THE EFFECTS OF SOIL DEPTH AND OTHER SOIL CHARACTERISTICS ON PLANT COMMUNITY DEVELOPMENT IN NORTH DAKOTA[1]

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Abstract: Revegetation of mined lands in North Dakota is challenging because of the poor physiochemical properties of the spoil material as well as the semi-arid climate. Topsoil and subsoil replacement is a successful method used to establish productive and diverse plant communities. Previous studies conducted by Merrill et al. (1998) and Power et al. (1981) determined adequate soil depth for optimal vegetation productivity during six years of study on soil wedges in Zap and Stanton, ND. Re-sampling of these sites in 2003 documented long-term effects of soil depth and other soil characteristics on plant community development. Results of the 2003 study differed from results of past studies. At the Zap, ND Double Soil Wedge (ZSW) in 2003, the highest vegetation production occurred on 40 to 120 cm of total soil depth and the highest species diversity occurred on the alfalfa (*Medicago sativa*) vegetation plots with 0 to 40 cm of total soil depth. In the previous study, the highest production occurred on 51 to 110 cm of total soil depth. At the Stanton, ND Soil Wedge (SSW) in 2003, the highest production occurred on 65 to 120 cm of total soil depth. In the previous study, the highest production occurred on 92 to 132 cm of total soil depth. Changes through time in soil characteristics at the ZSW and SSW sites were similar. Electrical conductivity (EC) was lower in 2003 compared to 1979 and increased with depth in 2003. pH was higher in 2003 compared to 1979 and also increased with depth in 2003. There was a weak correlation between total soil depth and plant community development after 30 years of establishment compared to a strong correlation observed after six years of vegetation establishment in the previous studies.

Additional Key Words: soil wedge, production, cover, diversity, electrical conductivity, pH, North Dakota

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Introduction

Re-vegetation of mined lands in west-central North Dakota is challenging because of the high clay and sodium content of the spoil material and the semi-arid climate. The clay and sodium content of the spoil limits infiltration and increases erosion during high intensity, short duration rain events, which are a common in semi-arid climates. An effective reclamation method used in this area is replacement of a suitable depth and type of soil material over sodic spoil to promote plant community and soil recovery on mined lands (Power et al., 1974). Several soil wedge studies were initiated to determine the suitable depth and type of soil needed to reclaim mined land in west-central North Dakota. Ries et al. (1978) conducted one of the first variable depth studies in Stanton, ND with 0, 5, 15 and 30 cm of topsoil placed over spoil with a Sodium Adsorption Ratio (SAR) of 25. Yields of crested wheatgrass (*Agropyron cristatum*) were consistently higher for the 30 cm plots compared to the other depths during a 9 year period. Other studies followed to test the addition of subsoil between topsoil and spoil material. Subsoil material was suspected to help minimize sodium movement towards the soil surface. Two soil wedges, the Zap Soil Wedge (ZSW) and the Stanton Soil Wedge (SSW), were established by the Agricultural Research Service (ARS) in 1975 and 1974, respectively. The soil wedges were constructed with motor scrapers and road graders to create large wedge-shaped areas of varying topsoil and subsoil depths over sodic spoil material.

The ZSW and SSW study sites are located in Mercer County, North Dakota. The ZSW is located west of Beulah on the Indianhead Lignite Mine and the SSW is located south of Stanton on the Glenharold Mine. Both mining operations extracted lignite from the Tongue River and Sentinel Butte members of the Fort Union Reserves. The ZSW has since been released to a private landowner and the SSW is part of an extended reclamation area.

The ZSW study, initiated by Merrill et al. (1998), was established with variable depths (0 to137 cm) and types (A, B, C) of subsoil and a uniform depth of a loam topsoil (20 cm). There were north and south facing slopes established on the wedge with 5% and 2% slopes, respectively (Figure 1). When established, subsoil material A, had an electrical conductivity (EC) of 7 mmhos cm^{-1} and 45% clay content (silty clay), subsoil B had an EC of 4 mmhos cm^{-1} and clay content of 34% (clay loam) and subsoil C had an EC of 1 mmhos cm^{-1} and 13% clay (sandy loam). The soil wedge was seeded with crested wheatgrass, Russian wildrye (*Psathyrostachys juncea*), spring wheat (*Triticum aestivum*), and alfalfa (*Medicago sativa*) in separate subplots across the wedge. Smooth brome (*Bomus inermis*) was seeded on spring wheat plots after completion of the study. Optimum yields for crested wheatgrass were obtained on 51 to 81 cm of total soil, optimum spring wheat yields were obtained on 89 to 110 cm of total soil and optimum Russian wildrye yields were obtained on 51 to 81 cm of total soil. Crested wheatgrass and Russian wildrye yields were highest on sandy loam subsoil (C) and spring wheat yields were highest on clay loam subsoil (B). Rabbits consumed most of the vegetation on the alfalfa plots within the first two years of the study. As a result, alfalfa plots were not sampled.

