ONGOING EVALUATION OF EFFECTS FROM VARIABLE TOPSOIL DEPTHS AT A COAL MINE IN NORTHEASTERN WYOMING[1]

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Abstract. After passage of the Surface Coal Mine Reclamation Act in 1977, studies on mine reclaimed areas in the late 1970's and early 1980's evaluated varying topsoil depths over unsuitable backfill on vegetation productivity and cover. In recent years, several of those earlier studies have been revisited to provide long-term results on vegetation productivity, cover and diversity. A more recent study developed in 1999 was conducted to evaluate variable topsoil depth on soil and vegetation factors at the North Antelope/Rochelle Mine (NARM). Backfill at this location did not exhibit unsuitable plant growth parameters, based on Wyoming Department of Environmental Quality (WDEQ) guidelines. The formal study evaluated vegetation parameters such as cover, production and diversity, and soil differences in pH, electrical conductivity (EC), and sodium adsorption ratio (SAR) between three treatment depths, i.e., 15, 30 and 56 cm. Reclaimed and two native vegetation reference areas were sampled three times during the 2000-2002 growing seasons. At the end of the 2002 monitoring, results were mixed. After that time, the reclaimed area only continued to be part of the ongoing vegetation monitoring program at NARM. Five years of continuous monitoring (2000-2004) were statistically analyzed to determine significant trends between topsoil depth treatments, as the seeded areas matured. No significant differences were found between treatments for two measures of cover and three measures of species richness. Although no significant differences were found between treatments for shrub density, positive increasing trends in the more shallow treatments are evident.

Additional Key Words: vegetation cover, shrub density, plant diversity, topsoil treatment depth.

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Introduction

Reclamation success is determined, in part, by appropriate revegetation that is evaluated quantitatively by measuring plant production, cover and species diversity (Ries and Nilson, 2000), in addition to shrub density, which is a challenge to attain in the Powder River Basin of northeastern Wyoming. Several historical investigations dating back to the late 1970's or early 1980's have been recently revisited to provide long-term results on the first three vegetation parameters (Bowen et al., 2002; Wick et al., 2004). A more recent study developed in 1999 was conducted to evaluate variable topsoil depth on soil and vegetation factors at the North Antelope/Rochelle Mine (NARM) in northeastern Wyoming. Reclaimed and two native vegetation reference areas were sampled three times during the 2000-2002 growing seasons. After that time, the reclaimed area by itself continued to be part of the ongoing vegetation monitoring program at NARM. The native reference areas were not sampled in 2003 and 2004 due to the partial disturbance by the mine pit advance in 2003 of one of the two original areas.

The vegetation diversity requirements of the Surface Mining Control and Reclamation Act (SMCRA) incorporate small scale ecological concepts such as plant species and structural diversity, as well as plant species composition, which may include dominant and rare species. Whatever method is selected for determining diversity, data should be collected over time to assess trends (Kern, 1999; Schuman, 1999). This paper outlines cover and diversity (species richness and composition) information gathered over five consecutive years at the original NARM study area constructed in 1999. In addition, shrub density data was also collected from 2002-2004 to evaluate the impact of more shallow replacement depths on shrub germination and survival. Shrub germination was essentially non-existent in 2000-2001; therefore, numbers are only presented for 2002-2004.

Materials And Methods

Treatment Design and Selection

The study site is located on the North Antelope/Rochelle Mine, about 32 km southeast of Wright, Wyoming (Schladweiler, 2003). Topsoil replacement depth treatments included: 1) "56 cm designated permit depth"; 2) 30 cm depth; and 3) 15 cm depth. The reclaimed treatment blocks were constructed on a uniform site to control variables other than topsoil depth (e.g., similar slope grade, aspect, stockpiled topsoil source and seed mix) and to reflect a landscape position that would best represent a pre- and post-mine Breaks Grass community. Within the original study, Upland Grass and Breaks Grass native reference areas were selected to compare with the resulting reclaimed environment.

