EVALUATION OF TOPSOIL DEPTH EFFECTS ON VARIOUS PLANT PARAMETERS WITHIN A RECLAIMED AREA IN NORTHEASTERN WYOMING[1]

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Abstract: A project was initiated in 1998 to investigate the effect of varying topsoil depths on soil parameters, plant cover, production and diversity on a coal mine in northeastern Wyoming. Soil and vegetation information was collected for three consecutive growing seasons (2000 through 2002) on reclaimed areas with three topsoil treatment depths (15, 30 and 56 cm) and from two native reference areas (Upland Grass and Breaks Grass) at the mine. For the vegetation analysis, total vegetation cover, total cover, average number of species and total number of species were the primary parameters. Vegetation production was measured in 2002 only. Analyzed soil parameters included pH, electrical conductivity and sodium adsorption ratio at 15 cm intervals throughout the treatment depth and the immediate underlying spoil material. Although three years of data has been collected for this project, the primary emphasis of this paper will be 2002. No significant differences in vegetation and soils were noted by treatment in the 2000 through 2002 data. Location effects, however, were numerous, which emphasizes the difficulty in utilizing native reference areas as standards for reclamation success on reclaimed areas. All vegetative parameters were generally higher in reference areas with the exception of production. Diversity indices on the reclaimed and reference areas were also evaluated. The Shannon-Wiener indices were significantly different by location throughout 2000 to 2002 and by treatment in 2001, i.e., the 30 cm treatment was significantly higher in diversity than the 56 cm treatment. Previous research has indicated diversity differences in topsoil depth treatment levels increase over time. For this project, differences in topsoil depth treatments will likely increase over time and/or with more typical precipitation patterns.

Additional Key Words: plant diversity, diversity indices, variable topsoil depth, soil chemistry, reclamation.

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Introduction

Oftentimes, the goal of achieving pre-mine cover and productivity values are in conflict with the attainment of diversity (Biondini and Redente, 1986; Redente et al., 1997). The historical, mandated use of uniform topsoil replacement depths may hinder the development of a diverse community at the landscape level (Munshower, 1994). Various tools such as variable topsoil depth exist within reclamation science today to promote diversity on reclaimed lands. Information pertaining to an investigation of the effect of varying topsoil depths on soil parameters, plant cover, production and diversity on a coal mine in northeastern Wyoming is presented in this paper. The research was funded by the Abandoned Coal Mine Land Research Program (ACMLRP) of Wyoming.

Methodology

Construction of the study site at the Powder River Coal Company (PRCC) North Antelope/Rochelle Coal Mine Complex (NARC) was completed during Fall 1998 to Fall 1999. Backfill suitability samples were analyzed in 1998 and indicated no inherent problems with salinity, sodium or texture. Permanent seeding with a shrub-grassland seed mixture (Table 1) occurred in Fall 1999. Soil and vegetation information was collected for three consecutive growing seasons (2000 through 2002) on reclaimed areas with three topsoil treatment depths (15, 30 and 56 cm) and from two native reference areas (Upland Grass and Breaks Grass) at the mine. The Upland Grass reference area is found on gently rolling, upland topography dominated by cool-season grasses and grasslike plants such as western wheatgrass (*Elymus smithii*), prairie junegrass (*Koeleria macrantha*), threadleaf sedge (*Carex filifolia)*, and needleandthread (*Stipa comata*) with numerous individuals of the half shrub fringed sagewort (*Artemisia frigida*). The Upland Grass vegetation type also contain significant amounts of the warm season grass blue grama (*Bouteloua gracilis*). The Breaks Grass vegetation type is found on steep, broken topography dominated by full and half shrubs with an understory of various grasses or grasslike plants such as western wheatgrass, thickspike wheatgrass (*Elymus lanceolatus)*, needleandthread, threadleaf sedge and blue grama . Numerous perennial forbs exist within the Breaks Grass vegetation type. The Upland Grass and Breaks Grass were selected to mimic the resulting reclaimed environment for the following reasons:

1) The source of replaced topsoil was a native Breaks Grass area,

2) The overall aspect and slope of the reclaimed area is a generally drier southwest facing, 5:1 slope,
3) Breaks Grass is one of the most diverse native plant communities to be compared, and
4) Reclaimed areas with less diversity resemble the native Upland Grass community.