The SSW study was initiated by Power et al. (1981) in 1974. This soil wedge was established to determine plant productivity responses to various depths of silt loam subsoil (0 to 229 cm) and silt loam topsoil (mixed, 0, 20, 60 cm) over sodic spoil material (SAR = 25). Mixed topsoil treatments consisted of half topsoil and half subsoil material. This site had a south facing slope only (Figure 2). Species of vegetation seeded in separate subplots across the soil wedge consisted of spring wheat, alfalfa, crested wheatgrass, and a native grass mixture of blue grama

(*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*). Spring wheat plots were re-seeded with smooth brome after completion of this study as well. Results for all topsoil depths examined during this study showed that alfalfa yields were highest on 20 cm of topsoil and 71 cm subsoil (where total soil depth was equal to 92 cm). Crested wheatgrass yields were highest on 71 to 92 cm of subsoil only. The native grass mixture yields showed no difference between the 20 cm and 60 cm topsoil plots, but had the highest yields on 51 to 71 cm subsoil. Spring wheat yields showed no difference between 20 and 60 cm of topsoil, but had highest yields on 71 to 92 cm of subsoil. Yields of all vegetation types were generally higher on 20 cm topsoil plots with total soil depths of 92 to 132 cm than on mixed, 0 and 60 cm topsoil depth plots.

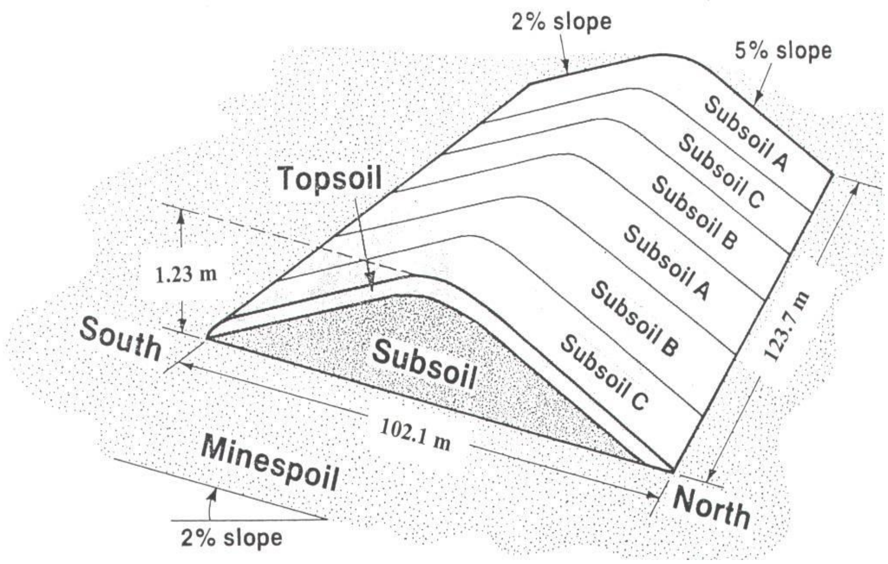

Figure 1. Schematic diagram of Zap, ND Double Soil Wedge (Doll et al., 1984). There were four subplots for each subsoil type in the diagram. Each subplot was approximately 4 m wide. Single species of vegetation were seeded in each subplot.

After completion of the ZSW and SSW studies in 1981, Doll et al. (1984) suggested that long-term studies of soil wedges are necessary for understanding plant community development through time over various soil depths on reclaimed mine lands. Objectives of this study were; (1) to examine long-term changes in plant communities in relation to variable soil depths and soil characteristics for the ZSW and SSW and (2) to examine plant community, variable soil depth and soil property relationships on the ZSW and SSW in 2003.

