Report on the Revegetation Problems at Coal Creek Sand Pit and Plant

by Mark Heifner, Ecologist

ABSTRACT: summary, main points, and conclusions

This report contains the results of a study of the soils at the Coal Creek Sand Pit in an attempt to determine why the autumn 2022 seeding on this site was so unsuccessful, although prior reclamation performed on other areas at this mining operation using the same methods and techniques were very successful. Results of soil tests by Colorado State University are presented and examined to define the properties of the reclamation soils in comparison to those same properties exhibited by the native prairie soils which were the source of the reclamation soils. It was found that some of the reclamation soils had very different properties than the native soils while other reclamation soils were nominally similar, although still degraded to some degree as expected as usually occurs with topsoil salvage and stockpiling. The extremely wet period from May to July 2023 may have aggravated already existing differences. It was found that soil derived from the large stockpile of soil accumulated over a couple of decades produced the greatest problems by preventing the growth of the grasses contained in the seed mixture. Evidence from the tests show that some of the soil in the stockpile was likely affected by anoxia during storage and the soil properties changed as a result. The soil became strongly alkaline, had a high sulphate content, and formed very dense and thick crusts. Growth experiments showed that grasses have great difficulty producing even cotyledons above the soil layer if the soil dries out and crusts. However, weeds such as Kochia can grow successfully because their seeds were more shallow in the soil and are adapted to successfully growing in such adverse soil. It is recommended that all crusted soils be mapped to determine the amount of land where these soils exist and then mechanically break up the surface soils while mixing in large amounts of organic matter (probably straw or hay) to keep the soil porosity high and hinder the development of solid crusts on the surface. The treated soil should then be replanted using a broadcast method immediately after treatment rather than drilling the seed. Also a change in the seed mixture should be made to include an alkali resistant species and a strong cover crop grass.

Introduction: In compliance with the Mined Land Reclamation Law for the Extraction of Construction Materials, upon closure of the mining operation and its processing plant, reclamation began and the backfilling, grading, and topsoiling of both sites (pit area and processing area) were completed in early 2022. Drill seeding of the sites was done in late September and early October 2022. Little autumnal germination of the seed occurred. The drill seeding was done using a rate of about 40 pure live seeds per square foot over a total area of 63.6 acres, with about 28 acres in the pit area and the remainder at the separate plant site.

The late fall and winter season began fairly dry but in January 2023 snowfall increased some and provided an adequate amount of moisture input to the soils so when the weather warmed good germination of the seed was expected. April and early May however were warm and quite dry with little rainfall. That all changed on May 10, 2023 when the weather patterns shifted to a very wet period that supercharged the soils with moisture. Record rainfall fell on that date and good rains fell on subsequent dates in May, some also with record breaking precipitation that produced periods of moderate to severe erosion not only at this site but in many other areas in eastern Colorado. Flooding occurred on many streams. This continued and by June some weather stations had already received so much rainfall that if no precipitation came for the rest of the year the total precipitation for 2023 would equal the normal annual precipitation amount. This wet period came to a close about July 10. After that there was only normal rainfall, at best, and at low frequency. But no drought conditions developed any where near this site.

In these conditions it was expected that grass growth at the Coal Creek sites would be robust and vigorous. At the plant site where erosion had not damaged the land this kind of growth did occur even with strong growths of annual weeds. Even many of the sedimentation locations where soils from uphill had collected, grass growth was adequate to excellent at the plant site.

However, at the Pit Area very little grass even came up even in areas where erosion had not severely impacted the surface growth medium. Erosion at the Pit Area was far less damaging than at the Plant Site, although wind erosion at the crest of the regraded pit slopes was severe leaving mostly sand on the surface. Yet some grass still came up to a very small degree even on those wind scoured locations. By late summer those areas had sufficient grass growth that they would succeed, although it would likely take longer than was seen elsewhere on other reclamation areas at this operation.

In July a pattern of grass growth from the seeding began to appear at the Pit Area. On the sandy , yellow colored soils, Green Needlegrass, Western Wheatgrass, and sparse amounts of other planted species began to grow fairly well but with a much lower density than expected, especially considering the amount of moisture that had charged the soils to considerable depth. It was clear that the amount of runoff into the central drainage course had not been great as there was limited erosion in the channel and only minor deposition. Even at the outlet where all drainage water meets at an exit into the adjacent drainage, erosion was only moderate when it was expected there would be a deep gully cut out and the adjacent drainage clogged with sediment. No gully, no severe sedimentation, and the flow channel through the pit was as expected with little erosion or sedimentation. Certainly far less than was expected considering the amount of precipitation that had occurred. Some of the soils that were placed on the slopes had moved down slope, but the amount of erosion in the Pit Area was far less everywhere than was expected showing that the slopes are clearly quite stable for being so early in the revegetation process. In fact it was almost like the rains had missed this area. But digging down into the soil just a short distance found moist soils at well below the field capacity except where the soil from the large soil stockpile had been placed in abundance. That was mostly on the south end of the pit area. Soils on the north end of the pit came from small piles along the edge of the former pit as well as a small stockpile near the north end of the pit that was up to about six feet deep.

The large stockpile, on the other hand, was huge with a maximum depth of about 20 to 24 feet and it had been there, building up for a couple of decades. Where that soil was spread in the pit it gathered and held moisture like a sponge and even after surrounding light colored soils had dried out, the soil in these areas still contained enough moisture to be a bit on the muddy side just a short distance below the surface. Not a good environment for the growth of native grasses that are well adapted to open droughty soils. But the weed growth on this dense soil was spectacular and mostly composed of Kochia, many of which were 4 to 5 feet tall and looked more like the initiation of a stand of forest. The soil was perfect for these weeds. However, the weeds were still far enough apart that grass could and usually would come up in the understory as was happening at the Plant Site. Something was clearly wrong with this soil but what was wrong was certainly not apparent other than the soil tended to hold a lot of water which could reduce oxygen penetration to allow the more deeply planted grass seeds and young roots to "breathe." Possibly the seed literally drowned in this soggy soil that was so slow to dry out. Or, possibly, something had happened to this soil in the stockpile that caused it to degrade to the point where it was not very suitable for growing these prairie grasses.

At this point it should be pointed out that out of about 100 acres of successful reclamation that Schmidt Construction had completed at this operational site at other locations and with no seeding failures or excessive weed growth anywhere on these other reclamation areas, this is the first seeding failure that has ever occurred. The Plant Site has a lot of erosion damage that is fixable, but it also has successful grass growth even with dense, "tree-like" Kochia plants. But there is something about the Pit Area that is very different from all the other sites that is limiting the use of the same seed mixture that has been so successful elsewhere on other reclaimed mining sites here, some even larger than this site and in less favorable locations with respect to slope grade and aspect (direction the slope faces). This is a key observation that needs to be kept in mind when reading the rest of this report. The failure was close to a total failure. In only some areas and only one kind of reclamation soil was there marginally successful growth of the planted grasses that have been so successful at this point on other sites.

Soil Sampling and Testing

On September 19, 2023 the site was visited with the purpose of collecting samples of the various soils in the Pit Area for testing at the Colorado State University Soil and Water Testing Laboratory in north Denver. It was clear prior to the sampling that at least 3 composite samples would be needed. First was the native soils in the surrounding prairie vegetation. This is the soil that all the soils stockpiled for reclamation came from. Thus it was the reference soil for the comparison of the reclamation soils in the pit. Second would be the light yellow colored soils on the slopes on the north end of the pit where some grass establishment was occurring. And third was the very dark colored soils that had been derived from the old soil stockpile and located here and there on the south end of the pit. A fourth sample would come from the location of the old stockpile if any soil could be found that had not obviously been mixed with the sand deposit underneath where the stockpile had been. That turned out to be challenging as all material was very dark and looked very much alike. It was expected that possibly a couple of more soil units might be identified in the course of the sampling that are clearly different from the primary two units in the pit. As it turned out one small unit was found along the sides of the drainage course that was a clear blend of the dark, heavy soil and the light yellow sandy soil that had mostly been deposited here by sheet erosion from the slopes above the drainage course. This blend was clearly not present elsewhere as the boundaries between the soil units are quite abrupt.

Prior to sampling Mr. Greg Olson was contacted to confirm the suspected sources of the soils that had been spread in the Pit Area. Greg Olson was the foreman of the crew that backfilled, graded and topsoiled both the Pit Area and the Plant Area. Although now retired he confirmed that my assumptions as to the source of soils was correct. He also pointed out that in the southeast corner of the pit was a large and deep backfill composed of materials removed from high spots in the pit prior to grading. This borrowed material was shown in this author’s grading plan for the pit. This fill area received a blend of the large stockpile soils, soil berms along the edge of the pit, and the pre-reclamation high spots located on the east side of the pit and north of the fill area. This area was not sampled as its texture, color, and vegetation growth was similar to the light yellow sandy soil with hints of the darker soil. It was considered insufficiently different to warrant a separate sampling.

So, a total of five soil units were sampled as described below. Each sample was a central slice of the soil profile to 6" depth and about 1 inch deep and 1 inch wide made with a spade. At least 5 different sample locations were used in each unit and in most 10 to 15 locations were sampled. Each unit samples were combined into a 1 gallon zip-lock freezer bag to transport off the site. Two cups (about 1 pound) of each of the composite soil samples were taken to the Soil Testing Lab on September 22 after thoroughly mixing each batch of samples and removing as much of the undecomposed organic matter as was possible. That included raw and dead plant tissues such as stems and leaves, and most of the living root material and anything else that was not a part of the granular soils. Naturally very fine roots and broken off root hairs were too difficult to remove.