Three-year old stockpiled topsoil salvaged from Breaks Grass areas was used for the reclaimed treatment area. Final slope contouring, backfill ripping and topsoil replacement activities were conducted from February to October 1998. 'Schuyler' barley (*Hordeum vulgare* L.) was seeded (34 kg/ha) in early December 1998 to establish a stubble mulch. The barley was mowed during the 1999 growing season (mid-July), which is a normal practice at NARM to reduce competition from volunteer barley plants with the permanent perennial seed mix. To reflect current reclamation practices at NARM, the reclaimed area was fertilized during seeding operations at the rate of

61 kg/ha of an 11-52-0 fertilizer. Nitrogen use at NARM is generally reduced to limit weed competition, while phosphorus is used to promote root growth. The permanent reclamation shrub-grassland seed mix was planted in late November 1999 (Table 1).

Sampling Methods

Vegetation sampling was conducted during late June or July, 2000, 2001, 2002, 2003 and 2004. All taxonomic nomenclature for encountered species followed Dorn (1992). Five 30 m point intercept cover transects, origin and direction randomly determined, were sampled within each reclaimed treatment replicate.

Total vegetation canopy cover consisted of all plant species encountered as a first hit on the point intercept transect, while total cover included total vegetation cover, as well as litter and rock (WDEQ-LQD, 2001). Within cover transects, sample hits were read at 1 m intervals along the entire length of the 30 m transect and included individual plant species, litter/rock and bare ground. Recorded hit information was used to assess absolute cover and relative cover. Absolute cover is the derivation of percent cover of a given category in a fashion that is operationally independent of the other categories, while relative cover is not operationally independent (WDEQ-LQD, 2001). Average number of species per transect and total number of species per treatment were also calculated for each site. Shrub density was collected by counting shrub individuals within 0.5 m on either side of the 30 m cover transect. Within this belt transect for shrub density, additional species were noted that were not found on either the cover transect or the shrub density belt transect. The cumulative total of these species is known as the total number of species encountered in a 30-meter belt transect.

For this study, average number of plant species and total number of plant species were used to describe species richness. Average number of plant species is the mean number of plant species encountered on any given transect within a particular reclaimed treatment. Total number of species is the sum of all plant species encountered within a particular reclaimed treatment. One additional parameter, total number of species encountered within a 30-meter belt transect, was also evaluated.

Statistical Analysis

Measurements (i.e., average number of species, total species, total vegetation cover, and total cover) were statistically analyzed for significant differences among topsoil treatment depths and years, as well as for a topsoil treatment depth x year interaction using a split plot in time analysis of variance (ANOVA). When F tests indicated significant ($p<0.05$) differences occurred among topsoil treatment depths, years or that a topsoil treatment depth x year interaction had occurred, then means were separated using Fisher's protected LSD. All calculations were facilitated by use of the GLM procedure of the Statistical Analysis System (SAS Institute, 1990).

Table 1. Shrub-grass seed mix used at the variable topsoil reclaimed study site on the North Antelope/Rochelle Mine in northeastern Wyoming in Fall 1999.

Drilled (Grain Box) Mix[1]	Common Name	Variety	Lifeform[2]	PLS (lbs/ac)	% of Mix
Elymus lanceolatus (Scribn. & Sm.) Gould	Thickspike wheatgrass	Critana	CSPG	2.25	13.30
Elymus smithii (Rydb.) Gould	Western wheatgrass	Rosana	CSPG	1.12	6.67
Andropogon scoparius Michx.	Little bluestem	Common	WSPG	1.12	6.67
Calamovilfa longifolia (Hook.) Scribn.	Prairie sandreed	Goshen	WSPG	0.56	3.33
Poa secunda Presl	Sandberg bluegrass	Common	CSPG	1.12	6.67
Stipa viridula Trin.	Green needlegrass	Lodorm	CSPG	1.12	6.67
Astragalus cicer L.	Cicer milkvetch	Lutana	PF	1.68	10.00
Penstemon strictus Benth.	Rocky Mountain penstemon	Common	PF	1.12	6.67
Spharalcea munroa (Dougl. ex Lindl.) Spach ex	Munro globemallow	Common	PF	0.56	3.33
Atriplex canescens (Pursh) Nutt.	Fourwing saltbush	Wytana	FS	1.12	6.67
Atriplex gardneri (Moq.) Dietr.	Gardner saltbush	Common	HS	1.12	6.67
Dribbled (Fluffy Box) Mix					
Bouteloua gracilis (Kunth) Lag. ex Griffiths	Blue grama	Hachita	WSPG	1.12	6.67
Artemisia tridentata Nutt. var. *wyomingensis* Young)	Big sagebrush	Wyoming	FS	1.68	10.00
Krascheninnikovia lanata (Pursh) Meeuse & Smit	Winterfat	Common	FS	1.12	6.67
TOTAL				16.81	100.00