Hypotheses for this study were; (1) production and diversity are significantly influenced through time by total soil depth (topsoil and subsoil) and soil characteristics (EC and pH), (2) production and diversity are significantly influenced through time by slope position (toe-, mid- and shoulder-slope positions) on the soil wedge and (3) production and diversity are significantly influenced by different subsoil types on the ZSW.

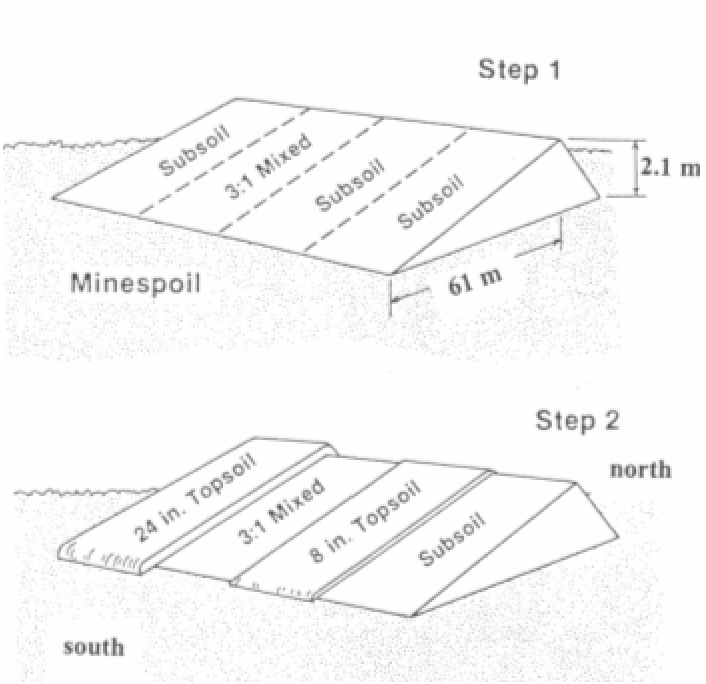

Figure 2. Diagram of Stanton, ND Soil Wedge (Doll et al., 1984). The basic design presented in the diagram is replicated 3 times. Step 1 is the layout of the subsoil material and Step 2 is the layout of the topsoil material. Length of wedge is approximately 243 m. Each subplot is approximately 4 m wide.

Methods and Materials

Preparation for vegetation and soil sampling in June and July of 2003 involved the removal of cattle from the study areas by the middle of May, 2003. North and south baselines on the ZSW were established at 0.5 meters from the north boundary and 8.1 meters from the south boundary because of deterioration of edges of the wedge. Boundaries of the toe-, mid- and shoulder-slope positions were determined based on geomorphology of the slope and documented as distances from north and south baselines. A stratified random sampling design with a baseline was used to determine plot locations (Chambers and Brown, 1983; Vogel, 1987). Two random production plots were chosen in the toe of the wedge, four plots in the mid-section of the wedge and two in the shoulder- position. Number of plots in each slope position was chosen based on the size of the area being sampled to achieve adequate representation of vegetation production for each position. Five basal cover readings, used to determine diversity values, were taken with a 10-pin point frame in toe-, mid- and shoulder slope positions to give a total of 15 frames per subplot. A total of 384 production plots and 720 10-pin point frame readings were taken at the ZSW site.

A baseline for the SSW was established 0.5 meters from the base of the wedge. Boundaries of toe-, mid- and shoulder-slope positions were determined based on geomorphology of the slope and documented as distances from the baseline. The same sampling strategy used at the ZSW was used at the SSW to give a total of 96 production plots and 180 10-pin point frame readings. Diversity was determined for both sites from cover data with Shannon's Diversity Index (Magurran, 1988)

Soil samples were collected in mid- to late-July with a truck mounted rotating soil probe. Soil was collected in 30 cm increments to a depth of 120 cm or to the subsoil-spoil contact and separated in predetermined increments and by natural breaks. A total of 144 soil samples were taken at the ZSW and 36 at the SSW in the center of randomly chosen production plots in each slope position. Samples were dried at 32˚C for four days, put into a soil de-aggregation machine and then passed through a 2-mm sieve. Topsoil and subsoil depths were determined in the field, $EC_{1:1}$ was determined with an Orion Model 550A EC meter and pH was determined from a 1:1 paste with a glass electrode (Orion Model 550A). Soil texture was determined on a subset of samples (206 samples) with the hydrometer method (Day, 1965).