1. **Natural Prairie:** A composite sample of many 6" deep pits completely surrounding the Pit Area. All the samples were combined to produce a total of about 12 pounds of collected soil, the most collected in any unit. The locations of these samples are shown on the map (not included in this report, but available). Digging here was moderately easy as the soil was silty and loose.

2. **Soil Stockpile:** A small composite sample of the remains of the bottom of the soil stockpile that appeared to be like the heavy dark soils in the pit that seemed problematic. Digging here was very easy. Five pounds collected.

3. **North End Sandy:** These samples were taken from the side slopes of the pit on both the east and west sides of the drainage course that divides the Pit Area approximately in half. Samples were not taken near the drainage course as that was clearly somewhat different from the soils on the slopes which far exceeded the streamside unit in area. Digging here was a little difficult due to slight crusting in places. Eight pounds collected.

4. **Along Drainage:** This was a small composite sample of soils adjacent to the drainage that were clearly a blend of the North End Sandy soil and the next unit (Loam on Slope). The revegetation here seemed to be the best on the whole site, but it could not

be determined directly whether that was due to added water from the nearby drainage or a different soil condition due to the blending that had occurred. But in many places in this unit the grass growth is the most vigorous and "healthy" looking. Digging here was quite easy and it was easy to go much deeper than 6", although the sampling was still restricted to the top 6". Seven pounds collected.

5. **Loam on Slope:** Many samples were taken from this unit at three different deposits of this soil unit in different topographic locations. These were all combined into one composite sample as the vegetation cover in each unit was highly similar - big Kochia plants and little else, not even *Salsola* (Russian Thistle). It was essentially a weed monoculture. No grass plants were seen anywhere in these units. Digging the samples was fairly easy except in some places the surface was so hard the shovel could not even penetrate the crust. Ten pounds collected.

The soil test results were received on October 6. These results are shown on the following pages. The test requested was the Complete Test which includes most of the significant soil parameters that are involved in producing and supporting plant growth or deficiencies that would limit plant growth. The results are reported with both the numerical value and a qualitative class such as Low, Medium, High, etc.

Examination of these results shows that the four reclamation soil units are, in many respects, quite different even though all of them came from soils that are represented by soil unit 1, Natural Prairie. These changes are the direct result of stripping, stockpiling in various ways, and then spreading on to the graded land years after stockpiling. It is quite clear that stockpiling soils can result in severe changes to the native soil including loss of nutrients, changes in soil texture, and changes in the total soil package that is intended to support at least some of the species that the soil originally supported and grew with considerable success for decades if not centuries. This brings to the question as to whether the soil is still fit to successfully grow the species that are planted plus various beneficial species that usually invade the newly established vegetation; the Native pioneer species that quickly invade disturbances. No soil tests were taken of soils that were successfully reclaimed in the past, but it is likely some of those replaced soils underwent considerable degradation in stockpiles, some of which were in place for long periods not all that different from the big stockpile on this current project site. And those soils worked quite well and well enough that the reclamation was

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37 E. Colorado Ave.
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Lab ID: 2023S2772
Sample ID: Native Prairie

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
1:1 Soil pH		7.1	Strongly Acid <5.4	Moderately Acid 5.4-5.7	Slightly Acid 5.8-6.4	Neutral 6.5-7.2	Slightly Alkaline 7.3-7.6	Moderately Alkaline 7.7-7.9	Strongly Alkaline >7.9
1:1 Soluble Salts (EC)	mmho/cm	0.1	Very Low <0.2	Low 0.2-0.7	Moderate 0.8-1.2	Moderately High 1.3-2.5	High 2.6-5.0	Very High >5.0	
Excess Lime		NONE							
Organic Matter LOI	%	11.2	Very Low <0.5	Low 0.5-1.5	Medium 1.6-3.0	High 3.1-5.0	Very High >5.0		
KCl Nitrate-N	ppm	6" 3	Very Low <5	Low 5-10	Medium 11-25	High 26-50	Very High >50	lb/1000 sq.ft. 0.1	Recommendation lb/1000 sq.ft.
Olsen Bicarbonate Phosphorus (P)	ppm	17	Very Low 0-3	Low 4-6	Medium 7-10	Optimum 11-15	High 16-20	Very High >20	Recommendation lb/1000 sq.ft.
Ammonium Acetate									
Potassium (K)	ppm	1121	Very Low <60	Low 60-120	Medium 121-160	Optimum 161-220	High 221-280	Very High >280	Recommendation lb/1000 sq.ft.
Calcium (Ca)	ppm	3109	Very Low <100	Low 100-200	Medium 201-300	Optimum 301-2500	High >2500	Very High >5000	Recommendation lb/1000 sq.ft.
Magnesium (Mg)	ppm	476	Very Low <25	Low 25-50	Medium 51-75	Optimum 76-100	High 101-200	Very High >200	Recommendation lb/1000 sq.ft.
Sodium (Na)	ppm	51							
Cation Exchange Capacity (CEC) or Sum of Cations	meq/100g	23	Sand 3-5	Loam 10-15	Silt Loams 15-25	Clay & Clay Loam 20-50	Organic Soils 50-100		
Base Saturation	%	100.0	H 0.0	K 13.0	Ca 68.0	Mg 18.0	Na 1.0		

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Lab ID: 2023S2772
Sample ID: Native Prairie

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
Mehlich-3									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Sulfate-S	ppm	5.1	<2	2-5	6-10		11-15	>15	
DTPA									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Zinc (Zn)	ppm	0.8	<0.3	0.3-0.5	0.6-0.8	0.9-1.2	1.3-2.0	>2.0	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Iron (Fe)	ppm	15.6	<1.0	1.0-2.5	2.6-5.0	5.1-15.0	15.1-30	>30	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Manganese (Mn)	ppm	4.3	<0.5	0.5-1.0	1.1-3.0	3.1-6.0	6.1-10.0	>10	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Copper (Cu)	ppm	0.4	<0.1	0.1-0.2	0.3-0.4	0.5-0.8	0.9-1.5	>1.5	
Hot Water Extraction									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Boron (B)	ppm	0.3	<0.2	0.2-0.5	0.6-0.8	0.9-1.5	1.6-2.5	>2.5	
Calcium Nitrate									
Chloride (Cl)	ppm								
Soil Texture									
% Sand	%								
% Silt	%								
% Clay	%								
Texture by Hydrometer									
Heavy Metals									
Arsenic (As)	ppm								
Cadmium (Cd)	ppm								
Chromium (Cr)	ppm								
Lead (Pb)	ppm								
Molybdenum (Mo)	ppm								
Selenium (Se)	ppm								
Sodium Absorption Ratio									
SAR									

*Test ratings are provided for general crop production. The ranges may be different for individual crops or for specific situations.

Comments:

Fertilizer recommendations were not requested.

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Lab ID: 2023S2773
Sample ID: Soil Stockpile

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
1:1 Soil pH		6.7	Strongly Acid <5.4	Moderately Acid 5.4-5.7	Slightly Acid 5.8-6.4	Neutral 6.5-7.2	Slightly Alkaline 7.3-7.6	Moderately Alkaline 7.7-7.9	Strongly Alkaline >7.9
1:1 Soluble Salts (EC)	mmho/cm	0.1	Very Low <0.2	Low 0.2-0.7	Moderate 0.8-1.2	Moderately High 1.3-2.5	High 2.6-5.0	Very High >5.0	
Excess Lime		NONE							
Organic Matter LOI	%	2.2	Very Low <0.5	Low 0.5-1.5	Medium 1.6-3.0	High 3.1-5.0	Very High >5.0		
KCl Nitrate-N	ppm	6" 5	Very Low <5	Low 5-10	Medium 11-25	High 26-50	Very High >50	lb/1000 sq.ft. 0.2	Recommendation lb/1000 sq.ft.
Olsen Bicarbonate Phosphorus (P)	ppm	18	Very Low 0-3	Low 4-6	Medium 7-10	Optimum 11-15	High 16-20	Very High >20	Recommendation lb/1000 sq.ft.
Ammonium Acetate									
Potassium (K)	ppm	214	Very Low <60	Low 60-120	Medium 121-160	Optimum 161-220	High 221-280	Very High >280	Recommendation lb/1000 sq.ft.
Calcium (Ca)	ppm	1373	Very Low <100	Low 100-200	Medium 201-300	Optimum 301-2500	High >2500	Very High >5000	Recommendation lb/1000 sq.ft.
Magnesium (Mg)	ppm	226	Very Low <25	Low 25-50	Medium 51-75	Optimum 76-100	High 101-200	Very High >200	Recommendation lb/1000 sq.ft.
Sodium (Na)	ppm	13							
Cation Exchange Capacity (CEC) or Sum of Cations	meq/100g	9	Sand 3-9	Loam 10-15	Silt Loams 15-25	Clay & Clay Loam 20-50	Organic Soils 50-100		
Base Saturation	%	100.0	H 0.0	K 6.0	Ca 73.0	Mg 20.0	Na 1.0		

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Lab ID:	2023S2773		Date Received: 9/22/2023
Sample ID:	Soil Stockpile		Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
Mehlich-3									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Sulfate-S	ppm	9.9	<2	2-5	6-10		11-15	>15	
DTPA									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Zinc (Zn)	ppm	0.9	<0.3	0.3-0.5	0.6-0.8	0.9-1.2	1.3-2.0	>2.0	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Iron (Fe)	ppm	60.4	<1.0	1.0-2.5	2.6-5.0	5.1-15.0	15.1-30	>30	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Manganese (Mn)	ppm	4.6	<0.5	0.5-1.0	1.1-3.0	3.1-6.0	6.1-10.0	>10	
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Copper (Cu)	ppm	0.8	<0.1	0.1-0.2	0.3-0.4	0.5-0.8	0.9-1.5	>1.5	
Hot Water Extraction									
			Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Boron (B)	ppm	0.4	<0.2	0.2-0.5	0.6-0.8	0.9-1.5	1.6-2.5	>2.5	
Calcium Nitrate									
Chloride (Cl)	ppm								
Soil Texture									
% Sand	%								
% Silt	%								
% Clay	%								
Texture by Hydrometer									
Heavy Metals									
Arsenic (As)	ppm								
Cadmium (Cd)	ppm								
Chromium (Cr)	ppm								
Lead (Pb)	ppm								
Molybdenum (Mo)	ppm								
Selenium (Se)	ppm								
Sodium Absorption Ratio									
SAR									

*Test ratings are provided for general crop production. The ranges may be different for individual crops or for specific situations.

