TOPSOIL AND SUBSOIL REPLACEMENT ON STRIPMINED LAND IN NORTH DAKOTA[1]

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INTRODUCTION

Commercial mining of lignite in North Dakota began to increase in the early 1960's 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. Strippable reserves in western North Dakota are estimated to underlie as much as 1.8 million acres. A general discussion of North Dakota lignite reserves and development potential has been given by Dalsted and Leistritz (1974).

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 5 cm 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. The purpose of this review is to evaluate published and unpublished research relating to the depth and quality of topsoil and subsoil needed for successful reclamation of North Dakota strip-mined lands. Much of the material was extracted from Doll, Merrill, and Halvorson (1984).

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.

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. Sandoval et al. (1973) and Schroer (1976 and 1978) reported that these overburden materials tend to be nonslaine 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.

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. The most important soil properties are sodium content, salinity, clay content and kinds of minerals. The water-holding capacity is dependent upon these properties.

TOPSOIL AND SUBSOIL DEPTH EXPERIMENTS

Initial Experiments on Topsoil Replacement

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 indicate that while gypsum applied to sodic spoil increased production, much higher yields were obtained when 5 cm of topsoil was applied (table 1). Straw mulching increased vegetative production both on topsoiled and nontopsoiled plots.

Identical experiments were initiated in 1973 at four mine sites (Merrill et al., 1983b) in which each of two topsoil applications (none or 30 cm) was combined with each of two gypsum treatments (none or 22 tons per ha). At the highly sodic Zap site, average yields from 1975 to 1978 without topsoil were less than half of yields when topsoil was applied (table 2). Gypsum had little effect on yields at Zap on either the no topsoil or topsoiled treatments. On the moderately sodic Beulah and Stanton sites, gypsum did not affect yields on

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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
	kg/ha			
None	0	71	678	1437
Gypsum	254	354	1031	835
Sulfur	53	69	1042	1777

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 re-spreading topsoil, since neither stands or yields were maintained when only gypsum was applied.

An additional experiment was initiated in 1972 to compare yields on a sodic (SAR 25), silty clay loam spoil to which 0, 5, 15, and 30 cm of topsoil had been applied. Each year yields were higher when 30 cm of topsoil was applied, but the rate of yield increase indicated that maximum yields were not obtained at the 30 cm depth even with adequate fertilization (Ries et al., 1978). Yields at this site declined as the experiment progressed. Part of this yield depression was attributed to upward movement of sodium from the spoil into the overlying topsoil (Sandoval and Gould, 1978).

In another experiment at the Knife River Mine yields of wheat and corn were compared on a site with moderately sodic spoil material to which 5, 15 30, and 60 cm of sandy loam topsoil was added. Yields of wheat and corn silage were highest on 60 cm of topsoil in the first two years. By the fifth and sixth years yields from plots with 30 cm of topsoil were higher than those with 60 cm. The low water-holding capacity of sandy loam is believed to be partially responsible for yields on 60 cm of topsoil not exceeding those on 30 cm in the last two years of this study.

Region-Wide Experiments

Fifteen wedge-type plots were constructed at surface coal mines in Wyoming, Montana, and North Dakota in 1977-1980 (Barth and Martin, 1984). Topsoil depth at a uniform gradient ranged from 0 to 152 cm. The spoil was considered representative of the site and topsoil was obtained from existing topsoil stockpiles at each location. The plots wer seeded to native and introduced grasses which included 'Nordan' crested wheatgrass [Agropyron desertorum (Fisch.) Schult.] at each site.

The response pattern of cool-season grass production to increasing topsoil depth was dependent on the physical and chemical characteristics of th

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	3.6	2.9	3.8	4.0	84
		1983	0.9	0.4	1.6	1.8	37
Beulah	11	1975-78	2.0	2.5	2.5	2.5	90
		1983	0.7	0.7	1.3	1.3	55
Stanton	12	1975-78	2.0	2.5	2.5	2.7	84
		1983	0.2	0.4	1.1	1.6	27
Zap	27	1975-78	0.9	0.7	1.6	1.8	47
		1983	---[3]	---	1.3	1.8	--

[1] 30 cm of topsoil applied

[2] 22 tons per ha of gypsum applied to spoil before topsoiling

[3] no yields obtained due to loss of stand

spoil (Barth and Martin, 1984). Spoil was classified as sodic, acid, generic, or soil-like.

