REVEGETATING TOPSOIL, SCORIA, AND SPOIL IN MONTANA[1]

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Abstract. A mining stipulation required a southeast Montana coal mine to compare plant performance throughout one decade where suitable coversoil (suitable spoil + surface substrate) was 1.2 meters (four feet) vs. 2.4 meters (eight feet) thick over sodic spoil. Execution did not faithfully implement design, leading to unexpected but useful findings that bear upon the value of biologically inert soil substitutes in revegetation. Three substrates comprised the top 4.5 dm of coversoil: stockpiled topsoil, "suitable" spoil, and scoria. Revegetation performance on these near-surface substrates and inclusion in the root zone of material adjudged "unsuitable" by regulators in Montana revealed that:

- For the first four years, topsoil treatments had far more plant cover than suitable spoil and scoria treatments, but in the dry year of 2006 (year 10), suitable spoil had the greatest plant cover and scoria had more plant cover than topsoil. By the conclusion of the study, the amount of plant cover and especially perennial cover among treatments had converged notably.
- Spoil was the least weedy substrate and particularly poor habitat for annual bromes. Topsoil consistently had the most annual bromes. Both soil substitutes, spoil and scoria, were colonized variably by sweetclover.
- Scoria was the premier species diversity substrate. After 10 years, topsoil had about the same number of species seeded and suitable spoil just a few more, whereas scoria had about 2.5 times as many species as were seeded.
- Scoria exhibited the greatest diversity and cover of forbs, potentially making it the best substrate for sage grouse habitat. Generic topsoil seeded with two seed mixes had the fewest forbs and native volunteers.
- Different seedings make shrub comparisons complicated, but while one topsoil seeding had the greatest shrub density in 2006 and 2007, suitable spoil had twice the shrub cover in 2007 by virtue of much bigger shrubs. Shrub density in all treatments declined sharply from the early years.
- "Unsuitably" heavy soil textures below 4.5 decimeters had no perceptible effect on plant performance. Neither did plant performance differ where SARs below 1.2 meters were in the 5-7 range vs. the mid-teens.

Additional Key Words: soil substitutes, substrate suitability, plant performance, plant cover, shrub density, species diversity.

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[1] Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30 – June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2009 pp 1015-1040
DOI: 10.21000/JASMR09011015
http://dx.doi.org/10.21000/JASMR09011015

Overview

A set of test plots at the Spring Creek Coal Mine (SCCM) in southeast Montana was used to investigate vegetational effects of sodic spoil, defined as SAR>20, at a depth of 1.2 meters (four feet) versus 2.4 m (eight feet) and to explore possible upward sodic migration, although a mechanism was not hypothesized. Test plot construction did not faithfully implement design, and the "sodic" material underlying blocks turned out to be only moderately sodic, invalidated testing the sodic hypothesis. Plant establishment and vegetational development on three substrates – topsoil, scoria, and spoil – can teach us more about coal revegetation than the initial hypothesis. All three substrates are used in mine reclamation at the SCCM and adjacent Decker Coal Mine. The plots, located in a nearly level upland, were seeded in fall 1995/spring 1996. Vegetation was monitored every two or three years for 11 years. Substrates were sampled via coring and augering in 2000 and by backhoe in 2007-08.

Data reported here came from annual monitoring (Prodgers, 1998, 1999, 2000, 2003, 2006, 2007), which are also included in Annual Mining Reports.

Design and Implementation

Experimental Design

The sample design incorporates two large blocks underlain by 1.2 meters of gray, sodic spoil, defined as SAR >20. The western block was to have 1.2 m of suitable fill above sodic material, the eastern block 2.4 m of suitable fill. Physical and chemical suitability of soils and regraded spoils are defined by the Montana Department of Environmental Quality (MDEQ, 1998a, 1998b). The term "suspect levels" indicates uncertainty, but at the same time they are enforceable standards. Suitable soil or soil substitutes must have SAR <10 for the upper lift and SAR <15 for lift two. These textural classes are not allowed for soil, soil substitutes, or regarded spoil: c, sic, si, s, and sc.

Each block was 70 by 175 m (1.23 hectares), whereas each cell was 27 x 15 m (0.04 ha). Treatments consisted of six substrate/seed mix combinations, each replicated thrice in each block for a total of 36 cells (2 blocks x 6 treatments x 3 replications) laid out in a rectangular pattern with buffers between each cell and a larger buffer between blocks (Fig. 1).

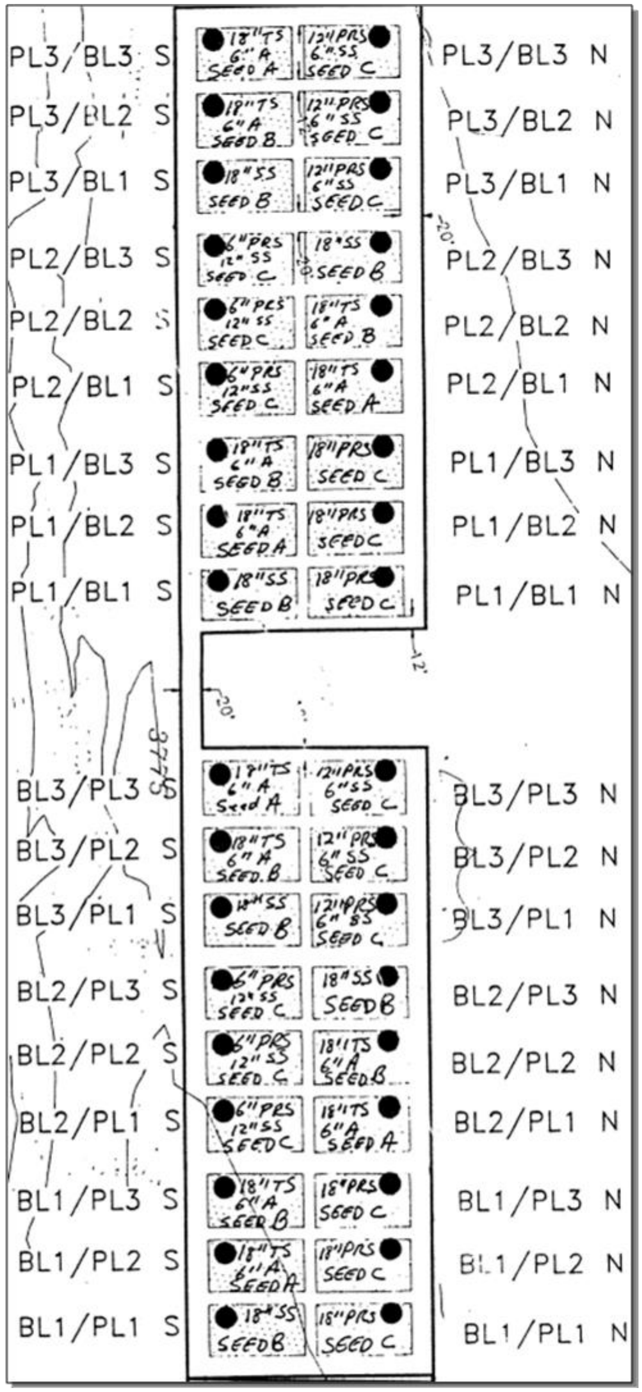

Figure 1. Plot layout at the Sodic Overburden Test Plots (SOBTP), Spring Creek Coal Mine. Upper block of 18 cells had 1.2 meters of suitable fill at the surface, lower block 2.4 meters. Cell layout within blocks is identical.