Comments:

Fertilizer recommendations were not requested.

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Lab ID: 2023S2774
Sample ID: North end sandy

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
1:1 Soil pH		7.6	**Strongly Acid**	**Moderately Acid**	**Slightly Acid**	**Neutral**	**Slightly Alkaline**	**Moderately Alkaline**	**Strongly Alkaline**
			<5.4	5.4-5.7	5.8-6.4	6.5-7.2	7.3-7.6	7.7-7.9	>7.9
1:1 Soluble Salts (EC)	mmho/cm	0.1	**Very Low**	**Low**	**Moderate**	**Moderately High**	**High**	**Very High**	
			<0.2	0.2-0.7	0.8-1.2	1.3-2.5	2.6-5.0	>5.0	
Excess Lime		NONE							
Organic Matter LOI	%	1.8	**Very Low**	**Low**	**Medium**	**High**	**Very High**		
			<0.5	0.5-1.5	1.6-3.0	3.1-5.0	>5.0		
KCl Nitrate-N		6"	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**lb/1000 sq.ft.**	**Recommendation lb/1000 sq.ft.**
	ppm	3	<5	5-10	11-25	26-50	>50	0.1	
Olsen Bicarbonate Phosphorus (P)	ppm	12	**Very Low**	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
			0-3	4-6	7-10	11-15	16-20	>20	
Ammonium Acetate									
Potassium (K)	ppm	228	**Very Low**	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
			<60	60-120	121-160	161-220	221-280	>280	
Calcium (Ca)	ppm	1225	**Very Low**	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
			<100	100-200	201-300	301-2500	>2500	>5000	
Magnesium (Mg)	ppm	216	**Very Low**	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
			<25	25-50	51-75	76-100	101-200	>200	
Sodium (Na)	ppm	27							
Cation Exchange Capacity (CEC) or Sum of Cations	meq/100g	9	**Sand**	**Loam**	**Silt Loams**	**Clay & Clay Loam**	**Organic Soils**		
			3-9	10-15	15-25	20-50	50-100		
Base Saturation	%	100.0	**H**	**K**	**Ca**	**Mg**	**Na**		
			0.0	7.0	71.0	21.0	1.0		

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Lab ID: 2023S2774
Sample ID: North end sandy

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
Mehlich-3									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Sulfate-S	**ppm**	**5.8**	<2	2-5	6-10		11-15	>15	
DTPA									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Zinc (Zn)	**ppm**	**0.5**	<0.3	0.3-0.5	0.6-0.8	0.9-1.2	1.3-2.0	>2.0	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Iron (Fe)	**ppm**	**8.5**	<1.0	1.0-2.5	2.6-5.0	5.1-15.0	15.1-30	>30	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Manganese (Mn)	**ppm**	**2.7**	<0.5	0.5-1.0	1.1-3.0	3.1-6.0	6.1-10.0	>10	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Copper (Cu)	**ppm**	**0.3**	<0.1	0.1-0.2	0.3-0.4	0.5-0.8	0.9-1.5	>1.5	
Hot Water Extraction									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Boron (B)	**ppm**	**0.3**	<0.2	0.2-0.5	0.6-0.8	0.9-1.5	1.6-2.5	>2.5	
Calcium Nitrate									
Chloride (Cl)	**ppm**								
Soil Texture									
% Sand	**%**								
% Silt	**%**								
% Clay	**%**								
Texture by Hydrometer									
Heavy Metals									
Arsenic (As)	**ppm**								
Cadmium (Cd)	**ppm**								
Chromium (Cr)	**ppm**								
Lead (Pb)	**ppm**								
Molybdenum (Mo)	**ppm**								
Selenium (Se)	**ppm**								
Sodium Absorption Ratio									
SAR									

*Test ratings are provided for general crop production. The ranges may be different for individual crops or for specific situations.

Comments:

Fertilizer recommendations were not requested.

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Lab ID:	2023S2775	Date Received:	
Sample ID:	Along drainage	Date Reported:	

Soil Analysis	Units	Results	Test Rating*						
1:1 Soil pH		**7.6**	**Strongly Acid** <5.4	**Moderately Acid** 5.4-5.7	**Slightly Acid** 5.8-6.4	**Neutral** 6.5-7.2	**Slightly Alkaline** 7.3-7.6	**Moderately Alkaline** 7.7-7.9	**Strongly Alkaline** >7.9
1:1 Soluble Salts (EC)	**mmho/cm**	**0.1**	**Very Low** <0.2	**Low** 0.2-0.7	**Moderate** 0.8-1.2	**Moderately High** 1.3-2.5	**High** 2.6-5.0	**Very High** >5.0	
Excess Lime		**NONE**							
Organic Matter LOI	**%**	**1.6**	**Very Low** <0.5	**Low** 0.5-1.5	**Medium** 1.6-3.0	**High** 3.1-5.0	**Very High** >5.0		
KCl Nitrate-N	**ppm**	**6"** **3**	**Very Low** <5	**Low** 5-10	**Medium** 11-25	**High** 26-50	**Very High** >50	**lb/1000 sq.ft.** 0.1	**Recommendation lb/1000 sq.ft.**
Olsen Bicarbonate Phosphorus (P)	**ppm**	**8**	**Very Low** 0-3	**Low** 4-6	**Medium** 7-10	**Optimum** 11-15	**High** 16-20	**Very High** >20	**Recommendation lb/1000 sq.ft.**
Ammonium Acetate									
Potassium (K)	**ppm**	**168**	**Very Low** <60	**Low** 60-120	**Medium** 121-160	**Optimum** 161-220	**High** 221-280	**Very High** >280	**Recommendation lb/1000 sq.ft.**
Calcium (Ca)	**ppm**	**1150**	**Very Low** <100	**Low** 100-200	**Medium** 201-300	**Optimum** 301-2500	**High** >2500	**Very High** >5000	**Recommendation lb/1000 sq.ft.**
Magnesium (Mg)	**ppm**	**187**	**Very Low** <25	**Low** 25-50	**Medium** 51-75	**Optimum** 76-100	**High** 101-200	**Very High** >200	**Recommendation lb/1000 sq.ft.**
Sodium (Na)	**ppm**	**11**							
Cation Exchange Capacity (CEC) or Sum of Cations	**meq/100g**	**8**	**Sand** 3-9	**Loam** 10-15	**Silt Loams** 15-25	**Clay & Clay Loam** 20-50	**Organic Soils** 50-100		
Base Saturation	**%**	**100.0**	**H** 0.0	**K** 6.0	**Ca** 73.0	**Mg** 20.0	**Na** 1.0		

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Lab ID:	2023S2775	Date Received:	
Sample ID:	Along drainage	Date Reported:	

Soil Analysis	Units	Results	Very Low	Low	Medium	Optimum	High	Very High	Recommendation lb/1000 sq.ft.
Mehlich-3									
Sulfate-S	ppm	7.7	<2	2-5	6-10		11-15	>15	
DTPA									
Zinc (Zn)	ppm	0.5	<0.3	0.3-0.5	0.6-0.8	0.9-1.2	1.3-2.0	>2.0	
Iron (Fe)	ppm	9.4	<1.0	1.0-2.5	2.6-5.0	5.1-15.0	15.1-30	>30	
Manganese (Mn)	ppm	2.5	<0.5	0.5-1.0	1.1-3.0	3.1-6.0	6.1-10.0	>10	
Copper (Cu)	ppm	0.4	<0.1	0.1-0.2	0.3-0.4	0.5-0.8	0.9-1.5	>1.5	
Hot Water Extraction									
Boron (B)	ppm	0.3	<0.2	0.2-0.5	0.6-0.8	0.9-1.5	1.6-2.5	>2.5	
Calcium Nitrate									
Chloride (Cl)	ppm								
Soil Texture									
% Sand	%								
% Silt	%								
% Clay	%								
Texture by Hydrometer									
Heavy Metals									
Arsenic (As)	ppm								
Cadmium (Cd)	ppm								
Chromium (Cr)	ppm								
Lead (Pb)	ppm								
Molybdenum (Mo)	ppm								
Selenium (Se)	ppm								
Sodium Absorption Ratio									
SAR									

*Test ratings are provided for general crop production. The ranges may be different for individual crops or for specific situations.

Comments:

Fertilizer recommendations were not requested.