Sodic spoil had pH values >8.0, SAR values from 25 to 81, and low rates of water infiltration. Production of perennial grasses increased as topsoil depth increased to a depth of 71 cm. Little change in production occurred on topsoil depths greater than 71 cm.

Acidic spoil was characterized by pH values ranging from 3.6 to 4.3. Production of perennial grasses increased linearly as topsoil depth increased to the maximum depth of 152 cm. In the region of Wyoming where these acidic sites were located forage production of 85 g m^{-2} was considered indicative of good range condition and this level of production was achieved on 97 cm of topsoil over acid spoil.

Generic spoil lacked distinguishing characteristics such as acidity or sodicity and differed from soil in terms of origin, biological activity, and ability to support plant growth. Perennial grass production increased with topsoil depth to a topsoil depth of 50 cm. No real increase in production occurred at topsoil depths greater than this.

Soil-like spoil was mildly alkaline, low in soluble salts, carbonaceous material, and heavy metals and was silt loam in texture. Although highest production of perennial grasses was obtained when spoil composed the entire growth medium, forage production was basically unrelated to topsoil depth.

Stanton Wedge Experiment

The details of an experiment constructed in 1974 at the Glenharold Mine at Stanton, North Dakota have been reported by Power et al. (1981). Subsoil was shaped into a wedge varying in depth from 0 to 2.1 m over sodic spoil. Topsoil depths of 0, 20 and 60 cm 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.

As reported by Power et al. (1981), alfalfa yields tended to increase as the subsoil depth increased to 71 or 91 cm (Table 3). Highest yields were obtained when topsoil was placed over subsoil, but no increases in yield were noted when depth of topsoil increased from 20 to 60 cm. Maximum yields were obtained when 20 inches of topsoil was placed over 71 cm of subsoil, giving a total soil replacement depth of 91 cm. When topsoil and subsoil were mixed, yields were similar to those obtained with subsoil alone, except at the 91 to 152 cm thicknesses. Yields on the other treatments generally tended to decrease at subsoil thicknesses above 71 cm.

Table 3. 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 (cm)			Mixed Subsoil-topsoil
	0	20	60	
cm	------tons/ha------			
10	0.69	1.39	1.41	0.47
30	1.19	1.66	1.77	0.85
51	1.39	1.97	1.97	1.30
71	1.50	2.24	2.11	1.57
91	1.30	2.15	2.02	1.72
122	1.10	2.13	2.02	1.84
152	1.05	2.15	1.90	1.88
183	1.16	1.70	1.68	1.68

Table 4. 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 (cm)			Mixed Subsoil-topsoil
	0	20	60	
cm	------tons/ha-------			
10	1.50	1.93	2.15	1.25
30	1.93	2.22	2.55	2.04
51	2.02	2.53	2.78	2.51
71	2.20	2.42	2.84	2.60
91	2.06	2.69	2.82	2.69
122	1.79	2.58	2.55	2.42
152	1.75	2.53	2.60	2.49
183	1.57	2.33	2.42	2.69

When no topsoil was applied, crested wheatgrass yields were highest at subsoil depths of 71 to 91 cm (table 4) but were always lower than when topsoil was applied. Yields obtained with 20 or 60 cm of topsoil were not different at similar subsoil depths above 51 cm. For subsoil depths below 51 cm, yields tended to be slightly higher (but not significantly) with 60 cm than with 20 cm of topsoil. When topsoil and subsoil were mixed, yields at thicknesses of 51 cm 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 71 or 91 cm except when topsoil and subsoil were mixed.

Highest yields of mixed native grasses (dominated by blue gramma and sideoats gramma) were obtained when topsoil was applied over 51 cm of subsoil, with no apparent difference between 20 and 60 cm of topsoil (table 5). When no topsoil was applied or topsoil and subsoil were mixed, highest yields were obtained at soil depths of 71 to 91 cm, 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 91 cm.

