AN INNOVATIVE APPROACH TO RECLAIMING PROCESSED OIL SHALE[1]

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Abstract.--A topsoil filled trench in a processed oil shale disposal pile was evaluated as a suitable technique for plant establishment. After 5 years overall plant survival is 87%. Root growth has occurred into the processed shale and although pH has increased slightly there has not been a significant increase in electrical conductivity.

INTRODUCTION

Reclamation research and the development of oil extraction processes for mining oil shale continues in the Uintah Basin of north-eastern Utah. Several processes for extracting the Kerogen (oil) from the shale are being discussed. These vary from an in situ retorting process to underground mining with the raw shale being brought to the surface for retorting. For surface-retorted shale, disposal is an environmental concern because of the vast quantities of processed shale produced.

Reclamation is a difficult undertaking due to the harsh environmental conditions common to the oil shale region. Soils in the area are extremely limited, varying from none in the cliffs and steep slopes of the canyons to alluvial-derived soils in canyon floodplains. The soils are light colored and vary from clayey to fine silts with gravelly phases that are highly calcareous and alkaline in various strata. The coarse-textured soils contain large pore spaces making them conducive to high evaporative moisture losses and low water-holding capacity.

The climate is arid, characterized by cold, snowy winters, hot dry summers, low relative humidity, high evaporation rate and widely fluctuating daily temperatures. Precipitation varies from 5 to 11 inches (127 mm to 280 mm) per year over a major portion of the Utah oil shale area, and is almost equally divided between winter and summer seasons. Winter is the major period for soil moisture accumulation. Summer precipitation comes from short-duration, generally high-intensity thunderstorms. Summer moisture is mainly lost through rapid runoff coupled with rapid evaporation from the moistened soil surface.

The three constraints of limited soil, inadequate precipitation and harsh climatic conditions greatly reduce the alternatives available for reclamation. Normally accepted practices and theories for revegetating western rangelands have limited applicability for establishing a vegetal cover. Even though the White River flows through a portion of the area, water is of such a premium for other uses that it would be very expensive to use for irrigation in vegetative rehabilitation.

Large volumes of shale residue will be created by the retorting process and must be disposed into canyon fills or replaced in mined-out areas. The Paraho process of retorting heats the oil shale to 900°F (482°C), leaving a residual material with high levels of salinity, low organic matter, low levels of available nutrients and a gravelly structure. Paraho processed shale ranges from black to grey in color, fine to gravelly in texture, is biologically sterile and may crumble under pressure. The pH value ranges from 8 to 12 and the electrical conductivity (EC) of the saturation extract is usually in excess of 10 mmho/cm^3.[3] The carbonate salt of magnesium is

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[3]VTN Colorado, Inc. 1977. Final Environmental Baseline Report. Federal Prototype Oil Shale Leasing Program. Tracts Ua and Ub. White River Shale Project.

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of low solubility and is not leached. Sulphate salts of sodium, magnesium and calcium are abundant and sodium sulphate and magnesium sulphate are more readily leached than calcium sulphate as indicated by Wagenet et al. (1982).

Processed shale will gradually break down physically under freezing/thawing and wetting/drying cycles. Richardson et al. (1981) reported that such action chemically weathers the shale and generally reduces the surface pH.

To support the establishment of adapted native plants, improved methods for optimizing the use of limited soil and moisture are needed. A reclamation plan for oil shale disposal areas was proposed that consisted of: planting container-grown, adapted, native shrubs, concentrating available topsoil in trenches constructed on a shale disposal deposit, harvesting water from small catchment slopes onto the topsoiled areas: and applying fertilizer only at low rates as needed by the native species.

The reclamation plan would optimize the use of limited soil available in site preparation for the disposed processed shale pile. All suitable topsoil and subsurface soil material would be stockpiled for later use on the disposal pile surface. The processed shale spoil would be compacted to stabilize the material and to reduce its permeability. As part of the compaction treatment, the surface of the disposed shale pile would be shaped into aesthetically pleasing contour terraces and slopes of various size hillocks, with and without terraces, depending on size, along with meandering drainage channels.