Within blocks, only the upper 4.5 decimeters (18 inches) of substrate differed. For example, within any block, a "suitable spoil" plot would have 1.2 m of suitable spoil from the surface down, whereas a plot with 4.5 dm of topsoil would have 7.6 dm (30 inches) of suitable fill below it, which in conjunction with 4.5 dm of topsoil would result in 1.2 m of total suitable material at the surface. The upper 4.5 dm was one of the following:

- Topsoil applied in two lifts. The upper 1.5 dm (6 inches), called A, originated as the upper 1.5 dm as stripped and salvaged before mining. It includes the A horizon and if present O or E horizons and possibly some upper B horizon. The lower 3.0 dm (12 inches), called B, originated as suitable salvage material below the first lift. It includes B and C horizons and all salvaged material other than the upper 1.5 dm (six inches). Topsoil was stockpiled before test plot construction. It was seeded with two mixes (Mixes 1 and 2, Appendix A), but where Mix 2 was applied, the topsoil was compacted during construction and was replaced, then reseeded in spring 1996, an undesired complication.
- The entire upper 1.2 or 2.4 m, according to block, was to be suitable material overlying sodic spoil. Surficial spoil was seeded with Mix 2, one of the seed mixes used on topsoil.
- Pit-run scoria. Three thicknesses were prescribed (1.5, 3.0, and 4.5 dm), but implemented depths varied somewhat from the prescribed thicknesses. All three depths were seeded with Mix 3, which was not applied elsewhere.

Design Implementation

Implementation deviated from design, but in the long run this study shed much light on long-held assumptions about what is "suitable" and the merits of various substrates for utility, structural diversity, species diversity, weed abundance, and the revegetation affinities of different substrates. In the 1998 monitoring report (Prodgers, 1999), I said "differences [1.2 meters] (four feet) belowground are unlikely ever to have an effect unless there is upward migration of salts." A mechanism for such upward movement was never identified, but if it was to occur, it would be difficult to detect any but the largest changes in SAR in a large field experiment built with mining equipment and spoil that varies from one spot to another in important characteristics, including sodicity.

Substrates. Test plot construction occurred over several years. Near-surface substrates (<4.5 dm) are characterized below:

- Topsoil was mostly clay loams with 25-40% clay, pH 7.7-7.9, and no sodic or salinity limitations.
- The upper 4.5 dm of suitable spoil (i.e., immediately below scoria and the upper 4.5 dm of spoil used as a soil substitute) was better than the spoil below it. It is important to recognize that this particular spoil, which will be called surficial spoil, far exceeded suitability criteria. Surficial spoil was mostly SiCL texture with about 35% clay, 5-25% rock fragments, EC<2dS/m, and SAR 0.5-6.
- Scoria texture was generally a sandy loam with 65-75% rock fragments, pH 8, and no salinity or sodic limitations.

The model was a layer cake, which is constructed by baking two thin cakes and placing one atop the other. Implementation was more like spreading one bowl of congealed batter atop the other. The thickness of material applied with trucks and dozers cannot be perfectly controlled, nor can chemical and physical uniformity within layers be assured across the application area. Implementation was further confounded by material that did not conform to specification, e.g., the sodic material was not as sodic as desired, it was not the same in both blocks, and some spoil in the upper 1.2 m (but not the upper 4.5 dm) was "unsuitable" texturally. Important deviations from the planned design follow:

- Spoil below approximately 4.5 dm differed from that above, and spoil characteristics below surficial spoil differed between blocks. In the 1.2-m block, the modal texture was a clay (which would make it "suspect," unsuitable), EC was 4-8 dS/m, and SAR was 9-15; at the high end, both conductance and SAR are borderline "unsuitable." In the 2.4-m block, the modal texture was a clay loam, EC was 3.5-8 dS/m, and SAR was 4-6. One might expect that the prevalence of clay combined with higher SARs in the 1.2-m block would impair plant performance – if indeed substrate characteristics below 4.5 dm had much effect on typical revegetation species.
- Topsoil was often closer to 6 dm thick than 4.5 dm.
- The most common textural classes occurring in "suitable spoil" in the 1.2-m block below the 4.5-dm surficial layer were clay, silty clay, and silty clay loam. The first two are unsuitable in Montana according to MDEQ (1998a). The most prevalent texture in the 2.4-dm block was clay loam followed by silty clay and clay; the latter two have been deemed unsuitable.

- Below the suitable spoil, a slightly darker colored gray spoil with a higher proportion of soft shale fragments was consistently identified. Depth to the gray spoil (the presumed sodic spoil) ranged from 1.2 to 1.5 meters in the 1.2-m block and from 2.4 to 2.6 meters in the 2.4-m block. Salinity levels were consistently within the slightly saline range. Soil pH was moderately to strongly alkaline. None of the laboratory SAR data exceeded the threshold level of SAR>20 but rather fell into the slightly to moderately sodic range. The chemistry of this material alone nullified the sodic test by virtue of acceptable SARs.
- Scoria thickness was less than stipulated in two of three treatments in the 1.2-m block, where pooled scoria thickness averaged 2.8 dm compared to 3.6 dm in the 2.4-m block. The nominal 1.5 dm layer of scoria in the 1.2-m block averaged 1.8 dm vs. 3.0 dm in the 2.4-m block. The nominal 3.0-dm layer was 2.5 dm in the 1.2-m block, 3.8 dm in the 2.4-m block. For most purposes, the nominally different scoria thicknesses can be combined as deviations from nominal depths preclude paired analysis.

<u>Seeding</u>. Seed mixes are detailed in Appendix A. Plots were initially seeded with a small Truax drill in fall 1995. Drill seeding scoria was a challenge effectively met. Only those treatments with scoria at the surface, all of which received Mix 3, never were reseeded, although two cells with 1.5 dm (nominal) pit-run scoria were damaged while reseeding other plots.

Where Mix 1 was applied, topsoil was replaced in spring 1996 due to compaction in constructing the test plots. Mix 1, called the silver sagebrush/drainage bottom seed mix, was seeded in 4/96 at a prescribed rate of 29 kgPLS/ha (26 pounds PLS/A). (The test site is a generic upland, not a “drainage bottom” as the seed mix name suggests.)

Seed Mix 2 was applied to both topsoiled and suitable spoil treatments. The combination of warm-season grasses, forbs including legumes, subshrubs, and shrubs was seeded in September 1995 and the cool-season grasses were interseeded in April 1996. What separate seedings intended to accomplish is unclear since both components germinated together. Total application rate was approximately 25 kg PLS/ha (22 pounds PLS/acre).

Mix 3 was applied at a lighter rate 11 kg PLS/ha (10 pounds PLS/acre) using fewer species than Seed Mixes 1 and 2. Big sagebrush was the species most heavily seeded, although drill seeding is far from optimal for this light-seeded shrub. About 57% of the bulk mix was inert matter mainly due to the sagebrush component.

Vegetation Sampling Methods

Canopy Coverage

Daubenmire's (1959) method of canopy-coverage estimation was applied to 1.0 x 0.5-meter frames. The frame was marked to indicate 1%, 5%, 10%, 15%, 25%, and 50% of the plot. For each species, canopy coverage was estimated to the nearest percent insofar as possible. A value of 0.5% cover was used in data analysis where the coverage of a species was less than 1%. Total plant cover as reported here is the sum of cover of the component species (stratified cover). Far more detailed species composition data were reported in annual mining reports (e.g., average canopy coverage, relative coverage, and frequency for each species).

Within the SOBTP area, each individual cell (replicate of a treatment) was sampled using a pair of transects running diagonally between corners (Fig. 2). The diagonals were 30 to 31 meters long. Sample frames were placed on both transects at meter locations 3, 9, 15, 21, and 27 for a total of 10 plots per cell.