Table 1. Shrub-Grass Mix Used at the Study Site in Fall 1999.

Species	Common Name	Variety	Lifeform	PLS kg/ha	% Mix
Drilled (Grain Box) Mix					
Agropyron dasystachyum	Thickspike wheatgrass	Critana	CSPG	2.25	13.31
Agropyron smithii	Western wheatgrass	Rosana	CSPG	1.12	6.67
Andropogon scoparius	Little bluestem		WSPG	1.12	6.67
Calamovilfa longifolia	Prairie sandreed	Goshen	WSPG	0.56	3.33
Poa sandbergii	Sandberg bluegrass		CSPG	1.12	6.67
Stipa viridula	Green needlegrass	Lodorm	CSPG	1.12	6.67
Astragalus cicer	Cicer milkvetch	Lutana	PF	1.68	10.00
Penstemon strictus	Rocky Mountain penstemon		PF	1.12	6.67
Spharalcea munroa	Munro globemallow		PF	0.56	3.33
Atriplex canescens	Fourwing saltbush	Wytana	FS	1.12	6.67
Atriplex gardneri	Gardner saltbush		HS	1.12	6.67
Dribbled (Fluffy Box) Mix					
Bouteloua gracilis	Blue grama	Hachita	WS	1.12	6.67
Artemisia tridentata	Big sagebrush	Wyoming	FS	1.68	10.00
Ceratoides lanata	Winterfat		FS	1.12	6.67
TOTAL				16.81	100.00

CSPG = cool season perennial grass; WSPG = warm season perennial grass; PF = perennial forb; FS = full shrub; HS = half shrub.

<u>Soil Sampling</u>

For the reclaimed area treatments, soil samples were collected at the beginning of each randomly selected cover transect (see Vegetation Sampling section). Samples were collected at 15-cm increments to the interface between topsoil and backfill. At that point, an additional 15 cm of backfill was collected. All soils were analyzed for pH and electrical conductivity (EC) on soil extracts, and approximately 25% of the samples were randomly selected for analysis of sodium adsorption ratio (SAR) on the same extract. If possible, at least one complete soil profile was analyzed for pH, EC and SAR within each treatment. In addition to soil sampling, three randomly located root profiles into underlying spoil were exposed to determine relative patterns of root distribution in each treatment.

In order to characterize the reference areas, undisturbed soils within the "treatment" replicates were sampled by locating random sites on the 30-m cover transect (see Vegetation Sampling section) to avoid soil sample locations that were only on the outside edge of the "treatment" replicate. At these locations, samples were described, bagged and analyzed by horizon. However, statistical evaluation was conducted by converting lab analysis results to 15-cm increments to mirror the methodology employed in the reclaimed area treatments.

Vegetation Sampling

For the reclaimed area treatments, five random 30-m cover intercept transects were sampled within each of three treatment replicates, i.e., 15 transects each in 15, 30 and 56 cm topsoil depth sites. Quantitative sampling was conducted during 2000, 2001 and 2002. Methodology followed WDEQ-LQD, Rules and Regulations, Appendix A (WDEQ-LQD, 2001), wherever applicable, or WDEQ Guideline 14 (WDEQ-LQD, 1996). Cover sampling was conducted within the 30-m line transects; sample hits were read at 1-m intervals along the entire length. Vegetation production within 1-m^2 quadrats was added in the 2002 sampling protocol.

In reference areas, three restricted random 30-m cover intercept transects were sampled within each of three reference area "treatment" replicates, i.e., top, middle and bottom, for a total of nine transects. Due to the small size of the reference area replicates, randomly generated origins were "restricted" to the periphery of each replicate. All other sampling and summarization was similar as described for the reclaimed area treatments above. Vegetation production within 1-m^2 quadrats was added in 2002 sampling only.

In order to evaluate species diversity, 2001 data were evaluated utilizing the following indices (Magurran, 1988) based on a review of indices listed in mine permits and various western state regulatory documents: Shannon-Weiner diversity index, Jaccard similarity index, Sorenson similarity index, Morisita-Horn similarity index, Simpson's diversity index, Motyka similarity index and Berger-Parker diversity index. Of these seven, only Shannon-Wiener, Morisita-Horn and Motyka were statistically evaluated by replicate. Based on lack of significance with Morisita-Horn and Motkya, the 2002 data were evaluated only by the Shannon-Wiener diversity index analysis.

