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Revegetating Processed Oil Shale and Coal Spoils on Semi-Arid Lands

Interim Report

Interagency Energy/Environment R&D Program Report

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REVEGETATING PROCESSED OIL SHALE AND COAL SPOILS ON SEMI-ARID LANDS
Interim Report

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The increased demand for energy within the United States will ultimately lead to an increased utilization of coal and oil shale in the semi-arid regions of our country. Coal production from the Western states has already increased significantly. In order to meet the current needs of those charged with revegetating the land disturbed by surface mining, an interim report has been prepared on the results of Forest Service studies instead of waiting until the research is completed several years from now. The results of this work should provide the reclamation specialist of a mining company or control agency with the tools to assist him in the establishment of a good ground cover to minimize the environmental problem from surface mining.

For further information contact Neil Frischknecht or Robert Ferguson, Intermountain Forest and Range Experiment Station, Provo, Utah or the Extraction Technology Branch of the Resource Extraction and Handling Division.

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ABSTRACT

Early revegetation studies sponsored by Colony Development Operation (1965-1973) showed that selected grasses and other plants can be successfully established on TOSCO II processed oil shale following leaching 62 percent of the soluble salts with 48 to 60 inches (1.2 to 1.5 m) of water.

Forest Service revegetation studies on TOSCO II processed shale (beginning in 1976) at Sand Wash, eastern Utah, within the salt desert shrub zone and at Davis Gulch, western Colorado, in the upper mountain brush zone, involved the use of amendments on processed shale without leaching salts.

At Sand Wash, seven species of the Chenopodiaceae family were far superior to other species on processed shale with or without supplementary water or a covering of soil. Where at least 1 foot (30 cm) of soil covered processed shale, an additional eight species showed good survival. Drip irrigation greatly benefited overall plant establishment on processed shale, whereas little improvement was seen from the same amount of water where depth of soil over processed shale was 1 foot (30 cm) or more.

At Davis Gulch, a covering of 8 to 12 inches (20 to 30 cm) of topsoil over processed shale greatly increased survival and growth of container-grown plants compared to a 2- to 3-inch (5 to 7.5 cm) covering of broken rock fragments or a cover of barley straw crimped into the processed shale. Through the third growing season at least, plant survival and growth on gravelly subsoil from the site was about equal to that where topsoil covered processed shale.

On a simulated mining tract at the Alton coal field, southern Utah, grass hay rotovated 8 inches (20 cm) deep into the soil increased seedling survival. Where several overburden materials were tested as growing media for plants, sandy loams and loam topsoils gave best results while a dark-colored carbonaceous shale material (clay loam) lying immediately above the coal seam gave better results than the poorest topsoil (silty clay).

These studies showed that where fall planting of seeds on arid and semi-arid sites often fails, spring planting of container-grown plants can ensure successful revegetation of disposal areas.

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ACKNOWLEDGMENTS

Studies on revegetation of processed oil shale reported herein were conducted in cooperation with The Oil Shale Company (TOSCO) which provided the processed shale for experiments. Studies at the Alton coal field were conducted in cooperation with the Bureau of Land Management, USDI (EMRIA), and Utah International Inc. Cooperators provided lands on which to conduct field studies, financial assistance, and technical review of study plans.

The assistance of TOSCO employees, Edward B. Baker, Joe M. Merino, and David L. Craig, in the establishment and maintenance of the study areas at Davis Gulch and Sand Wash is gratefully acknowledged.

David B. Crouch, Senior Environmental Engineer, and Robert W. Poyser, Environmental Engineer, Utah International Inc., participated in planning one of the studies on the Alton coal field.

Special thanks are given to Larry G. Sip, Resource Area Manager, Bureau of Land Management, Kanab, Utah, for assistance with various details pertaining to the field work at the Alton site.

SECTION 1

PROCESSED OIL SHALE

INTRODUCTION

Oil shale lands occur primarily in the Green River geological formation in Utah, Colorado, and Wyoming. The area involved encompasses some 25,000 square miles (64,750 km^2) or 16 million acres (6.5 million ha). Of this, approximately 17,000 square miles (44,030 km^2) or 11 million acres (4.5 million ha) is believed to contain shale suitable for commercial development. This is the world's largest known area of oil reserves, estimated to contain some 600 billion barrels of oil. These shales underlie a variety of topographical areas including high plateaus, isolated mesas, and broad basins where average annual precipitation ranges from an estimated 20 inches (51 cm) on the high plateaus to 6 inches (15 cm) or less in the broad basins.

Approximately 72 percent of the oil shale deposits occur on federally owned lands, where an estimated 80 percent of the oil shale reserves lie. Also, each of the three States involved, Utah in particular, own sizeable areas of oil shale lands; other areas are owned privately, mainly by oil companies. These lands are presently used for grazing of domestic livestock, wildlife habitat, hunting, recreation, oil and gas, and other extractive mineral operations.

Over the years, several patented processes have been developed for extracting oil from shale, including both in situ retorting and underground mining followed by surface retorting. The latter process recovers greater amounts of oil, but disposal of the processed shale is an environmental concern. Disposal embankments will require revegetation. Processed shale from the TOSCO II retorting process was used in the revegetation studies described in this report.

The generally accepted practices and theories for revegetating western ranges are inapplicable for establishing plants on raw, processed oil shale, which has been heated up to 900°F (482°C) or higher in the oil extraction process. High levels of salinity, low organic matter, and low levels of available nutrients in processed shale require amendments before successful revegetation can take place. Aridity of many potential disposal sites adds greatly to the problem.

Early research on processed oil shale in Colorado (described later) shows that successful revegetation with grasses is possible following heavy leaching of salts, but subsequent capillary rise of salt to the surface presents another problem. The discovery of ways to revegetate spoils using a minimum amount of water in addition to breaking the capillary rise of salts is important. An especially difficult problem is the development of methods to ensure continuity of vegetative cover following drought which is common in the arid regions involved. Rehabilitation measures on disturbed areas and spoil materials must enhance the environment along with establishing vegetative cover.

REVIEW OF PRESENT KNOWLEDGE

Disposal of Processed Shale

At present, surface disposal is the most efficient method of handling processed shale (Merino and Crookston 1977). Studies on disposal embankments of TOSCO II processed shale by Heley and Terrell (1974) for Colony Development Operation revealed that compaction by haul rigs probably would be adequate for stability of the major portion of disposed materials. This provides a bulk density of around 85 pounds per cubic foot (1,362 kg/m^2). The moisture requirement for placement and compaction at that bulk density is approximately 13 percent. At that moisture level, dust can be easily controlled, and the grid roller providing optimum compaction leaves a packed surface which retains precipitation and resists dusting. Surface wetting causes a crust to form on the material to aid in longer-term dust prevention.

Other findings are: (1) that a segmented wheel, self-propelled machine provides maximum compaction and lowest overall operation cost; (2) an 18-inch- (46 cm) thick layer should be used in all areas; (3) a spreading and leveling blade should be used prior to any compaction; (4) frontal slopes of disposal piles should not exceed 15 degrees (preferably 4:1) to allow equipment operation and revegetation; and (5) standing water should not be permitted on working surfaces.

Laboratory tests conducted by Dames and Moore (1974) for the Colony Development Operation showed that processed shale lost significant strength upon saturation. Considering that a small portion of the frontal face of disposal piles could become saturated at various periods during the year, the investigators recommended that benched slopes of 25 percent (4 horizontal to 1 vertical) be used rather than the proposed slopes of 33 percent (3:1). They also recommended that slopes be benched at every 50-foot- (15 m) height interval and that the width of benches be approximately 20 feet (6 m).