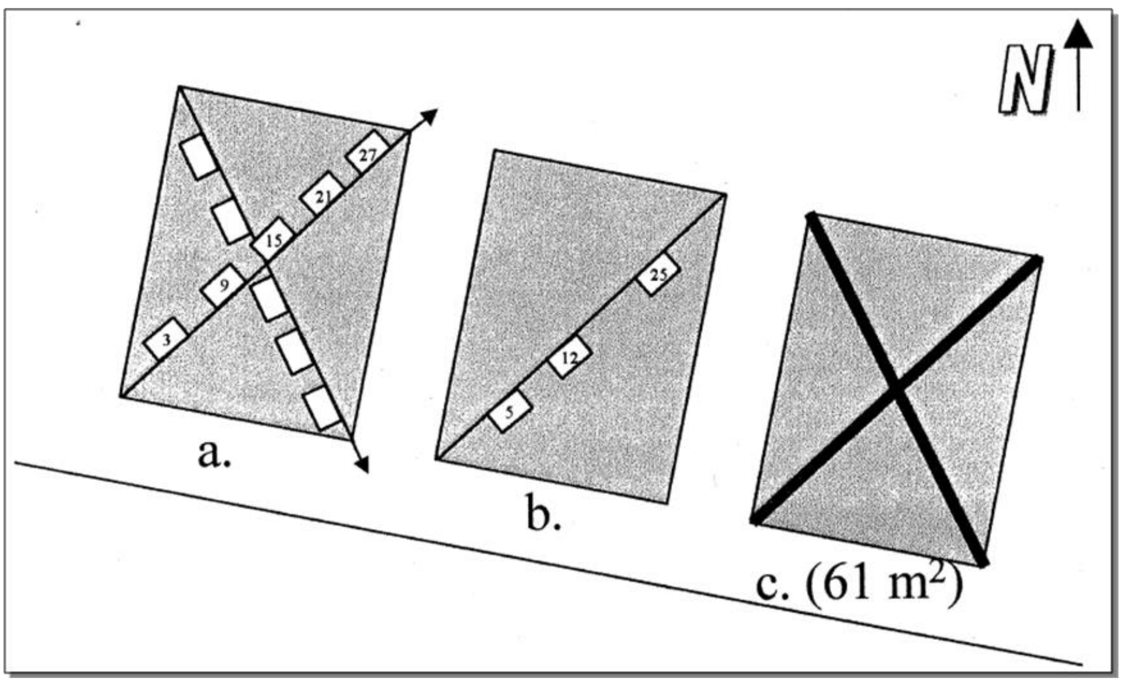

Figure 2. Vegetation sampling consisted of 10 cover frames in constant locations (a), three harvest plots on a single transect with changing locations (b), and one-meter-wide belt transects on both diagonals (c).

Peak Standing Crop

Peak standing crop is not reported here due to space limitations and because canopy coverage was sampled more intensively and quantified species composition. Different plot locations were sampled each year. Suffice to say that the productivity dynamic was more pronounced than two-dimensional canopy coverage, but the trends were the same.

Shrub Density

In rangeland, shrubs are the stuff of structural and physiognomic diversity. The diagonal transects also served as one-meter-wide belt transects, an area of approximately 62 m^2 per cell. Shrubs were counted if the main stem entered the ground within 0.5 meters of the tape. Shrubs were tallied by 25-cm height classes but were reported here by 50-cm height classes to make Table 2 less cluttered.

Diversity

Diversity derives from canopy coverage. Species diversity was expressed as species richness, species density, and evenness or equitability. Species richness is simply the number of species in samples of standard size or area, although it can be modified to ignore common weeds. Species density is the average number of species per 0.5 m^2 frame. The Shannon function ("equitability") was calculated using natural logs and relative cover data; it was applied to growth-forms as well as species. The formula follows (Pielou, 1977):

$$H = -\sum p_i \ln p_i \text{ where } p_i \text{ is the relative cover of the } i\text{th species or growth-form} \qquad (1)$$

Results

Seedling Density and Plant Establishment

Two years after seeding, perennial seedling density was good in topsoil/Mix 1, fair in suitable spoil and topsoil/Mix 2, and variable but generally unsatisfactory in scoria/Mix 3, especially 3 dm of scoria.

One year later in 1999, total stratified plant cover was in the 80-90% range in topsoiled treatments compared to about 40% in suitable spoil and 17-30% in scoria. Paired treatments had equivalent canopy coverage in the 1.2- and 2.4-m blocks with two exceptions. The 3.0 dm scoria treatment in the 2.4-m block had more cover than the 1.2-m block, and conversely the 4.5-dm scoria treatment had more plant cover in the 1.2-m block than the 2.4-m block when compared using 10% confidence intervals. But perennial cover was usefully related to perennial seedling density data the preceding year (r^2 = 0.70); cover differences were likely more related to seeding vagaries than site factors. (The relation of seedling density and plant cover would have been stronger for a single type of substrate rather than combining topsoil, scoria, and spoil.)

While topsoil treatments had equal plant cover with Seed Mixes 1 and 2, Mix 2 resulted in more weeds, but remember, topsoil/Seed Mix 1 was re-topsoiled and reseeded. Weeds comprised 44% of relative cover where Mix 2 was applied to topsoil compared to 11% where Mix 1 was seeded. How revegetation starts can have long-lasting consequences, and topsoil with Mix 2 remained weedy throughout the study, more so in wet years.

Shrub Density

Across treatments, shrub density declined sharply at first, then more slowly. Initially, the 2.4-dm block had more shrubs, but at the conclusion of the study shrub density had equilibrated at the same level (Table 1).

Eleven years after seeding, the Topsoil/Mix 1 treatment had the highest shrub density (5,870/ha from Table 2). Greasewood was the most common shrub. Shrubs can successfully establish on topsoil in conjunction with cool-season grasses, but competition takes a toll on size and vigor.

Second in density but first in shrub cover was suitable spoil with 4,370 shrubs/ha, this from the seed mix that provided just 850 shrubs/ha when applied to topsoil (Table 2) – so there is some validation for those who say that substrate matters. Fourwing saltbush was the most prevalent shrub.

Table 1. Mean Shrub Density, 1.2- and 2.4-m Blocks, SOBTP, 2003-2007.

YEAR	1.2-m BLOCK (4' BLOCK)	2.4-m BLOCK (8' BLOCK)
	----Mean Indiv. Shrubs/Ha----	
2000	9,100	18,100
2003	7,490	10,350
2006	2,580	2,670
2007	2,460	2,520

Table 2. Shrub Densities (individuals/ha) by Height Class, SOBTP, 2007.

TREATMENT Height Classes (cm)	SHRUB DENSITY (individuals/ha) <50	50-100	>100	TOTAL	<50	50-100	>100	TOTAL
	1.2-m Suitable Fill				2.4-m Suitable Fill			
4.5 dm TOPSOIL/1	2842	2132	0	**4,974**	2295	4481	0	**6,776**
4.5 dm TOPSOIL/2	382	383	0	**765**	601	328	0	**929**
SUITABLE SPOIL/2	3333	1804	655	**5,792**	482	1967	492	**2,941**
1.5 dm SCORIA/3	55	492	273	**820**	546	546	328	**1,420**
3.0 dm SCORIA/3	710	383	55	**1,148**	547	164	55	**766**
4.5 dm SCORIA/3	656	492	109	**1,257**	2013	164	109	**2,286**

Table 3. Average Forb and Shrub Cover on SOBTP Substrates, 2007.

SUBSTRATE (n samples)	PERENNIAL FORBS	SHRUBS
	---------------% canopy coverage---------------	
TOPSOIL (4)	0.1	5.7
SUITABLE SPOIL (2)	5.2	**20.2**
SCORIA (6)	**7.6**	14.0

Cover presents a different picture of shrub abundance than density (Fig. 3 and 4). Topsoil/Mix 1 had just 6% shrub canopy coverage compared to 20% in suitable spoil. Spoil tends to have big, robust shrubs, whereas shrubs are anemic on topsoil in competition with grasses and weeds, and stems are easily broken. Overall, suitable spoil was the premier shrub substrate.

The scoria treatments collectively averaged just 1,280 shrubs/ha (from Table 2) despite being seeded with 3.4 kg/ha (three pounds/acre) of big sagebrush. A more appropriate seeding technique, such as broadcasting and harrowing, likely would have yielded greater density. Despite having the lowest density, scoria shrub cover was about 14%, midway between topsoil and spoil (Table 3). Big sagebrush was denser than fourwing saltbush, but the Chenopod had far more cover.