This shaping would provide a catchment slope for harvesting precipitation and a flat terrace for transplanting plants. Trenches approximately 18 inches (46 cm) deep and 24 inches (61 cm) wide, the shape depending on the equipment used, would be dug in the terraces and possibly in the drainage channels. These would be filled with topsoil. The topsoil, being a better medium than shale in which to plant the transplants for successful establishment, would also provide some inoculum of soil microorganisms, a partial source of native plant seeds, and a buffer against high salt concentrations that might develop from the processed shale. Percolation of harvested water through the topsoil in the trench may increase the salinity levels around the root zone but is expected to be within the tolerance range of the transplanted native species. Prior to planting the soil would need to go through a winter moisture accumulation period.

METHODS

To try the aforementioned hypothesis on a field planting basis, studies were conducted on a processed shale pile at Anvil Points, Colorado. An oil shale disposal pile was made available by the Paraho Company to conduct the study. An eight-foot deep pile of approximately 1 acre (0.4 ha) was made of processed shale material that had gone through various temperature treatments for oil extraction. The pile was originally laid down in a series of compaction studies but was topped out with an 18 inch (45 cm) layer of typically retorted shale. The revegetation studies described below were conducted on this pile over a 6 year period starting in 1979.

A year prior to the revegetation studies, two 1:4 slopes approximately 10 ft (3 m) by 120 ft (36 m) were constructed on the shale pile: one slope facing north and the other one south (fig. 1). Trenches of approximately 2 x 2 ft (0.6 m x 0.6 m) were dug at the base of each slope and moisture collection pans were installed for water harvesting.

The following March (1979) both trenches were filled with moist local topsoil (fig. 1). The 10 inch (25 cm) thick layer of soil was mainly a silty clay loam having a pH of 8 to 8.6 and EC of about 1.1 mmho/cm^3. The soil was allowed to settle and to accumulate additional moisture from precipitation and water harvesting from the slopes. In April 1979, five native species were planted in the two trenches at a spacing of 28 inches (70 cm) between plants. This procedure was replicated ten times in each trench.

The five container-grown transplants used were fourwing saltbush (Atriplex canescens, (Pursh) Nutt.), shadscale (A. confertifolia, (Torr and Frm.) Wats), cuneate saltbush (A. cuneta, A. Nels.), greasewood (Sarcobatus vermiculatus (Hook.) Torr., and western wheatgrass (Agropyron smithii, Rydb.).

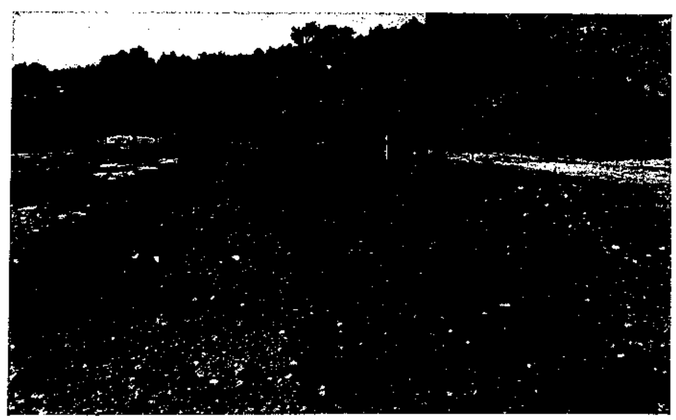

Figure 1.--Topsoil filled trench in processed shale disposal pile prior to planting.