Data were analyzed with one-way analysis of variance and multiple correlation analysis using Jmp, Version 4.0.4 (2001). Past vs. present data and 2003 production data were analyzed with one-way analysis of variance. Multiple correlation analysis was used to determine the strength of the relationship among production, total soil depth, EC and pH. A collinear relationship between slope position and total soil depth (as a result of wedge design) allowed for depth ranges to be determined for each slope position.

Results and Discussion

Climate data was obtained from the Beulah, ND NOAA station. This station is 8 km to the east of the ZSW and 37 km to the west of the SSW and has the most complete records in the area. Precipitation was highly variable between the sampling years (1976-1981, 2003). Precipitation timing and amounts in 2003 was most similar to 1978. Spring and summer precipitation values in 2003 and 1978 were 13.7 and 10.2 cm, respectively, in the spring and 13.1 and 14.2 cm, respectively, in the summer (Table 1). Mean air temperatures were also similar between 2003 and 1978 with average monthly temperatures approximately 13.7 and 16.9˚C in May and June, respectively (Table 2).

Table 1. Total precipitation in centimeters at the Beulah, ND NOAA station.

	1976	1977	1978	1979	1980	1981	2003
				cm			
Jan.-Mar.	4.4	3.8	1.6	4.3	2.8	1.1	4.4
Apr.	7.3	0.4	4.4	4.5	1.9	1.0	2.6
May	1.7	8.1	5.8	2.0	0.5	3.0	11.1
June	13.3	7.9	6.4	6.1	9.0	11.3	7.5
July	1.3	6.1	7.8	11.4	2.2	5.5	5.6
Apr.-July	23.6	22.4	24.3	24.0	13.6	20.8	26.8
Aug.-Dec.	8.3	24.8	12.2	7.1	21.2	17.3	12.2
Annual	36.2	51.0	38.1	35.3	37.6	39.2	43.4

Comparison of Past and Present Data

Crested wheatgrass plot production values were significantly higher (F<0.01) in 1978 compared to 2003 for the ZSW and SSW (Table 3). This was due to invasion of other weedy plant species into the crested wheatgrass plots as a result of years of grazing. In the previous study by Merrill et al. (1998), the crested wheatgrass plots consisted of a monoculture of crested wheatgrass. This grass is a non-native, aggressive cool season grass with higher productivity than more diverse plant communities. As seen in other studies, when non-seeded species invade a site and increase diversity, production values decrease (Bowen, 2003; Schladweiler et al., 2003). Productivity was also significantly higher (F<0.01) in 1978 compared to 2003 for Russian wildrye plots. Grazing impacts could have also influenced decreased productivity in 2003 compared to 1978. Spring wheat plots, which were reseeded with smooth brome in 1982, will be referred to as smooth brome plots for the duration of the paper because of the different characteristics of smooth brome compared to spring wheat. Smooth brome plot productivity was highest on sandy-clay loam subsoils (B), crested wheatgrass plot production was highest on sandy loam subsoils (C), Russian wildrye plot production was highest on sandy-clay loam subsoil B, and there was not a significant difference in alfalfa plot productivity by subsoil type. Plant relationships with subsoil type examined in 2003 were similar to relationships examined by Merrill et al. (1998), indicating no significant change through time.

Table 2. Mean monthly temperature in degrees Celsius at the Beulah, ND NOAA station.

	1976	1977	1978	1979	1980	1981	2003
				˚C			
Apr.	7.7	9.1	5.8	0.5	8.7	8.2	9.3
May	12.9	17.4	14.4	9.7	14.9	12.0	13.0
June	18.6	18.9	16.9	17.9	18.2	15.3	16.8
July	20.8	21.2	20.3	21.3	22.3	20.8	22.3
Apr.-July	15.0	16.7	14.3	12.3	16.0	14.1	15.3

Productivity was significantly lower (F<0.01) in native mixture and alfalfa plots at the SSW in 1978 compared to 2003. Invasion of smooth brome into other plots on the SSW caused increased yields of less productive plots. Smooth brome is a very aggressive species with high aboveground biomass and invaded other plots once it was seeded after completion of the Power et al. (1981) study.