Table 5. 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 (cm) 0	20	60	Mixed Subsoil-topsoil
cm	------tons/ha-----			
10	0.09	0.69	0.58	0.02
30	0.45	0.94	0.67	0.16
51	0.67	1.05	0.87	0.65
71	0.74	1.08	1.05	0.85
91	0.81	0.92	1.01	0.83
122	0.78	0.92	0.90	0.96
152	0.72	0.87	0.94	0.90
183	0.74	0.83	0.78	0.92

Average wheat yields for 1975 and 1978 were highest when topsoil was applied over 71 to 91 cm of subsoil (table 6). At each subsoil depth, no yield differences were apparent between 20 and 60 cm of topsoil. When no topsoil was applied, highest yields (but lower than with topsoil) were obtained when about 71 cm of subsoil was applied. When topsoil and subsoil were mixed, highest yields (lower than with topsoil) were obtained at the 51 cm depth. Yields when topsoil was applied tended to remain the same or decrease slightly when the subsoil depth exceeded 91 cm.

Table 6. 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 (cm) 0	20	60	Mixed Subsoil-topsoil
cm	------tons/ha-----			
10	0.42	1.47	1.79	0.47
30	1.26	1.98	1.94	1.32
51	1.41	2.15	2.13	1.85
71	1.71	2.14	2.26	1.86
91	1.70	2.28	2.09	1.80
122	1.63	2.30	2.23	1.83
152	1.58	2.24	2.21	1.89
183	1.49	2.14	2.04	1.91

Yields obtained when 20 and 60 cm 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 71 or 91 cm. At equal total soil depths, yields were consistently higher with 20 cm of topsoil than with 60 cm except for crested wheatgrass at 91 cm. The topsoil was sandy loam in texture, with an available volumetric 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 20 cm of topsoil are likely related to this high water-holding capacity.

As noted in the preceding discussion, yields for each subsoil-topsoil combination tended to reach a maximum at subsoil depths of 71 to 91 cm 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.

Zap Double Wedge Experiment

Another wedge experiment was initiated in 1975 at the Indianhead Mine near Zap (Merrill et al., 1982b) in which 25 cm 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 7). 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 107 cm thick at the summit and which sloped to zero thickness at the north and south limits of the wedge.

Table 7. 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	1979,1981
		-----------tons/ha----------		
Midslope	A	1.02	3.11	1.34
	B	0.93	3.25	1.59
	C	0.70	3.90	1.93
Summit	A	0.98	3.02	1.16
	B	0.98	3.09	1.19
	C	0.52	2.60	1.68

Average crested wheatgrass and spring wheat yields were related to topographic position, total soil thickness and subsoil properties (table 7). 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. As total soil thickness decreased below the midslope position, yields 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 51 to 91 cm. Highest yields of crested wheatgrass were obtained at soil thicknesses of 51 to 81 cm and highest yields of spring wheat at thicknesses of 89 to 100 cm. 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.

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

In an experiment near the Falkirk mine nonsaline, nonsodic spoil materials of different textures were placed in trenches and then covered with topsoil or subsoil below topsoil (Halvorson et al., 1980). Two series of four trenches were excavated to a depth of 4.6 m and three trenches in each series were refilled with gravelly loamy sand, clay loam, or silty clay loam to within 23, 46, or 69 cm of the original soil surface. The fourth trench in each series was refilled with gravelly loamy sand spoil to within 1.5 m of the surface, and then with the original clay loam subsoil to within 23, 46, and 69 cm of the surface. Topsoil was then replaced to refill each trench to the level of the original soil surface; parallel strips of topsoil, at depths of 23, 46, and 69 cm extending the full length of each trench.

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 69 cm depth (table 8). Yields at similar topsoil depths for the other three treatments were not different. On all treatments, yields tended to increase as the topsoil depth increased except for the 69 cm topsoil depth over silty clay loam, where higher yields were consistently obtained at the 46 cm depth. On one of these trenches the concave portion of the trench was located in the middle on plots with 46 cm of topsoil. The runon water which collected on these plots was probably enough to improve yields above those on 69 cm of topsoil (Wollenhaupt and Richardson, 1982).

Highest yields for topsoil depths of 46 or 69 cm over subsoil, clay loam, or silty clay loam were equal to or better than yields from the undisturbed plots except for barley in 1980 and wheat in 1982 (table 8). Over gravelly loamy sand without subsoil yields with 69 cm of topsoil were about 85% of yields on the undisturbed plots.