[1] Nomenclature according to Dorn, R.D. 1992. Vascular plants of Wyoming. 2nd ed. Mountain West Publishing, Cheyenne, Wyoming. 340 pp. [2]CSPG = cool-season perennial grass; WSPG = warm-season perennial grass; PF = perennial forb; FS = full shrub; HS = half shrub. PLS = Pure Live Seed.

Results And Discussion

At this relatively young reclaimed area (five years), significant plant parameter differences in reclaimed treatments were limited. Several significant differences, however, were found between years. Refer to Table 2 for results of average number of species, total number of species, total vegetation cover, and total cover.

Total Vegetation

Analysis of variance for total vegetation indicated there were significant differences among years ($F_{4,8}$ = 5.07, P = 0.02), with average values for years 1 (51.3) and 2 (48.2) being significantly greater than average values for years 5 (37.4) and 3 (35.3); average value for year 4 (42.5) was intermediate (L.S.D. = 9.86). There were no significant differences among treatments ($F_{2,4}$ = 2.4, P = 0.21), and there was no year x treatment interaction ($F_{8,16}$ = 0.92, P = 0.53). Significantly higher vegetation values in years 1 and 2 may have resulted from input from the presence of the barley cover crop in the first year and annual forb (AF) or annual grass (AG) input in both years.

Table 2. Comparison of plant parameter means for each reclaimed treatment and year at the reclaimed study site on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Vegetation Parameter	Treatment	Year 2000	2001	2002	2003	2004	Average
Average No. Species[2]	15 cm	4.1	5.5	5.8	5.1	4.3	5.0
(number/transect)	30 cm	4.2	6.6	6.0	4.9	4.5	5.2
	56 cm	4.1	5.3	4.9	5.4	4.1	4.8
Total No. Species[2]	15 cm	7.0	11.3	12.7	10.3	8.0	9.9
(number/treatment)	30 cm	6.7	13.7	12.3	9.0	8.0	11.2
	56 cm	7.0	10.0	11.3	11.0	7.3	9.3
Total Vegetation[3]	15 cm	51.8	42.4	33.1	39.8	30.7	39.6
(%)	30 cm	49.8	44.4	36.4	42.7	41.3	42.9
	56 cm	52.2	57.6	36.4	45.1	40.2	46.3
Total Cover[3]	15 cm	76.9	82.4	83.6	75.8	68.7	77.5
(%)	30 cm	75.8	82.0	81.8	76.7	61.3	75.5
	56 cm	74.4	89.3	86.0	75.3	76.7	80.3

[1]Means for a parameter within a treatment in a particular year that are followed by the same letter are not statistically different (p>0.05) based on Fisher's protected LSD.
[2]Results from two factor ANOVA analysis.
[3]Results from one factor ANOVA analysis.

Total Cover

Analysis of variance for total cover indicated there were significant differences among years ($F_{4,8}$ = 7.22, P = 0.009), with average values for years 2 (84.6) and 3 (83.2) being significantly greater than average values for all others (year 4 = 75.9, year 1 = 75.7, and year 5 = 71.8) (L.S.D. = 6.60). There were no significant differences among treatments ($F_{2,4} = 0.81$, $P = 0.51$), and there was no year x treatment interaction ($F_{8,16} = 1.35$, $P = 0.29$). The litter component of total cover may have contributed to higher values in years 2 and 3, resulting from a lag effect of higher total vegetation values in years 1 and 2.

Average Number of Species (Species Richness)

Analysis of variance for average number of species once again indicated there were significant differences among years ($F_{4,8} = 10.6$, $P = 0.003$), with average values for years 2 (5.82), 3 (5.58), and 4 (5.16) being significantly greater than those for years 5 (4.31) and 1 (4.13) (L.S.D. = 0.754). Again, there were no significant differences among treatments ($F_{2,4} = 2.47$, $P = 0.20$), and there was no year x treatment interaction ($F_{8,16} = 1.58$, $P = 0.21$). Fewer species may be expected in the first year after seeding. Lack of species in year 5 is likely attributed to lack of and poor timing of precipitation.