Table 3. Past vs. present mean production for all soil depths on the ZSW and SSW. Dash indicates no data was available for that year. All values are significantly different from each other in each vegetation category at the 0.01 probability level.

Year	Crested wheatgrass (ZSW)	Russian wildrye (ZSW)	Crested wheatgrass (SSW)	Native mixture (SSW)	Alfalfa (SSW)
			Mean Production		
			(kg ha-1)		
1976	-	-	3206	828	1073
1977	520	-	1084	1041	577
1978	3103	2172	4527	1432	786
1979	1419	1149	1819	845	2630
1980	448	245	-	-	-
1981	1432	854	-	-	-
2003	2110	1698	3504	3043	3614

The significantly different production observed among sampling years at both sites demonstrates the complexity of plant-soil-climate relationships. Plants are influenced by climate and soil parameters in addition to competition between plant species. Soils are influenced by plant inputs and establishment as well as climate variables. Changes in soil quality through time contribute to variations plant community production; however, climatic influences on plant establishment may be more important.

Soil EC decreased and pH increased between 1979 and 2003 for both the ZSW and SSW (Table 4). Decrease in EC was due to leaching of the soils for close to 30 years as well as high spring precipitation in 2003 compared to 1979. This indicates that changes in soil properties can lead to changes in plant community properties through time. EC and pH both increased with depth in 2003 due to effects of the sodic spoil material at the ZSW and SSW.

Table 4. Average soil EC and pH values from all soil depths. * indicates significance at the 0.01 level of probability. "All subsoils" are significantly different from each other at the 0.01 level of probability. 1979 and 2003 EC values are significantly different for subsoil type (A,B,C) and 2003 pH values are significantly different for subsoil type (A,B,C).

	ZSW				SSW			
	EC		pH		EC		pH	
	mmhos cm^{-1}				mmhos cm^{-1}			
	1979	2003	1979	2003	1979	2003	1979	2003
All Subsoils	4.69*	1.85*	7.31*	7.72*	3.02*	1.62*	7.39*	8.14*
Subsoil A	5.94*	3.15*	7.29	7.51*	-	-	-	-
Subsoil B	4.32*	1.63*	7.35	7.94*	-	-	-	-
Subsoil C	3.78*	0.90*	7.29	7.65*	-	-	-	-

Production Results for 2003

Production values were significantly lower ($F<0.01$) in toe slope positions for smooth brome and crested wheatgrass plots with total soil depths ranging from 0 to 40 cm at the ZSW. Highest productivity for 2003 was found on 40 to 120 cm depths. Crested wheatgrass plot production was significantly higher ($F<0.01$) than production values of other vegetation types for toe and shoulder slope positions. Crested wheatgrass plot production was significantly higher ($F<0.05$) than production of other vegetative plots for the mid slope position.

Production was significantly higher ($F<0.01$) in the mid slope position for crested wheatgrass and alfalfa plots on the SSW. This is equivalent to 60 to120 cm total soil. No statistical relationship could be determined among vegetation plots because the number of observations (n) was less than 20 at the SSW (Table 5).

There was a significant ($F<0.01$) but weak relationship ($R^2=0.1836$) at the ZSW among production and soil properties. Total soil depth had the greatest affect on total production compared to other soil properties. At the SSW, there were weak relationships that were not significant ($R^2=0.2038$) among production, total soil depth and soil properties. There has been substantial change after 30 years of development on the wedges. Plant community production is no longer as dependent upon soil depth and soil properties compared to initial establishment. Production may be more influenced by other soil properties not examined in this study or by precipitation and temperature.

Table 5. Average production values in kg ha^{-1} for the ZSW and SSW. †, *, ** indicate statistical significance at the 0.10, 0.05, and 0.01 levels of probability, respectively.