Table 8. 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.

	Overburden Material				
	Gravelly loamy sand		Clay loam	Silty clay loam	Undisturbed plots
Topsoil Thickness	No Subsoil	Subsoil			
cm	tons/ha				
	Wheat 1979				
23	0.74	1.02	1.08	0.90	
46	1.08	1.18	1.14	1.28	1.11
69	1.23	1.29	1.20	1.03	
	Barley 1980				
23	0.22	0.38	0.37	0.40	
46	0.37	0.43	0.42	0.65	0.74
69	0.46	0.55	0.55	0.57	
	Corn Silage 1981				
23	11.3	20.4	16.1	18.1	
46	15.5	21.1	20.6	27.6	24.4
69	20.1	22.9	23.3	20.8	
	Wheat 1982				
23	0.87	1.43	1.46	1.50	
46	1.09	1.43	1.48	1.63	1.72
69	1.39	1.57	1.60	1.58	
	Corn Silage 1983				
23	6.1	14.6	14.5	16.6	
46	7.8	13.3	14.6	17.1	13.5
69	12.6	17.3	16.2	15.9	

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 8 cm of water was applied to wheat in 1982 and 15 cm 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 9) generally followed the same trends as yield without irrigation (table 8). However, when 69 cm 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). When the first irrigation was applied in both years, crops growing on treatmens with gravelly loamy sand without subsoil were already under greater moisture stress than crops on the other treatments. Final yields may have been related

Table 9. 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		
cm	----------tons/ha------------------			
		Wheat		
23	1.51	2.02	2.18	2.08
46	1.73	2.27	2.15	2.13
69	1.76	2.40	2.22	2.05
		Corn silage		
23	25.5	41.2	37.4	37.9
46	30.4	42.3	41.6	43.2
69	34.4	41.0	42.8	38.9

more to the degree of moisture stress before irrigation than to the total amount of water available during the growing season.

These results indicate that replacement of topsoil is required for restoration of optimum yield levels. Yields with 23 cm of topsoil were lower than those with 46 or 69 cm of topsoil, while yields with 69 cm tended to be slightly higher than with 46 cm. 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 treatment, optimum yields were obtained with 46 to 69 cm of topsoil and were equal or better than on the undisturbed plots. When 69 cm 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 81 to 89 cm for restoration of optimum productivity when the overburden is coarse-textured.

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 soils 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. 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 topographic position, 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, adequate data are available to substantiate the formulation of general site-specific guidelines.

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 1.2 m. 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 1.2 m 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.

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 3, 4, 5, 6), highest yields were obtained only when topsoil was respread; yields were consistently lower when topsoil and subsoil were mixed prior to respreading. The topsoil 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 will 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 nnderlying 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 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 subsoil materials are coarse-textured.

When sandy loam topsoil was placed over moderately sodic clay loam spoil in the Knife River experiment yields of both wheat and corn after six years tended to be higher when 30 cm of topsoil was replaced than when 60 cm was replaced. This is attributed to the higher water-holding capacity when the top 60 cm of the root zone consisted of 30 cm of sandy loam plus 30 cm of clay loam instead of 60 cm of sandy loam. Higher yields were initially obtained with 60 cm of topsoil, probably because moisture levels in the spoil were low immediately after reclamation. In the Stanton wedge experiment yields at total soil depths of 71 and 91 cm were consistently higher with 20 cm of sandy loam topsoil than with 60 cm; the underlying subsoil was clay loam in texture. The yield data for this experiment (tables 3, 4, 5, and 6) suggest that about another 30 cm of subsoil was needed for optimum yields with 60 cm than with 20 cm of sandy loam topsoil.

Subsoil materials of different texture were compared in the double wedge experiment at Zap, (table 2). 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 7); crested wheatgrass yields followed the same trend in 1978 when the highest yields were obtained, but when moisture was more limiting (1978 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.

The increased yields with increasing depth of loam topsoil over gravelly loamy sand spoil in the Falkirk trenches were attributed partially to the increased water-holding capacity of the replaced topsoil. Replacement of 69 cm of topsoil was not sufficient for optimum yields, representing about 85% of maximum yields. By interpolation at least 81 to 89 cm of medium or fine-textured materials are needed for optimum yields over gravelly sandy loam.