Total Number of Species (Species Richness)

Analysis of variance for total number of species differed from the others because there was a significant year x treatment interaction ($F_{8,16}$ = 4.96, P = 0.003), indicating treatments did not behave similarly over the years. Mean separations for treatments, done separately for each year, indicated there was a significant separation for year 2 only, with treatment = 2 (30 cm) average (13.7) being significantly greater than either treatment = 1 which is the 15 cm treatment (11.3) or treatment = 3 which is the 56 cm treatment (10.0) averages. Treatments were statistically identical for the other years (Fig. 1) (L.S.D. = 2.23). Previous statistical calculations and observations in the original study (Schladweiler, 2003; Schladweiler et al., 2005) indicated the 30 cm treatment may enhance species richness due to less canopy effect from cool-season perennial grass (CSPG). This same trend has continued throughout 2003 and 2004 (Table 3).

Total Number of Species Per 30 Meter Belt Transect (Species Richness)

In addition to Average Number of Species per Transect and Total Number of Species per Replicate as measures of species richness, the total number of species per 30-meter belt transect was also statistically analyzed. No significant differences were found among treatments.

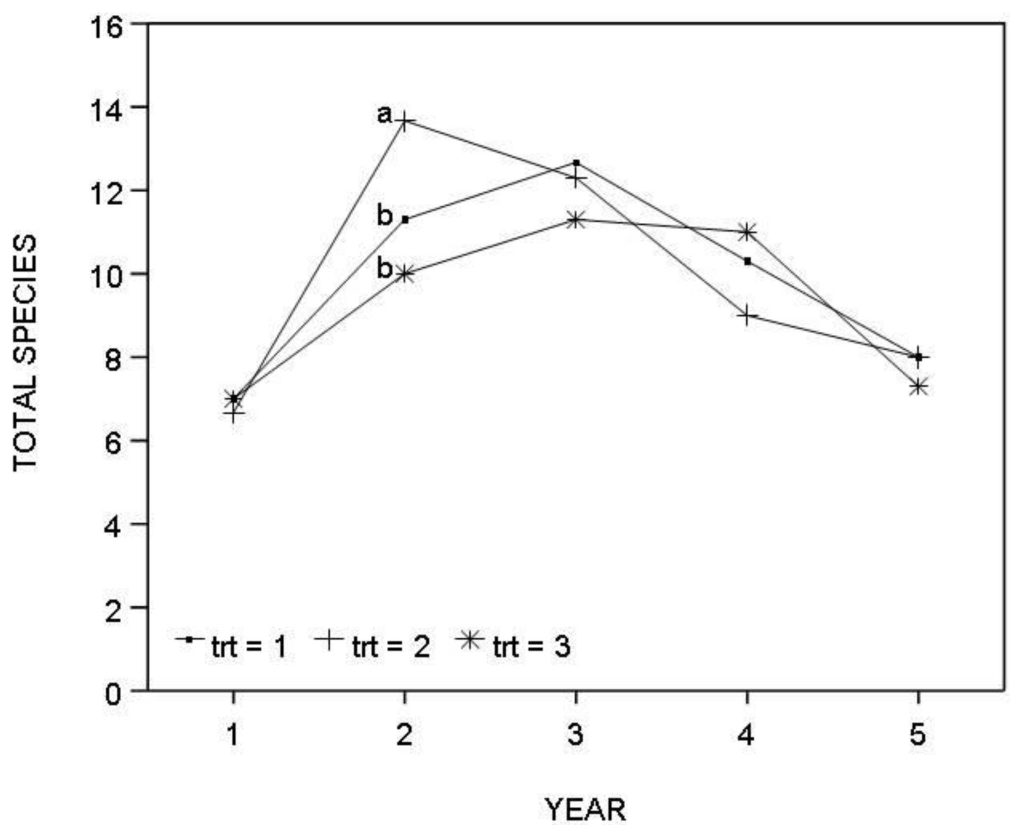

Figure 1. Graphical representation of the year x treatment interaction for Total Number of Species; L.S.D. = 2.23.