Two additional treatments were initiated on the shale disposal piles. These treatments compared survival and growth of plants in basins created in the shale with responses of plants planted in the flat surface. Basins were about 6 inches (15 cm) deep and 2 feet (60 cm) in diameter. The space between plants was 6.5 ft (2 m) by 8.2 ft (2.5 m). The same species were used in this study as with the two soil-filled trenches. Thus, this portion of the study consisted of two surface treatments with five species replicated five times. Western wheatgrass was grown in 6 inch (15 cm) deep containers, while all others were grown in 12 inch (30 cm) deep containers.

At planting time, all plants received 1 litter of water with a soluble 20-20-20 fertilizer which provided nitrogen at a rate of 30 lb/acre (33.6 kg/ha).

Data obtained from the plants included survival, plant height and crown cover. The amount of vegetal cover was estimated using a 10 inch (0.23 m) square grid divided into 4 inch x 4 inch (10 cm x 10 cm) units. Data were statistically analyzed using a 5 plot analytical design that allowed comparison of species performance over the three treatments.

To monitor any migration of salts in the soil profile, three sites were chosen in each trench for obtaining soil samples on which to analyze soil electrical conductivity (ECe) and pH. Sampling was initiated in June 1981, two years after filling the trenches and continued each June through 1984. A one-to-one soil/wäter ratio was used in making the soil analysis.

During excavations for soil analysis in processed shale, rhizomes and smaller roots of western wheatgrass were noted growing in shale material adjacent to the soil filled trench. Also, shrub roots were observed growing throughout the soil trench profile and in the underlying processed shale material. In 1983 a detailed sampling and analysis was conducted.

Sampling occurred in June 1983 at the north and south trenches. Samples were taken from transects at the ends of both trenches. Therefore, the five species were sampled four times. Soil samples were taken at seven depths under each species. Approximately 1.8 lbs (800 g) of soil were taken at each depth, placed in ziplock bags and returned to the laboratory for analysis. In the laboratory each soil was weighed and the roots extracted. The root material was weighed and a root weight to soil weight was calculated. These ratios were tested by an analysis of variance (ANOVA).

Precipitation has been greater than the average of 11 inches (28 cm) since the initial year of planting. The highest amounts of precipitation amounts occurred in 1983 and 1984 which was near 20 inches (51 cm). In 1981 precipitation was 14.9 inches (38 cm) and in 1982 it was 12 inches (31 cm).

RESULTS

Plant Survival

The survival, height, and cover of each living plant on the shale disposal pile at Anvil Points have been estimated annually since June of 1980 (table 1). In the soil trench plantings, fourwing saltbush and greasewood show 100% survival. Western wheatgrass suffered only 10% mortality in the south trench. Shadscale and cuneate saltbush suffered the greatest overall mortality in the two soil trenches, 10% and 10% in the north trench and 30% and 20% in the south trench, respectively.

The basin plantings show the highest mortality of the different establishment techniques tested on the Anvil Points oil shale disposal site. An overall survival of 64% was recorded for the basin plantings in June of 1984. Greasewood (100%), fourwing

Table 1.--Mortality of plants grown on oil shale disposal pile at Anvil Points, Colorado over a 5 year period.

Species	No. Planted	1980	1981	1982	1983	1984	Total	% Survival
Fourwing Saltbush	30	0	0	1	0	0	1	97
Shadscale	30	6	3	0	0	4	13	57
Cuneate Saltbush	30	2	1	1	1	0	5	83
Greasewood	32	0	0	0	0	0	0	100
Western Wheatgrass	30	1	0	0	0	0	1	97
TOTALS	152	9	4	2	1	4	20	87

saltbush, and western wheatgrass (both 80%) have the highest percentage survival and cuneate saltbush (60%) and shadscale (0%) the lowest. Shadscale mortalities in the basin plantings occurred during the first two years of the study.

The flat plantings had very little change in survival since 1981. There was a single loss of shadscale in 1984. Survival rates were 100% for all species except shadscale, which was 60%.

Mortality by year as shown in table 1, indicates that the greatest plant mortality occurred during the first year. This may be attributable to an intensive spring rainfall in 1980 that flooded the basin plantings.