Earlier Revegetation Studies on Processed Oil Shale

Several investigators studied revegetation of processed (spent) oil shale for Colony Development Operation during the period 1965-1973. Brief summaries of those studies follow:

Initial Field Study--

A field study in 1965 described by Haberman (1973) involved growing four grasses on five different media: (1) soil, (2) shale ash, (3) processed shale, (4) mixture of shale ash with soil, and (5) mixture of processed shale with soil. Shale ash was left after spent shale had been ignited at higher temperatures to utilize energy from remaining carbon. The processed shale and mixtures of processed shale with soil proved better growing media for plants than plain shale ash alone or in a mixture. Tall wheatgrass[1] produced more growth than other plant species tested.

Chemical and Physical Properties Affecting Plant Growth--

Schmell and McCaslin (1973) found that spent shales from the TOSCO and Bureau of Mines retorts were highly saline, highly alkaline, low in available P and N, and questionable in available K. In the greenhouse, tall wheatgrass and Russian wildrye showed poor growth in spent shale, and mixtures of up to 50 percent shale and 50 percent soil produced far less plant growth than would be acceptable in the field. Following leaching of about 62 percent of the soluble salts from spent shale, tall wheatgrass grew well when both nitrogen and phosphorous were applied, but additional potassium and micronutrients did not affect plant yields. Leaching of 62 percent of the soluble salts reduced the conductivity of saturation extract below 4 mmhos/cm. The dark-colored, crushed, spent shale in a glasshouse reached temperatures of 140° to 150°F (60°C to 66°C) at about 1/2-inch (1.3 cm) depth, which can be lethal for germinating seeds.

Studies by Berg (1973) which supplement and confirm the above findings are summarized as follows:

1. The texture of TOSCO II processed shale is a silt loam having a moderate water infiltration rate unless compaction occurs, in which case the infiltration rate would be slow.

2. The pH of samples taken from plot studies was within the range suitable for plant growth.

[1]Scientific names and common names are shown in the appendix.

3. Soluble salt content was very high in processed shale and also from some samples taken from plot and greenhouse studies.

4. Nitrogen available to plants as NO_3 and NH_4 was very low in non-fertilized processed shale, suggesting that vegetation grown in processed shale would probably require long-term nitrogen fertilization. Phosphorous levels were low and potassium levels were moderate to low.

5. Zinc, iron, copper, and manganese in processed shale appeared to be adequate for plant growth.

6. Boron may occur in toxic quantities in processed shale, but there was no evidence of toxicity in field plots. Boron appears to be leachable which would reduce its toxicity.

7. The sodium adsorption ratio decreases with leaching. Without leaching, the sodium content is high in processed shale.

Effects of Amendments--

From extensive greenhouse studies conducted in 1968, 1969, and 1970, Schaal (1973) found that seed germination occurred in spent shale, but growth was greatly retarded and plants died before reaching maturity. Sawdust and peat amendments produced limited improved growth; however, nitric acid (1 percent) promoted good growth. Phosphoric acid produced limited improved plant growth, but plant color was pale green. A weekly addition of a complete fertilizer promoted growth equal to plants in normal soil. In these studies plants were watered to prevent wilting and the excess water drained out through cracks in the bottom of wooden flats.

In 1968-1969, field experiments by Schaal (1973) at Colony Development Operations' semi-works site in Parachute Creek, Colorado, showed that leached processed shale, mulched with peat and sawdust and fertilized, provided an excellent medium for growth of tall wheatgrass and Russian wildrye. Engelmann spruce, juniper, large- and small-leaf cottonwood, Chinese elm, golden willow, sagebrush, and penstemon all grew well in this medium; however, the longevity of these plant species is not known.

On plots in the middle fork of Parachute Creek, Berg (1973) observed no differences in plant growth from sawdust amendments on processed shale at rates of 10, 20, and 40 tons per acre (22, 44, and 88 metric tons/ha). Also, no differences in plant growth were noted from the six following mulch treatments: (1) none, (2) unprocessed crushed oil shale, (3) talus composed of flat rock fragments 1 inch (2.5 cm) and less in diameter, (4) jute mesh, (5) barley straw, and (6) talus, over talus that had been mixed 3 inches (7.5 cm) deep into spent shale. The better-than-expected growth in the unmulched plot was attributed to careful and frequent sprinkling with water during germination and seedling establishment along with partial shade and a northeast exposure. Water application was judged to be between 47 and 60 inches (119 and 152 cm) during the 16-month period, May 1971 through September 1972. This would allow between 7 and 20 inches (18 and 51 cm) of water for leaching of salts above the potential evapotransspiration of 40 inches (101 cm) for the same period.

Following leaching, in September 1972, the saturation extract conductivity of the processed shale profile showed the following range: 1.9 mmhos/cm at 0-4 inches (0-10 cm), 4.1 mmhos/cm at 8-12 inches (20-30 cm), 7.5 mmhos/cm at 12-16 inches (30-41 cm) and 11.0 mmhos/cm at 20-25 inches (51-63 cm). By comparison, a bulk sample of unleached processed shale has a saturation extract conductivity of 13.0 mmhos/cm.

In this study, Berg observed that two native wheatgrasses (western, streambank) and three introduced wheatgrasses (fairway, pubescent, tall) along with sweetclover, made excellent early growth after planting in 1971. Indian ricegrass, sand dropseed, hard fescue, and Russian wildrye were somewhat slower establishing and all except Indian ricegrass formed good ground cover the following years. Thirty bare-root transplants each of Rocky Mountain juniper and skunkbush sumac showed 71 and 72 percent survival, respectively, during the first year; however, considerable mouse damage occurred in 1972, which was attributed to the excelsior mat that was used as mulch.

In a cooperative study at Parachute Creek between the Soil Conservation Service and Colony Development Operation, Merkel (1973) observed very little plant survival on pure processed shale, mixed success on 50/50 processed shale-soil mixture, and excellent survival and growth on native soil. The study involved planting seeds of 11 grasses and 4 shrubs, plus transplants of 12 shrub species. All plots were mulched with excelsior material and fertilized with 459 pounds per acre (515 kg/ha) of 34-0-0 fertilizer plus 540 pounds per acre (605 kg/ha) of 0-45-0 fertilizer. Water was applied to transplants at the July planting and once per week thereafter until August rains came.

Three shrubs exhibited 60 percent or better survival on processed shale: New Mexico locust, New Mexico forestiera, and Russian olive. Exhibiting somewhat lower survival (40 percent) on processed shale were fourwing saltbush and skunkbush sumac.

FOREST SERVICE STUDIES IN UTAH AND COLORADO

Greenhouse studies on TOSCO II processed shale were begun by the Intermountain Forest and Range Experiment Station in the winter of 1975-1976, followed by field studies in the spring of 1976. A greenhouse bioassay study of five nonmine waste amendments on processed shale showed that sewage sludge had significantly greater beneficial effects on seed germination and plant growth than wood fiber, straw, sugar beet pulp, or cow manure (Williams and Packer 1977). Sewage sludge apparently ties up the sodium salts in spent shale and was found to be a beneficial amendment even in the absence of leaching with water. Three of the other four amendments (wood fiber, straw, and cow manure) aided plant survival and growth, especially when combined with leaching. Sugar beet pulp was not beneficial, nor was the addition of sulfur. As expected, seed germination and plant growth were both improved as a result of leaching spent shale with water.

Field studies were established at two main locations: (1) Sand Wash, in the salt desert shrub vegetation type, southwest of Vernal, Utah, and (2) Davis Gulch, at the head of Parachute Creek, on the Roan Plateau in Western Colorado.

Effects of Drip Irrigation and Depth of Soil Over Processed Shale

The first study at Sand Wash, Utah, had the following objectives: (1) to evaluate effects of soil depth over processed shale, (2) to evaluate effects of drip irrigation, and (3) to evaluate response of individual species.

