of crested wheatgrass, and soil water use from the top 2 feet during the growing season was similar at both midslope and summit positions. Total water use by wheat was greater on the plots with the fine-textured moderately saline subsoils (A and B) than on plots over the coarse-textured nonsaline subsoil (C). With crested wheatgrass, growing season water use was not different between the different subsoil materials but was significantly higher at midslope than at summit positions.

The relative effect of topographic position was greater for crested wheatgrass than for wheat. The most rapid period of growth and water use by crested wheatgrass is earlier in the season than that of wheat; therefore, crested wheatgrass would be expected to be more responsive to stored soil moisture in early spring. On the other hand, wheat plots were cultivated and the surface soil was loose and friable; growing season rainfall could be less subject to runoff because it would infiltrate into the soil more rapidly. The established root system of the cool-season perennial wheatgrass could utilize moisture at the lower depths early in the season, while utilization of stored moisture by wheat would be limited by the rate of development of the root system. These factors may partially explain the differential response of these two plants to topographic location. It should also be noted (Figure 5) that higher yields of both crops were obtained on the steeper, moister north slope than on the gentler, dryer south slope.

Wheat yields were always higher over the more saline and more sodic fine-textured subsoils than over the nonsaline, nonsodic coarse-textured subsoil, while crested wheatgrass yields, except in 1978 on the summit position, were always higher over the nonsaline, nonsodic coarse-textured subsoil. Even though both crops are classified as moderately salt tolerant (Merrill **et al.**, 1980b), this differential response between the two species may be due to differences in salt tolerance, but it may also be due to both seasonal growth differences and to seasonal differences in root growth.

Falkirk Trench Experiment:

An experiment simulating reclamation was initiated in the fall of 1978 near the Falkirk mine at Underwood (Halvorson **et al.**, 1980 and 1982) in which various thicknesses of soil materials were replaced over nonsaline, nonsodic overburden materials differing in texture. Two series of four trenches were excavated to a depth of 15 feet, and three trenches in each series were refilled with an overburden material to within 9, 18, or 27 inches of the original soil surface. The fourth trench in each series was refilled with gravelly loamy sand overburden to within 5 feet of the surface, and then with the original clay loam subsoil (second lift) to within 9, 18, and 27 inches from the surface. Topsoil was then replaced in such a way as to refill each trench to the level of the original soil surface; parallel strips of topsoil, at depths of 9, 18, and 27 inches then extended the full length of each trench (Figure 6). Thus, each of the following four overburden and subsoil treatments were overlain with topsoil depths of 9, 18, and 27 inches:

1. Gravelly loamy sand overburden
2. Gravelly loamy sand overburden overlain by clay loam subsoil, giving a total replaced soil depth of 5 feet
3. Clay loam overburden
4. Silty clay loam overburden

Properties of the soil and overburden materials are given in Table 15. Crops were grown each year on adjacent undisturbed plots for comparison with yields on the "reclaimed" trench plots. Wheat was grown in 1979 and 1982, barley in 1980, and silage corn in 1981 and 1983. Since the plots were cropped continuously, moisture levels at planting were generally low. Rainfall during the growing season was limited each year, especially during parts of the growing season in 1980 and 1983.

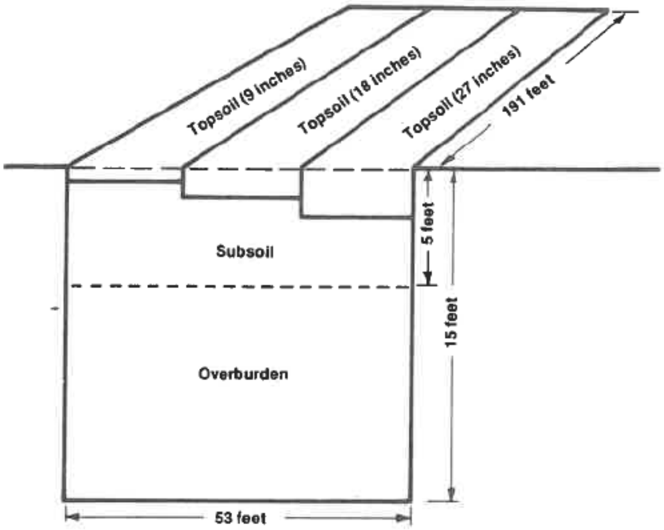

Figure 6. Cross-section of a trench in the Falkirk experiment showing the placement of topsoil, subsoil, and overburden materials. Subsoil was replaced in only one treatment (gls + subsoil); in the other three treatments, topsoil was replaced directly over the overburden at depths of 9, 18, and 27 inches.

Table 15. Chemical and physical properties of soil and overburden materials used in the Falkirk trench plots.

Properties	Soil[1]		Overburden		
	Topsoil	Subsoil	Gravelly loamy sand	Clay loam	Silty clay loam
Clay (%)	26	32	9	29	30
Water content at 15 bars (% vol.)[2]	17	19	8	19	22
pH	7.4	7.5	7.7	7.5	7.6
EC (mmho/cm)	0.9	0.7	1.0	2.7	2.3
SAR	0.8	1.1	1.3	1.4	1.0

[1] Topsoil texture was loam, subsoil was clay loam.

[2] Permanent wilting percentage, expressed as volumetric moisture.

Throughout the experiment, yields at similar topsoil depths tended to be lower on treatments with gravelly loamy sand without subsoil than on other treatments, except for wheat yields in 1979 at the 27-inch depth (Table 16). Yields at similar topsoil

Table 16. Crop yields from the Falkirk trench plots from 1979 to 1983 as affected by thickness of soil replacement and overburden material, and from the undisturbed comparison plots.