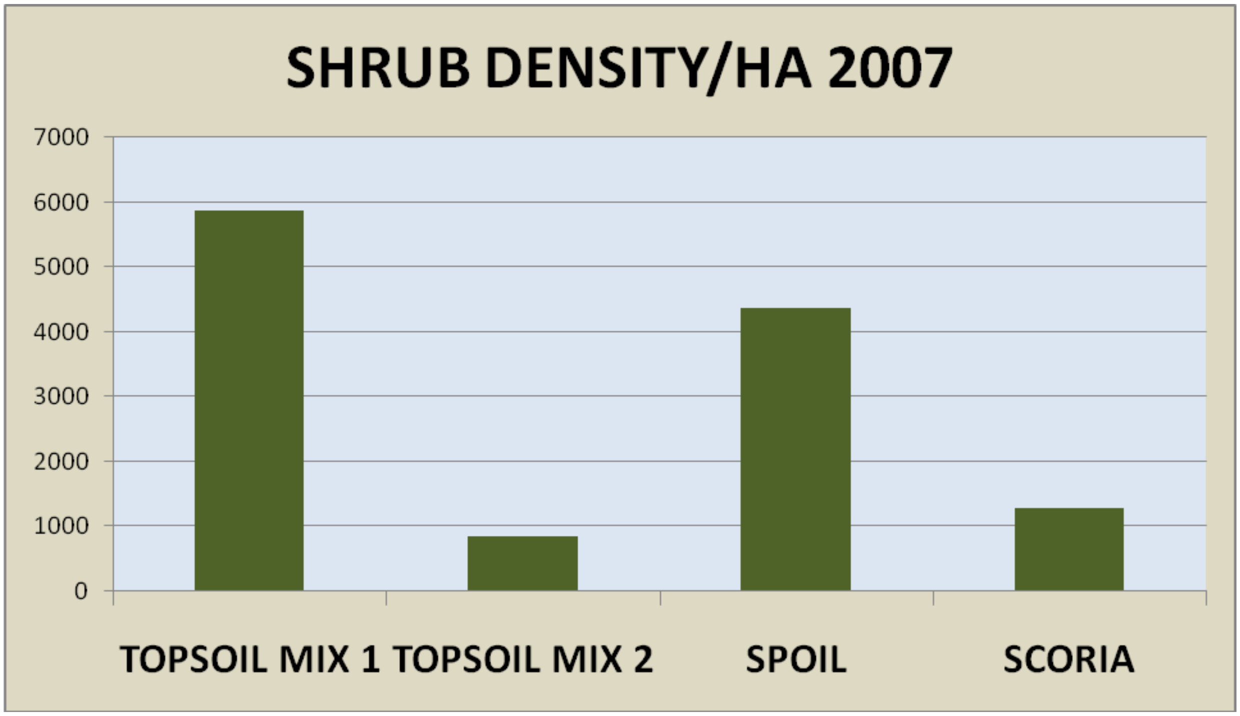

Figure 3. Shrub Densities in 2007 by Surface Substrate, Treatments Pooled.

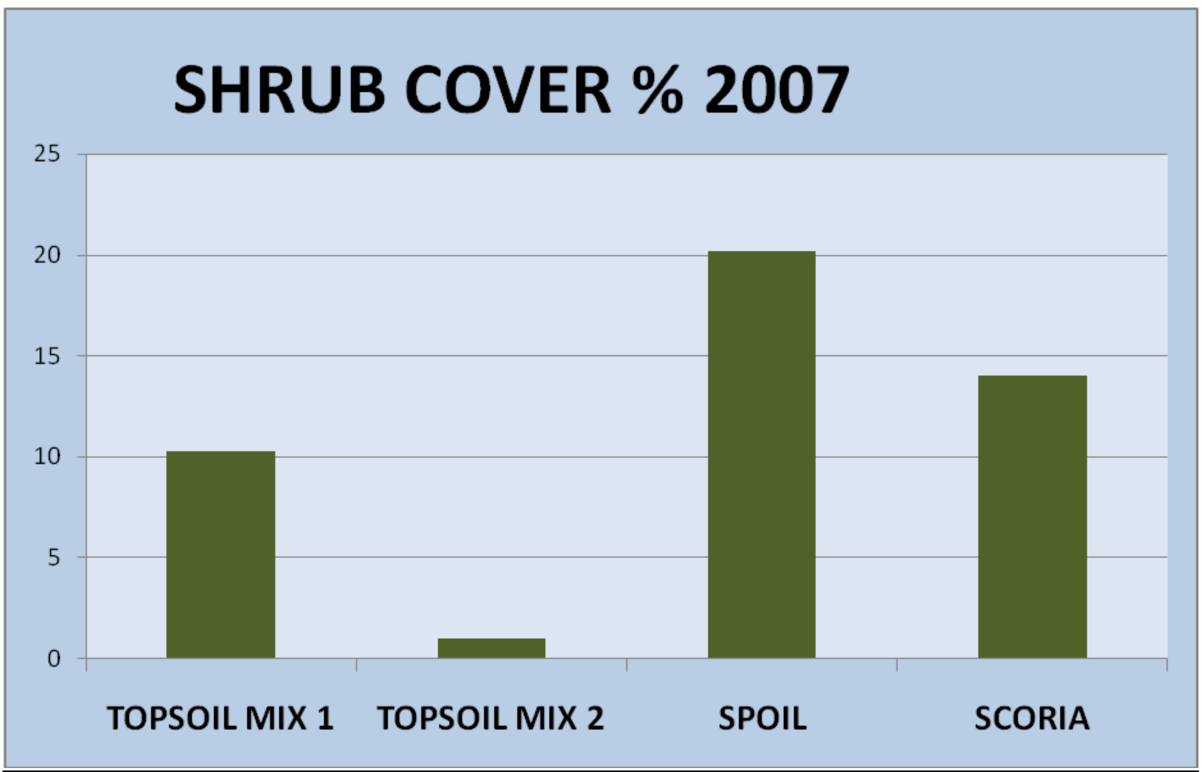

Figure 4. Shrub Canopy Coverage in 2007 by Surface Substrate, Treatments Pooled.

Shrub densities reported here are by no means the maximum attainable, just the outcome of particular treatments and environmental conditions. Undoubtedly the shrub component in spoil could be increased over the amount demonstrated here by properly seeding more appropriate shrub species. Likewise, scoria could support more shrubs if seed weight and seeding technique were matched, and the amount and size of shrubs grown in topsoil could be increased by decreasing the amount of grasses seeded and the amount of viable annual brome seed in topsoil.

Diversity

While the functional implications of species diversity are more often assumed than demonstrated and a variety of measurements and derivative calculations makes comparisons difficult, diversity along with productivity are fundamental attributes of plant communities.

Species diversity trends among treatments were established early (Table 4). Topsoil had the same perennial richness from two seed mixes, whereas one of those same mixes yielded more perennials when seeded into suitable spoil. In just three years, scoria, seeded with just one dozen species, had more perennials than other substrates seeded with 18-19 perennial species. Whereas scoria recruited native perennials rarely seen in revegetation, topsoil recruited weeds (Fig. 5).

Table 4. Mean Species Richness from Uniform Cover Sampling, 1999.

UPPER 4.5 dm COVERSOIL	SEED MIX	SPECIES SEEDED 1995-96	SPECIES RICHNESS Total	Perennials
Topsoil 1.5 dm A/ 3 dm B	1	19	19.5	10.5
Topsoil dm A/ 3 dm B	1	18	21	10.5
4.5 dm Suitable Spoil	2	18	19	14.5
Scoria All Thicknesses	3	12	23	16

Table 5 summarizes diversity at the conclusion of the study. Richness data for 2006 were included with the 2007 data to show that species diversity, as most other vegetational parameters, varies among years and precipitation regimes. Species richness in the two topsoil treatments conforms to the "what you seed is what you get" paradigm (Tables 4 and 5). Spoil, similarly seeded, shows a tendency for a little greater diversity despite being weedy, and weeds typically count just as much as desired perennials in species diversity. Scoria is the premier diversity substrate. The number of species occurring was two to almost three times the number of species seeded.