In late April 1976, approximately 375 tons (340 metric tons) of TOSCO II processed oil shale were transported by truck from Colony Development Operations at Parachute Creek, Colorado, to the Sand Wash area approximately 50 miles (80 km) southwest of Vernal, Utah, for revegetation trials. (The Sand Wash site is on land owned by the State of Utah and leased to TOSCO, with whom the Intermountain Station has a cooperative agreement).

At the experimental site, spent shale was spread and compacted approximately 2-1/2 feet (76 cm) deep in a V-shaped ravine that had been modified for this purpose. This area was 40 feet (12 m) wide and 75 feet (23 m) long. Soil previously removed in shaping the area was spread over the center portion of the spent shale in the form of a double-edged wedge so that replaced soil varied in depth from zero at the two outside edges to approximately 3 feet (91 cm) deep in the center (Figure 1).

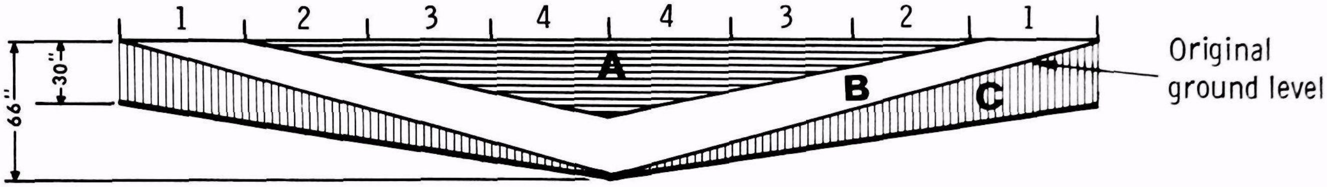


Figure 1. Cross-section diagram of experimental site depicting cut in native soil (C), processed oil shale fill (B&C), and native soil fill (A).

Treatments on strips 5 feet (150 cm) wide and 75 feet (23 m) long extending from both outside edges toward the center of the 40-foot (12 m) area are depicted in Figure 1, as follows: (1) spent shale with sewage sludge amendment and straw mulch; (2) spent shale covered with 0 to 1 foot (0 to 30 cm) of replaced soil; (3) spent shale covered with 1 to 2 feet (30 to 60 cm) of replaced soil; and (4) spent shale covered with 2 to 3 feet (60 to 90 cm) of replaced soil.

The sewage sludge was spread on the two outside 5-foot (150 cm) strips of processed shale to a depth of 1 to 3 inches (2.5 to 7.5 cm) and roto-tilled to a depth of about 4 inches (10 cm).

On May 4 to 5, 1976, 20 species of container-grown plants were planted in plots 5 feet (150 cm) long and 2-1/2 feet (75 cm) wide with four replications on each treatment. A randomized-block, split-plot design was used, with one-half of the plots to receive supplementary water by drip irrigation (Figure 2). Plots contained two rows of four plants each. Rows were spaced 15 inches (37.5 cm) apart, as were the four plants within rows.

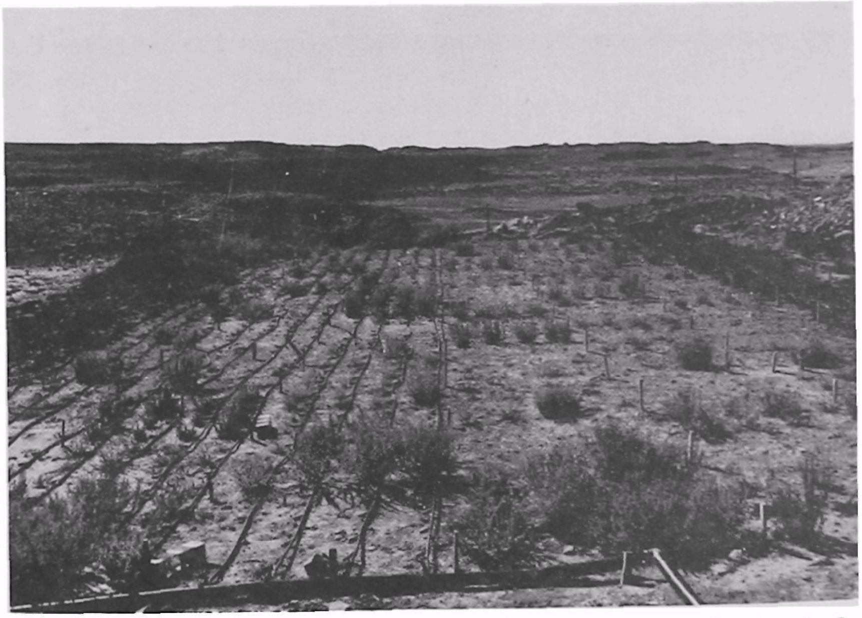


Figure 2. Differential plant survival on both drip-irrigated and non-irrigated plots at end of the second growing season at Sand Wash.

Prior to establishing the drip irrigation system in 1976, approximately 1 quart (0.95 liter) of water was added to each plant in all four blocks (replications) at the time of planting on May 4 and again on May 18 and June 2. Initial water was necessary to aid establishment of all plants because site preparation in the spring did not allow for undisturbed on-site accumulation of winter moisture. Thereafter, water was added to only two blocks (replications) through emitters that allowed each plant to receive water at the rate of 1 gallon (3.8 liters) per hour, as follows:

1976

July 7: 20 minutes; July 30: 15 minutes; August 15: 30 minutes; September 3: 15 minutes; September 20: 30 minutes.

1977

May 5: 15 minutes; September 23: 15 minutes.

1978

No supplementary water.

The amount of precipitation received at the study site from the date of planting through December 1976 is unknown. At Ouray, 12 miles (19 km) to the northwest, total precipitation for the period was 1.95 inches (5 cm). Precipitation during 1977 was 6.36 inches (16.2 cm) on this site. Precipitation for the first 6 months of 1978 was 2.34 inches (5.9 cm).

In the spring of 1977, plants that received supplementary water (two blocks) by drip irrigation the previous summer, were making new growth earlier than plants not irrigated (two blocks).

Most plants showed good survival over winter on both irrigated and nonirrigated plots, with the following exceptions: narrowleaf low rabbitbrush, inland saltgrass, and Swainsonpea showed heavy mortality on nonirrigated plots; cattle saltbush showed heavy mortality on both irrigated and nonirrigated plots; big saltbush and blue saltbush showed heavy winter mortality on irrigated plots, and mortality continued over summer. The higher winter mortality for two species on irrigated plots suggests that the supplementary water in the summer of 1976 did not allow these plants to harden against frost, which is similar in effect to not hardening against drought.

By the end of the second growing season (October 1977), five native shrub species and two introduced species were thriving under all conditions ranging from processed shale without a soil covering to soil covering 0 to 3 feet (0 to 0.91 m) deep over processed shale. The endemics included Gardner saltbush, broadscale saltbush, Bonneville saltbush, short-winged saltbush, and fourwing saltbush. The introduced species were Mediterranean camphorfume and prostrate summer cypress. Survival on processed oil shale having no soil covering was slightly higher on irrigated plots, but where soil covered the shale, survival was as good on nonirrigated as on irrigated plots. Plants were generally taller on drip-irrigated plots.

A second group of eight species showed very poor survival on the processed shale itself, but varying success where soil covered shale, depending upon the depth of covering. Three of the eight species (winterfat, plumed whitesage, and inland saltgrass) showed good survival on plots having some covering of soil over spent shale. Height growth increased with soil depth, at least to the 1-foot (30 cm) depth. For the two shrubs, survival was as good on nonirrigated plots as on irrigated plots. However, saltgrass showed much better survival on irrigated plots under all conditions of soil covering.