2002 Statistical Methodology

Vegetation and soil data were analyzed using SAS (SAS/STAT, 1990) considering three primary statistical methodologies, i.e., two-factorial weighted ANOVA because the number of transects or sampled parameter points were not equal, split plot in time and repeated measures. Split plot analysis was utilized since depth considerations at each point cannot be considered random. Dependent variables included pH, EC, SAR, percent total cover (TOTCOV), percent total vegetation cover (TOTVEG), average number of species per transect (ASPEC) and total number of species within a replicate (TOTSPEC). ANOVA was run by depth over location, treatment and location*treatment interaction separately by site (Reclaimed, Upland Grass and Breaks Grass). Mean separation tests were completed by Tukey's HSD (Snedecor and Cochran, 1989). The significance criteria used in this study were $p < 0.05$.

Results and Discussion

Although data were collected in 2000 and 2001, for the purposes of this paper, only the results of the ANOVA analysis and the split plot analysis for the 2002 data set are presented. However, 2000, 2001 and 2002 data are included in the repeated measures analysis.

Soils

Soil pH and EC in the top 15 and 30 cm depths of the reclaimed soil profile were significantly greater than both native reference areas (Table 2) which indicates mixing of the original soil profile during topsoil salvage and replacement operations. Values for SAR within the reclaimed areas were significantly higher at deeper depths than the reference areas which also indicates mixing of the original soil profile and possible interaction with underlying spoil material.

Table 2. Significant ANOVA Tests of the 2002 Means for Various Parameters (by Location).

Dependent Variable	Depth	Mean Values* R	U	B	Results
pH	0-15 cm	7.29a	6.60b	6.36b	Reclaimed pH significantly greater than Upland Grass and Breaks Grass reference areas.
EC (dS/m)	0-15 cm	1.59a	0.57b	0.46b	Reclaimed EC significantly greater than Upland Grass and Breaks Grass reference areas.
	15-30 cm	2.24a	0.85b	0.54b	
	30-45 cm	3.20a	1.22b	0.70b	
SAR	30-45 cm	3.02a	1.20b	0.83b	Reclaimed SAR significantly greater than Upland Grass and Breaks Grass reference areas.
	45-60 cm	3.13a	1.11b	0.45b	
	60-75 cm	4.35a	1.25b	0.62b	

NOTE: Similar letter designation after means indicate lack of significant differences.
*R = Reclaimed; U = Upland Grass; B = Breaks Grass.

Mean separations for 2002 data, as determined by split plot in time analysis, are presented in Table 3. In the reclaimed soil profile, pH was significantly lower at the 0-15 cm, 15-30 cm and 30-45 cm intervals than the 60-75 cm depth, indicating the difference between topsoil and underlying spoil. Values for EC and SAR were both significantly lower at the surface than at depth within the reclaimed area, which reverses an earlier trend in 2000 and 2001. Lower EC and SAR values are due to leaching of salts over time.

Statistical differences among locations and by depth are not likely biologically significant at this point due to the low range of values of pH, EC and SAR. No significant gradient for pH, EC and SAR exists on the reclaimed treatments within this study. On the other hand, inherent gradients were, as expected, identified for pH, EC and SAR on native areas.

Soil pH values of the native areas were generally lower in the upper horizons than in the lower horizons, which is to be expected as soil organic matter increases with time due to the decomposition of plant materials, microbial activity and leaching of base cations. Due to homogenous, replaced soil material on the reclaimed area in this study, higher pH material is mixed throughout the replaced topsoil depth and could be found in the upper portion of the soil profile. Once the deeper depths are reached in the native areas, it is possible that the pH is higher in the native soil than the reclaimed soil. The same argument would apply to EC trends, which indicated there are soil materials with higher ECs throughout the replaced topsoil depth, especially in the upper sampling intervals.

Table 3. Significant 2002 Means Derived by Split Plot in Time Analysis for Various Parameters (by Location).