	ZSW				SSW			
	smooth brome	crested wheatgrass	russian wildrye	alfalfa	smooth brome	crested wheatgrass	native mix	alfalfa
	kg ha^{-1}				kg ha^{-1}			
Toe slope	1510*	1787*	1350	1418	2985	2618†	2720	2750*
Mid slope	1748*	2031*	1722	1675	4021	3698†	2819	4361*
Shoulder slope	1825*	2289*	1604	1561	3432	3443†	3183	3309*
Subsoil A	1504**	1821*	1262**	1620	-	-	-	-
Subsoil B	1874**	2021*	1778**	1620	-	-	-	-
Subsoil C	1745**	2261*	1757**	1508	-	-	-	-

Diversity Results for 2003

Diversity values were only calculated for the ZSW because of a low number of observations (n<20) for the SSW. Alfalfa plots had significantly higher diversity (F<0.01) in toe slope positions (0-40 cm soil depths) compared to other vegetation species plots and slope locations. Alfalfa is a less aggressive species than smooth brome or crested wheatgrass and also fixes nitrogen in the soil. These characteristics make alfalfa plots more susceptible to native and introduced plant invasion because of low competition compared to other vegetation species and high nitrogen availability in the soil. Species, which invading the alfalfa plots from surrounding experimental plots, consisted of smooth brome and crested wheatgrass. Other native and introduced species found in the alfalfa plots from the surrounding area are listed in Table 6. There were a variety of native and introduced species established on the ZSW which may be a result of invasion by surrounding vegetation or seed distribution through cattle grazing. Again, most of the diversity was found in reduced depths of replaced soil because these areas more conducive to higher diversity and lower production (Bowen, 2003; Schladweiler et al., 2003). In the previous study by Merrill et al. (1998), rabbits also fed on alfalfa stands and caused a weak establishment. This made alfalfa plots more vulnerable to invasion by native and introduced species leading to higher diversity values than other vegetation plots.

There were significant differences (F<0.01) in diversity values by subsoil type for crested wheatgrass, Russian wildrye and alfalfa (Table 7). Differences can be attributed to plant soil textural preferences, along with other soil parameters not examined in this study. A significant, but weak relationship (R^2=0.1168) existed among diversity, soil depth, EC and pH; therefore, diversity may be influenced more by other soil parameters not examined in this study.

Table 6. List of native and introduced species found on ZSW.

Common Name	**Scientific Name**	**Native/Introduced**
American vetch	*Vicia americana*	Native
Aster	*Aster ericoides*	Native
Ball cactus	*Coryphantha vivipara*	Native
Blue grama	*Bouteloua gracilis*	Native
Buffalograss	*Buchloe dactyloides*	Native
Common yarrow	*Achillea millefolum*	Native
Curlycup gumweed	*Grindelia squarrosa*	Native
Dandelion	*Taraxacum officinale*	Introduced
Field bindweed	*Convolvulus arrensis*	Introduced
Foxtail barley	*Hordeum jubatum*	Native
Fringed sagebrush	*Artemesia frigida*	Native
Green needlegrass	*Nassella viridula*	Native
Kentucky bluegrass	*Poa pratensis*	Native
Mustard sp.	*Mustard sp.*	-
Needle-and-thread grass	*Stipa comata*	Native
Netseed lambsquarters	*Chenopodium berlandieri*	Introduced
Peppergrass	*Lepidium densiflorum*	Introduced
Prairie junegrass	*Koeleria macrantha*	Native
Pussytoes	*Antennaria sp.*	Native
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Native
Threadleaf sedge	*Carex filifolia*	Native
Tumblegrass	*Schedonnardus paniculatus*	Native
Western salisfy	*Tragopogon dubius*	Introduced
Western wheatgrass	*Psacopynum smithii*	Native
Wilcox paniculum	*Panicum wilcoxianum*	Native
Yellow sweetclover	*Melilotus officinalis*	Introduced

Table 7. Diversity determined with Shannon's Diversity Index for ZSW. Higher diversity values in the table indicate more vegetation diversity. * indicates statistical significant at the 0.01 level of probability.