Topsoil Thickness	Overburden Material: Gravelly loamy sand, No Subsoil	Gravelly loamy sand, Subsoil	Clay loam	Silty clay loam	Undisturbed plots
inches					
			Wheat 1979		
			bushels/acre		
9	10.3	15.2	16.1	13.5	17.4
18	16.2	17.6	17.0	19.0	
27	18.4	19.2	17.7	15.3	
			Barley 1980		
			bushels/acre		
9	4.1	7.1	6.8	7.4	13.8
18	6.9	8.1	6.8	12.1	
27	8.6	10.1	10.3	10.6	
			Corn Silage 1981		
			tons/acre		
9	5.1	9.1	7.2	8.1	10.7
18	6.9	9.4	9.2	12.3	
27	9.0	10.2	10.4	9.3	
			Wheat 1982		
			bushels/acre		
9	13.0	21.3	21.7	22.4	25.6
18	16.3	21.2	22.1	24.2	
27	20.7	23.4	23.9	23.5	
			Corn Silage 1983		
			tons/acre		
9	2.8	6.6	6.5	7.4	6.0
18	3.5	6.8	6.5	7.6	
27	5.6	7.7	7.2	7.1	

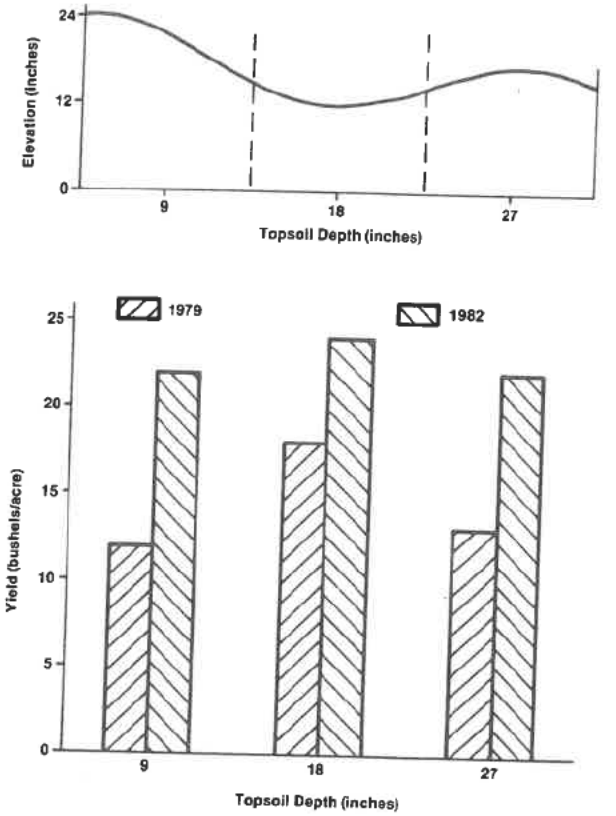

Figure 7. Yield of wheat in 1979 and 1982 as affected by microtophography (elevations) of different topsoil depths in the trench filled with silty clay loam overburden.

depths for the other three treatments were not different. On all treatments, yields tended to increase as the topsoil depth increased except for the 27-inch topsoil depth over silty clay loam, where higher yields were consistently obtained at the 18-inch depth.

Highest yields for topsoil depths of 18 or 27 inches were equal to or better than yields from the undisturbed comparison plots each year, except for trenches filled with gravelly loamy sand (Table 16). Over gravelly loamy sand without subsoil, yields with 27 inches of topsoil were about 85 percent of yields on the undisturbed plots.

Beginning in the first year of the experiment, uneven settling (differential subsidence) occurred on most of the trenches (Wollenhaupt and Richardson, 1982). On one of the trenches filled with silty clay loam, the center of the plot, covered with 18 inches of topsoil, subsided more than the outside plots covered with 9 or 27 inches (Figure 7). Consequently, rainfall and snowmelt tended to run off the outside plots and accumulate on the center plots. The difference in elevation between the outside and center of the trench was about 1 foot, with short slopes (25 feet or less) up to 6 percent. Wheat yields for 1979 and 1982 (Figure 7) were higher in the concave center plot of the trench than on the convex outer plots. Yield differences were relatively greater in 1979 when moisture stress was greater than in 1982 when moisture conditions were more favorable. These results explain why yields were higher with 18 inches of topsoil than with 27 inches on the silty clay loam treatment. They also emphasize the effect of topographic location on crop yields within relative short distances and with small changes in elevation.

Since yields for the first three years of the experiment were low due to both low rainfall and continuous cropping, a trickle irrigation system was installed in 1982 and 1983 on part of the plots to obtain treatment comparisons at higher moisture levels. A total of 3 inches of water was applied to wheat in 1982 and 6 inches to corn in 1983; the amounts applied were not adequate for maximum yields so that treatment comparisons would not be masked. The substantially higher yields with irrigation for both crops (Table 17) generally followed the same trends as yield without irrigation (Table 16). However, when 27 inches of topsoil was placed over gravelly loamy sand, yields tended to be lower in comparison with highest yields on the other three treatments when irrigation was applied (78 percent as compared to 84 percent). This may indicate that a greater thickness of soil needs to be replaced to obtain maximum yields under higher moisture conditions. When the first irrigation was applied in both years, however, crops growing on treatments with gravelly loamy sand without subsoil were already under greater moisture stress than crops on the other treatments. Final yields may have been related more to the degree of moisture stress before irrigation than to the total amount of water available during the growing season.

Table 17. Yield of wheat in 1982 and corn silage in 1983 under irrigation at Falkirk trench plots as affected by thickness of soil replacement and overburden material.

Topsoil Thickness	Overburden Material			
	Gravelly loamy sand		Clay loam	silty clay loam
	No Subsoil	Subsoil		
inches	Wheat			
	bushels/acre			
9	22.5	30.0	32.4	30.9
18	25.6	33.7	32.0	36.1
27	26.1	35.7	33.0	30.4
	Corn Silage			
	tons/acre			
9	11.5	18.6	16.9	17.1
18	13.7	19.1	18.8	19.5
27	15.5	18.5	19.3	17.5

Most of the differences in yield between the different overburden materials appear to be related to their water-holding capacity. Total water content of the top 5 feet of each treatment was determined at planting and harvest from 1979 through 1982, and averages for all topsoil thicknesses of each treatment are given in Table 18. The data refer to total water content, not to available water; the water content of the silty clay loam overburden at the permanent wilting percentage is nearly three times as high as that of the gravelly loamy sand (Table 15). However, soil water depletion from planting to harvest is indicative of the water-supplying capacity of the different overburden materials. When average yields for all soil thicknesses for each treatment are compared, yields tended to increase as water depletion increased from 1.5 to 1.8 inches but did not increase when depletion increased from 1.8 to 2.3 inches. The data obtained do not adequately explain why the greater water depletion on the silty clay loam treatments is not reflected by increased yields. The increase in soil water from harvest to planting the next spring is also indicative of the capacity of these materials to retain nongrowing season moisture for crop use.

Table 18. Average moisture levels in the top 5 feet of the Falkirk trench plots at planting and at harvest from 1979 to 1982 averaged for all topsoil thicknesses.