Five species showing little or no survival where the soil covering was less than 1 foot (30 cm) thick over spent shale included: black sagebrush, pygmy sagebrush, narrowleaf low rabbitbrush, scarlet globemallow, and Swainsonpea. Where soil covering was at least 1 foot (30 cm) thick, survival of these species was as good on nonirrigated plots as on irrigated plots. (Seed of the first four species in this group came from the Desert Experimental Range where annual precipitation averaged 6.8 inches (17.3 cm). Swainsonpea is an introduced legume from Russia.)

At the end of the 1977 growing season, most plants of Mediterranean camphorfume and scarlet globemallow had been eaten by cottontail rabbits entering the area where water had washed a small hole under the fence. Fourwing saltbush also showed some damage caused by rabbits. One plant of Mediterranean camphorfume (Figure 3) that was not grazed by rabbits grew to a height of 26 inches (66 cm).

Figure 3. Single plant of Mediterranean camphorfume is 26 inches high on a plot where soil is 2 feet deep over processed shale (other plants of this species were browsed by rabbits).

Exceptionally good growth of several species occurred in the second growing season (1977) where runoff water from a high intensity summer storm ponded along the edge of the processed shale plot. Flower stalks of prostrate summer cypress grew to 56 inches (142 cm) high and fourwing saltbush to 32 inches (81 cm) (Figure 4).

A

B

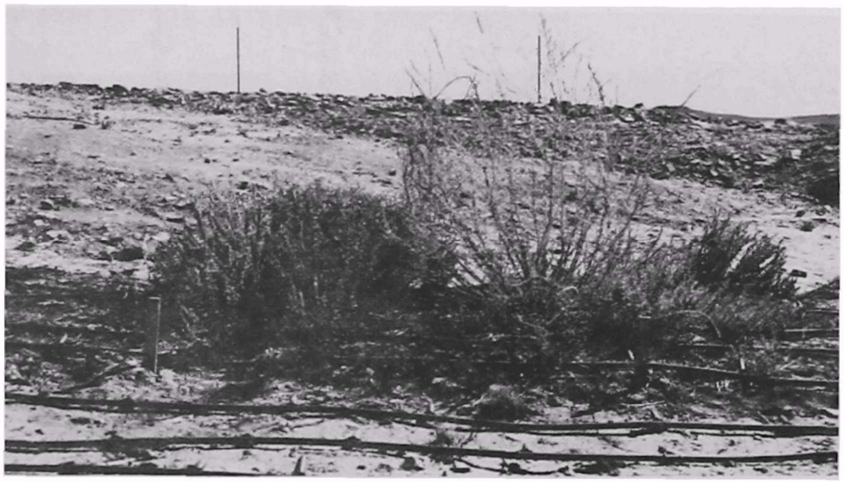


Figure 4. (A) Fourwing saltbush plant on irrigated processed shale grew to a height of 32 inches (81 cm) in second growing season.

(B) Prostrate summer cypress is tallest species with Bonneville saltbush to left and Gardner saltbush to right.

Comparison of Fall-Planted Seeds with Spring-Planted Container-Grown Plants

The second study at Sand Wash had the following objectives:

(1) To evaluate response of fall-planted seeds and spring-planted container-grown plants of the same species;

(2) To evaluate differences in types of replaced overburden; and

(3) To evaluate differences in growth and development of the various species.

In late September 1976, an additional 475 tons (431 metric tons) of processed shale were transported by truck from the Colony Development site in Parachute Creek, Colorado, to a second experimental site at Sand Wash. Results from the planting of container-grown stock in the first study had shown best results from soil-covered processed shale. Therefore, the top 8 to 12 inches (20 to 30 cm) of soil from an area 50 feet (15 m) wide and 100 feet (30 m) long at the end of a small basin was stockpiled, and the area was leveled for placement of the processed shale. The processed shale was spread over the area to a depth of approximately 30 inches (76 cm). Washed gravel about 1 inch (2.5 cm) in size was spread to a depth of 6 inches (15 cm) over half of the area covered by processed shale. This in turn was covered with 1 foot (30 cm) of native soil. Native soil was spread over the other half of the processed shale to a depth of 18 inches (46 cm).

On December 14, 1976, seeds of 25 shrubs were planted in single rows and replicated four times for comparison with container-grown plants of the same species grown in the greenhouse. Plots were 5 feet (1.5 m) wide and 10 feet (3 m) long for accommodating one row of fall-planted seed and one row of container-grown plants. Container-grown plants of 25 species grown in the greenhouse since January 1977 were planted on the new study site at Sand Wash, May 3, 1977. Rows and plants within rows were spaced 30 inches (76 cm) apart. This is twice the distance between plants in the study established on processed shale at Sand Wash in early May 1976.

Because of drought in the winter of 1976-1977, only sparse germination resulted from seeds sown the previous fall. When counts were made in May 1977, 18 of the 25 species seeded showed some seedlings present, and 14 of this number showed some surviving plants at the end of the 1977 growing season.

In contrast to low survival of plants from seed, survival was excellent for nearly all container-grown plants put out May 3, 1977. Supplementary water was added to these plants on two occasions, but most pronounced growth occurred in the center of the experimental area where runoff water had puddled from high intensity storms. In the puddled area, some plants grew as high as 24 inches (61 cm) in the first growing season. One plant that came from seed of a natural hybrid between fourwing saltbush and Castle Valley "clover" grew to a height of 20 inches (51 cm) with a crown spread of 30 inches (76 cm). Results showed that where supplementary water was available, plants made excellent growth in the area, even in the first growing season.

Effects of Soil Amendments on Growth of Selected Shrubs and Forbs in the Mountain Brush Zone of Western Colorado

In May 1976, approximately 400 tons (363 metric tons) of TOSCO II spent oil shale, stockpiled a year earlier for research purposes, were spread through a small basin on the Roan Plateau above Parachute Creek, Colorado. Eleven species of container-grown shrubs and forbs were planted on three different exposures (north, south, and level), on four types of soil material as follows:

1. Compacted processed oil shale, 2-1/2 feet (0.76 m) deep, covered with 6 to 10 inches (15 to 25 cm) of native topsoil;

2. Compacted processed oil shale, 2-1/2 feet (0.76 m) deep, covered with 1 to 4 inches (2.5 to 10 cm) of rock fragments obtained at the study site;

3. Compacted processed oil shale, 2-1/2 feet (0.76 m) deep, with barley straw tilled into the top 6 inches (15 cm) at the rate of 2 tons per acre (0.73 metric tons/ha);

4. Three feet (91 cm) of subsoil material only.

Mortality occurred among some species during the first 90 days after planting, a portion of which was caused by rodents prior to construction of a rodentproof fence. Replacement plantings were made in September 1976 where planting stock was available.

By October 1976, overall survival of the initial planting was 78 percent on the topsoil-covered plots, 69 percent on subsoil, 59 percent on rock fragment-covered plots, and 27 percent on straw-amended shale plots. Plant survival on three different exposures was not widely different: 61 percent on the level, 56 percent on the south exposure, and 57 percent on the north exposure.

By the beginning of the second growing season (May 1977), the effects of soil amendments and topographical exposure on plant survival were beginning to show (Table 1). Data in Table 1 include the replacement plantings of September 1976.

TABLE 1. PERCENT PLANT SURVIVAL AFTER 1 YEAR, BY SITE TREATMENT AND TOPOGRAPHICAL ASPECT

	Aspect			
Treatment	North	Level	South	Treatment Mean
Topsoil	79	89	79	82
Rock mulch	62	69	53	61
Straw amendment	35	38	36	36
Subsoil only	76	74	76	75
Aspect mean	63	67	60	

During the first week in June 1977, container-grown plants of prostrate summer cypress, Utah sweetvetch, rubber rabbitbrush, green ephedra, and fourwing saltbush were used to replace losses suffered by those species through the end of May. In addition, big sagebrush was used to replace mountain mahogany on all plots, and red elder was used to partially replace the losses of blueberry elder.