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Lab ID: 2023S2776
Sample ID: Loam on slop

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
1:1 Soil pH		**8**	**Strongly Acid** <5.4	**Moderately Acid** 5.4-5.7	**Slightly Acid** 5.8-6.4	**Neutral** 6.5-7.2	**Slightly Alkaline** 7.3-7.6	**Moderately Alkaline** 7.7-7.9	**Strongly Alkaline** >7.9
1:1 Soluble Salts (EC)	**mmho/cm**	**0.1**	**Very Low** <0.2	**Low** 0.2-0.7	**Moderate** 0.8-1.2	**Moderately High** 1.3-2.5	**High** 2.6-5.0	**Very High** >5.0	
Excess Lime		**NONE**							
Organic Matter LOI	**%**	**2.1**	**Very Low** <0.5	**Low** 0.5-1.5	**Medium** 1.6-3.0	**High** 3.1-5.0	**Very High** >5.0		
KCl Nitrate-N	**ppm**	**6"** **2**	**Very Low** <5	**Low** 5-10	**Medium** 11-25	**High** 26-50	**Very High** >50	**lb/1000 sq.ft.** 0.1	**Recommendation lb/1000 sq.ft.**
Olsen Bicarbonate Phosphorus (P)	**ppm**	**10**	**Very Low** 0-3	**Low** 4-6	**Medium** 7-10	**Optimum** 11-15	**High** 16-20	**Very High** >20	**Recommendation lb/1000 sq.ft.**
Ammonium Acetate									
Potassium (K)	**ppm**	**155**	**Very Low** <60	**Low** 60-120	**Medium** 121-160	**Optimum** 161-220	**High** 221-280	**Very High** >280	**Recommendation lb/1000 sq.ft.**
Calcium (Ca)	**ppm**	**1956**	**Very Low** <100	**Low** 100-200	**Medium** 201-300	**Optimum** 301-2500	**High** >2500	**Very High** >5000	**Recommendation lb/1000 sq.ft.**
Magnesium (Mg)	**ppm**	**240**	**Very Low** <25	**Low** 25-50	**Medium** 51-75	**Optimum** 76-100	**High** 101-200	**Very High** >200	**Recommendation lb/1000 sq.ft.**
Sodium (Na)	**ppm**	**11**							
Cation Exchange Capacity (CEC) or Sum of Cations	**meq/100g**	**12**	**Sand** 3-5	**Loam** 10-15	**Silt Loams** 15-25	**Clay & Clay Loam** 20-50	**Organic Soils** 50-100		
Base Saturation	**%**	**99.0**	**H** 0.0	**K** 3.0	**Ca** 80.0	**Mg** 16.0	**Na** 0.0		

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Lab ID: 2023S2776
Sample ID: Loam on slop

Date Received: 9/22/2023
Date Reported: 10/6/2023

Soil Analysis	Units	Results	Test Rating*						
Mehlich-3									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Sulfate-S	**ppm**	**9.7**	<2	2-5	6-10		11-15	>15	
DTPA									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Zinc (Zn)	**ppm**	**0.7**	<0.3	0.3-0.5	0.6-0.8	0.9-1.2	1.3-2.0	>2.0	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Iron (Fe)	**ppm**	**15**	<1.0	1.0-2.5	2.6-5.0	5.1-15.0	15.1-30	>30	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Manganese (Mn)	**ppm**	**2.5**	<0.5	0.5-1.0	1.1-3.0	3.1-6.0	6.1-10.0	>10	
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Copper (Cu)	**ppm**	**0.5**	<0.1	0.1-0.2	0.3-0.4	0.5-0.8	0.9-1.5	>1.5	
Hot Water Extraction									
			Very Low	**Low**	**Medium**	**Optimum**	**High**	**Very High**	**Recommendation lb/1000 sq.ft.**
Boron (B)	**ppm**	**0.3**	<0.2	0.2-0.5	0.6-0.8	0.9-1.5	1.6-2.5	>2.5	
Calcium Nitrate									
Chloride (Cl)	**ppm**								
Soil Texture									
% Sand	**%**								
% Silt	**%**								
% Clay	**%**								
Texture by Hydrometer									
Heavy Metals									
Arsenic (As)	**ppm**								
Cadmium (Cd)	**ppm**								
Chromium (Cr)	**ppm**								
Lead (Pb)	**ppm**								
Molybdenum (Mo)	**ppm**								
Selenium (Se)	**ppm**								
Sodium Absorption Ratio									
SAR									

*Test ratings are provided for general crop production. The ranges may be different for individual crops or for specific situations.

Comments:

Fertilizer recommendations were not requested.

Comparisons of Reclamation Soil Sample 2 with 1

Soil Sample Group	1		2		***Difference***	***percent difference***
Description	Natural Prairie		Soil Stockpile			
grass establishment	Standard Target		none			
weeds	a little Salsola		Kochia			
visual soil character	sandy; light brown		Sandy, dark brown			
RESULTS						
Quantitative (ppm)					**bold = significant difference**	
KCL Nitrate-N		3		5	2	66.7%
	very low		low			
Olsen Bicarb P		17		18	1	5.9%
	high		high			
Potassium		**1121**		**214**	**-907**	**-80.9%**
	very high		optimum			
Calcium		**3109**		**1373**	**-1736**	**-55.8%**
	high		optimum			
Magnesium		**476**		**226**	**-250**	**-52.5%**
	very high		very high			
Sodium		**51**		**13**	**-38**	**-74.5%**
Sulfate		**5.1**		**9.9**	**4.8**	**94.1%**
	low medium		medium			
Zinc		0.8		0.9	0.1	12.5%
	medium		medium			
Iron		**15.6**		**60.4**	**44.8**	**287.2%**
	High		very high			
Manganese		4.3		4.6	0.3	7.0%
	Optimum		optimum			
Copper		0.4		0.8	0.4	100.0%
	Medium		optimum			
Boron		0.3		0.4	0.1	33.3%
	Low		low			
Quantitative (other units)						
pH		**7.1**		**6.7**	**-0.4**	**-5.6%**
	neutral		neutral			
Soluble salts (mmohs/cm)		0.1		0.1	0	0.0%
	very low		very low			
Orangic Matter (%)		**11.2**		**2.2**	**-9**	**-80.4%**
	very high		medium			
CEC - texture (meq/100g)		**23**		**9**	**-14**	**-60.9%**
	silt loam		sand			
Base Saturtion (%)		100		100	0	0.0%
H		0		0	0	0.0%
K		**13**		**6**	**-7**	**-53.8%**
Ca		68		73	5	7.4%
Mg		18		20	2	11.1%
Na		1		1	0	0.0%
calculated SAR		12.6		10.1	-2.5	-19.8%
	high		marginally high			

Comparisons of Reclamation Soil Sample 3 with 1

				percent
Soil Sample Group	**1**	**3**	***Difference***	***difference***
Description	Natural Prairie	North end sandy		
grass establishment	Standard Target	fair grass growth		
weeds	a little Salsola	weak Salsola;		
visual soil character	sandy; light brown	sandy; light yellow		
RESULTS				
Quantitative (ppm)			**bold = significant difference**	
KCL Nitrate-N	3	3	0	0.0%
	very low	very low		
Olsen Bicarb P	**17**	**12**	**-5**	**-29.4%**
	high	optimum		
Potassium	**1121**	**228**	**-893**	**-79.7%**
	very high	high		
Calcium	**3109**	**1225**	**-1884**	**-60.6%**
	high	optimum		
Magnesium	**476**	**216**	**-260**	**-54.6%**
	very high	very high		
Sodium	**51**	**27**	**-24**	**-47.1%**
Sulfate	5.1	5.8	0.7	13.7%
	low medium	low medium		
Zinc	0.8	0.5	-0.3	-37.5%
	medium	low		
Iron	15.6	8.5	-7.1	-45.5%
	High	optimum		
Manganese	4.3	2.7	-1.6	-37.2%
	Optimum	medium		
Copper	0.4	0.3	-0.1	-25.0%
	Medium	medium		
Boron	0.3	0.3	0	0.0%
	Low	low		
Quantitative (other units)				
pH	**7.1**	**7.6**	**0.5**	**7.0%**
	neutral	slightly alkaline		
Soluble salts (mmohs/cm)	0.1	0.1	0	0.0%
	very low	very low		
Orangic Matter (%)	**11.2**	**1.8**	**-9.4**	**-83.9%**
	very high	medium		
CEC - texture (meq/100g)	**23**	**9**	**-14**	**-60.9%**
	silt loam	sand		
Base Saturtion (%)	100	100	0	0.0%
H	0	0	0	0.0%
K	**13**	**7**	**-6**	**-46.2%**
Ca	68	71	3	4.4%
Mg	18	21	3	16.7%
Na	1	1	0	0.0%
calculated SAR	12.6	16.8	4.2	33.3%
	high	very lhigh		