Table 3. Total number of plant species encountered during cover sampling within each treatment on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Year	Type	Treatment	Total # Based on Cover Sampling
2000	Reclaimed Area	15 cm topsoil	20
		30 cm topsoil	21
		56 cm topsoil	15
2001	Reclaimed Area	15 cm topsoil	20
		30 cm topsoil	21
		56 cm topsoil	15
2002	Reclaimed Area	15 cm topsoil	18
		30 cm topsoil	21
		56 cm topsoil	16
2003	Reclaimed Area	15 cm topsoil	15
		30 cm topsoil	14
		56 cm topsoil	14
2004	Reclaimed Area	15 cm topsoil	19
		30 cm topsoil	15
		56 cm topsoil	13

[1] Includes both sampled and observed species. No measure of statistical significance was conducted.

Species Composition

Perennial cool-season grass species such as thickspike wheatgrass, western wheatgrass and slender wheatgrass tended to increase with time in the reclaimed sites (Table 4), while annual forbs such as Mexican-fireweed (*Kochia scoparia* (L.) Schrad.) decreased. In 2002, drought resulted in reduced cover of most species, likely a result of cumulative drought stress from five years of reduced precipitation. Seeded perennial forbs (PF) such as cicer milkvetch and Rocky Mountain penstemon (*Penstemon strictus* Benth.), were generally present in the 15 and 30 cm topsoil replacement depths. Volunteer forbs such as tufted milkvetch (*Astragalus spatulatus* Sheld.), silverleaf phacelia (*Phaselia hastata* Dougl. Ex Lehm.) and American peavetch (*Vicia americana* Muhl. ex Willd) were present in the 15 and 30 cm topsoil replacement depths. The presence of annual forb (AF) and annual grass (AG) species was generally reduced from 2000-2004 compared to historical reclaimed sampling of similar aged sites at NARM (NARM, various dates) and was generally uniform, in presence, over the three topsoil replacement treatments.

Table 4. Comparison of individual species percent absolute cover at the NARM reclamation study sites in northeastern Wyoming.

		2000			2001			2002			2003			2004		
Scientific Name	**Common Name**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**
Cool Season Perennial Grasses																
Elymus lanceolatus (Scribn. & Sm.) Gould	Thickspike wheatgrass	2.89	6.22	10.4	5.78	6.22	10.4	8.67	8.22	11.1	18.9	20.9	18.9	11.1	12.0	13.3
Elymus elongatus (Host) Runem. var. *ponticus* (Podp.) Dorn	Tall wheatgrass							0.22								
Pseudoroegneria spicata (Pursh) A. Love spp. *inermis* (Scribn. & J.G. Sm.) A. Love	Beardless wheatgrass								0.45							
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould var. *riparius* (Scribn. & J.G. Sm.) Dorn	Riparian wheatgrass							7.56	9.11	6.44	3.56	4.22	6.44	1.55	1.78	1.33
Elymus smithii (Rydb.) Gould	Western wheatgrass	4.89	7.33	8.00	4.89	7.33	8.00	5.33	4.67	3.11	5.78	7.56	5.41	8.00	13.3	8.67
Elymus spicatus (Pursh) Gould	Bluebunch wheatgrass		0.22			0.22		0.67	0.44	0.22			0.44	4.22	7.56	5.33
Elymus trachycaulus (Link) Gould ex Shinners	Slender wheatgrass	4.49	7.55	10.4	8.89	7.55	10.4	3.11	4.44	4.89	1.33	1.56	0.67		0.44	0.22
Hordeum jubatum L.	Foxtail barley		0.22			0.22										
*Koeleria macrantha (*Ledeb.) Schultes	Prairie junegrass												0.22			
Oryzopsis hymenoides (R.&S.) Ricker ex Piper	Indian ricegrass		0.44	0.22		0.44	0.22									
Poa canbyi (Scribn.) Piper	Canby bluegrass								0.22	0.44						
Poa secunda Presl	Sandberg bluegrass							1.78	0.45	0.45	2.00	0.67	1.78	1.11	0.89	1.11
Stipa comata Trin. & Rupr.	Needle and thread	0.22		0.22	0.22		0.22				0.67				0.22	0.22
Stipa viridula Trin.	Green needlegrass	0.22	1.34	0.45	0.22	1.11	0.45	0.89	2.00	1.56	3.33	3.33	2.00	2.22	3.56	2.00
Total Cool Season Grasses		12.7	23.3	29.7	20.0	23.1	29.7	28.2	30.0	28.2	35.6	38.2	35.9	28.2	39.8	32.2
Warm Season Grasses																
Calamolvilfa longifolia (Hook.) Scribn.	Prairie sandreed											0.22				
Total Warm Season Grasses												0.22				

Table 4. Comparison of individual species percent absolute cover at the NARM reclamation study sites in northeastern Wyoming. (cont.)