By the end of September 1977, 64 percent of the surviving plants (including all surviving serviceberry and snowberry) had completed two growing seasons. The remaining plants had survived one growing season. Considering the overall percent survival over all exposures, the following six species were most successful: (in descending order) big sagebrush, fourwing saltbush, Siberian peashrub, rubber rabbitbrush, green ephedra, and prostrate summer cypress (Table 2). All had survival percentages greater than 60 percent. However, big sagebrush had only been established for one growing season.

TABLE 2. PERCENT PLANT SURVIVAL AFTER SECOND GROWING SEASON BY SPECIES, SITE TREATMENT, AND ASPECT (DAVIS GULCH, COLORADO)

	Topsoil-covered shale			Rock-mulched shale			Straw-amended shale			Subsoil			
Species	N[1]	L[2]	S[3]	N	L	S	N	L	S	N	L	S	Total Survival
Saskatoon serviceberry	50	80	20	0	0	60	0	0	0	np[4]	np	np	25
Big sagebrush	100	89	100	100	100	100	90	70	90	90	100	100	94
Fourwing saltbush	91	100	100	100	100	91	71	62	71	100	91	100	87
Siberian peashrub	90	100	100	100	100	100	80	75	19	100	90	100	83
True mountainmahogany	0	10	0	0	0	0	0	0	0	0	0	0	2
Rubber rabbitbrush	91	80	70	91	100	71	47	40	53	np	100	100	73
Green ephedra	69	75	100	80	100	82	41	39	80	100	100	83	75
Utah sweetvetch	62	57	56	62	62	57	50	0	7	100	100	100	48
Prostrate summer cypress	100	83	71	62	83	100	38	50	83	62	50	62	66
Tatarian honeysuckle	100	100	100	30	17	25	0	0	0	90	91	77	50
Blueberry elder	83	90	40	17	31	0	0	0	8	31	36	60	28
Mountain snowberry	80	30	80	30	70	10	0	0	0	40	40	0	32
Total survival	79	76	73	61	66	58	37	30	32	73	77	78	
Mean		76			61			33			76		

[1]N = North exposure

[2]L = Level

[3]S = South exposure

[4]np = Species not planted on this plot

Only minor differences in plant suvival were apparent on the three exposures--the more mesophytic species such as serviceberry, honeysuckle, elderberry, and snowberry suffering greatest mortality on the south-facing slope.

In terms of plant vigor and growth rate, all plant species have grown best on the topsoil-covered and subsoil plots. Only fourwing saltbush and prostrate summer cypress have grown well on the processed oil shale in the absence of a soil covering. Even so, these two species have little more than half the height growth on the shale plot as on topsoil or subsoil plots, as shown in Table 3.

TABLE 3. COMPARATIVE HEIGHT OF TWO SPECIES ON FOUR GROWING MEDIA

	Subsoil		Topsoil-covered shale		Rock-mulched shale		Straw-amended shale	
	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm
Fourwing saltbush	38	(97)	36	(91)	26	(66)	19	(48)
Prostrate summer cypress	27	(69)	24	(61)	15	(38)	13	(33)

Raindrop splash on processed shale having no covering gives small plants a black color which would appear to reduce photosynthesis. Plants of all species were smallest where there was no covering over processed shale.

During the second winter (1977-1978), some mortality occurred among all species except serviceberry, fourwing saltbush, and true mountain-mahogany (though only one plant of the latter species had survived to August 27, 1977) (Table 4). Increased growth through the early part of the third growing season is depicted in Figure 5.

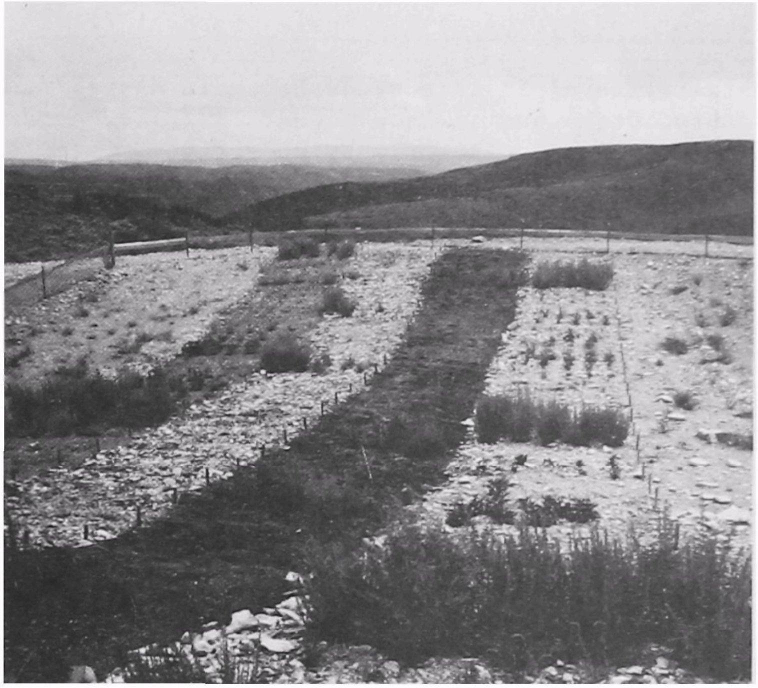
TABLE 4. PERCENT MORTALITY BY PLANT SPECIES AND SITE TREATMENT, BETWEEN SEPTEMBER 1977 AND JUNE 1978 (DAVIS GULCH, COLORADO)

	Topsoil covered shale	Rock mulched shale	Straw amended shale	Subsoil
Serviceberry	0	0	*	np
Big sagebrush	4	0	28	3
Fourwing saltbush	0	0	0	0
Siberian peashrub	0	3	8	0
Mountainmahogany	0	*	*	*
Rubber rabbitbrush	4	0	14	0
Green ephedra	4	4	36	0
Utah sweetvetch	7	14	50	7
Prostrate summer cypress	0	0	21	27
Tatarian honeysuckle	0	12	*	0
Blueberry elder	4	0	0	0
Snowberry	10	0	0	25

* = No surviving plants, 9/77

np = Species not planted on this plot

A



B

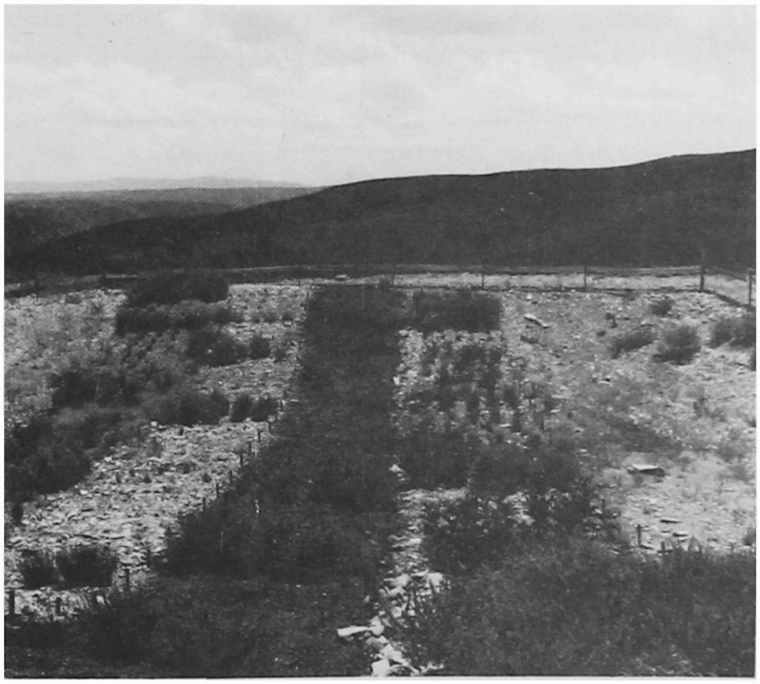


Figure 5. (A) Experimental plots at Davis Gulch in western Colorado at end of second growing season.