Comparisons of Reclamation Soil Sample 4 with 1

Soil Sample Group	1	4	*Difference*	*percent difference*
Description	Natural Prairie	along drainage		
grass establishment	Standard Target	fair grass growth		
weeds	a little Salsola	Kochia and Salsola		
visual soil character	sandy; light brown	sandy; dark brown		
RESULTS				
Quantitative (ppm)			**bold = significant difference**	
KCL Nitrate-N	3	3	0	0.0%
	very low	very low		
Olsen Bicarb P	**17**	**8**	**-9**	**-52.9%**
	high	medium		
Potassium	**1121**	**168**	**-953**	**-85.0%**
	very high	optimum		
Calcium	**3109**	**1150**	**-1959**	**-63.0%**
	high	optimum		
Magnesium	**476**	**187**	**-289**	**-60.7%**
	very high	high		
Sodium	**51**	**11**	**-40**	**-78.4%**
Sulfate	**5.1**	**7.7**	**2.6**	**51.0%**
	low medium	medium		
Zinc	0.8	0.5	-0.3	-37.5%
	medium	low		
Iron	**15.6**	**9.4**	**-6.2**	**-39.7%**
	High	optimum		
Manganese	**4.3**	**2.5**	**-1.8**	**-41.9%**
	Optimum	medium		
Copper	0.4	0.4	0	0.0%
	Medium	medium		
Boron	0.3	0.3	0	0.0%
	Low	low		
Quantitative (other units)				
pH	**7.1**	**7.6**	**0.5**	**7.0%**
	neutral	slightly alkaline		
Soluble salts (mmohs/cm)	0.1	0.1	0	0.0%
	very low	very low		
Orangic Matter (%)	**11.2**	**1.6**	**-9.6**	**-85.7%**
	very high	medium		
CEC - texture (meq/100g)	**23**	**8**	**-15**	**-65.2%**
	silt loam	sand		
Base Saturtion (%)	100	100	0	0.0%
H	0	0	0	0.0%
K	**13**	**6**	**-7**	**-53.8%**
Ca	68	73	5	7.4%
Mg	18	20	2	11.1%
Na	1	1	0	0.0%
calculated SAR	**12.6**	**7.3**	**-5.3**	**-42.1%**
	high	good		

Comparisons of Reclamation Soil Sample 5 with 1

				percent
Soil Sample Group	**1**	**5**	***Difference***	***difference***
Description	Natural Prairie	Loam on slope		
grass establishment	Standard Target	no grass growth		
weeds	a little Salsola	robust Kochia		
visual soil character	sandy; light brown	dark sandy clay loam;		
		thick mud when wet;		
		hard crust when dry		
RESULTS				
Quantitative (ppm)			**bold = significant difference**	
KCL Nitrate-N	3	2	-1	-33.3%
	very low	very low		
Olsen Bicarb P	**17**	**10**	**-7**	**-41.2%**
	high	medium		
Potassium	**1121**	**155**	**-966**	**-86.2%**
	very high	medium		
Calcium	**3109**	**1956**	**-1153**	**-37.1%**
	high	optimum		
Magnesium	**476**	**240**	**-236**	**-49.6%**
	very high	very high		
Sodium	**51**	**11**	**-40**	**-78.4%**
Sulfate	**5.1**	**9.7**	**4.6**	**90.2%**
	low medium	medium		
Zinc	0.8	0.7	-0.1	-12.5%
	medium	medium		
Iron	15.6	15	-0.6	-3.8%
	High	otimum		
Manganese	**4.3**	**2.5**	**-1.8**	**-41.9%**
	Optimum	medium		
Copper	0.4	0.5	0.1	25.0%
	Medium	otimum		
Boron	0.3	0.3	0	0.0%
	Low	low		
Quantitative (other units)				
pH	**7.1**	**8**	**0.9**	**12.7%**
	neutral	strongly alkaline		
Soluble salts (mmohs/cm)	0.1	0.1	0	0.0%
	very low	very low		
Orangic Matter (%)	**11.2**	**2.1**	**-9.1**	**-81.3%**
	very high	medium		
CEC - texture (meq/100g)	**23**	**12**	**-11**	**-47.8%**
	silt loam	loam		
Base Saturtion (%)	100	99	-1	-1.0%
H	0	0	0	0.0%
K	**13**	**3**	**-10**	**-76.9%**
Ca	68	80	12	17.6%
Mg	18	16	-2	-11.1%
Na	1	0	-1	-100.0%
calculated SAR	**12.6**	**2.2**	**-10.4**	**-82.5%**
	high	very good		

found to be acceptable to the Division of Reclamation, Mining and Safety in a period of 3 to 4 years after seeding. So there is no way to compare the experience of soil recovery on those sites with this site, but those were all successful quite quickly. That shows the seed mixture is well suited for returning the land to a vegetation that is at least similar to the original vegetation and subsequently develops in that direction to produce a vegetation that is compatible with the natural prairie on the Lowry Range.

So, even though the same experience should have been seen at this site, clearly this site is somehow very different from previous sites in spite of using the same techniques here as were used there. To aid in finding possible causes of virtually a complete failure of the seeding of a major part of the Pit Area (most of the south end) a comparison of each of the reclamation soils to the native soils is needed to find what changed and what stayed nominally the same. But also included in that is a need to examine the unusual growth environment of 2023 with regard to record high moisture, sheet erosion of the upper portions of the replaced soils, and other factors including possible leaching of nutrients and alterations in the texture of the soils through modification of the clay and silt components of the soil that may have occurred within the 2023 growth environment.

These comparisons are contained in the spreadsheet printouts included on the four pages after the lab results. One additional factor was included in these sheets that was not included in the soil testing and that is SAR (Sodium Adsorption Ratio) which was calculated for each soil from the reported amounts of sodium, calcium, and magnesium in each soil. This too shows a wide range of values and in these kinds of prairie soils that contain high amounts of these three elements those difference can produce major changes in the physical properties of the soil colloids which is where the nutrient transfer from soil to plant roots occurs. If the SAR is unfavorable then the plants growing in that soil can grow very poorly or, in the extreme, not at all. This is an important factor and can be limiting, but other soil factors can compensate to some extent for an unfavorable SAR. Time often corrects an unfavorable SAR, but sometimes it just makes it worse. It all depends on the conditions of the environment and how that interacts with soil chemistry and physics. Although the raw test results are interesting the rest of this discussion on results will revolve around the test comparison spreadsheet results where each of the reclamation soils is compared to Soil Unit 1 the Natural Prairie soil that was the parent of all reclamation soils.

Soil Unit 2 vs Soil Unit 1: This is the comparison of the *remains* of the large stockpile with the prairie soils. It is assumed, probably correctly, that these topsoil materials should be the most altered of all as these samples came from the very bottom of the original soil stockpile.

There are two columns on the left side of the spreadsheet. One shows the numerical difference between the two soil units and the other shows the percent difference. The rows that are bold are the soil factors with a significant difference between the original soil and the soil unit. (Note: this type of marking is used on all the comparison spreadsheets.)

It is clear that the stockpile soil is extremely different from the original soil and that is primarily applicable to the mineral nutrients. The loss of these nutrients may have been through leaching of the nutrients further down into the material underneath where the topsoil was stockpiled. But it is far more likely that these nutrients were consumed by organisms in the soil or in reactions that caused the nutrients to become bound into other insoluble compounds or the abundant Kochia weeds that grew on this material after being exposed. In all likelihood it is not a single cause but a blend of various causes which will be discussed later. It has, in fact, been found that planting the stockpiles with the same species to be used in the reclamation helps to maintain the biological properties of that soil. Unfortunately that is only true within the rooting depth of the plants. Below that depth there is a very different environment which can be anoxic (zero or nearly zero oxygen content) and frequently an abundance of various bacteria that are well adapted to live in anoxic environments that can drastically alter the chemistry of the stockpiled soil. More about this will be discussed later. The references listed at the end of this report are studies of stockpile changes in various situations around the world and are potentially relevant to this site.

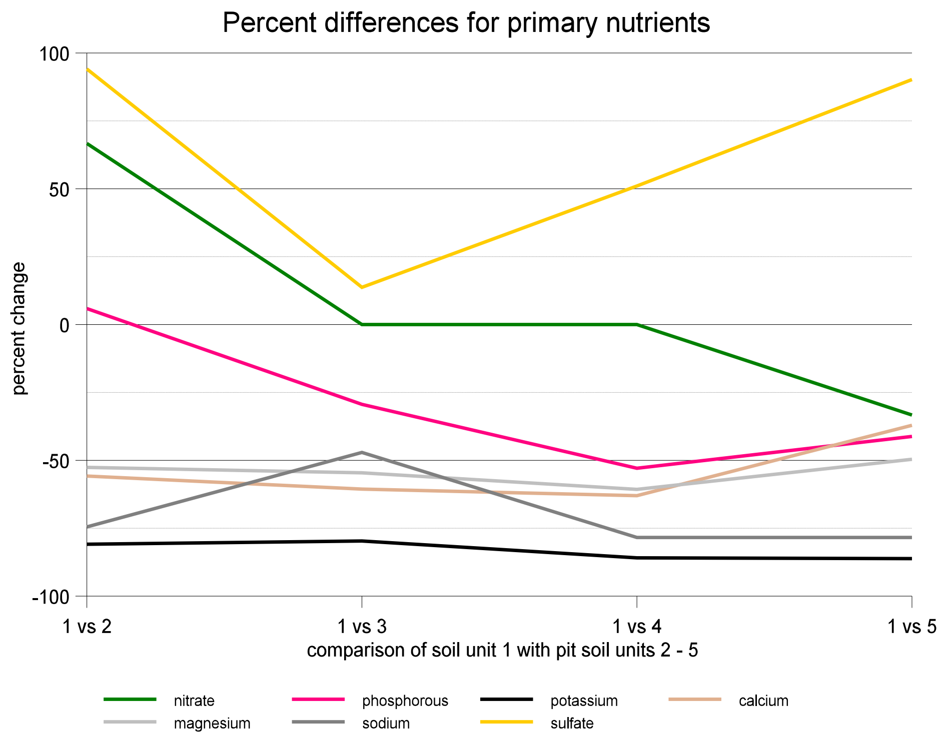
Soil Unit 3 vs Soil Unit 1: On this spreadsheet the primary nutrients also declined significantly from the original soil unit. However, Soil Unit 3 is, on the whole, not all that different from the original soil. As this material came from shallow soil stockpile/berms along the edge of the pit, degradation from compaction, biological activity in the stockpile, and leaching was likely somewhat less. In short, the small stockpiles/berms along the edge retained more of the original soil characteristics but still ended up somewhat different. However, apparently not limiting as reclamation grass growth is developing on this unit.