Overburden Material	Water Content		
	Planting	Harvest	Depletion
	inches/five feet		
Gravelly loamy sand	10.8	9.2	1.6
Gravelly loamy sand plus subsoil	13.9	12.1	1.8
Clay loam	15.8	14.1	1.7
Silty clay loam	17.2	14.8	2.4

These results indicate that replacement of topsoil is required for restoration of optimum yield levels. Yields with 9 inches of topsoil were lower than those with 18 or 27 inches of topsoil, while yields with 27 inches tended to be slightly higher than with 18 inches. Lowest yields were obtained with gravelly loamy sand overburden, but when subsoil was added, yields tended to be equivalent to those when overburden was clay loam or silty clay loam. On the clay loam, silty clay loam, and gravelly sandy loam with subsoil treatments, optimum yields were obtained with 18 to 27 inches of topsoil and were equal or better than on the undisturbed plots. When 27 inches of topsoil was placed over gravelly loamy sand, yields were about 84 percent of maximum yields on the other treatments without irrigation and about 78 percent of those when irrigated. By interpolation, this would suggest that soil materials of medium to fine texture should be replaced to a total thickness of at least 32 to 36 inches for restoration of optimum productivity when the overburden is coarse-textured.

COMPARISONS OF YIELDS FROM RECLAIMED AND UNDISTURBED SOILS

An experiment was conducted from 1980 through 1982 to compare yields from undisturbed and reclaimed soils. Three experimental sites were selected at each of two locations, one near the Knife River Mine at Beulah and the other near the Baukol-Noonan Mine at Center. At each location, one site was located on an undisturbed prime soil, one on an adjacent undisturbed nonprime soil, and the third on a newly reclaimed soil. Prime and nonprime soils were classified by the criteria established by the Soil Conservation Service of the United States Department of Agriculture.

The prime site at Beulah was Grail clay loam; the top 8 feet of the profile was clay loam in texture, and the 8 to 10-foot depth was loam. The nonprime site was Max loam; the top foot was loam in texture, from 1 to 8 feet was clay loam, and the 8 to 10-foot depth was clay. The nonprime site was located approximately 300 feet from the prime site; both sites were about four miles southeast of the Knife River Mine. The reclaimed area (within the Knife River Mine) was reshaped and respread with one foot of topsoil over slightly sodic spoil (SAR 5) in the spring of 1980; the texture of the topsoil was clay loam and that of the spoil was clay.

The prime site at Center was Arnegard loam; the texture to the 10-foot depth was loam. The nonprime soil was Parshall sandy loam; the top 3 feet and the 7 to 10-foot depth were sandy loam, with a loamy sand layer between 3 and 7 feet. The sites were located about 200 feet apart and were one mile from the Baukol-Noonan Mine. The reclaimed site in the Center mine was reshaped and respread with 2 feet of subsoil and 1 foot of topsoil over nonsodic spoil in the spring of 1980. The topsoil and subsoil were loam in texture, and the underlying spoil was silt loam.

Identical plot areas were laid out at each of the six sites. Each plot was split with corn seeded on one half and small grain (barley in 1980 and 1981, wheat in 1982) on the other half. Corn and small grain were rotated between subplots each year so that in 1981 and 1982, small grain was grown following corn and corn was grown following small grain.

At both locations, reclamation of the reclaimed sites was completed in the spring of 1980 just prior to establishment of the experimental plots. In 1980, small grain yields were not obtained because of poor stands and poor growth from the reclaimed sites at both Beulah and Center. Corn silage yields at both sites were lower on the reclaimed sites than on the undisturbed sites (Table 19). In 1981 and 1982, yields from the reclaimed sites tended to approach or equal those from the undisturbed sites. Similar yield trends have been noted when newly reclaimed soils were cropped in other experiments. Until the soil structure and moisture levels become reestablished in disturbed soils, optimum crop yields cannot be expected. At these two sites, the yields from reclaimed soils in the last two years generally tended to approach or equal those from undisturbed soils. It should be noted that soil and spoil materials at both locations were medium to fine in texture.

Table 19. Yields of small grains and corn on undisturbed and reclaimed soils at the Knife River Mine at Beulah and the Baukol-Noonan Mine at Center.

Mine	Soil	Year 1980	1981	1982
		Small grains[1]		
		---------bushels/acre---------		
Beulah	Undisturbed			
	Prime	1.4	12.5	33.2
	Nonprime	19.8	22.4	34.1
	Reclaimed	--[2]	18.4	21.1
Center	Undisturbed			
	Prime	21.4	39.9	31.0
	Nonprime	4.1	28.6	19.7
	Reclaimed	--[2]	19.3	29.6
		Corn Silage		
		------------tons/acre------------		
Beulah	Undisturbed			
	Prime	1.7	6.0	9.0
	Nonprime[3]	2.7	7.2	8.2
	Reclaimed	1.1	10.8	7.2
Center	Undisturbed			
	Prime	12.7	10.4	10.2
	Nonprime	7.5	7.1	9.6
	Reclaimed	6.2	9.3	9.4

[1] Barley in 1980-81, wheat in 1982

[2] Not harvested due to drought and/or poor stand

[3] Fallowed in 1979, all other undisturbed sites at both locations were cropped in 1979

DISCUSSION

The depth of soil materials that must be replaced to restore soil productivity is dependent upon the chemical and physical properties of the underlying spoil. In turn, the potential productive capacity (or productivity index) of reclaimed soil is related to the chemical and physical properties of the root zone, which may include not only replaced soil materials but also the uppermost portion of the reshaped spoil. The productivity index at any specific site is also dependent upon topographic position. Furthermore, the yields given herein for the various experiments are a reflection not only of the productivity index, but also of seasonal climatic conditions, of soil and crop management practices, and of disease and insect infestations. While the cumulative effect of all these factors may initially appear to complicate evaluation of the results, the authors feel that adequate data are available to substantiate the formulation of general site-specific guidelines.

When adequate amounts of suitable soil and spoil materials are available, soils can be reclaimed to productive levels which frequently exceed the premine capacity. But suitable materials are not always available, either in quantity or quality, for optimum productivity. The materials that are available must then be properly utilized for restoration to the best possible postmine use. To do this, the properties and characteristics that govern the productive capacity of soils must be known, and the processes that affect changes in soil characteristics must be understood. Fortunately, much of this information is available in published reports of soils research. The results of this research need to be adapted to define the desirable properties and characteristics for optimum productivity for use as a guide (or standard) for planning the reclamation of stripmine soils.