(B) Experimental plots at end of third growing season.

Treatment strips, left to right: (1) topsoil over processed shale; (2) rock mulch over processed shale; (3) straw rotovated in processed shale; and (4) subsoil only.

Microclimatic Factors of Processed Oil Shale Disposal Piles

Initial data retrieval in this study began in May 1977, at Sand Wash (Uintah County, Utah) and in late August 1977, at Davis Gulch (Garfield County, Colorado). The primary objectives of the study are to quantify microclimatic factors at these potential disposal sites and to compare the microclimate of exposed processed oil shale with that of disturbed soil.

At both sites, data on soil and air temperatures and precipitation are being recorded by automatic data logging systems.[2] At the Sand Wash site, information is being obtained on relative humidity, wind speed, and wind direction. At both study sites, data on soil moisture content are monitored periodically through the use of thermocouple psychrometers. The data logging systems are designed to read all sensors at hourly intervals. The automatic data logging system at Sand Wash has functioned well and minor maintenance and repairs have been readily accomplished due to year-around accessibility of the study site. However, at Davis Gulch, a heavy winter snowpack forced the discontinuation of data gathering for a 6-month period during the winter of 1977-1978. The system was reactivated on May 31, 1978.

A preliminary summary for the month of August 1977, at Sand Wash, illustrates differences that may occur between the temperature of processed oil shale and disturbed native soil for different depths (Table 5).

[2]All data obtained so far at both study sites have been stored on magnetic tape but have not yet been evaluated.

TABLE 5. MEAN TEMPERATURES OF PROCESSED SHALE AND NATIVE SOIL AT VARIOUS SOIL DEPTHS FOR AUGUST 1977

	Mean Min. (°C)		Mean (°C)		Mean Max. (°C)	
	Processed shale	Native soil	Processed shale	Native soil	Processed shale	Native soil
3/4" depth	9.4	9.4	27.8	22.8	54.4	44.1
4" depth	27.8	19.4	34.4	26.1	40.6	36.1
8" depth	22.8	25.0	25.0	27.2	26.7	28.9
16" depth	20.0	22.8	20.6	23.3	21.1	23.9
32" depth	16.7	18.3	17.2	19.4	17.8	20.0

The highest temperature recorded at the 3/4-inch depth during the month was 66.7°C on processed oil shale, compared to 49.4°C on soil. Processed oil shale absorbed more heat than native soil in the upper 4 inches (10 cm), but from 8 inches (20 cm) to 32 inches (81 cm) native soil was 2° to 3°C warmer than processed shale. Soil profile temperatures are undoubtedly related to soil moisture content, and future analyses of soil temperatures will consider this relationship.

CONCLUSIONS

On a revegetation test site at Sand Wash in the salt desert shrub zone of eastern Utah, seven shrub species belonging to the Chenopodiaceae family were superior to other plant species on unleached processed oil shale. The superior species included five endemic saltbushes (Gardner, broadscale, Bonneville, short-winged, fourwing) and two introduced species (Mediterranean camphorfume and prostrate summer cypress).

Two other chenopods (winterfat, plumed whitesage) and inland saltgrass exhibited very low survival on processed oil shale itself, but high survival on plots having some covering of soil over processed shale; their height growth increased with depth of soil covering, at least to the 1-foot (30 cm) depth.

Five species showing little or no survival where the soil covering was less than 1 foot (30 cm) thick over processed shale included black sagebrush, pygmy sagebrush, narrowleaf low rabbitbrush, scarlet globemallow, and Swainsonpea. Three shrubs failing to survive winter temperatures on this site included big saltbush, cattle saltbush, and blue saltbush.

Supplementary water from a drip-irrigation system was most beneficial on processed oil shale and least beneficial where 1 foot (30 cm) or more of soil covered processed shale. (Drip-irrigated plots received approximately 1 liter of water per plant on five different occasions in the first growing season, twice in the second growing season, and none in the third season.) In the second growing season, the processed shale plots on the edges of the test site received additional supplementary water as surface runoff from adjacent slopes, which appeared to enhance plant growth.

On a second site at Sand Wash, transplanting container-grown seedlings in May 1977 proved more successful than planting seeds of the same species the previous fall. Although replanting seeds in the fall of 1977 resulted in good seedling stands in 1978, it can be expected that good survival from fall seeding will occur only in years when winter and spring moisture is above average. Spring planting of container-grown plants can ensure successful establishment of shrub species.

In the mountain brush zone of western Colorado (Davis Gulch) a covering of topsoil approximately 1 foot (30 cm) thick was superior to other amendments on processed oil shale. Eleven of 12 species tested showed good survival and growth on this treatment.

Where barley straw was used as an amendment on processed oil shale, only fourwing saltbush and prostrate summer cypress showed high survival. Even so, their height growth was only about half that where topsoil covered the shale or where plants were grown on a gravelly loam subsoil from the site.

A covering of 2 to 3 inches (5 to 7.5 cm) of broken rock fragments over processed shale was superior to the barley straw amendment with respect to plant survival and growth, but inferior to topsoil or subsoil.

Preliminary results from studies of microclimate showed that processed shale absorbed more heat in the surface 4 inches (10 cm) than native soil, but native soil was 2°C to 3°C warmer than processed shale at depths of 8 to 32 inches (20 to 80 cm). Cooler temperatures in processed shale below the 8-inch (20 cm) depth appeared related to higher moisture content. In late summer, temperatures at 3/4 inch (2 cm) deep averaged 17°C higher in processed oil shale than in native soil.

RECOMMENDATIONS

Disposal embankments of processed oil shale should be covered with 1 foot (30 cm) or more of local topsoil which has shown good capability for supporting vegetation. Use of topsoil increases the number of species adapted for revegetating disposal embankments and greatly reduces the need for fertilizers.

Several native saltbushes and two introduced Chenopodiaceae species that showed excellent performance in these studies should be considered for use in revegetating processed oil shale disposal embankments in the arid salt desert shrub zone. Grasses that should be considered for use in that zone include four native species (Indian ricegrass, galleta, blue grama, alkali sacaton) and two introduced grasses (crested wheatgrass, Russian wildrye). Galleta, blue grama, and alkali sacaton are warm-season grasses that require adequate summer moisture for successful establishment.

In the more mesic mountain brush zone, the Chenopodiaceae and other shrubs that performed well in these studies should be considered for revegetating processed oil shale disposal areas that have been covered with 1 foot (30 cm) or more of topsoil. Native grasses that should be considered for use in the mountain brush zone include: beardless bluebunch, streambank, thickspike, and western wheatgrasses, and Great Basin wildrye; introduced grasses include smooth brome, fairway, intermediate, tall, and pubescent wheatgrasses.

Use of container-grown plants on arid and semi-arid sites can ensure successful revegetation of disposal areas where fall planting of seeds has failed. One liter or more of water per plant should be applied at the time of planting and as needed during the first growing season.

Whereas supplementary water might not be required beyond the first growing season for plant survival, additional moisture stored in the processed shale underlying a covering layer of topsoil would enhance plant growth. By leaving the surface of disposal areas on arid sites slightly lower than the surrounding terrain, moderate amounts of runoff water from adjacent areas can be stored in the processed shale. Surface configurations such as contour furrowing and/or pitting should be employed on disposal areas to increase water infiltration and prevent runoff and erosion.