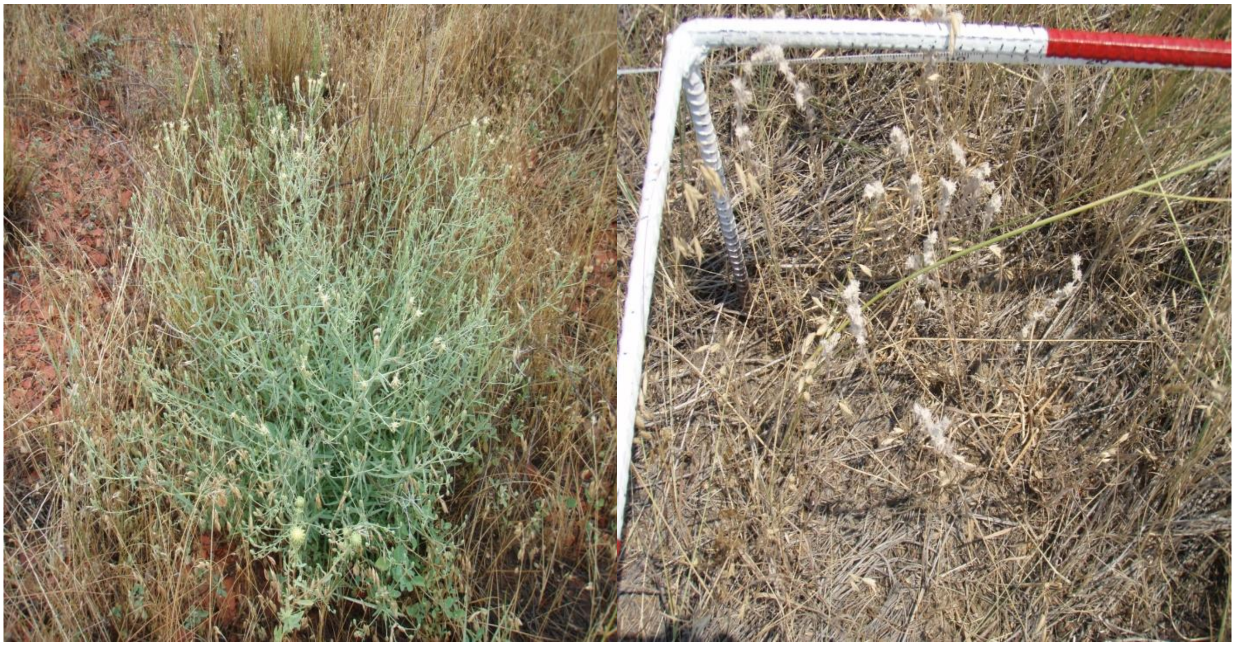

Figure 5. While scoria (left) recruited seldom-seen native perennials such as *Brickellia eupatorioides*, topsoil (right) seeded with Mix 2 recruited annuals like *Logfia arvensis*.

Applying Claude Shannon's formula to both species and growth-forms indicated that scoria housed the most equitable assemblages (Table 5). Spoil was intermediate and topsoil least equitable.

Species density was the least discriminating measure of species diversity (Table 5). It is strongly influenced by common, repeated weeds and perennials. Species density was highest in topsoil/Mix 1, which has a decent variety of perennials but also rather uniform weeds. Slightly lower were the scoria treatments, and lowest were the treatments seeded with Mix 2, both topsoil and spoil. However, spoil has far fewer weeds than topsoil, so in that respect lower species density is a boon.

The temporal dynamic in species diversity (Fig. 6) is attenuated in comparison to plant cover or productivity, but it too varies in relation to chaning environmental factors.

Table 5. Species Diversity Summary for SOBTP, 2006-07.

UPPER 4.5 dm COVERSOIL	SEED MIX	SPECIES SEEDED 1995-96	SPECIES RICHNESS 2007	2006	SPECIES DENSITY (2007)	SHANNON[1] Species (2007)	ln Grw. Fms.[2] (2007)
Topsoil 1.5 dm A/ 3.0 dm B							
1.2-meter block	1	19	18	12	6.0 +- 0.4	1.98	1.08
2.4-meter block	1	19	17	11	5.8 +- 0.4	1.85	1.08
Topsoil 1.5 dm A/3.0 dm B							
1.2-meter block	2	18	20	15	4.7 +- 0.4	1.94	1.11
2.4-meter block	2	18	17	12	4.6 +- 0.4	1.62	0.90
4.5 dm Suitable Spoil (Surficial Spoil)							
1.2-meter block	2	18	24	17	4.8 +- 0.5	2.19	1.36
2.4-meter block	2	18	16	15	4.7 +- 0.3	1.71	1.26
1.5 dm Pit-run Scoria							
1.2-meter block	3	12	29	26	5.2 +- 0.4	2.56	1.47
2.4-meter block	3	12	28	25	5.5 +- 0.5	2.10	1.42
3.0 dm Pit-run Scoria							
1.2-meter block	3	12	25	20	5.5 +- 0.4	2.31	1.30
2.4-meter block	3	12	25	26	5.6 +- 0.5	2.12	1.48
4.5 dm Pit-run Scoria							
1.2-meter block	3	12	27	28	5.9 +- 0.5	2.44	1.49
2.4-meter block	3	12	31	37	5.4 +- 0.4	2.38	1.65

[1] The Shannon function, sometimes called equitability, reveals whether dominance is concentrated in one species or growth-form or spread “equitably” among several.
[2] The six growth-forms were annual + biennial forbs, annual grasses, perennial forbs, perennial grasses, subshrubs, and shrubs.

Canopy Coverage and Species Composition

Total Canopy Coverage. Over the years, a few significant differences in plant cover emerged between paired treatments in different blocks, some favoring one block, some the other (Table 6). In 2003, the 2.4-meter block had significantly more total plant cover than the 1.2-meter block. In the other four sample years, plant cover was higher in the 1.2-m block, although statistically they were equivalent.

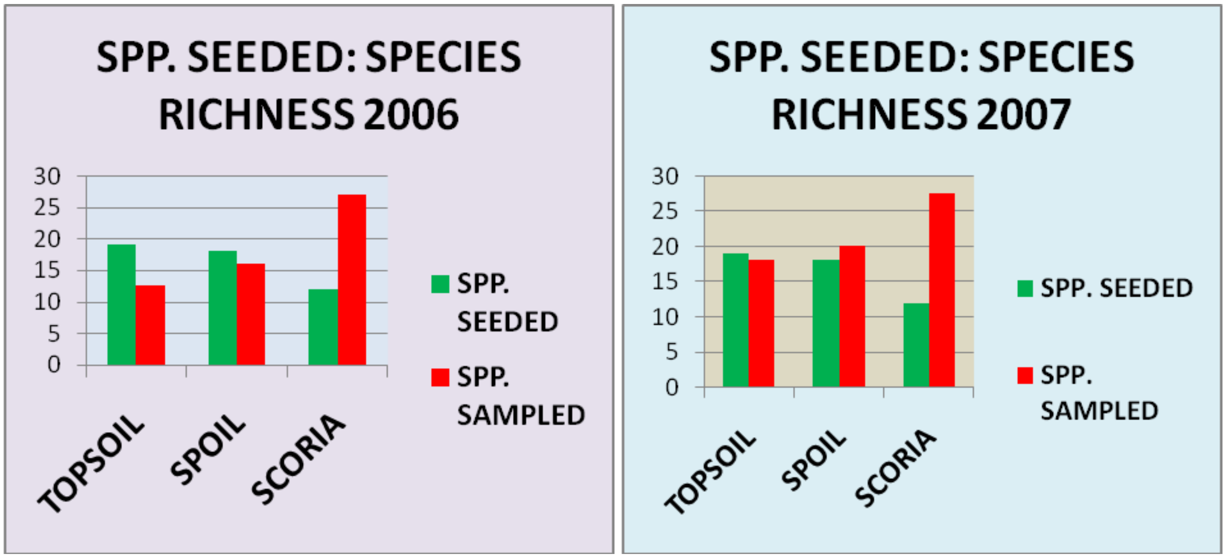

Figure 6. Temporal Species Richness Dynamic.