Water uptake from spoil may often be restricted. 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 the spoil was severely restricted due to low hydraulic conductivity. Barth and Martin (1984) reported water removal from only about 10 cm of generic, sodic, or acid spoil material. Measurements of root mass in the Falkirk trenches in 1982 indicated that the majority of roots remained in the topsoil over gravelly loamy sand. Whether roots were somehow restricted from penetrating into the gravelly loamy sand or did not grow there because of a lack of available moisture could not be determined.

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. Materials used in the root zone must have a suitable water-holding capacity and not restrict the growth of roots.

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 10 to 15 cm when 30 cm 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 have shown that 30 cm of soil is not sufficient for optimum yields. In the Knife River experiment, 30 cm of topsoil over moderately sodic spoil (SAR 12) appeared to be sufficient for optimum yields after two or three years. On the Stanton wedge experiment, the underlying spoil was sodic (SAR 25), and total soil depths for optimum yields varied from 76 cm for perennial grasses to 114 cm for wheat (tables 3 through 6). On the Zap double wedge experiment, the underlying spoil was moderately sodic, and highest yields of crested wheatgrass were obtained at soil depths of 51 to 71 cm and wheat at depths of 114 cm. 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 30 cm 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 slighly saline (EC<6) or somewhat sodic (SAR<10), from 60 to 76 cm 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), 30 to 45 cm of subsoil should be respread. If the underlying spoil is moderately sodic (SAR 10-20), the subsoil depth should be increased to 60 to 90 cm. When the spoil is sodic (SAR >20), from 90 to 120 cm 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 30 cm. These suggested guidelines are summarized in Table 10.

Table 10. Suggested guidelines for soil replacement based upon spoil properties.

Spoil Properties			Depth of Soil Replacement		
Texture	EC	SAR	Topsoil	Subsoil	Total
	mmho/cm			cm	
Coarse[1]	<6	<12	30	60-75	90-105
Medium[2]	<6	<12	30	30-45	60-75
--[3]	--	12-20	30	60-90	90-120
--[3]	--[3]	>20	30	90-120	120-150

[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.

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. 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.

During soil development, the topsoil ("A" horizon) develops into the most favorable medium for plant growth; at least 30 cm 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. 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. 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 underlying spoil has undesirable properties, more than 1.2 m of soil materials may need to be replaced to provide an effective rooting zone depth of 1.2 m. Therefore, the depth of subsoil 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 vailable for replacement is not adequate to meet he criteria established for soils of optimum prouctivity. 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 30 cm 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 60 to 75 cm of subsoil which is loam or finer in texture should be applied. If the underlying spoil is silt loam or finer in texture, 30 to 45 cm of subsoil should be respread. If the underlying spoil is moderately sodic (SAR 10 to 20), the subsoil depth should be increased to 60 to 90 cm. When the spoil is sodic (SAR>20), from 90 to 120 cm 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 30 cm.

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 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.

LITERATURE CITED

Barth, R. C. and B. K. Martin. 1984. Soil depth requirements for revegetation of surface-mined areas in Wyoming, Montana, and North Dakota. J. Environ. Qual. 13:399-404.
http://dx.doi.org/10.2134/jeq1984.00472425001300030016x

Carlson, C. W., D. L. Grunes, J. Alessi, and G. A. Reichman. 1961. Corn growth on Gardena surface and subsoil as affected by applications of fertilizer and manure. Soil Sci. Soc. Am. Proc. 25:44-47.
http://dx.doi.org/10.2136/sssaj1961.03615995002500010021x

Carter, F. S., and E. C. Doll. 1983. Wheat yields on prime and nonprime soils and soil mixtures in a greenhouse study. North Dakota Agric. Exp. Stn., Land Rec. Res. Ctr. Tech. Rpt #3.

Dalsted, N. L. and F. L. Leistritz. 1974. North Dakota coal resources and development potential. North Dakota Agric. Exp. Stn. Farm Res. 31(6):3-11.

Doll, E. C., S. D. Merrill, and G. A. Halvorson. 1984. Soil replacement for reclamation of stripmined land in North Dakota. North Dakota Agric. Exp. Sta. Bull. 514. 24 p.