SECTION 2

SURFACE-MINED COAL SPOILS

INTRODUCTION

Increased need for coal to supply the Nation's energy requirements will lead to strip mining of coal deposits in several western states. The restoration of vegetative cover on strip mined lands is imperative. This section discusses known revegetation techniques for coal mine spoils in the Western United States and includes new research from Utah.

Lands occupied by Utah's coal fields where strip mining is most likely to occur are semi-arid or arid areas where average annual precipitation ranges from 7 to 17 inches (18 to 43 cm). Vegetation presently occupying these areas varies from the juniper-pinyon type, dominating the Alton coal field in Kane County, to the salt desert shrub type in the Emery-Carbon coal fields. A wide variety of soil types is present from sand to heavy clays. Soils are often poorly developed and badly eroded. Organic matter content and plant nutrients are low. Most soil and mine spoil material has a basic pH.

The evapotranspiration demand is very high throughout the growing season and is intensified by periods of high winds. In addition, much of the precipitation is ineffective in replenishing soil moisture due to surface runoff or diminutive amounts of less than 0.25 inches (0.6 cm) per event. Moreover, the extreme variability in the occurrence of rainfall and winter snows makes any seeding or planting program risky without supplementary water to aid plant establishment.

REVIEW OF PRESENT KNOWLEDGE

Use of Topsoil

In most cases, that portion of the coal overburden brought to the surface during mining operations is less suitable for plant establishment and growth than the stripped topsoil material. Clays and shales brought to the surface from depths of up to 100 feet (30 m) are often fine textured and are more saline, more sodic, and have higher pH values than topsoil layers. As pointed out by Packer and Aldon (1978), the physical and chemical properties of spoils that discourage good plant growth can usually be circumvented or improved. Two basic approaches have been used to treat mine spoils for better plant growth: cover undesirable spoils with suitable soil materials, or apply amendments designed to alter the properties of the spoils.

A number of advantages accrue when topsoil material is stockpiled and spread on top of mine overburden. The population of important soil-building microorganisms may be enhanced by the spreading of topsoil, as discussed by Cundell (1977). Studies conducted at the Northern Great Plains Research Center, Agricultural Research Service, and the North Dakota Agricultural Experiment Station (1975) indicated that a topsoil covering of as little as 2 inches (5 cm) appeared to produce benefits greatly out of proportion to the amount of soil material used. Water infiltration was increased, surface runoff and erosion was reduced, and plant survival and growth were enhanced. After five seasons of growth, a fair stand of desirable cool-season grasses existed. Farmer et al. (1974) found that topdressing of mine overburden at the Decker Coal Mine in Montana appeared to be a highly desirable revegetation practice. Even in semi-arid and arid regions, poorly developed topsoil material can be expected to have better fertility than raw spoils.

One disadvantage in the use of topsoil, in addition to the expense, may be the presence of weed seeds. Beauchamp et al. (1975) found that the top 2 inches (5 cm) of topsoil from three different vegetative types (sagebrush-grass, saltbush, and greasewood) in Wyoming contained sufficient seed to revegetate the area with more than the original density. However, it was noted that the quality of the newly established vegetation would be seriously altered, since most of the species were those normally found in secondary succession. In arid environments, it would be desirable to eliminate competition from annual weeds in order to give the seeded perennial species as much soil moisture as possible.

Soil Amendments

The use of chemical and/or organic amendments on strip mine spoils may be necessary when spoils are high in exchangeable sodium, low in water infiltration capacity, and deficient in plant nutrients. The sodium adsorption ratio may be decreased in the upper levels of sodic mine spoils through the application of gypsum or sulfur. Sodic spoil materials can also be chemically reclaimed by using soluble calcium salts such as calcium chloride and calcium nitrate; however, such treatment would require a source of irrigation water and would be expensive. Also, the incorporation of organic amendments into soil or overburden material will often enhance establishment and growth of plants. The greatest obstacle to the use of organic amendments is the high cost of transportation from source of supply to the mine site. Nearly all areas suitable for the strip mining of coal in Utah are a considerable distance from large population centers where organic amendments such as sewage sludge or municipal refuse could be obtained. Other amendment materials such as hay, straw, and composted sawmill refuse are more readily available, though often expensive to purchase and transport in large quantities.

Sanks and Amirtharajah (1976) tested combinations of pulverized municipal refuse, sewage sludge, and clay overburden as growing media for grass. The clay overburden was obtained from a stockpile at the Big Sky Mine in Montana. The study was conducted in a greenhouse, where the root zone was continually kept moist. All clay mixtures of municipal refuse, digested sewage sludge, and combinations of refuse and sludge produced 4 to 6 times as much growth on a dry weight basis as did unfertilized clay. They also found, in subsequent studies, that grass growth was better in fertilized topsoil than from mixtures of clay overburden and solid waste, but that mixtures of clay and/or solid waste produced many times as much growth as unfertilized topsoil. These studies, although conducted under greenhouse conditions, show that organic material can improve the physical and chemical properties of mine spoils and perhaps of many topsoil materials.

Some organic soil amendments can, on the other hand, be harmful to plant establishment. In a greenhouse test using mountain rye and adding bark to topsoil and spoil material, the effect of the added bark was negligible on emergence, and leaf length and ovendry weights were depressed (Aldon et al. 1975). Another laboratory study (Aldon and Springfield 1973) showed that manure, sawdust, bark, and straw did not affect the emergence and early growth of mountain rye and fourwing saltbush on 3-year-old mine spoils.

Mulching

The use of surface mulches as an aid to establishing vegetation has long been practiced. Some types of mulch, though undoubtedly beneficial, would most likely prove too expensive to obtain and apply. Gravel, broken rock, plastic, and treated paper are examples of effective but often costly materials.

Organic mulches may conserve moisture, reduce temperature, prevent erosion, help control competition from certain weeds by reducing light, and supply organic acids and essential plant nutrients. Materials such as straw, hay, and sawdust can be spread with a blower and held in place with asphalt emulsion. On gentle terrain, mulching material can be tacked to the soil with a crimper or sheepsfoot roller. Wood fiber can be applied with a hydromulcher.

Hodder et al. (1970) found that a straw mulch consisting of about 0.75 to 1 ton per acre (1,700 to 2,200 kg/ha) tacked down with about 300 gallons per acre (2,800 liters/ha) of asphalt emulsion is an effective mulching treatment on coal mine spoils.

Investigations in New Mexico have also shown the advantages of using mulch for establishing perennial species. Springfield (1972) found that the most effective mulch was straw or a white petroleum resin. These materials reduced moisture losses and lowered midafternoon soil temperatures during the periods of seed germination and seedling emergence. Gould et al. (1975), however, felt that mulching spoil material may have been detrimental to establishment of native range plants because of competition resulting from grain and weed species in mulching material.

Any mulching technique should be tailored to suit specific conditions. Excessive mulch can be harmful by intercepting precipitation, which is then lost to evaporation, or by preventing optimum seed germination and seedling emergence.

Fertilization

Fertilization of strip mine spoils with inorganic fertilizers will undoubtedly improve the chances for revegetation success, and in some cases will be a necessity. Inorganic fertilizers will not, however, guarantee success if spoil properties are exceptionally poor, such as those that are high in exchangeable sodium.

Howard et al. (1977) found that the addition of nitrogen at 60 pounds per acre (67 kg N/ha) or phosphorus at 60 pounds per acre (67 kg P/ha) to mine overburden materials from the Wyodak and Seminoe coal mines and the Utah International Uranium Mine in Wyoming, resulted in significantly greater yields of alfalfa and thickspike wheatgrass than from unfertilized overburden. These investigators also found that some shrub species responded to fertilization while others did not. From these experiments and our own past experience, it is apparent that many shrub and tree species can be established without fertilization.