Perhaps the biggest surprise was that after one decade plant cover (and production) on different substrates converged (Fig. 7). Just a few years after seeding, plant cover had reached dynamic equilibrium on topsoil but continued to increase on soil substitutes until, in the very dry year of 2006, all of the soil substitutes had more plant cover than topsoil. When the study concluded in the wet year of 2007, topsoil had regained its supremacy, but spoil wasn't far behind, and plant cover in all treatments was far more similar than in the early years.

<u>Perennial Canopy Coverage</u>. More pertinent to satisfactory revegetation than total canopy coverage, perennial plant cover was consistently higher in the 1.2-m block (Table 7). Using a paired t-test on mean perennial cover in Table 7, the difference was significant at P=0.015. High variance for the 2.4-m block across treatments precluded identifying a more assuredly real difference. (The confidence intervals in Table 7, equivalent to an unpaired t-test, indicate no significant difference.)

Whereas Table 6 and Figure 7 showed that topsoil had the greatest plant cover in the wet year of 2007, Table 7 and Figure 8 reveal that this particular suitable spoil had the greatest perennial cover, and scoria was not far behind topsoil seeded with Mix 2. The lack of annuals in spoil also must be considered a major advantage in reclamation.

Table 6. Summary Comparison of Total Plant Canopy Coverage, SOBTP, 1999, 2000, 2003, 2006, and 2007. (Means and 90% Confidence Intervals.)

UPPER 4.5 dm COVERSOIL	SEED MIX	YEAR	1.2-m SUITABLE SUBSTRATE		2.4-m SUITABLE SUBSTRATE	
			---------% Canopy Coverage---------	May-June Precp. Cm		Differ p = 0.10
Topsoil 1.5 dm A/ 3.0 dm B	1	1999	84.9 +- 4.1	5.6	81.6 +- 4.6	No
		2000	68.4 +- 4.6	12.2	65.6 +- 3.9	No
		2003	74.5 +- 4.7	9.6	91.2 +- 5.4	Yes
		2006	44.7 +- 5.7	4.8	46.8 +- 4.6	No
		2007	93.2 +- 5.9	13.2	95.4 +- 5.7	No
Topsoil 1.5 dm A/3.0 dm B	2	1999	92.9 +- 6.2	5.6	85.8 +- 7.7	No
		2000	57.8 +-6.1	12.2	52.1 +- 6.0	No
		2003	93.4 +- 8.0	9.6	88.4 +- 8.5	No
		2006	41.4 +- 5.1	4.8	33.5 +- 3.8	No
		2007	96.6 +- 5.4	13.2	82.6 +- 4.4	Yes
4.5 dm Suitable Spoil	2	1999	38.9 +- 10.9	5.6	40.0 +- 6.8	No
		2000	43.1 +- 7.7	12.2	45.5 +- 6.5	No
		2003	63.4 +- 11.9	9.6	75.8 +- 11.5	No
		2006	55.4 +- 9.4	4.8	71.4 +- 8.6	No
		2007	70.9 +- 9.7	13.2	95.1 +- 9.3	Yes
1.5 dm Pit-run Scoria/ 3.0 dm Suitable Spoil	3	1999	21.8 +- 6.4	5.6	21.3 +- 5.0	No
		2000	43.7 +- 10.0	12.2	21.2 +- 4.7	Yes
		2003	56.0 +- 10.7	9.6	62.5 +- 9.8	No
		2006	55.9 +- 8.1	4.8	49.9 +- 8.6	No
		2007	67.6 +- 7.9	13.2	85.6 +- 7.4	Yes
3.0 dm Pit-run Scoria/ Suitable Spoil	3	1999	17.6 +- 3.8	5.6	29.9 +- 4.9	Yes
		2000	32.1 +- 5.9	12.2	28.6 +- 8.3	No
		2003	46.1 +- 6.9	9.6	68.3 +- 10.6	Yes
		2006	52.5 +- 8.6	4.8	46.4 +- 5.3	No
		2007	65.3 +- 7.6	13.2	76.2 +- 7.6	No

Table 6 Continued

UPPER 4.5 dm COVERSOIL	SEED MIX		1.2-m SUITABLE SUBSTRATE		2.4-m SUITABLE SUBSTRATE	
			---------% Canopy Coverage---------			Differ
				May-June Precp. Cm		p = 0.10
4.5 dm Pit-run Scoria	3	1999	27.9 +- 4.2	5.6	17.3 +- 5.0	Yes
		2000	36.7 +- 6.7	12.2	24.0 +- 6.0	Borderline
		2003	49.7 +- 5.6	9.6	66.9 +- 12.5	No
		2006	50.3 +- 6.2	4.8	45.1 +- 8.0	No
		2007	72.7 +- 6.9	13.2	69.6 +- 7.2	No
	AVERAGE	1999	47.3	5.6	46.0	No
		2000	46.9	12.2	39.5	No
		2003	63.8	9.6	75.5	Yes
		2006	50.0 +- 4.8	4.8	48.9 +- 10.2	No
		2007	68.6 +- 18.1	13.2	64.5 +- 24.3	No

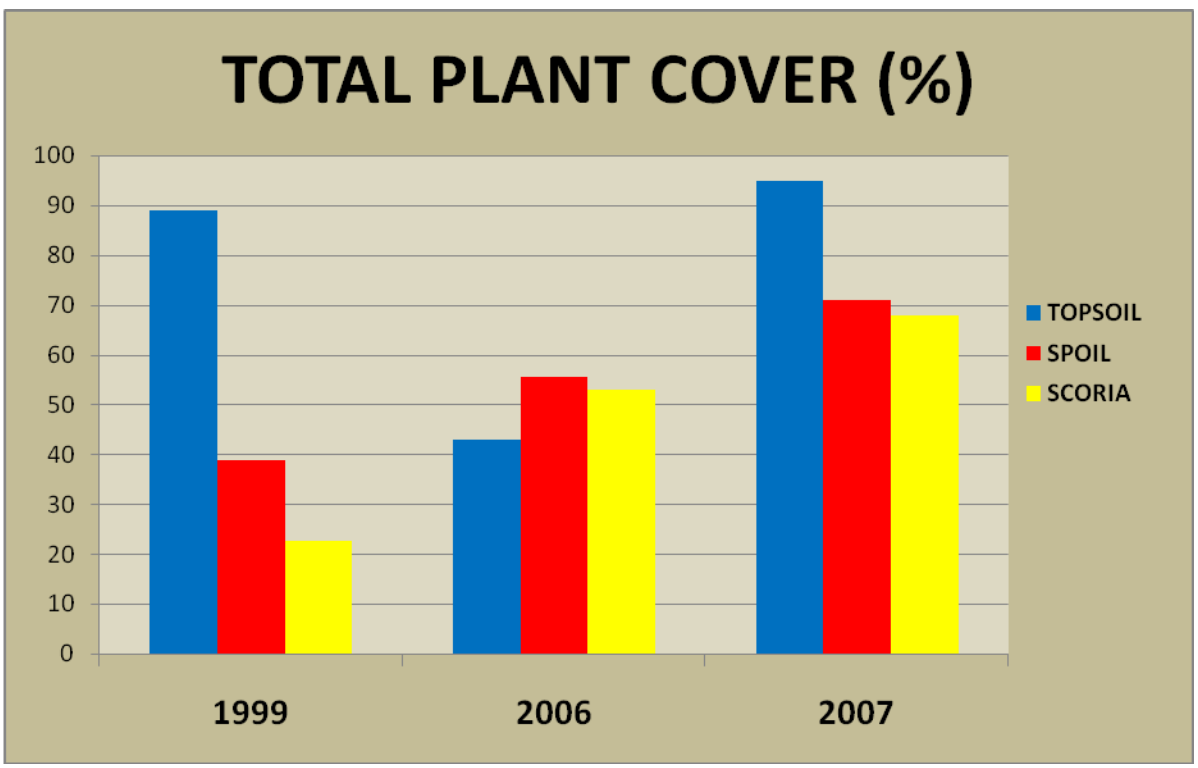

Figure 7. Temporal Dynamic of Total Plant Cover.