Characteristics of productive North Dakota soils:

Undisturbed soils are continually changing in response to environmental factors, but over a long period of time have reached a "steady state" in which these changes are extremely slow. These environmental factors have been described by Jenny (1941) as 1) climate, 2) living organisms, 3) parent material, 4) topography and 5) time. Climate is the only one of these factors that is not affected to some degree during reclamation. When soils are drastically disturbed by stripmining, this "steady state" is disrupted, and reclaimed soils immediately begin to change in response to these environmental factors. The objective of reclamation is to restore soils as nearly as possible to a "steady state" and to ensure that subsequent changes in response to the above soil-forming factors will result in increased productivity. Research in North Dakota has shown that the two most important soil properties that can be modified by changes in the soil environment during reclamation are 1) water infiltration and retention and 2) soluble salt and/or sodicity levels. Modifications of these properties can result from changes in topography and parent material (underlying spoil) and will be discussd in more detail in a following section.

The properties of agricultural soils in the stripmining area of western North Dakota have been discussed by Omodt **et al.** (1975 pages 34-37). They state that the most productive soils in western North Dakota are located on concave slopes and concave landscape positions, are medium or finer in texture, contain less than 10 percent free lime, the topsoil contains 2 percent or more organic matter and is no more than slightly saline or sodic, and the subsoil is no more than slightly saline or somewhat sodic. A discussion of the relation of soil and overburden properties to their use in reclamation is given by Patterson and Schroer (1980, pages 19-33).

These criteria specify the desirable chemical and physical properties of the soil, but not the optimum depth of the rooting zone. Power **et al.** (1974) stated that in western North Dakota small grains exhibit root activity to the fourth foot, perennial grasses to the fifth or sixth foot, and alfalfa to the eighth foot. Schroeder and Bauer (1984) noted little change in soil water below 4 feet in revegetated spoil and undisturbed grassland sites at four mines in western North Dakota over a seven-year period. Unpublished data from the Falkirk trench experiment show no changes in soil water below 5 feet during the four years of the experiment (moisture levels in the top 5 feet are given in Table 18). Bauer (1980) monitored soil water use by wheat in central North Dakota for five years on Heimdal silt loam , a nonsaline, nonsodic well-drained soil of medium texture. The results given in Table 20 are typical of those obtained in this experiment. Moisture depletion was from the top 2 or 3 feet early in the season, and from the top 4 feet later in the season. Moisture depletion below 4 feet was minimal. Moisture was determined using a neutron scattering moisture meter, so small differences (0.20 inches or less) between sampling dates are probably not significant. Danielson (1967) stated that irrigated crops tend to remove water approximately in the proportions 40:30:20:10 from successively deeper quarter fractions of the root zone. The data in Table 20 tend to subtantiate this pattern of water uptake by dryland crops. Unpublished NDSU data from both reclaimed and undisturbed sites in western North Dakota also support this pattern of water use.

For maximum productive capacity, reclaimed soils should have the chemical and physical properties listed by Omodt **et al.** (1975) with a minimum **effective** root zone depth of 4 feet. These criteria can be used as a guide for determining the needed depth of soil replacement. The lower portion of the root zone may be either replaced subsoil or spoil materials which have satisfactory properties. When the supply of suitable soil and spoil materials is plentiful, replacement of more soil materials than needed to provide an adequate root zone depth will not increase postmine productivity. If the underlying spoil has undesirable properties, more than 4 feet of soil materials will usually need to be replaced to provide a buffer between replaced soil material and the underlying spoil. Frequently, the amount and quality of soil materials available for replacement is not adequate to meet these optimum criteria. In this case, available suitable materials must be effectively utilized, possibly in combination with other less suitable materials, to provide the best possible postmine land use.

Table 20. Available soil water at various soil depths at Carrington in 1971 between wheat planting to harvest. Wheat yield was 39 bushels per acre. Adapted from Bauer (1980).

	Available soil water at various soil depths (feet)						Rainfall[1]
Date	0-1	1-2	2-3	3-4	4-5	5-6	
	inches						
4/30	0.60	0.45	1.00	0.90	1.50	1.20	--
6/09	0.40	0.65	1.10	1.05	1.50	1.30	2.63
6/28	0.75	1.00	1.50	1.20	1.45	1.20	4.65
7/19	-0.50	0.00	0.80	0.75	1.30	0.95	1.65
8/17	-0.80	-0.45	0.20	0.75	1.30	1.15	1.02

[1] Rainfall received since preceding sampling date

Relation of soil and spoil properties to depths of replacement:

During soil development, the topsoil ("A" horizon) evolves into the most favorable horizon for plant growth. An active microbial population becomes established, a dynamic organic matter content develops, stable aggregates form which facilitate entrance and movement of air and water into the soils, and available nutrient elements accumulate. Replacement of the original topsoil materials provides a medium for the relatively rapid reestablishment of favorable topsoil properties even though the structure and the chemical and microbiological processes are severely disrupted during removal, stockpiling and respreading. Without the replacement of topsoil, the development of these favorable properties would be extremely slow. Carlson **et al.** (1961) reported that when topsoil was removed during land levelling in North Dakota, replacement of a few inches of topsoil helped restore productivity. In the Stanton wedge experiment (Tables 7, 8, 9, 10), highest yields were obtained only when topsoil was respread; yields were consistently lower when topsoil and subsoil were mixed prior to respreading. The topsoil, or first lift, removed before mining usually consists of all the "A" horizon and portions of the upper "B" horizon. Carter and Doll (1983) reported that the productivity of a mixture of "A" and upper "B" horizon materials was equal to that of "A" horizon materials. Topsoil must be replaced on all reclaimed soils for rapid reestablishment of productivity.

The subsoil, that portion of the rooting zone below the topsoil, serves mainly as a reservoir for nutrients and moisture. In the most productive undisturbed soils, the subsoil willl be suitable for extensive root development and water movement and retention. However, the subsoil characteristics that develop during soil formation do not have as marked an effect upon soil productivity as do the characteristics of the topsoil. Subsoil replacement serves two purposes, as was discussed by Omodt **et al.** (1975) and Patterson and Schroer (1980). First, if the underlying spoil is coarse-textured with a low water-holding capacity, finer-textured second lift materials will increase the available water-holding capacity within the root zone. Second, if the underlying spoil has undesirable properties for plant growth, replaced subsoil serves as a buffer by placing the undesirable spoil materials below the root zone. If the properties of the underlying spoil are such that it is a favorable plant growth material, it can serve as the lower portion of the root zone. The depth of subsoil, or second lift, that must be replaced to restore optimum productive levels therefore depends upon the characteristics of the underlying spoil.