		2000			2001			2002			2003			2004		
Scientific Name	**Common Name**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**
Introduced Perennial Grasses																
Agropyron cristatum (L.) Gaertn.															0.22	
Bromus inermis Leyss.														0.44		
Total Introduced Perennial Grasses														0.44	0.22	
Annual Grasses																
Bromus japonicus Thunb. ex Murray	Japanese brome	0.22		0.45	0.22		0.45	0.22	0.22	2.00	1.11	1.55	0.67		0.22	0.89
Bromus tectorum L.	Cheatgrass			0.45			0.45	0.22	0.44	1.33	1.55	0.44	2.67	0.44	0.22	0.22
Hordeum vulgare L.	Common Barley	1.33	0.67	2.89	1.33	0.67	2.89									
Total Annual Grasses		1.55	0.67	3.79	1.55	0.67	3.79	0.44	0.66	3.33	2.66	1.99	3.34	0.44	0.44	1.11
Perennial Forbs																
Ambrosia psilostachya DC.	Cuman ragweed		0.22			0.22										
Ambrosia tomentosa Nutt.	Skeletonleaf ragweed								0.22							
Astragalus biculcatus (Hook.) Gray	Two-grooved milkvetch										0.44			0.44		
Astragalus cicer L	Cicer milkvetch	1.11	2.00		1.11	2.00		0.89	0.45		0.44	0.22				
Astragalus spatulatus Sheld.	Tufted milkvetch	0.22			0.22											
Cirsium arvense (L.) Scop.	Canada thistle	0.22			0.22											
Grindelia squarrosa (Pursh) Dunal	Curlytop gumweed		0.67			0.67		0.45	0.45	0.22						
Medicago sativa L.	Alfalfa	1.11	1.33		1.11	1.33			1.11		0.22					
Penstemon strictus Benth.	Rocky Mountain penstemon		0.22	0.22		0.22	0.22	0.22								
Phaselia hastata Dougl. Ex Lehm.	Silverleaf phacelia	0.22			0.22											
Tragopogon dubius Scop.	Yellow salsify	0.45	0.67		0.45	0.67			0.22							
Vicia americana Muhl. ex Willd	American peavetch	0.22	0.44		0.22	0.44		0.67	0.45	0.22		0.22				
Total Perennial Forbs		3.55	5.55	0.22	3.55	5.33	0.22	2.23	2.90	0.44	1.06	0.44		0.44		

Table 4. Comparison of individual species percent absolute cover at the NARM reclamation study sites in northeastern Wyoming. (cont.)

		2000			**2001**			**2002**			**2003**			**2004**		
Scientific Name	**Common Name**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**	**15cm**	**30cm**	**56cm**
Annual Forbs																
Alyssum alyssoides (L.) L.	Pale madwort	0.22	0.44		0.22	0.44					0.22	0.89		0.22		
Camelina microcarpa Andrz. ex DC.	Littlepod falseflax	0.22	0.22	0.22	0.22	0.22	0.22		0.22	0.22	0.22					
Kochia scoparia (L.) Schrad.	Mexican-fireweed	13.1	9.55	21.3	13.1	9.55	21.3	0.67	1.56	2.89	0.22		3.11			1.11
Lactuca serriola L.	Prickly lettuce	0.89	2.66	0.89	1.33	2.66	0.89	0.22	0.22	0.67						
Melilotus officinalis (L.) Pallas	Yellow sweetclover							0.89	0.67	0.67	0.67	0.22				
Polygonum aviculare L.	Prostrate knotweed	0.67	0.89	1.11	0.67	0.89	1.11			0.22						
Salsola australis R. Br.	Prickly Russian thistle	1.78	0.89	0.22	1.78	1.33	0.22							0.22	0.89	0.89
Total Annual Forbs																
Sub or Half Shrubs																
Krascheninnikovia lanata (Pursh) Meeuse & Smit	Winterfat													0.22		
Total Half Shrubs														0.22		
Full Shrubs																
Artemisia tridentata Nutt. var. *wyomingensis* (Beetle & Young)	Wyoming big sagebrush							0.22					0.67	0.22		
Total Full Shrubs							0.22					0.67	0.22		

Note: The above plants are listed in alphabetical order in lifeform groups of CSPG, AG, PF, AF and FS, respectively. Canby bluegrass and Sandberg bluegrass are combined in Dorn (1992) but separated for purposes of collection and presentation because both are commercially available seed.