Sweetclover and annual bromes boosted total plant cover in the 2.4-m block. By the year 2000 if not earlier, yellow sweetclover was far more abundant on suitable spoil in the 2.4-m block. Subsequently, it spread to adjacent scoria. By the conclusion of the study, the 2.4-m block had almost three times more sweetclover than the 1.2-m block (Table 8). No explanation is evident.

The 2.4-m block also had more annual bromes in the latter years. One possibility is that years of sweetclover provided more mineral N to the spoil and scoria treatments in the 2.4-m block, sustaining more cheatgrass. In the 1.5- and 3.0-dm scoria treatments, the 2.4-m treatments had much more sweetclover and annual bromes than the 1.2-m treatments. The particular suitable spoil used in the SOBTPs was poor annual brome habitat, another factor in its favor.

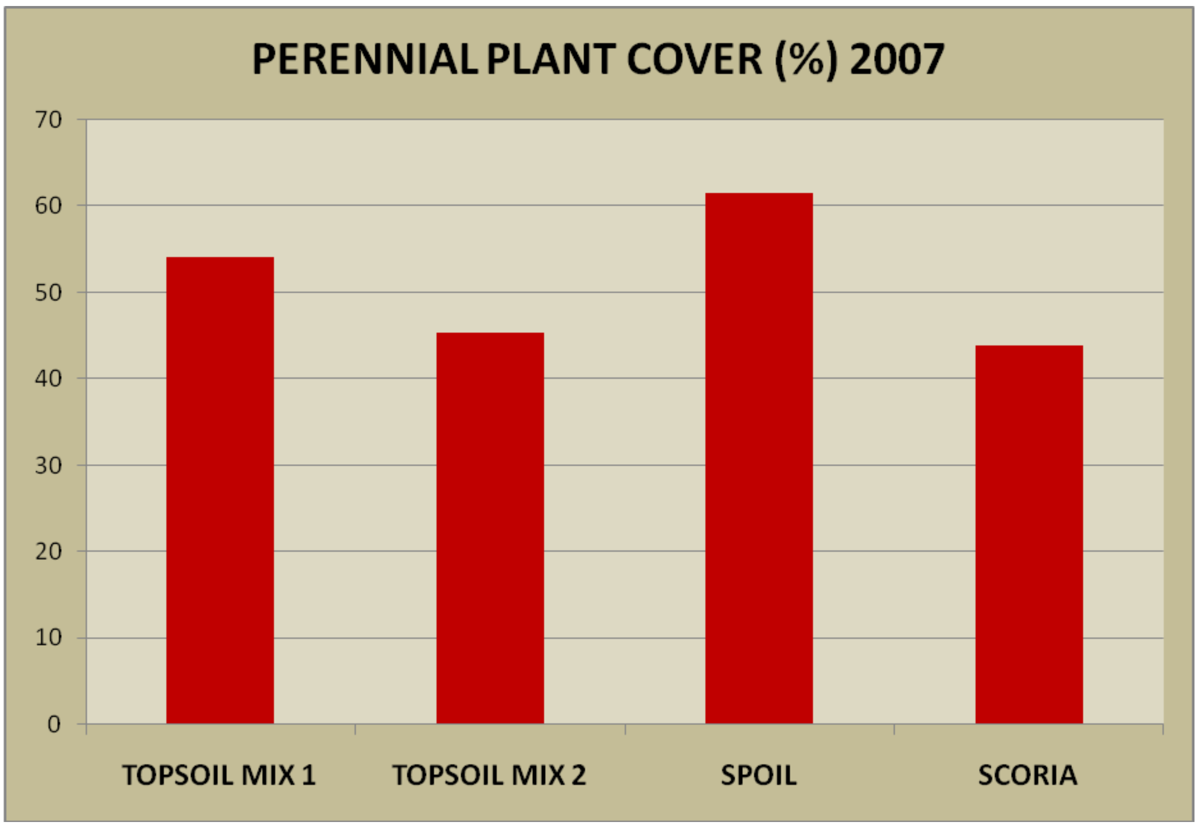

Figure 8. Perennial Plant Cover in 2007.

Table 7. Summary Comparison of Perennial Plant Canopy Coverage, SOBTP, 2007. (Means and 90% Confidence Intervals.)

UPPER 4.5-dm COVERSOIL	1.2-m SUITABLE SUBSTRATE			2.4-m SUITABLE SUBSTRATE			
	% Canopy Coverage						
	Perennial	Sweet-clover	Ann. Bromes	Perennial	Sweet-clover	Ann. Bromes	Differ p = 0.10
Topsoil 1.5 dmA/ 3.0 dm B Seed Mix 1	62.7	--	23.7	45.8	--	47.0	YES
Topsoil 1.5 dmA/3.0 dm B Seed Mix 2	49.4	0.3	32.4	41.4	0.8	35.8	NO
4.5 dm Suitable Spoil/Mix 2	63.0	2.2	6.9	60.1	30.5	3.8	NO
1.5 dm Scoria/ 3.0 dm S. Spoil	43.5	14.5	5.6	40.3	30.4	13.1	NO
3.0 dm Scoria/ 1.5 dm S. Spoil	52.9	4.7	6.5	32.8	26.2	16.6	YES
4.5 dm Scoria	52.2	13.0	6.5	38.8	13.6	14.7	NO
AVERAGE	54.0 +- 5.8	5.8	13.6	43.2 +- 7.5	16.9	21.8	NO

Table 8. Mean Canopy Coverage of Select Growth-Forms in 2007.

	1.2-m BLOCK	2.4-m BLOCK
	% Canopy Coverage	
Perennial Cover	54.3 +- 5.8	43.5 +- 7.5
Sweetclover	5.8	16.9
Annual Bromes	13.6	21.8

With an average of 10% more perennial plant cover in the 1.2-m block and significantly more perennial cover in two of six treatments (Table 7), the 1.2-m block in my opinion has more satisfactory revegetation than the 2.4-m block. Certainly there is no basis to conclude that 2.4-m covers function better. One might also conclude that:

- SARs in the low to mid-teens at a depth >4.5 dm in the 1.2-m block did not negatively affect plant growth when compared to SARs half as high in the 2.4-m block.
- A prevalence of clay and silty clay textures below 4.5 dm in the 1.2-m block likewise did not prevent satisfactory revegetation 10 years following seeding. Textures were somewhat lighter in the 2.4-m block.
- The upper 4.5 dm of rooting media had far greater influence on vegetation than deeper strata. In Superfund remediation at Butte, Montana, 4.5-dm coversoils over genuinely phytotoxic mine waste have been satisfactorily if not diversely vegetated after more than one decade.
- Repeated sweetclover crops in the non-topsoiled treatments in the 2.4-m block were associated with more cheatgrass, not more perennial plant cover.
- Extreme coarseness of substrate was limiting in the short run but not in the long run. Texture of the nominal 1.5-dm-scoria replicate (actual thickness 2.8 dm) in the 1.2-m block was an extremely channery sand with 2.5% clay, which violates Montana's "suspect level" (MDEQ, 1998b). Conventional wisdom would predict severe vegetational impairment from such a coarse substrate, and initially all scoria treatments had low seedling density and plant cover. When compared after 10 and 11 years to the nominal 3.0-dm-scoria treatment (actually 2.5 dm), same block, an extremely channery sandy loam with 11% clay, total plant cover was similar (Table 6). Perennial cover was higher in the sandy loam, however (Table 8). From visual observations, cobble-size chunks of scoria had fewer plants than finer scoria.