Water-holding capacity:

The water-holding capacity of a soil is a fixed property which is dependent primarily upon texture and bulk density. While the water-holding capacity can be slightly altered by changes in organic matter and degree of aggregation, coarse-textured soils will always be more droughty than finer-textured soils. The water-holding capacity of reclaimed soils can be improved by selective placement of medium and fine-textured materials in the root zone or by increasing the effective depth of the root zone when available second lift materials are coarse-textured.

When sandy loam topsoil was placed over moderately sodic clay loam spoil in the Knife River experiment (Tables 4 and 5), yields of both wheat and corn after six years tended to be higher when 12 inches of topsoil was replaced than when 24 inches was replaced. This is attributed to the higher water-holding capacity when the top 2 feet of the root zone consisted of 12 inches of sandy loam plus 12 inches of clay loam instead of 24 inches of sandy loam. Higher yields were initially obtained with 24 inches of topsoil, probably because moisture levels in the spoil were low immediately after reclamation. In the Stanton wedge experiment (Table 12), yields at total soil depths of 28 and 36 inches were consistently higher with 8 inches of sandy loam topsoil than with 24 inches; the underlying subsoil was clay loam in texture. The yield data for this experiment (Tables 7, 8, 9, and 10) suggest that about another foot of subsoil was needed for optimum yields with 24 inches than with 8 inches of sandy loam topsoil.

Subsoil materials of different texture were compared in the double wedge experiment at Zap (Figure 5 and Table 14), interpretation of differences due to subsoil characteristics are complicated by the interacting effects of slope, aspect, and soil and crop management. Wheat yields were higher on the fine-textured subsoil, irrespective of soluble salt and sodicity levels (Table 14); crested wheatgrass yields followed the same trend in 1978 when the highest yields were obtained, but when moisture was more limiting (1979 and 1981), yields were highest on the coarse-textured subsoil which was also lowest in soluble salts and sodium. In general, these results are consistent with the effects of topsoil texture discussed previously for the Knife River and Stanton experiments.

When the overburden was nonsaline and nonsodic, as in the Falkirk trench plots, replacement of 27 inches of loam topsoil over gravelly loamy sand was not sufficient for optimum yields (Table 16). The replacement of clay loam subsoil over gravelly loamy sand resulting in a total soil depth of 5 feet was probably more than adequate for optimum yields. Yields with 27 inches of topsoil without subsoil were about 85 percent of maximum yields in this experiment and by interpolation suggest that at least 32 to 35 inches of medium or fine-textured materials would be needed for optimum yields over gravelly loamy sand. When the texture of the overburden was silty clay loam or clay loam, optimum yields were obtained with 18 or 27 inches of topsoil. Throughout this experiment, yields tended to increase as topsoil depths increased from 9 to 27 inches, although yield differences between the 18 and 27 inch depths were minimal. Relative yield differences between topsoil depths tended to decrease as the experiment progressed, and differences due to topsoil depths would be expected to decrease as structure and root channels were formed in the overburden material.

These results emphasize the importance of the water-holding capacity of the upper portion of the root zone and show that spoil materials which have favorable chemical and physical characteristics are acceptable for the lower portion of the root zone. However, these spoil materials have not been subjected to the weathering processes which take place in the lower horizons during soil development. Yields immediately after soil replacement in the Knife River (Table 4) and Falkirk (Table 16) experiments suggest that the development of favorable conditions for plant root development may require several years. Conversely, yields on the reclaimed soils at Beulah and Center (Table 19) tended to approach yields on similar undisturbed soils after two or three years. Until more definitive data are available concerning the development of favorable characteristics for root growth in spoil materials, replacement of at least 1 foot of subsoil, in addition to 1 foot of topsoil, over good quality spoil materials seems to be desirable unless properties of the subsoil indicate that it is less desirable for plant growth than the underlying spoil.

Effects of soluble salt:

Soluble salts, including sodium salts, are mobile in the soil and tend to become redistributed in the root zone of disturbed soils and may move upward from spoil materials into replaced soil materials (Sandoval and Gould, 1978). When soluble salts are present, an understanding of salt transport within and below the root zone is needed for planning for the permanent restoration of productivity. When the soil is sufficiently permeable to the 4 or 5-foot depths, soluble salts in the upper root zone can leach downward. Sandoval **et al.** (1972) increased the soluble salt level in the surface layer of a sodic clay soil in western North Dakota by deep plowing, but after five years, soluble salt concentrations in the top 12 inches had decreased from 5.8 to about 2.1 mmho/cm, with slight decreases in the 12 to 36-inch depths. Merrill **et al.** (1980a) reported that soluble salts had leached out of the top 12 inches and accumulated in the 12 to 36-inch zone after the first year from a respread moderately saline subsoil over which no topsoil had been applied. In an experiment reported by Schroeder and Doll (1984), soluble salt level of the topsoil of a reclaimed soil decreased from 6.1 to 2.7 mmho/cm in three years. Moderate levels of soluble salts (EC 7) in the fine-textured subsoil at Zap (Table 14) did not affect yields as much as the coarse texture of the nonsaline subsoil.

In general, soluble salts do not appear to be a serious problem in reclaimed soils in North Dakota, although research data are limited. When spoil characteristics and the topographic configuration are conducive to the formation of perched water tables, the possibility exists for the eventual development of saline seeps due to lateral salt movement at some locations.

Effects of sodicity levels:

When the sodium content of a soil or spoil material is high and the soluble salt content is low, clays become dispersed, water movement is restricted, and conditions become unfavorable for root growth. When soil materials are placed over highly sodic spoil, sodium may tend to move upward and the lower portions of the replaced soil may become unsuitable for root growth. Sufficient soil material must be replaced so that the effective root zone will be deep enough for optimum production after upward sodium movement has ceased. Merrill **et al.** (1983a) have discussed the factors involved in sodium movement in reclaimed soils in North Dakota; their data show that upward movement of sodium was usually about 4 to 6 inches when 12 inches of soil was replaced over highly sodic spoil. They stated that as the depth of replaced soil was increased, the upward movement of sodium would also increase. Upward sodium movement will depend upon the sodium content and permeability (hydraulic conductivity) of the underlying spoil.