Shrub Density

Higher shrub (both full and sub) densities were noted in the more shallow replacement depths. During 2002-2004 sampling, the highest number of shrubs (both full and half combined) was found in the 15 cm treatment at 42.6 shrubs/m^2, while the 30 and 56 cm treatments were 28.1 and 19.8 shrubs/m^2, respectively (Table 5). Several seedlings, i.e., plants less than 2 cm in height, were noted in 2002 and appeared to have recently germinated. Seedlings primarily consisted of the full shrub Wyoming big sagebrush (*Artemisia tridentata* Nutt.), but also included half-shrubs such as winterfat (*Krascheninnikovia lanata* (Pursh) Meeuse & Smit), Gardner saltbush (*Atriplex gardneri* (Moq.) Dietr.), and broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby). During 2004 sampling, individuals of big sagebrush averaged 6.66 cm in height. The open canopy available in the more shallow topsoil replacement areas accounted for germination and growth of shrubs at least three years after seeding (Owens and Norton, 1989; Williams et al., 2002).

Table 5. Shrub density summary for reclaimed area treatments on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Year	Type	Treatment	Shrubs # Per 30 m^2 Belt Transect		
			Sub	Full	Total
2002	Reclaimed Area	15 cm topsoil	1.67	38.0	39.7
		30 cm topsoil	1.00	20.0	21.0
		56 cm topsoil	1.33	7.33	8.66
2003	Reclaimed Area	15 cm topsoil	2.33	42.0	44.3
		30 cm topsoil	4.33	26.0	30.3
		56 cm topsoil	5.00	20.3	25.3
2004	Reclaimed Area	15 cm topsoil	5.3	38.3	43.7
		30 cm topsoil	7.7	25.3	33.0
		56 cm topsoil	14.7	10.7	25.4

[1] Shrubs not present in 2000 and 2001.

Comparison of Reclaimed Treatments to Older Reclaimed Area at NARM

The oldest shrub-grassland reclaimed area at NARM, seeded with the mixture outlined in Table 1, was seeded in 1991; replacement topsoil depth in this area was 56 cm, but source of the replacement topsoil was direct-hauled not stockpiled as in the current study. This area was monitored by NARM for vegetative cover in 1995, 1998 and 2001 with production measured in 1996, 1999 and 2002 (NARM, various dates). AF and AG comprised 50% absolute cover in 1995, which dropped off to zero by 2001, while both lifeform categories in the current study experienced a rapid decrease in cover from 2000-2002. Cool season perennial grass (CSPG) absolute cover increased in the older reclaimed area from 1995-2001 from 14 to 43%. Perennial forb (PF) absolute cover peaked in 1998 at 20% and dropped off in 2001 to 6%. Warm-season perennial grass (WSPG) absolute cover increased from 1% in 1995 to 8% in 2001. Full shrub (FS) and half-shrub (HS) absolute cover was 1 and 0%, respectively, in 1995 and 4 and 2%, respectively, in 2001. Shrub density in the older reclaimed area peaked in 1995 at 3.9 shrubs/m^2 and decreased by 2001 to 1.6/m^2.

Climatic Influences

Climatic conditions were drought-like during the study period (1998-2004), based on mine records. The drought likely played a significant role in the resulting plant community, but could have had both a positive and negative impact, i.e., positive in the sense of somewhat depressed cool-season grass growth but negative in that overall growth was also affected. The 2004 growing season was particularly affected by the timing and lack of precipitation. Critical spring moisture was not present or severely limited in 2004 (Table 6).