Plant Height and Cover

A summary and analysis of the data for height and cover collected on the plantings at Anvil Points since 1979 is presented in table 2. Several species have shown remarkable growth under the various treatments (fig. 2). Fourwing saltbush, cuneate saltbush, western wheatgrass, and greasewood have shown the best growth of the species used in the studies conducted at Anvil Points. Shadscale plants that have survived have shown good growth. Cuneate saltbush has showed a decrease in overall cover in the last year. The height and cover values for the 5 species tested at Anvil Points is given in table 3 for the three major treatments. The plants in the trenches have shown slightly greater height values when compared to the basin and flat plantings. However, the cover values for the two trenches are almost double those for the basin and flat plantings, indicating that topsoil trench technique does create an environment conducive to greater plant growth than would be experienced with direct plantings into the processed shale.

Table 3.--Average height (ht) in inches and cover (cvr) 4"x4" grids by treatment for plants grown in the oil shale disposal pile for five years.

Species		N-Trench	S-Trench	Basin	Flat
Fourwing Saltbush	ht	31	31	31	30
	cvr	28	38	40	33
Shadscale	ht	7	9	0	10
	cvr	8	5	0	11
Cuneate Saltbush	ht	10	12	8	15
	cvr	25	21	13	37
Greasewood	ht	47	47	31	24
	cvr	73	72	32	24
Western Wheatgrass	ht	24	29	29	20
	cvr	46	83	9	2
Average	ht	25.2	25.7	19.7	19.8
	cvr	37.2	43.4	19.4	21.4

Figure 2.--Plants growing in topsoil filled trench after five years at Anvil Points, Colorado.

Table 2.--Average height (ht) in inches and cover (cvr) number of 4" x 4" grids of plants growing in oil shale disposal pile over a 5 year period.

Species		1979	1980	1981	1982	1983	1984
Fourwing Saltbush	ht	12	14	23	26	28	31
	cvr	--	9	16	23	35	35
Shadscale	ht	3	3	5	5	7	9
	cvr	--	1	1	4	5	8
Cuneate Saltbush	ht	5	5	7	7	11	11
	cvr	--	3	8	14	26	24
Greasewood	ht	10	13	20	25	29	37
	cvr	--	4	13	21	35	50
Western Wheatgrass	ht	8	9	28	13	20	26
	cvr	--	1	78	10	27	35

MIGRATION OF SALTS

Beginning in 1981 soil samples were collected from various depths in the topsoil trench and in the adjacent shale. The samples were analyzed for pH and EC. The summary for pH is shown in table 4. There was a sustained increase in pH from 1981-1983, but the 1984 readings are lower than the 1983 values. The 1984 figure is well within the tolerance levels for all the species growing in the trench and it would appear that the pH may level off in future years. The ANOVA also shows significant differences among the depths sampled. The pH of the topsoil samples were all significantly different from the other topsoil samples.

The ANOVA for EC shows that there were no significant differences between years. The 1984 average was the lowest of the years samples (table 4). There were significant differences between depths with the topsoil samples having lower EC values than most of the shale samples. The surface shale sample which was extremely high in 1983 averaging 15.8 mmhos/cm^3, had a dramatic decline to only 2.2 mmhos/cm^3. The topsoil EC values are well within the range of tolerance for species that would be used for reclamation.

The general trend with time appears to show an initial increase in salts then a leveling off. This is shown by the increase of pH from 1981 to 1983 with a decline in 1984. The other measure of salts, EC, shows no significant increases over the four years it has been monitored.