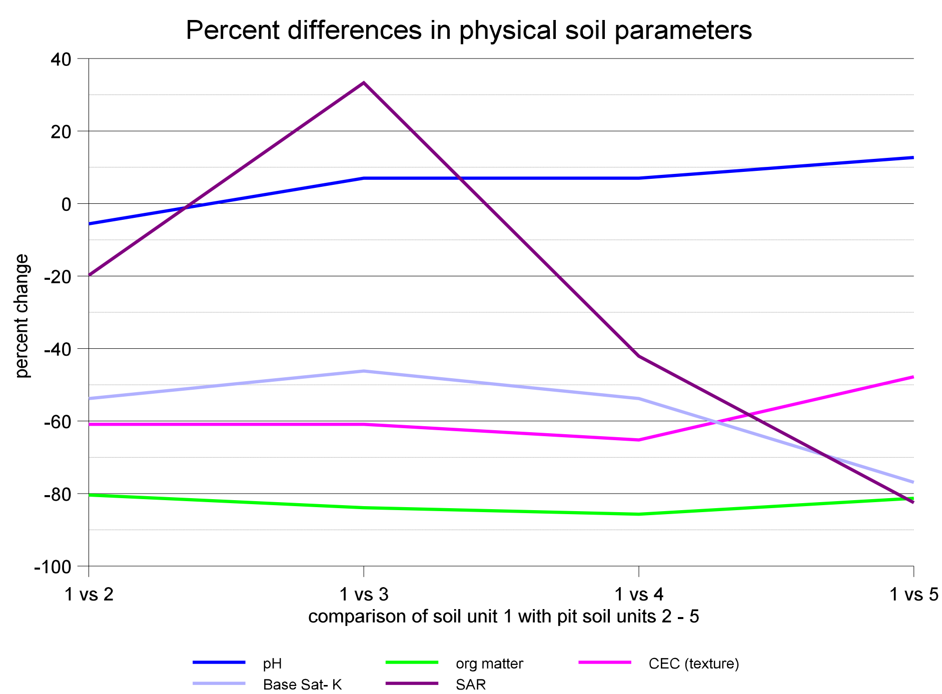
Soil Unit 4 vs Soil Unit 1: Here, once again, there is a drastic drop in nutrients compared to the native soils from which Soil Unit 4 was derived. This soil unit came primarily through the erosion and streamside deposition of the Soil Unit 5 areas to the south mixed with sheet erosion from Soil Unit 3 upslope from the edge of the drainage. However, the grasses that were growing here were doing quite well with good height and an abundance of healthy leaves. Weeds, mostly Kochia, were present in abundance which limited the grass growth for this year. But with the drainage channel just feet to the side and slightly downslope there was a good supply of moisture. The surface was loose and the soil easy to dig into. The best grass growth on the Pit Area was found here.

Soil Unit 5 vs Soil Unit 1: This soil is located usually in large areas on both the east and west facing slopes at various heights above the drainage course on the south end of the pit. The soil is very dark in color, sometimes almost black when damp, and once again very deficient in primary nutrients. However, it is also very alkaline with a pH of 8 compared to the almost neutral pH (7.1) of the native soils. This high pH is higher than units 3 and 4 (pH 7.6), but should not be extremely limiting to the growth of the grasses in the seed mixture. Most of the grasses in the seed mixture can handle a pH of 8 fairly well. Some more alkali species might be a better choice for this soil unit. One feature that will be examined later is that the soil produces a bit of a slimy mud when wet that when dry often forms a thick hard crust - an almost sure sign of a shrink-swell soil containing particular kinds of clay that are not conducive to good vegetation growth. One unique feature of this soil is a much higher sulfate content than the other soils which could be somewhat limiting to plant growth. That high sulfate content could be highly indicative of sulfate metabolizing anaerobic bacteria that release hydrogen sulfide that can make the soil become very dark brown to black. The sulphate content here is similar to Soil Unit 2 which is not surprising but also indicative of a major difference with the native soils.

In summary, the nutrients in the reclamation soils in the pit are definitely and fairly consistently lower than in the native soils and in some nutrients the differences are quite pronounced. However, the amounts should not be extremely limiting to the growth of the native grass species in the seed mixture. Simply put, the grasses should have grown in these soils although their vigor might have been less in some soil units. Low nutrients are certainly a factor, but clearly has a low subjective correlation with what was seen in the revegetation.

Following are a couple of graphs that show the patterns present in the soil nutrient and physical parameters in all the reclamation soil units (2 through 5) with the native soils surrounding the site. No well defined pattern is seen in the graphing of the parameters. Perhaps something else was limiting growth or the pattern seen in these graphs is part of a larger phenomenon that is causative. A few interesting aspects have been noted that need individual consideration.





Growth Tests

It is apparent that the soils have some problems and not the least of which is low yet mostly adequate nutrients for fair growth of the species in the seed mixture. Where the nutrients that were fairly rich in the native soils went, at this point, is a bit of a mystery and could have a multitude of explanations none of which are particularly apparent at this point. The high sulphate content of the soil units 2 and 5 are related but are not present in any other soil units. That may be a large and significant difference that is linked to poor growth of grass in unit 5.

There are actually two aspects that need to be examined - first is the germination of the desired grass plants and the associated question regarding the source of the large amount of weeds in the reclamation area, particularly Kochia. The second aspect is whether the seed will grow in the reclamation soils to an adequate degree that revegetation actually has a chance of occurring. These two tests are done under fairly controlled conditions and can be done at the same time.

For these tests two clean plastic tubs were used. One had about 2 inches of soaked but not dripping peat moss put in the bottom and the other had about 2 inches of sand put in the bottom. Each tub had adequate drainage holes and was lined with landscape cloth to keep the peat moss or sand from coming out of the tub. An equal blend of soil units 2, 4, and 5 were put on top of the sand to a depth of at least 1 ½ inches. The soil was fairly well packed down simulating what would be the case on the site. The topsoil is placed on what remains of the sand deposit that was mined.

Seed taken from the seed bin on the seed drill at the Coal Creek processing plant site was sprinkled over the peat moss and another inch of damp peat moss was placed on top of the seed.

Seeding the tub containing soil was a more delicate process as two purposes were tested at the same time. The two tests were, first, to see if seed even germinated in the soil and, second, what is the best seeding depth in this soil.

Four V-shaped grooves were made in the damp soil. The depth of the grooves were 0.5, 0.75, 1.0, and 1.25 inches deep. These four groves were equally spaced along the long dimension of the tub and about 2 inches apart. In each groove 15 grass seeds were planted at equal distances from each other. Tweezers were used to insure that each seed was placed at the bottom of groove and not touching an adjacent seed. After planting the soil was gently pushed back into the grooves and the soil was watered by misting so as not to stir the seed bed.

Both tubs were placed in the sun as would be the case at the reclamation site, but if the growth media became fairly dry the tubs were watered by misting which was much gentler than would have happened at the site. They were allowed to grow for 14 days. Following are photographs of the results of these two tests.

Seed germination and purity test.

Seed germination and planting depth in reclamation soil (units 2, 4, an 5 equal amts.)

As can be seen the germination and purity test was an outstanding success in an ideal seed germination medium of peat moss. Nearly all the seed germinated and not a single weed plant came up. So the seed is healthy and is not contaminated. That was the most probable outcome and that is what happened.

Sadly, the other test was almost a total failure using exactly the same seed. It did show that planting at a depth of about 1 inch is probably close to ideal for this soil. At that depth about 35% of the seed germinated and produced shoots. (Not bad but far from ideal.) Interestingly, no weeds came up in these soil samples which may indicate the weed seed bank is currently fairly well expended and most of the viable weed seed either came up and produced the weeds on the site or the seed was dead or never germinated or weed seedlings died due to other factors in the soil. But it is important to note that this experiment had to be modified about 7 days into the test and that modification had a great deal to do with the success that did occur, as limited and feeble as it was.

After 7 days the soil became so heavily crusted that any seedlings that had come up were struggling to even stay alive. It was like they were trying grow up through rock that had lithified around them. To keep the test going the soil was watered and then a thin layer of damp peat moss was sprinkled over the top of the soil. This layer, which was no more than 1/4 inch deep, managed to retard the crusting tendency so the seedlings could continue to grow. No seedlings that had come up died and a few new ones appeared over the next week with only one additional watering with misting. Essentially, the peat moss acted as a mulch that kept the soil damp and limited crust formation in the hot sunlight. Obviously many seeds either never germinated or if they did the cotyledons died before they could force themselves through the crust that became so hard after 6 days and two waterings that it could not be dented with a fingernail. With each watering the surface of the soil became a slippery and somewhat slimy mud that was probably composed mostly of clay particles. The slimy texture may be important as will be discussed later.