When the underlying spoil was sodic, the early experiments (Tables 1 to 3 and Figures 1 and 2) have shown that 12 inches of soil is not sufficient for optimum yields. In the Knife River experiment, 12 inches of topsoil over moderately sodic spoil (SAR 12) appeared to be sufficient for optimum yields after two or three years (Tables 4 and 5). On the Stanton wedge experiment, the underlying spoil was sodic (SAR 25), and total soil depths for optimum yields varied from 30 inches for perennial grasses to 45 inches for wheat (Tables 7 through 10). On the Zap double wedge experiment, the underlying spoil was moderately sodic, and highest yields of crested wheatgrass were obtained at soil depths of 20 to 28 inches and wheat at depths of 45 inches.These results indicate that crops are able to utilize some moisture from sodic materials; Merrill **et al.** (1982 a and b) reported that while some water was extracted from sodic spoil in the Stanton wedge experiment, water uptake from spoil was severely restricted due to low hydraulic conductivity.

In areas where the spoil materials are sodic, the productivity of the soils before mining is often low. The amount of soil materials suitable for replacement is frequently inadequate, and less desirable materials must be used. Reclamation of such areas poses special problems, and research data are limited. Water movement and downward leaching of salts (including sodium) are restricted. In some situations, application of gypsum or a source of soluble calcium will be beneficial. The authors feel that additional research is warranted to study the use and amelioration of poor quality soil and spoil materials in reclaiming stripmined soils.

Suggested guidelines for soil depth replacement:

Replacement of topsoil is required for restoration of productivity on all reclaimed soils, but the amount of subsoil that will be needed is dependent upon the chemical and physical characteristics of the underlying spoil. Although the productivity index of the reclaimed soil will be related to the topographic location and shape, gradient, and aspect of the slope, sufficient data are not available to justify variation in the depth of soil replacement based on topography. The suggested guidelines given below are related to the depth and properties of the root zone needed for optimum production. When the properties of the spoil and the amount and quality of available soil materials are not sufficient for restoration to this productive level, the postmine land use must be adjusted accordingly. For efficient utilization of less than "ideal" soil and spoil materials, consideration must be given to the effects of various properties of topsoil and subsoil materials and to interactions between these properties.

When available, at least 1 foot of topsoil (first lift) should always be respread when soils are reclaimed. When the underlying spoil is coarse-textured (sandy loam or coarser) and no more than slightly saline (EC<6) or somewhat sodic (SAR<10), from 24 to 30 inches of subsoil (second lift) which is loam or finer in texture should be applied. If the underlying spoil is fine-textured (silt loam or finer), 12 to 18 inches of subsoil should be respread. If the underlying spoil is moderately sodic (SAR 10-20), the subsoil depth should be increased to 24 to 36 inches. When the spoil is sodic (SAR>20), from 36 to 48 inches of subsoil should be applied. If topsoil and subsoil materials are sandy loam or coarser, it is proposed that the suggested depths of subsoil replacement be increased by about 12 inches. These suggested guidelines are summarized in Table 21.

Table 21. Suggested guidelines for soil replacement based upon spoil properties.

Spoil Properties			Depth of Soil Replacement		
Texture	EC	SAR	Topsoil	Subsoil	Total
	mmho/cm		-------------------	inches	-------------------
Coarse[1]	<6	<12	12	24-30	36-42
Medium[2]	<6	<12	12	12-18	24-30
--[3]	--	12-20	12	24-36	36-48
--[3]	--[3]	>20	12	36-48	48-60

[1] Sandy loam or coarser

[2] Loam or finer

[3] Not applicable, SAR dominant property

These suggestions are somewhat higher than the optimum levels reported in some of the experiments that were discussed. However, until more research data are available describing the changes that occur in unweathered spoil materials placed within the root zone and until the movement of sodium in soils reclaimed over sodic spoil can be more precisely predicted, care must be exercised to ensure that adequate soil materials are replaced to ensure permanent restoration to optimum productive levels. It should be emphasized that these guidelines were developed with the assumption that topsoil losses through erosion would be minimized by following good soil management practices.

Implications of soil replacement to premine characterization:

The importance of adequate premine characterization of all soil and overburden materials cannot be overemphasized. The properties and volume of soil materials suitable for respreading must be calculated. The amount and location of all desirable and undesirable strata in the overburden must be identified. **The average properties of the reshaped spoil and the magnitude of expected variations from this average must be calculated before initial removal of topsoil and subsoil.** When the overburden has undesirable properties such as coarse texture or high sodicity, sufficient soil materials must be replaced to ensure optimum production over those sites within the reshaped spoil which have higher levels of these undesirable properties. If, on the other hand, undesirable overburden strata can be selectively placed below the root zone during mining, the surface properties of the reshaped spoil may be such that less subsoil will need to be replaced. This has two important implications. First, if the amount of available soil materials is not sufficient to result in optimum postmine productive levels over undesirable spoil, selective placement of good quality spoil within the root zone could result in higher postmine productivity. Second, even when sufficient soil materials are available, selective placement of high quality spoil at the surface may justify the replacement of less subsoil. The decision then becomes an economic consideration in which the cost of selective placement is equated to the savings from decreased removal, stockpiling, and respreading of soil materials.

Research Needs:

The soil replacement guidelines given in the preceding section are based upon the results of experiments which have been conducted for relatively short periods. These experiments have shown that productivity can initially be restored to a level equal to or better than that before mining. Studies of chemical and physical changes in these newly reclaimed soils suggest that the initial productivity may be maintained or even increased with time, but this is a tentative observation which must be verified by longer studies. Experiments need to be conducted over a long period of time in which the best soil management practices are followed; chemical and physical changes must be closely monitored so that the characteristics of the soils can be predicted when they approach the "steady state" characteristic of undisturbed soils. In these studies, movement of soluble salts and sodium need to be precisely described. Changes in physical characteristics such as aggregation, bulk density, and permeability must be quantitatively described. The effects of topography on all chemical and physical factors need to be delineated. Some new experiments need to be initiated on soils reclaimed over spoil materials which differ in both chemical and physical properties. Some of the experiments cited in this review should be seeded to perennial grasses and maintained for periodic cropping and for sampling to follow changes in soil characteristics. The Knife River topsoil experiment (Tables 4 and 5), the Stanton wedge experiment (Tables 6 through 12, the Zap double wedge experiment (Tables 13 and 14), and the Falkirk trench experiment (Tables 15 and 16) should be included in this long-time study.