Location	Parameter	Depth (cm)	Mean	Grouping
Reclaimed	pH	0-15	7.29	bc
		15-30	7.35	bc
		30-45	7.27	c
		45-60	7.61	ab
		60-75	7.71	a
Breaks	pH	0-15	6.36	b
		15-30	6.80	ab
		30-45	7.04	a
		45-60	7.67	a
		60-75	7.63	a
Reclaimed	EC	0-15	1.59	c
		15-30	2.24	b
		30-45	3.20	a
		45-60	3.18	a
		60-75	2.81	ab
Reclaimed	SAR	0-15	0.89	d
		15-30	1.66	c
		30-45	3.02	b
		45-60	3.13	b
		60-75	4.35	a

Vegetation

Little or no significant differences in vegetation were noted by treatment for the 2002 data. Location effects, however, were numerous (Table 4), which emphasizes the difficulty in using native reference areas as standards for reclamation success on reclaimed areas.

Table 4. Significant ANOVA Tests of the 2002 Means for Various Vegetation Parameters (by Location).

Dependent Variable	Mean Values* R	U	B	Results
Total Vegetation Cover (%)	35.3b	44.8a	47.9a	Reclaimed pH significantly greater than Upland Grass and Breaks Grass reference areas.
Average No. Species (#/30m^2 transect)	5.58b	6.07b	7.15b	Reclaimed EC significantly greater than Upland Grass and Breaks Grass reference areas.
Production (g/m^2)	60.0a	43.4b	40.0b	Reclaimed total vegetation cover significantly lower than Upland Grass and Breaks Grass reference areas.

NOTE: Similar letter designation after means indicate lack of significant differences.
*R = Reclaimed; U = Upland Grass; B = Breaks Grass.

After three years of sampling, average number of species per sample and total percent vegetative cover were generally higher in the reference (native) areas, with total vegetation cover higher and biomass lower in the reference areas as compared to the reclaimed areas (Table 5). This is due to the relatively young age of the reclaimed area and relatively low precipitation throughout the 2000, 2001 and 2002 growing seasons. Although similar precipitation patterns affected both reclaimed and reference areas, the effect was much more on the newly seeded reclaimed area where many species had difficulty germinating during the extremely dry conditions. Cool season perennial grass growth on reclaimed areas compensated for dry conditions and provided sufficient growth to exceed native area growth. The least amount of vegetative cover was noted during the 2002 sampling. Typically, total cover percentages are higher in reclaimed environments than native areas as litter accumulates with time. With continued sampling it is expected that the total vegetation cover and total cover percentages will likely be greater in the reclaimed sites Additional statistical analysis is being conducted on reclaimed vegetation treatment means only. Results were not available but will be presented in June.

Table 5. 2002 Reference and Reclaimed Area Vegetation Sampling Summaries (based on simple mean comparison only).

Area	Treatment Equivalent	Average Number Species/Sample	Total Vegetation Cover (%)	Total Cover (%)	Biomass (g/m^2)
Upland Grass	Top	5.8	44	85	40.3
	Middle	5.8	46	82	42.3
	Bottom	6.7	44	84	47.4
Breaks Grass	Top	7.3	44	82	39.5
	Middle	7.3	51	86	36.6
	Bottom	6.8	49	84	43.8
Reclaimed	15 cm	5.8	33	82	54.9
	30 cm	6.0	36	82	64.5
	56 cm	4.9	36	86	63.2

Average number of species and total number of species were generally higher in the reference areas (Table 5). Although this is a newly reclaimed area, the problem of comparing diversity with native areas also exists when evaluating older reclaimed areas (Stark and Redente, 1985; Redente et al., 1997; Bowen et al., 2002).

Production was higher in the reclaimed areas in 2002. Typically, one would expect reclaimed production to be much higher than native areas (Biondini and Redente, 1986; Redente et al., 1997; Bowen et al., 2002), but the drought over the last three years has had a marked effect on both the reclaimed and native areas. Precipitation for the period October 1999 through September 2000 was below normal and may explain reduced growth for the 2000 growing season. According to records from the mine site, the total annual precipitation for that period was 25.3 cm, with the majority of the moisture during the months of April and May. Similar patterns existed for the period October 2000 through September 2001 for the 2001 growing season, i.e., total precipitation was 26.7 cm with the majority during the months of June and July. Records for the period October 2001 through September 2002 indicated a total precipitation of 25.0 cm, with unusually high precipitation in the months of August and September. Although annual results were approximately 25-30% below average at the study site, much of the precipitation came in large events that were not effective for increasing soil moisture.