These results led to the next test which was an examination of the propensity of each of the soil units to form a hard, nearly rock like crust. Obviously, such crusts would be very limiting to the growth of seeds planted at about an inch below the surface. So why did the weed seeds germinate so easily? Those tiny seeds were likely located near the top of the soil layer and weeds such as Kochia are well adapted to grow in almost any soil while the native grasses are not so well adapted unless they are very lucky to be near the surface of the soil and the soil was at least moist most of the time while germination is occurring. The initial conclusion from this is that drill seeding into a soil that forms such intense crusts may not be the proper approach and broadcast seeding immediately after discing or otherwise breaking of the soil would be better to get more seeds near the surface. The alternative to that is to spread a mulch over the soil after planting or planting into a soil that has a great deal of additional organic matter already added. More on these alternatives will be discussed later. But first the crusting issue needs to be examined more closely.

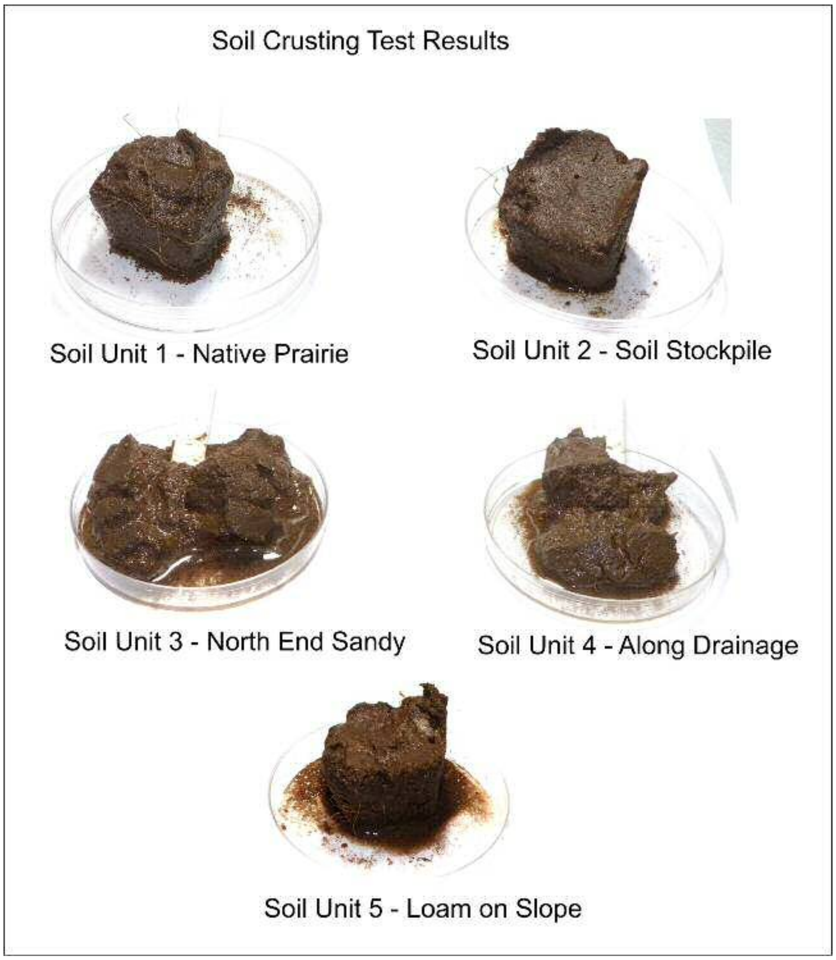
Soil Crusting Issues

To start with here is a photograph of the soil that came out of the planting depth test.

Crusting of the soil in the soil depth test. These chunks of soil (units 2, 4 and 5 combined) are so hard they are difficult to break by hand. It is literally a low grade sedimentary rock. The breaking up of the crust occurred after completion of the seeding depth test.

It is quite apparent from this photo that growing something in this soil will be challenging at best. This kind of crusting is common in many semi-arid soils and is usually due to a high clay content that when it dries forms a crust of some kind. Often bentonitic clays are found in these soils and that can give the soil a slimy texture when wet. Sometimes soils like this are basically a rock when dried. In this hard of a crust there is usually more than just clay particles clinging to each other; microorganisms an also contribute to such crusts. There are actual chemical reactions that have occurred that has altered the nature of the soil. Organic matter is apparent in the texture of some of the hard surfaces and the soil tests found it was about 2%. Not high, but certainly adequate. But in these crusts the organic matter is incorporated into the crust. Fortunately, that organic matter is released when the soil is wetted and turns to mud. Unfortunately with sunshine the soil promptly returns to the poorly consolidated rock that is hostile to grass plants. But this test was a blend of three soil units. What are the individual soil unit's propensities to form crusts? Do they vary or are all of the soil units the same with regard to crust formation?

This is a very simple test. Simply place some soil in a pot, water it, and then let it dry out to see if a crust forms. This was done with small coconut fiber pots. A few tablespoons of each soil unit was placed in separate pots, watered until the water ran out the bottom of the pot, and then allowed to dry. Then using a pair of scissors the pot is cut away so the soil inside can be examined. The result was 5 chunks of soil that were quite solid. So all the soils form crusts. But how hard is the crust and when exposed to water does it remain in a solid mud chunk or does it fall apart? To test that each chunk of soil was placed in a separate petri dish. Then 30 ml of distilled water was added to the petri dish to see what behavior each soil would be when exposed to plenty of water. The following photo of the 5 tests shows what happens.



Each of these tests look a bit like chunks of fudge, but the soils here when wet tend to be that color and texture, especially soil units 2, 4, and 5. Dried out they become a lighter brown to even a light cream color. After absorbing 30 ml of water soil units 1, 2, and 5 remained in a chunky shape although it was not a very strong chunk. More like soft fudge. But units 3 and 4 fell almost completely apart. The latter is what is desired. This shows that from the standpoint of growing vegetation in these soils, units 3 and 4 will likely succeed in grass establishment and growth but soil unit 5 will likely take some time to change its structure so it can easily support plant growth of anything but superficial weeds and it is not likely to support those for long. The Kochia loves a disturbed situation and as unit 5 continues to develop the Kochia will not be very successful growing on it, unless the soil is freshly redisturbed. Redisturbing the soil will likely cause it to go right back to something like it is today - solid, big weed plants. However, over considerable time unit 5 will correct itself, but may never be a good growth medium until it is able to incorporate a great deal of organic matter after years or poor growth.

Discussion and Conclusions

This study of the soils at the Pit Area has defined many possible factors that can explain why the revegetation of portions of this area essentially failed in spite of a prodigious water supply from rain. Soil tests defined the characteristics of each of the soils as well as the natural prairie soils from which the reclamation soils were derived. Yet only one of the 4 reclamation soil units is vaguely similar to the original soils. That was soil unit 3 and that unit has a good possibility of producing the desired revegetation cover. Soil unit 4 which is a blend of units 5 and 3 also shows good promise except there is very little of this unit present on the site. Soil unit 5 which originated from the large, deep, and old stockpile at present shows no potential success due to its physical and chemical characteristics and the fact that it is a shrink-swell soil, possibly bentonitic, that forms very dense crusts when exposed to sunshine and slimy mud when wet. Simulated growth tests showed that, at best, it produces very little grass growth if the soil is mulched. Soil unit 2 which was derived from the base of the soil stockpile unit 5 was taken from is fairly similar to unit 5 and yet the 2 have some differences that are likely important.

The literature (see references) contains studies of how topsoil stockpiling degrades over time with storage and sometimes the degradation is extreme. All of those papers conclude that if one desires the very best vegetation growth, using soil haulback techniques are needed so stockpiling is completely avoided. Stockpiling for even one year considerably degrades topsoils through changes in both the physical and especially the biotic factors. In fact, after 20 years of stockpiling the original soil is of no real value in achieving quick reclamation success and may be worse than using subsoil. Reclamation with those soils is better than starting with crushed rock, but sometimes crushed rock would be easier to revegetate.

The best way to retain some of the quality of the original soil is to limit stockpile depth to no greater than about 2 meters (6 feet), plant the soil with the species one will use in the final revegetation, and put the soil back on the graded land within a couple of years. Cover crops on the stockpiles can also help, but whatever is planted it needs to be deeply rooted so some biological activity is maintained and oxygen can diffuse into the soil to keep it from becoming anaerobic and anoxic when the worst things happen to quality soil.

At this site two of the soil units have evidence that the stockpile was anaerobic for quite some time during its storage. Nearly all of the nitrogen was consumed and the high sulphate content may indicate that anaerobic bacteria were active for quite a long time in the soil. A good deal of that sulphate probably came from organic matter in the soil as it was digested by the anaerobic bacteria. Even though soil unit 5 has an alkaline reaction (pH of 8) that is almost 10 times more alkaline than the native soil. The presence of the sulphate along with iron and other elements would have likely produced small pockets of sulphuric acid laced soil that drastically altered some of the clays in the soil. Such altered clays in soils resist vegetation growth. The fact the soil is a loam is irrelevant to it propensity to lock out grass seeds that are planted at or below the maximum crust depth.

What is needed in a fertile soil is a condition where the soil particles aggregate into tiny masses. In effect that creates a soil with microscopic marbles of clays, silts and organic matter that allow water and air to pass through the soil as well as fine roots and fungi to grow into those tiny voids. Soil unit 4 in particular and unit 3 to a lesser extent allow that to occur and thus grass growth can range from robust to adequate. Thus altering soil unit 5 to be more open and prevent the formation of an impenetrable crust can make it a better reclamation soil. To some extent the tall and vigorous Kochia plants are initiating that process naturally, but if the growth pattern of Kochia follows its usual pattern next year the Kochia plants will be even more abundant but too small to produce roots that penetrate deeply in the soil. Redisturbance could extend the period of heavy Kochia growth and add more organic matter into the soil profile. However, creating a good revegetation environment with prolonged heavy weed growth is not an acceptable method. It works, but there are better ways to accomplish that end goal. Pioneer species in fresh natural disturbances tend to exhibit a weed-like growth pattern that prepares the site for more permanent plants, but introduced and somewhat noxious weeds like Kochia are not pioneer species that launch the establishment of healthy "climax" vegetation assemblages like prairie grasslands. On balance, Kochia and Salsola (the two major tumbleweeds) are nothing but pests that damage productive land.