If the depth of soil replacement is to be related to the properties of the reshaped spoil, techniques need to be refined to estimate the average properties of the reshaped spoil using data from the premine overburden characterization. The average variation in these properties must also be known since sufficient soil materials must be replaced over the entire area to ensure optimum postmine productive levels at those spoil sites which have the least desirable properties. If site-specific soil replacement guidelines are to be utilized, reliable estimates for depth of soil replacement must be made before initial removal of topsoil and subsoil materials.

At sites on which the available soil materials are not adequate in either quality or quantity for restoration of optimum productivity, some soil and/or spoil materials may be available which have less than optimum properties for use in reclamation. Research is needed to develop methods for the most effective utilization of marginal soil and spoil materials; all possibilities for restoration of better postmine productivity by proper utilization of submarginal materials need to be investigated.

Methods to relate the potential productive capacity (productivity index) of both undisturbed and reclaimed soils to soil properties and characteristics need to be adapted for use in reclamation planning and evaluation. Current soil productivity indexes are based upon the correlation of field classification with laboratory measurements of chemical, physical and mineralogical properties and with landscape position. Discussions of the relation of soil types (field classification) to chemical and physical properties have been given by Omodt **et al.** (1975) and Patterson and Schroer (1980). Refining and adapting these productivity indexes for use in reclamation will facilitate the most effective use of available soil and spoil materials for restoring optimum postmine productivity.

SUMMARY

Restoration of stripmined lands to a level of productivity equal to or better than existed before mining is required by law in North Dakota. Reclamation costs are a significant part of the cost of mining coal and these costs are passed on to the consumers. These costs can be minimized if the chemical and physical properties of available soil and spoil materials are well characterized and then used to determine the needed depth of soil replacement to restore acceptable levels of productivity. Initial research showed that respreading of soil materials was the fastest and most practical method of restoring soil productivity. Postmine productivity was governed by the amount and quality of soil materials available for respreading and to the chemical and physical characteristics of the reshaped spoil. In many instances, more soil needed to be replaced to restore premine productivity than was available as topsoil, so subsoil materials also needed to be removed and respread. When the underlying spoil was of good quality with desirable properties, lesser amounts of subsoil materials needed to be respread for restoration of optimum productivity. When the underlying spoil has undesirable properties, larger amounts of subsoil were needed.

If soil and spoil properties are to be used as a basis for determining needed depths of soil replacement, the properties which govern the productive capacity of the most productive soils in the area need to be identified and quantified. These criteria could then be used as a "standard" to assure the most effective utilization of all available soil and spoil materials at any specific site. Research cited in this report indicates that the most productive soils in western North Dakota have an effective root zone at least 4 feet in depth which is medium or finer in texture. The topsoil is nonsaline and nonsodic, contains less than 10 percent free carbonates, and has an organic matter content of 2 percent or more. The subsoil is no more than slightly saline or moderately sodic. The most productive soils are located at the base of concave slopes or in well-drained depressional areas which receive runon water from surrounding higher areas; however, available research data are not sufficient to justify adjusting the depth of soil replacement to topographic location. The most important soil and spoil properties to be considered in reclamation planning are 1) water-holding capacity (texture) and 2) soluble salts and sodium levels.

During soil development, the topsoil ("A" horizon) develops into the most favorable medium for plant growth; at least 1 foot of topsoil should always be respread when soils are reclaimed. The subsoil, that portion of the rooting zone below the topsoil, serves mainly as a reservoir for nutrients and moisture. Subsoil replacement serves two purposes. First, if the underlying spoil is coarse-textured with a low water-holding capacity, finer-textured second lift materials will increase the available water-holding capacity within the root zone. Second, if the underlying spoil has undesirable properties for plant growth, replaced subsoil serves as a buffer by placing the undesirable spoil materials below the root zone.

If the properties of the underlying spoil are such that it is a suitable plant growth material, it can serve as the lower portion of the root zone. When the supply of suitable soil and spoil materials is plentiful, replacement of excess soil materials over spoil with desirable properties will not increase postmine productivity. If the underlying spoil has undesirable properties, more than 4 feet of soil materials may need to be replaced to provide an effective rooting zone depth of 4 feet. Therefore, the depth of subsoil, or second lift, that must be replaced to restore optimum productive levels depends upon the characteristics of the underlying spoil. Frequently the amount and quality of soil materials available for replacement is not adequate to meet the criteria established for soils of optimum productivity. In these cases, available suitable materials, possibly in combination with other less suitable soil and spoil materials, must be effectively utilized to provide the best possible postmine land use.

Suggested depths of soil replacement are given below. When available, at least 1 foot of topsoil should be respread on all reclaimed soils. When the underlying spoil is coarse-textured (sandy loam or coarser) and no more than slightly saline (EC<4) or somewhat sodic (SAR<10), from 24 to 30 inches of subsoil which is loam or finer in texture should be applied. If the underlying spoil is silt loam or finer in texture, 12 to 18 inches of subsoil should be respread. If the underlying spoil is moderately sodic (SAR 10 to 20), the subsoil depth should be increased to 24 to 36 inches. When the spoil is sodic (SAR>20), from 36 to 48 inches of subsoil should be applied. If topsoil and subsoil materials are sandy loam or coarser, it is proposed that the suggested depths of subsoil replacement be increased by about 12 inches. These guidelines are summarized in Table 21, and are somewhat higher than the optimum depths reported in some of the experiments that were cited. However,, until more research data are available describing the changes that occur in unweathered spoil materials placed within the root zone, and until the movement of sodium into replaced soil materials from sodic spoil is more fully understood, care must be exercised to ensure that adequate soil materials are replaced to ensure restoration to optimum productive levels.