ROOT BIOMASS

A detailed sampling of the two soil trenches was made in June of 1983 to evaluate the penetration of the roots of the various plants into the soil trench and into the adjacent shale material. The results are shown in table 5. Western wheatgrass had the highest average root biomass with .3982 g/1000 g of soil while greasewood had the lowest at .1950 g/1000 g soil. However, none of the root biomass values for the five species were significantly different. ANOVA results comparing root biomass at the various depths did show significant differences. The surface samples (shale and soil) and the 60 cm shale samples had the highest root weights (.4077, .3807, and 5521 g/1000 g soil, respectively). Of the total root biomass western wheatgrass accounted for 31%, fourwing saltbush 22%, shadscale 17%, cuneate saltbush 16% and greasewood 15%. The majority of the root biomass from western wheatgrass occurred at the 60 cm shale depth.

The root biomass in the 60 cm shale sample occurred just above or right at the compacted shale layer and biomass would decrease rapidly at lower depths (fig. 3). This suggests that a compacted shale zone could be used to restrict water movement into a shale disposal pile. Water accumulating at the interface could be utilized by deep rooted shrubs and may actually function as a perched water table. Researchers have been concerned that roots would stay within the soil trench and not penetrate the shale, however, this data supplies sufficient evidence that roots will venture into the shale particularly

Table 4.--pH and EC values from different depths in the topsoil trenches at Anvil Points for the period from 1981-1984. Values followed by common letters are not significantly different as tested by ANOVA and Fisher's LSD (F-value ≤.005, α ≤.05).

pH

Sample depth	1981	1982	1983	1984
0-2 cm topsoil	7.90	8.08	8.60	8.29[b]
15 cm topsoil	7.41	7.78	8.35	8.07[a]
30 cm topsoil	7.52	7.76	8.25	7.99[a]
45 cm topsoil	7.61	7.89	8.33	7.97[a]
0-2 cm shale	8.72	8.55	8.70	8.31[bc]
15 cm shale	8.11	8.50	8.67	8.49[cd]
60 cm shale	8.14	8.70	8.77	8.65[d]
Average	7.92[a]	8.18[b]	8.53[c]	8.25[b]

EC

Sample depth	1981	1982	1983	1984
0-2 cm topsoil	4.4	1.9	1.9	1.0[a]
15 cm topsoil	2.0	3.4	3.2	2.4[a]
30 cm topsoil	3.0	4.8	3.0	5.3[b]
45 cm topsoil	3.7	5.1	5.0	5.7[ab]
0-2 cm shale	16.7	17.9	14.1	2.2[a]
15 cm shale	4.5	8.9	5.5	1.6[a]
60 cm shale	6.2	7.2	8.1	7.6[c]
Average	5.8[a]	7.0[a]	5.8[a]	3.7[a]

Table 5.--Root weights (g) per 100 g of soil taken from Anvil Points soil trenches in June of 1983. Values followed by common letters are not significantly different as tested by ANOVA and LSD ($F \leq .01$ and $\alpha \leq .05$).

Depth	Western Wheatgrass	Fourwing Saltbush	Shadscale	Cuneate Saltbush	Greasewood	Average
Topsoil						
0-2 cm	.1183	.0758	.0290	.1051	.0212	$.0699^{a}$
15 cm	.4715	.6450	.3350	.1506	.3015	$.3807^{bc}$
30 cm	.3760	.1893	.1003	.1763	.1386	$.1760^{ab}$
45 cm	.1656	.1138	.2146	.1794	.3153	$.1977^{ab}$
Shale						
0-2 cm	.0206	.0084	.0214	.0160	.0712	$.0275^{a}$
15 cm	.5520	.5489	.3413	.3020	.2941	$.4077^{bc}$
60 cm	1.1836	.3960	.4632	.4940	.2236	$.5521^{c}$
Average	$.3982^{a}$	$.2825^{a}$	$.2150^{a}$	$.2034^{a}$	$.1951^{a}$	

if the shale is not compacted. The root biomass at the 15 cm depth was not different between the soil and shale samples.

Figure 3.--Roots of vascular plants growing in topsoil filled trench and penetrating processed shale. Anvil Points, Colorado.

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