Nutrients in the reclamation soils are low, but that is to be expected as the soils are disturbed. There are some that believe adding fertilizers will help with the growth and sometimes it does, especially if the growth medium has extremely low nutritional levels. More often though adding fertilizers will primarily help the weeds as weeds are highly opportunistic and will take advantage of the fertilizer well before the desirable vegetation becomes well enough established to actually utilize the fertilizer. Studies have shown that if a natural vegetation is desired then fertilizer works against that goal. Using fertilizer in moderate amounts can be helpful after the desired vegetation is well established. But, in most situations, it is not needed.

Sodium adsorption ratio (SAR) is high in both the native soil and in the similar soil unit 3 but it is low to normal in other soils. This could be a hindrance to growth in soil unit 3 but growth there is showing some good promise. Natural soils in a semi-arid land such this often have a high SAR, but here that factor does not appear to limit the native soil productivity. High SAR can contribute to minor amounts of crusting and some slimy texture, but other factors are usually much more important.

One question that remains is why did the revegetation program work so poorly on this site and so well elsewhere? Without a doubt the heavy rains for 2 months contributed a good deal to the failure. More clayey soils like soil unit 5 probably remained almost saturated or even supersaturated in some places for a long enough period of time that any grass seed that did germinate in that soil died of suffocation. Oxygen cannot be absorbed in saturated soils and roots will quickly die without oxygen, especially young roots. This is especially true if some of the clay has bentonite properties. Leaching of nutrients in more porous soils likely occurred to some extent and that might have contributed to soil tests showing low nutrient levels for some ions. Erosion, especially sheet erosion, was common during the large thunderstorms. That washes seedlings out of the soil and exposes the roots of slightly more established plants. And, once again, if soils in unit 5 had been adversely affected by anaerobic and anoxic conditions in the stockpile then that would have likely been quite detrimental to the grass species that were planted. Those species are dryland species that do not do well in wet soils early in their lives. These species are adapted to dry conditions and have very limited ability to withstand wet soils for a long period of time that is much less than the 2 months that was experienced in 2023.

However, this site is the highest altitude site of all the mining sites at this location. The soils in general here are derived from layers of sediment that primarily washed to the north from the Palmer Divide over the last couple of million years. During that time the environment at the source of the soils likely changed a great deal as ice ages came and went, droughts occurred as well as huge floods impacted the sedimentation. It could be that the subsoil here is different than it is at other locations and that could result in differences in topsoil and subsoil composition. During the mining the cut faces showed a very wide range of material from nearly pure sand to dense pockets of clay while at other mining locations sand was the primary subsoil and parent material in the pit walls. Such situations can be avoided by doing very detailed examination of soil and subsoil conditions and properties prior to mining, but that is rarely done in sand mines. And often adverse conditions are simply missed in such surveys.

In previous reclamation there were situations where old soil stockpiles were used in reclaiming the site, but those soils did not have the dark appearance of the stockpiles here. It could be that there was a fundamental difference between topsoil salvage and conditions there when compared to here. The bottom line is likely that every mining operation and every subsequent reclamation process is different in a large number of ways. I can say that in the course of my involvement with these sand mining pits since the 1990's, I have never seen a soil anywhere on this site that is like Soil Unit 5 here.

In conclusion, the problems on this site may well have been a result of geological processes that occurred in the Pleistocene Epoch that resulted in the deposition of materials here that were quite different from what was deposited at lower elevation mining areas. It also needs to be noted that some of the very fine materials in the soils here came from windblown dust coming from the east and northeast that has mixed with the fluvial deposits originating on the Palmer Divide. It is possible that the undesirable materials here came from far away and were deposited over the entire landscape but subsequently eroded away when the current valleys and drainages were created in post-Pleistocene times. This would leave the higher elevation areas with somewhat different soil profiles than the lower areas where soils were derived from older deposits. Of course, this is conjecture, but the surrounding land shows some evidence that the subsoil conditions on the higher lands differ from those at lower elevations.

In conclusion, the testing and growth experiments show that at least soil unit 5 is clearly problematic showing a shrink-swell characteristic, the dark color produced by anaerobic bacteria in an anoxic condition, a high sulphate content that is a metabolic product of anaerobic bacteria, and either the incorporation of bentonitic clays from the native soils or the formation of such clays during storage of the salvaged soil. Thus, no single cause can be found. The cause of the deleterious properties of soil unit 5 are due to the interaction of multiple factors operating in various ways to produce a soil that has some very serious problems. In time they will all correct themselves, but there are ways to accelerate that correction.

Solutions to the Problems

The main question at hand now is what to do about the inability for portions of this land to support the desired vegetation growth as occurred on all the other reclamation projects at this mining operation. The law requires mined land be returned to a "subsequent beneficial use" and that often includes the establishment of an appropriate vegetation. Obviously that does not include a vegetation cover composed of weeds.

The first step is to determine how much of the revegetation area is affected by heavy crusted soils. That can be done using a GPS while following the boundaries of strongly crusted soils which may include some fringe areas to unit 5 where the components that produce the crusting washed into adjacent soil units and created crusting there. A preliminary estimate is that approximately 1/3 of the total Pit Area potentially has heavily crusted soils. Because treatment is only needed on crusted soils defining that area rather than assuming that is the case may result in a smaller area of treatment. It is already known that not all areas of Soil Unit 5 have crusted soils; just most of it. Once it is known how much and where the crusts are present a plan can be created to treat those areas and leave the non-problematic soils undisturbed.

The customary treatment of heavily crusted soils is to break up the crust and blend in organic matter which can be anything from peat moss to compost to crimped straw or hay. The cost of some organic matter is prohibitively high for large areas but less expensive organic matter is much more affordable. The main idea is to introduce materials that will breakup the solid soil covers that form crusts. That allows water and air to penetrate as well as pathways for plant roots and top growth to become established to reduce the success of the crusting process to seal the top of the soil with what amounts to a low grade limestone rock. Carbonates in the soil are the primary vehicles in producing the crust as not only do they solidify after being wet but they also tend to bond to clay particles and allow them to "fuse" together producing thin layers of shale mixed into the limestone crust. In determining any additional organic matter the existing weed biomass should be considered a potential organic matter. Although discing the weed plants into the soil will introduce a lot of weed seed that will happen anyway if it has not already occurred.

If it is found that all the crusting involves Soil Unit 5 areas and little else then a change in the seed mixture should be considered. The pH of that soil unit is pretty alkaline and replacing some of the grasses in the mixture with grasses that are more tolerant to alkaline conditions (e.g. Alkali

Sacaton) could be a wise decision. Also including a vigorous cover crop could allow some grass to become established well before the perennial grasses can accomplish that end. That also provides some strong competition for the weeds and help reduce the impact of those opportunistic weeds that are very strong competitors against perennials.

Reseeding after the breakup and treatment of the soil should probably be by broadcast seeding rather than drilling. Although the amount of seed is double the drilling rate, broadcasted seed tends to settle in at various depths while drill seeding, a more agricultural process, places seeds at a more uniform depth. Nature reseeds the land using broadcasting rather than drilling and in this case, broadcasting seems to be a better approach so seed is not trapped in or below a crust. Drilling would also work, but with such variable environment broadcasting seems to logically match the growth conditions better.

Treatment of the offending soils should be done not later than March 15 and can be done anytime before then provided the soil is not solidly frozen. Broadcast seeding should be done immediately (within 36 hours) after treating the crusts. Drill seeding can wait a few weeks if necessary.

The problem areas are fixable, but it will take some additional effort and time. It is sad that this happened on the last reclamation project at this mine site, but that does happen sometimes. All the other reclamation work was quite successful. But, it could have been much worse if the pit area had eroded so badly in the rains that the whole project would need to be redone after all the salvaged soils had washed away and were down in Coal Creek somewhere or in the drainage between the site and Coal Creek.

Literature that explores the degradation of topsoil stockpiles:

1. https://www.mdpi.com/2673-6489/2/2/17

This paper explores the effects of stockpile height on the degradation of topsoil stockpiles at two mining operations in British Columbia. Excellent.

2. **Stockpiling disrupts the biological integrity of topsoil for ecological restoration** Justin M. Valliere , Haylee M. D'Agui , Kingsley W. Dixon , Paul G. Nevill , Wei San Wong, Hongtao Zhong, Erik J. Veneklaas; Plant and Soil volume 471, pages 409–426 (2022)

3. **EFFECT OF TOPSOIL STOCKPILING ON SOIL PROPERTIES AND ORGANIC AMENDMENTS ON TREE GROWTH DURING GOLD MINE RECLAMATION IN GHANA;** Paul Kofi Nsiah and W. Schaaf, Journal American Society of Mining and Reclamation, 2019 Vol.8, No.1

4. **Soil Stockpiling for Reclamation and Restoration activities after Mining and Construction**, Patti Strohmayer, Restoration and Reclamation Review, Vol 4, No 7, Spring 1999.

Note: Hard copies of these papers are available from Mark Heifner upon request.

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