Results for the Shannon-Wiener analysis for 2000, 2001 and 2002 data are presented in Table 6. Larger Shannon-Wiener values indicate more diverse systems. Shannon-Wiener values are often in the range of 1-3 but could be as large as 5 (Allen, 2003). Significant differences existed by: 1) location in 2000; 2) by treatment within the reclaimed area in 2001; and, 3) location in 2002. Shannon-Wiener, Motyka and Morisita-Horn were evaluated by replicate and by treatment. Shannon-Wiener indices were significantly different by location, with the exception of treatment in 2001. The 30-cm treatment was significantly different from the 56-cm treatment. Motyka and Morisita-Horn indices were not significant between treatments or locations. Previous research has indicated differences in treatment levels do occur over time (Redente et al., 1997; Bowen et al., 2002). Differences in treatment will likely increase over time due to plant succession and/or changes in the reclaimed soil profile.

Soil-Plant Trends

No significant differences in measured soil or plant parameters were evident by the end of the second growing season in the variable depth treatments, which may reflect the young age of the reclaimed area and/or reduced precipitation during the 2000 through 2002 growing seasons. Although no quantified methods of root distribution were employed in this study, roots did not visually appear to be negatively impacted by the presence of underlying spoil.

Significant differences among means within the combined 2000/2001/2002 data as determined by repeated measures analysis are presented in Table 7. Significant differences were found between locations for pH, EC and SAR. For pH and EC, the significant differences were in the upper 15 and 30 cm intervals, while SAR differences were found with depth. The pH and EC results were similar to 2000 and 2001. However, the 2002 results for SAR varied from 2000 and 2001 results in that differences were found at depth rather than the upper 30 cm. This may be a result of sampling variability between years or it may indicate chemical changes taking place nearer the topsoil/spoil interface.

Table 6. Shannon-Wiener H' means for 2000, 2001 and 2002 cover data, summarized by location and treatment. Similar letter designation after the number in the last column indicates no statistical difference. NA = Not applicable.

Year	Location	Treatment	Mean Value
2000	Reclaimed	NA	1.32b
	Upland Grass	NA	1.97a
	Breaks Grass	NA	1.95a
2001	Reclaimed	15 cm	1.80ab
		30 cm	2.17a
		56 cm	1.62b
2002	Reclaimed	NA	1.95a
	Upland Grass	NA	1.88a
	Breaks Grass	NA	1.56b

Table 7. Significant Main Effects for Combined 2000/2001/2002 Means for Repeated Measures Analysis.

Depth (cm)	Dependent	Significant	Results
0-15, 15-30	pH	Location	Reclaimed pH significantly higher than both reference areas.
0-15	pH	Year	Significant difference in at least 2 years.
0-15, 15-30	EC	Location	Reclaimed EC significantly higher than both reference areas.
15-30, 30-45	SAR	Location	Reclaimed SAR significantly higher than both reference areas.
0-15	TOTCOV	Year	Significant difference in at least 2 years.

The WDEQ's approach to diversity varies by district. In addition to indices of diversity or similarity, a matrix table of proposed technical standards by lifeform, based on premine species contributing greater than 2% relative percent cover, is utilized to measure revegetation success. Montana utilizes a similar approach, i.e., 70% performance standard for major lifeform species that contribute at least 1% relative cover to a premine physiognomic type (MDEQ, 2000). Although options remain open, the majority of companies and regulators appear to be moving away from the use of similarity or diversity indices.

Conclusion

Significant differences were found between native and reclaimed areas, which exemplifies the difficulty in selecting native areas as a revegetation success standard for reclaimed areas. Inherent differences resulting from the mining process, i.e., homogenous, replaced soil material, make it difficult to compare native areas that have well defined profiles with horizons. Based on current and previous research, however, it appears that utilizing variable topsoil depth is one tool that should be available for reclamation of selected post-SMCRA lands. For example, this research project indicates that a relatively shallow depth of 30 cm provided site stabilization and increased diversity over deeper topsoil depths. A depth of 15 cm did not appear to provide as much site stabilization as the deeper depths based on visual extent of rill erosion. Use of varying topsoil depth ranges will depend upon site characteristics such as slope and aspect, as well as physical and chemical quality of the topsoil and underlying spoil material.

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