<u>Species Composition</u>. The issues of growing forbs and sagebrush to create sage grouse habitat, overlooking the paucity of sage grouse and abundance of designated crucial habitat in the vicinity, have recently been promoted at the mine. The sodic overburden test plots can shed some light insofar as the three substrates have different suitabilities for forbs and shrubs. Insipid

blue flax can always be grown on topsoil, but other substrates have an affinity for both more abundant forbs (Table 3) and greater diversity (Table 5 and Fig. 6).

Topsoil/Seed Mix 1. The most abundant of seeded species initially was green needlegrass followed distantly by thickspike and western wheatgrass. The most abundant shrub was black greasewood. At the conclusion of the study, the most important grasses were field brome, thickspike wheatgrass, and western wheatgrass. The main shrub remained greasewood, but winterfat and fourwing saltbush also were important. Hard fescue, considered a native taxon when seeded, increased from 1% actual cover in 2000 to 15% canopy coverage in 2007 – it qualifies as an invasive species as it also spread to scoria where it wasn't seeded. Legumes were minor to absent from both topsoil treatments (Fig. 9).

Figure 9. Topsoil treatments were initially more productive but remained weedy, especially topsoil seeded with Mix 2 (right).

Topsoil/Seed Mix 2. Green needlegrass and western wheatgrass initially were most abundant, but field brome and kochia were already well represented in 2000. Six to seven years later, western wheatgrass was the most abundant perennial and annual bromes remained common. In one 2.4-m replicate, field brome was more abundant than all perennial grasses combined. Annual forbs, mainly tumblemustards, were common throughout the study and comprised 10% of relative cover 11 years after seeding.

Suitable Spoil/Mix 2. Where Seed Mix 2 was applied to topsoil, the average relative cover of annual bromes was 29%. On suitable spoil, it was 3%. (See Fig. 10, right.) This alone speaks well of the particular suitable spoil used in this study as a soil substitute. The species of highest cover were fourwing saltbush and yellow sweetclover while western and thickspike wheatgrass were the main grasses. Warm-season grasses fared better than on other substrates too. Unseeded prairie milkvetch (*Astragalus adsurgens*) comprised 7.6% of relative cover in the 1.2-m block but only 0.4% in the 2.4-m block where sweetclover was prevalent.

Figure 10. Suitable spoil had fewer shrubs than topsoil/Seed Mix 1 but much larger shrubs. A major advantage of this particular suitable spoil (shown abutting generic revegetation on right) is that it is poor cheatgrass/field brome habitat.

Scoria/Mix 3. With the six replicates pooled, the best-represented species were fourwing saltbush, western wheatgrass, thickspike wheatgrass, yellow sweetclover, bluebunch wheatgrass, white locoweed (*Oxytropis sericea*), and field brome. Several warm-season grasses were present, although not particularly abundant. While thickspike wheatgrass is the obvious first choice for a sandy loam or even loamy sand and it established most strongly, western wheatgrass was more prevalent after one decade. We have seen this on permanent scoria revegetation at the mine. The average relative cover of white locoweed was 5.1%, that of prairie milkvetch 1.5%. (See Fig. 11 showing the two main native legumes.) The list of volunteer forbs included: *Aster falcatus, Chaenactis douglasii, Crepis* sp., *Cryptantha celosioides, Dalea purpurea, Eriogonum* *flavum, Grindelia squarrosa, Hedeoma hispidus, Heterotheca villosa, Ipomopsis congesta, Lesquerella alpina, Machaeranthera canescens or M. tanacetifolia, Phacelia hastata, Sphaeralcea coccinea, Stephanomeria runcinata,* and the two legumes previously quantified.

Figure 11. *Astragalus adsurgens*, left, volunteered on both spoil and scoria; this specimen was cropped by deer or antelope. *Oxytropis sericea*, right, was an important native legume on scoria but rarely seen on spoil.

Conclusion

The upper 4.5 dm of substrate is all-important. Below that depth, excessively heavy "suspect" subsoil textures were not necessarily impairing to revegetation. Neither were SARs of 5 vs. 13 influential. Extremely coarse surficial substrates of suitable particle size began slowly but finished their first decade well vegetated with seeded species and volunteers.

Topsoil initially had more plant cover than soil substitutes, but after one decade plant abundance among substrates converged and surficial spoil had more perennial cover than topsoil in both 2006 and 2007. Surficial spoil was the premier shrub substrate and the least weedy. Scoria provided the most diverse plant assemblage despite being seeded with one-third fewer species. Few could have predicted how well the soil substitutes would work in the long term as plant growth media. Abundant sweetclover seems to benefit annual bromes more than desired perennial species.

I raised the following concern in the 1998 monitoring report: "The issue of how plant nutritional needs, especially for nitrogen, can be achieved in coversoils lacking organic matter and a healthy soil foodweb or nitrogen fixation is bound to be a central topic in subsequent evaluations." It wasn't. Spoil comprising a primary succession scenario rivaled topsoil in plant abundance after one decade. The scoria treatments were initially limited by poor seeding and enduringly by coarse texture, but in the final (wet) year of study, average stratified plant cover on scoria was 73%. Especially in the early years, scoria had less plant cover than other substrates, but it excelled in recruiting volunteer species. The two are interrelated.

While we didn't analyze soil microbiology, it is interesting that two of the main native volunteers on spoil and scoria were legumes and presumably nitrogen-fixers in conjunction with appropriate *Rhizobium* sp. The introduced legume volunteer and nitrogen-fixer, sweetclover, was far more abundant on soil substitutes than topsoil.

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Appendix A Seed Mixes

Mix 1: Silver Sagebrush/Drainage Bottom Seed Mix

	Kg PLS/ha	Pounds PLS/A
Native western wheatgrass	4.6	4
Sodar streambank wheatgrass	3.4	3
Forestburg switchgrass	2.6	2.3
Critana thickspike wheatgrass	2.3	2
Pryor slender wheatgrass	3.4	3
Lodorm green needlegrass	2.3	2
Trailhead basin wildrye	2.6	2.3
Sand dropseed	0.6	0.5
Durar hard fescue	1.1	1
Appar blue flax	0.6	0.5
Western yarrow	0.3	0.3
Eski sainfoin	0.3	0.3
Yellow prairie clover	0.2	0.2
Bandera penstemon	0.2	0.2
Silver sagebrush	0.8	0.7
Winterfat	1.1	1
Fourwing saltbush	0.5	0.4
Greasewood	0.2	0.2
Gardner saltbush	0.5	0.4
Inert	1.9	1.7
	----	----
	29.4	26

Mix 2: Sagebrush-Grassland mixture.

	Kg PSA/Ha	Pounds PLS/A
Rosana western wheatgrass	3.4	3
Critana thickspike wheatgrass	3.4	3
Lodorm green needlegrass	3.4	3
Nezpar Indian ricegrass	2.3	2
Durar hard fescue	2.8	2.5
Needle-and-thread	0.8	0.7
Secar bluebunch wheatgrass	2.3	2
Prairie junegrass	0.4	0.4
Native blue grama	0.6	0.5
Dakotah switchgrass	1.1	1
Western white yarrow	0.3	0.3
Appar blue flax	0.3	0.3
Yellow prairie coneflower	0.3	0.3
Eski sainfoin	0.2	0.2
Winterfat	1.1	1
Fourwing saltbush	0.3	0.3
Wyoming big sagebrush	0.6	0.5
Gardner saltbush	0.4	0.4
Inert	0.5	0.4
	----	----
	24.6	21.8

Mix 3: Scoria Shrub/Forb/Legume mixture.

	Kg PSA/Ha	Pounds PLS/A
Secar bluebunch wheatgrass	0.7	0.6
Rosana western wheatgrass	0.4	0.4
Barkoel prairie Junegrass	0.1	0.1
Wyoming big sagebrush	3.6	3.2
Silver sagebrush	0.4	0.4
Fourwing saltbush	0.5	0.4
Winterfat	1.2	1.1
Gardner saltbush	1.7	1.5
Appar blue flax	0.3	0.3
Western white yarrow	0.2	0.2
Yellow prairie coneflower	0.2	0.2
Eski sainfoin	1.8	1.6
	----	----
	11.3	10.0