The importance of adequate premine characterization of soil and overburden materials which identifies the amount and extent of materials with desirable or undesirable strata cannot be overemphasized. The average properties of the reshaped spoil and the respread soil materials must be determined before mining begins if the depth of soil replacement is to be determined on a site-specific basis. When the overburden has undesirable properties such as coarse texture or high sodium levels, sufficient soil materials must be replaced to ensure optimum production over those sites within the reshaped spoil which have highest levels of these undesirable properties. If, on the other hand, undesirable overburden strata can be selectively placed at a deeper depth during mining, the surface properties of the reshaped spoil may be such that less subsoil will need to be replaced. This has two important implications. First, if the amount of available soil materials is not sufficient to result in optimum postmine productive levels over undesirable spoil, selective surface placement of good quality spoil could result in higher postmine productive levels. Second, even when sufficient soil materials are available, selective placement of high quality spoil at the surface may justify the replacement of less subsoil. The decision then becomes an economic consideration in which the cost of selective placement is equated to the savings from decreased removal, stockpiling, and respreading of soil materials.

The soil replacement guidelines given above are based upon the results of experiments which have been conducted for a relatively short period. Current evaluations of these results indicate that the initial productive levels can be expected to be maintained or to increase with time, but these experiments need to be monitored for a number of years to confirm this observation. At these sites and at other sites on reclaimed soils, movement of soluble salts and sodium needs to be more precisely described. Changes in physical properties of reclaimed soils such as aggregation, bulk density, and permeability need to be monitored. Research is needed to develop methods for the most effective utilization of marginal soil and spoil materials. As data of these kinds become available, soil replacement guidelines can be further refined.

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GLOSSARY

AGGREGATE: Many fine soil particles held together in a single cluster, such as a clod or crumb. Many properties of an aggregate differ from those of an equal mass of unaggregated soil.

BULK DENSITY: The weight of oven-dry soil per unit bulk volume, including air space. Usually expressed as grams/cubic centimeter.

ELECTRICAL CONDUCTIVITY (EC): A physical quantity which measures the readiness with which a medium conducts electricity. EC can be related to the soluble salt content of saturated soil extracts, and is expressed as mmhos/cm at 25°C. (See Salinity).

EXCHANGEABLE SODIUM PERCENTAGE (ESP): The degree of saturation of the soil cation exchange complex with sodium. It may be calculated by the formula:

$$\text{ESP} = \frac{\text{Exchangeable Sodium}}{\text{Cation Exchange Capacity}} \times 100$$

Units are usually expressed as milliequivalents per 100 g. soil. For characterization of soil materials for reclamation suitability in North Dakota, current regulations assume that ESP 5 is equivalent to SAR 4, and ESP 12 equivalent to SAR 10 (See Sodium Absorption Ratio, Sodicity).

FIRST LIFT: The uppermost layer of undisturbed soil materials removed and segregated during surface mining to be respread as topsoil. (See Topsoil).

HYDRAULIC CONDUCTIVITY: The rate of flow of water through a unit cross section of soil per unit of hydraulic gradient under specified temperature and hydraulic conditions. Usually expressed as centimeter/hour, but time may be expressed in minutes or days.

MOLARITY: A measure of the chemical concentration of a solution, expressed as gram molecular weight per liter of solution.

NONPRIME SOILS: Any soils not classified as prime soils. (See Prime Soils).

OVERBURDEN: Undisturbed consolidated or unconsolidated materials overlying a coal seam to be mined.

PERMEABILITY: The ease with which water can pass through a bulk mass of soil or a layer of soil. This can be either a qualitative term, or a quantitative term if the rate of movement is specified (See Hydraulic Conductivity).

PRIME SOILS: Productive soils that meet technical criteria established by the U.S. Department of Agriculture, among which are rooting depth, water-holding capacity, temperature, pH, susceptibility to erosion, and soluble salt and sodium levels. Prime soils in North Dakota occur in well-drained depressional areas and in lower positions of concave slopes which receive runon water. Federal and North Dakota reclamation laws require segregation and separate handling of prime soil materials.

ROOT ZONE: That part of the soil which is invaded by plant roots.

SALINITY: A measure of the concentration of soluble salts in soil; salinity in this bulletin is measured by electrical conductivity (EC) of the saturation extract expressed as mmhos/cm, as given below:

Category	**EC**
Nonsaline or very slightly saline	< 2
Slightly saline	2-4
Moderately saline	4-8
Strongly saline	8-16
Very strongly saline	>16

SATURATION EXTRACT: The solution extracted from a saturated soil paste prepared using distilled water.

SECOND LIFT: The second layer of undisturbed soil material which underlies the first lift, and which is removed and segregated during surface mining to be replaced as subsoil. (See Subsoil).

SODICITY: A measure of the relative level of exchangeable sodium in a soil. A sodic soil typically contains a sufficient level of exchangeable sodium to interfere with the growth of most plants. Sodicity in this report will be measured by the sodium absorption ratio (SAR) as given below:

Category	**SAR**
Non or very slightly sodic	<4
Somewhat sodic	4-10
Moderately sodic	10-20
Sodic	>20

(See Sodium Absorption Ratio)

SODIUM ABSORPTION RATIO: A ratio used to express the relative activity of sodium in a saturation extract, as given in the following equation:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

in which ionic concentrations are expressed in milliequivalents per liter. (See Sodicity, Saturation Extract).

SPOIL: Overburden that has been disturbed and haphazardly mixed during surface mining.

SUBSOIL: The soil below the topsoil in which plant roots grow, used synonymously with second lift in this bulletin. The root zone of reclaimed soils can be composed partially of reshaped spoil materials as well as subsoil materials removed as second lift. Current North Dakota stripmine regulations base the suitability of subsoil materials upon EC below 4 and SAR below 10 (ESP below 12). (See Second Lift, Topsoil).

TOPSOIL: Dark-colored surface soil materials, used synonymously with first lift in this bulletin. First lift materials are usually removed to the depth of the first easily-identified color change, and contain the soil A horizon and may contain all or part of the B horizon. Current North Dakota stripmine regulations base the suitability of topsoil materials upon EC below 2, SAR below 4 (ESP below 5), calcium carbonate equivalent below 10 percent on medium and fine-textured materials, and organic matter above 1.5 percent. (See First Lift, Subsoil).

WATER-HOLDING CAPACITY: The ability of the soil (or spoil material) to hold water. Water content may be expressed as either gravimetric water or volumetric water. Gravimetric water is expressed as percentage of the weight of water per unit weight of oven-dry soil. Volumetric water can be expressed either as percentage of the volume of water per unit volume of soil or as depth of water per unit depth of soil (such as inches per foot or centimeters per meter).

Definitions in this glossary were adapted from the following sources:

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