Halvorson, G. A., S. W. Melsted, S. A. Schroeder, M. W. Pole, C. M. Smith and E. Diebert. 1980. Root zone management in North Dakota coal reclamation. North Dakota Agric. Exp. Stn. Farm Res. 37:9-12, 23.

Merrill, S. D., E. J. Doering, J. F. Power, and F. M. Sandoval. 1983a. Sodium movement in soil-minespoil profiles: Diffusion and Convection. Soil Sci. 136:308-316.
http://dx.doi.org/10.1097/00010694-198311000-00005

Merrill, S. D., E. J. Doering, and F. M. Sandoval. 1983b. Reclamation of sodic minespoils with topsoiling and gypsum. Paper No. 83-2141, Summer Annual Meeting, American Society of Agricultural Engineers, St. Joseph, Mich. 17p.

Merrill, S. D., J. F. Power, and S. J. Smith. 1982a. Water use and movement in the root zone of soil-minespoil profiles. Proc. North Dakota Acad. Sci. 36:43.

Merrill, S. D., R. E. Ries, and J. F. Power. 1982b. Effect of subsoil quality and depth upon crop growth and water use on minesoil reclaimed by topsoil and subsoil spreading. Agron. Abst. p. 253. Am. Soc. Agron., Madison, Wisconsin.

Merrill, S. D., F. M. Sandoval, J. F. Power, and E. J. Doering. 1980. Salinity and sodicity factors affecting suitability of materials for mine-land reclamation. Adequate Reclamation of Mined Lands? Symposium. p. 3-1:3-24. Soil Con. Soc. Am. and WRCC-21 Committee, Billings, MT. March 26-27, 1980.

Omodt, H., F. W. Schroer, and D. D. Patterson. 1975. The properties of important agricultural soils as criteria for mined land reclamation. North Dakota Agric. Exp. Sta. Bull. #492.

Patterson, D. D., and F. W. Schroer. 1980. Soil and overburden resources of the project area. p. 5-36. In F. L. Leistritz and T. A. Hertsgaard (eds.). Environmental, Economic and Social Impacts of a Coal Gasification Plant in Western North Dakota. North Dakota Agric. Exp. Sta. Bull. # 509.

Power, J. F., R. E. Ries, F. M. Sandoval, and W. O. Willis. 1975. Factors restricting revegetation of strip-mined spoils. p. 336-346. In F. Clark (ed.). Proc. Fort Union Coal Field Symposium, Mont. Acad. Sci., Billings, MT.

Power, J. F., F. M. Sandoval, R. E. Ries, and S. D. Merrill. 1981. Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Sci. Soc. Am. J. 45:124-129.
http://dx.doi.org/10.2136/sssaj1981.03615995004500010027x

Power, J. F., W. O. Willis, F. M. Sandoval, and J. J. Bond. 1974. Can productivity of mined land be restored in North Dakota. North Dakota Agric. Exp. Stn. Farm Res. 31(6):30-32.

Ries, R. E., F. M. Sandoval, and J. F. Power. 1978. Reestablishment of grasses on land disturbed by mining in the Northern Great Plains. Proc. First Int. Grassland Congress, p. 700-703.

Sandoval, F. M. and W. L. Gould. 1978. Improvement of saline and sodium affected disturbed lands. p. 485-504. In F. W. Schaller and Paul Sutton (eds.). Reclamation of Drastically Disturbed Lands. Am. Soc. of Agronomy, Madison,

Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis. 1973. Lignite mine spoils in the Northern Great Plains--Characteristics and potential for reclamation. p. 117-133. In Symposium on Research and Applied Technology on Mined-Land Reclamation. Pittsburgh, PA. March 7-8, 1973.

Schroer, F. W. 1976. Chemical and physical characterization of coal overburden. North Dakota Agr. Exp. Sta. Farm Res. 34(1):5-11.

Schroer, F. W. 1978. Characterization of coal overburden and strip-mined spoils in North Dakota. North Dakota Agr. Res. Sta. Res. Rep. #68.

Wollenhaupt, N. C. and J. L. Richardson. 1982. The role of topography in revegetation of disturbed lands. In Mining and Reclamation of Coal Mined Lands in the Northern Great Plains, Proceedings, Montana Agric. Exp. Sta. Res. Rpt. 194.