Weather plays a key role in resulting plant communities (Frarck et al., 1992) and lack of WSPG may have resulted from timing of precipitation, especially during a drought period. Since much of the moisture in the Powder River Basin typically comes during April-June, which is optimum for the growth of CSPG, lack of well-timed summer precipitation limits the growth of WSPG species in favor of CSPG, resulting in reclaimed areas dominated by the latter grasses. Precipitation that results from summer thunderstorms in July and August are not generally plant available, based on high intensity storms and runoff. Cover of HS and FS in native areas is generally higher than the reclaimed area. Both the lack of WSPG and desirable HS and FS are a longterm reclamation challenge in this portion of Wyoming.

Table 6. Precipitation amounts (mm) recorded at the North Antelope/Rochelle Mine weather station.

Month	Year						
	1998	1999	2000	2001	2002	2003	2004
January	4.06	0.00	6.60	11.94	0.00	5.59	0.76
February	10.16	0.00	6.10	13.21	0.51	8.38	7.87
March	34.29	13.97	9.40	2.03	1.02	19.56	4.83
April	21.84	44.20	71.63	52.07	30.99	41.91	13.72
May	55.12	27.43	57.40	9.91	50.29	24.64	40.39
June	71.88	117.60	26.42	44.96	16.51	89.41	10.92
July	43.69	34.54	40.13	72.90	20.83	17.27	50.80
August	7.87	15.24	10.16	24.13	72.14	9.14	8.13
September	0.00	42.67	18.80	14.99	29.46	14.99	21.84
October	0.76	2.79	30.99	18.80	9.40	10.92	25.15
November	0.00	2.03	3.56	6.35	7.62	4.32	5.59
December	0.00	1.52	2.03	3.30	3.56	5.08	0.51
Total	249.68	302.01	283.21	274.57	242.32	251.21	190.50

Conclusions

Higher total vegetation canopy cover was achieved at the deeper topsoil replacement depths, but the deeper depths tended to suppress plant diversity including shrubs. Species richness (e.g., average number of species per cover transect) trended higher in the 30 cm reclaimed treatment than the 15 and 56 cm topsoil treatments with the exception of 2003. The highest total number of species encountered based on canopy cover sampling was in the 30 cm reclaimed treatment, many of which were desirable seeded and volunteer PG and PF. Species richness included AF and AG, but these species were reduced in number and abundance due to drought conditions during the study time period. Alternatively, total vegetation cover on the 56 cm reclaimed treatment was greater than the 15 cm treatment, while the 30 cm treatment was intermediate and not significantly different from either. In 2004, more Wyoming big sagebrush seedlings were noted in the 15 cm reclaimed treatment than the 30 or 56 cm reclaimed topsoil depth treatments due to more bare ground in the shallow topsoil treatment. Comparison of the current study area to a 1991 reclaimed area indicated a consistent general pattern of species establishment.

Prior research has found that thicker topsoil replacement depths generally resulted in higher cover or productivity (Power et al., 1976; Schuman et al., 1985; Redente et al., 1997; Bowen et al., 2002). Biondini et al. (1985) and Redente and Hargis (1985) found that forbs and shrubs performed best on 15 cm of topsoil; total production was higher with deeper topsoil depths. Although the current reclaimed area was only five years old, initial results indicated a general trend of higher cover values on the deeper reclaimed treatment depth, while average number of species was greater on the more shallow reclaimed treatments. Shrub establishment was generally higher on the more shallow treatments. Limited statistically significant differences in reclaimed treatment within this study may be attributable to the young age of the reclaimed area (Redente et al., 1997; Bowen et al., 2002), and it would be expected that over time, shallow reclaimed treatment areas would exhibit more diversity.

In summary, a mosaic of different topsoil depths, including the shallow 15 and 30 cm depths and the mandated 56 cm depth, creates the broadest range of vegetation response under a standard regime of revegetation practices. Every effort should be made to provide opportunity for diversification within a reclaimed plant community, as well as between communities and on a landscape scale. Without flexibility in topsoil replacement depths, seedbed preparation and seeding innovation, aggressive CSPG tend to dominate the landscape and will not encourage diversification of lifeforms. Historical, standard seeding techniques have given way to multiple seeding dates of CSPG vs. shrubs and WSPG, broadcasting of shrubs and warm-season grasses, seeding mosaics, and reduced grass rates in the seed mixtures. The capacity to replace different thickness of topsoil should be a reclamation practice available to mine operators.

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