	ZSW			
	smooth brome	crested wheatgrass	russian wildrye	alfalfa
	kg ha^{-1}			
Toe slope	1.3898	1.0969*	1.3898	1.9835*
Mid slope	1.3853	1.455*	1.3853	1.5837*
Shoulder slope	1.2360	0.869*	1.2359	1.5828*
Subsoil A	1.2488	0.839*	1.7044*	1.6867*
Subsoil B	0.9024	1.2026*	0.9179*	1.4718*
Subsoil C	1.2769	1.3793*	1.4225*	1.9915*

Summary

The long-term relationships established among plant communities, total soil depth and soil characteristics on reclaimed lands were very different from the relationships observed during initial vegetation establishment. Through time, the plant community and soil quality may have changed to achieve balance. This relationship among vegetation, soil depth and soil quality in 2003 provides evidence that pre-determined soil depths established in previous studies (Power et al., 1981; Merrill et al., 1998) were needed more for initial establishment than for long-term development of the plant community. The seed mix used to reclaim a disturbed area seems to be as important as soil depth through time. The use of smooth brome and crested wheatgrass in vegetation strips may have masked some important results that could have been identified if a more native seed mix was used. Recently established soil wedges (Schladweiler et al., 2002) will be of more value for long-term studies because of the native seed mixes used.

More work can be conducted on the ZSW and the SSW in the future. Both of these wedges are marked and documented for future research and soil samples are currently undergoing further analyses. There are also wedge sites located in Montana (Barth and Martin, 1984), Colorado (Redente and Hargis, 1985), New Mexico (contact Bruce Buchanan) and Wyoming (Pinchak et al., 1985; Bowen, 2003) that offer unique opportunities to learn more about localized long-term relationships between plant community development, soil depth and soil properties.

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Literature Cited

Barth, R.C., and B.K. Martin. 1984. Soil Depth Requirements for Re-vegetation of Surface-mined Areas in Wyoming, Montana, and North Dakota. Journal of Environmental Quality 13:399-404. http://dx.doi.org/10.2134/jeq1984.00472425001300030016x http://dx.doi.org/10.2134/jeq1984.133399x.

Bowen, C. K. 2003. Influence of Topsoil Depth on Plant Community and Soil Attributes of Reclaimed Mine Land After 24 Years. MS Thesis. UW, Laramie, Wyoming.

Chambers, J.C., and R.W. Brown. 1983. Methods for Vegetation Sampling and Analysison Re-vegetated Mined Lands. US Forest Service, Intermountain Forest andRange Experimentation Station, Ogden, Utah. General Technical Report INT-151.

Day, P.R. 1965. Particle Fractionation and Particle Size Analysis. *In* C. A. Black (ed.)Methods of Soil Analysis, Part I, Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. ASA, Madison, Wisconsin.

Doll, E.C., S.D. Merrill, and G.A. Halverson. 1984. Soil Replacement for Reclamationof Strip Mined Lands in North Dakota. North Dakota Agricultural ExperimentStation Bulletin 514.

JMP 4.0.4. 2001. Division of SAS, SAS Institute.

Magurran, A.E. 1988. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, New Jersey. http://dx.doi.org/10.1007/978-94-015-7358-0.

Merrill, S.D., R.E. Ries, and J.F. Power. 1998. Subsoil Characteristics and Landscape Position Affect Productivity of Reconstructed Mine Soils. Soil Science Society of America Journal 62:263-271. http://dx.doi.org/10.2136/sssaj1998.03615995006200010034x.

National Oceanic and Atmospheric Administration (NOAA). 2003. Website available: http://cdo.ncdc.noaa.gov/ancsum/ACS?stnid=32076699999. Viewed: December 20, 2002.

Pinchak, B.A., G.E. Schuman, and E.J. DePuit. 1985. Topsoil and Mulch Effects on Plant Species and Community Responses of Re-vegetated Mined Land. Journal of Range Management 38(3):258-261. http://dx.doi.org/10.2307/3898981.

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.

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 Science Society of America Journal 45:124-129. http://dx.doi.org/10.2136/sssaj1981.03615995004500010027x.

Redente, E.F. and N.E. Hargis. 1985. An Evaluation of Soil Thickness and Manipulation of Soil and Spoil for Reclaiming Mined Land in Northwest Colorado. Reclamation and Revegetation Research 4:17-29.

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.

Schladweiler, B.K., G.F. Vance, and R. Haroian. 2003. Evaluation of topsoil depth effects on various plant parameters within a reclaimed area in northeastern Wyoming. Proceedings of the 2003 National Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings, MT, June 3-6, 2003.
https://doi.org/10.21000/JASMR03011086

Vogel, W.G. 1987. *A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation*. US Department of Agriculture, Northeastern Forest Experiment Station, Berea, Kentucky.