Studies at the Rosebud Mine near Colstrip, Montana, reported by Willmuth and DePuit (1977) also show that inorganic fertilizers can greatly enhance the growth of seeded grasses on mine spoils. They found, however, that legumes responded negatively to fertilization above certain levels and durations. Multiple year fertilization at low levels proved more beneficial than single season fertilization at higher levels in terms of perennial grass production.

As pointed out by Packer and Aldon (1978), the degree of dependence that established vegetation on mine spoils has on continued fertilization is not known. Long range nutrient requirements of plant communities on mine spoils still must be determined.

The work of Williams and Aldon (1978), and Aldon (1975) has conclusively shown that the survival and growth of numerous shrub species can be increased if steps are taken to ensure that the growing medium contains endomycorrhizal fungi. Research on this aspect of revegetating near-sterile soil material is in its infancy. As successful techniques are developed for inoculating seedlings, revegetation success should improve.

Seeding and Planting Methods

Packer and Aldon (1978) have reviewed methods of seeding and planting on coal mine spoils in the semi-arid and arid portions of the western United States. In semi-arid areas where much of the annual precipitation is received as autumn rain and winter snow, the usual practice is to seed in late autumn and plant nursery stock in early spring. Late fall seedings are best when mixtures of grasses, forbs, and shrubs are used because the winter period provides stratification of the seed. However, when only grasses are used, early spring seeding often appears advisable. Willmuth and DePuit (1977) found this to be true in their studies at Colstrip, Montana.

In the arid regions of New Mexico, the planting of fourwing saltbush nursery stock can be successfully accomplished in late July and early August when summer storms produce 0.4 inches (10mm) or more of precipitation at each occurrence (Aldon 1973). Most likely other adapted shrubs can be similarly established in regions where summer storms provide much of the annual precipitation. The coal fields of southern Utah fit this description.

The choice of whether to drill or to broadcast seed will depend upon the specific conditions at each site. When soil materials have settled or have been compacted, drilling is advisable. Drilled seed is mostly covered with soil, providing for more satisfactory germinating conditions. When the soil material surface is still loose and rough, such as immediately after grading, broadcasting may be successful. Broadcasting is also appropriate on steep, rough terrain where mechanized equipment is not operable.

Drilling of seed is not compatible with seedbed preparation methods such as pitting or gouging. The drilling operation would destroy the depressions that are made to catch rainfall and to decrease surface runoff. Following this type of seedbed treatment, direct seeding should be done immediately, especially before appreciable rainfall occurs.

The establishment of shrubs and trees is desirable in some revegetation programs, especially where wildlife habitat restoration is important. Shrub and tree seedlings are difficult to establish by direct seeding in arid regions. Seeding shrubs in a mixture with perennial grasses imposes stress of competition for soil moisture, and many shrubs are not good competitors. Woody species can be established more reliably by planting bare-root or container-grown nursery stock. Many species survive better when container-grown seedlings are used, but some are established equally well as bare-root stock. The key to successful planting of woody species is to use high quality stock and plant properly. Adapted species can usually be established if planted when soil moisture is plentiful or when supplementary watering can be provided during the first growing season.

Selecting Species for Revegetation

Selection of plant species for revegetating mine spoil areas will depend primarily on what species are adapted to the local soils and environment. Of secondary importance is the desired plant composition, which depends on the use planned for the land. Determining what plants can be grown on a specific mining area is a basic prerequisite of any revegetation plan.

In semi-arid shortgrass prairie regions, the best native species to seed include western wheatgrass, blue grama, sideoats grama, and buffalograss. Adapted introduced grasses include smooth brome, crested wheatgrass, and Russian wildrye. Native shrubs adapted to the area are big sagebrush, rubber rabbitbrush, and green rabbitbrush.

At the Decker Mine in Montana, several species of wheatgrass dominated the first-season production from a mixture of species. Slender wheatgrass was especially vigorous. Smooth brome and sideoats grama were also notable components of the stand.

May et al. (1971) found that both western wheatgrass and inland saltgrass were well adapted to vegetative establishment on overburden piles near Kemmerer, Wyoming. On saline-alkali soil materials, species such as tall wheatgrass, alkali sacaton, Russian wildrye, and inland saltgrass may be the best choice.

Shrub and tree species used in the revegetation of spoils are primarily those that are native to the region, plus other adapted species suited to specific soil conditions. In the Montana, Wyoming, and North Dakota areas, shrubs such as silver buffaloberry, smooth sumac, snowberry, winterfat, the sagebrushes, and the rabbitbrushes may be used.

There are numerous native and exotic plant species that can be used in strip mine reclamation. Nearly everyone involved in research on revegetation of disturbed areas is constantly testing and evaluating plants for particular environments. Species adaptability evaluations are one of the main objectives of the research in Utah coal fields, as mentioned later in this report.

Availability of Plant Material

The availability of plant material, including seed and nursery stock, can occasionally be an obstacle in revegetation programs. Fortunately, seeds of a sufficient number of grass species are obtainable in large quantities from commercial seed dealers. These are grasses commonly used in the western United States for range and pasture reseeding. Many native grasses and ecotypes are not grown commercially. Where such species are especially well adapted, efforts must be made to contract with seed collectors to gather them; and such seed will be expensive. Sometimes the use of only a small amount of seed may enable the establishment of a desirable species which can subsequently spread by natural reproduction. Also, a species might gain a foothold from the planting of container-grown plants at wide intervals over the site.

Seed of some shrub species is routinely collected by commercial seed dealers. Bitterbrush, fourwing saltbush, saskatoon serviceberry, blueberry elder, cliffrose, big sagebrush, and rubber rabbitbrush are examples of shrub species for which seed is usually obtainable. Others such as ephedra, winterfat, mountainmahogany, skunkbush sumac, and wildrose are usually available in limited quantities. The availability of seed of many shrubs (and native forbs) often depends upon whether climatic conditions in local areas have been conducive to a good seed crop.

Seed of most shrub and forb species is often too expensive to use in large scale direct seeding. This is one reason why many species are grown in nursery beds and greenhouses for transplanting to the field site. In so doing, rare or expensive seed is used more efficiently. Most planting stock of species not used for landscaping is grown by Federal and State nurseries. One commercial greenhouse operator in Salt Lake City, Utah (Native Plants, Inc.) has attempted to specialize in native shrubs for revegetation programs.

Equipment for Revegetation

Equipment useful in revegetating mine spoil areas is usually readily available. Earthmoving machines and farm implements can be used to prepare the seedbed. Only where spoil and soil materials are extremely rocky or where the terrain is steep is specialized equipment needed. The U.S. Forest Service Equipment Development Center at Missoula, Montana, is testing two new machines, the rotovator and the gouger, for their usefulness in preparing disturbed areas for seeding and planting. Both machines were used in the studies described later.

The rotovator functions as a heavy-duty rototiller. It may be used to loosen up the soil material and to incorporate various types of soil amendments in the top foot (30 cm) of the soil. The gouger forms regularly spaced, small basins (depth can be regulated) that serve to collect precipitation and decrease surface runoff and erosion.

One of the most useful pieces of equipment for direct seeding on rough sites is the rangeland drill, a rugged seeder with high clearance for working over large rocks. It can be converted to a deep-furrow implement by removing the depth bands. The depth of the furrow can be controlled by taking off or adding disk arm weights. Packer and Aldon (1978) briefly discuss several other types of direct seeding equipment and their uses.

Certain equipment would be required for installing any needed irrigation system. If irrigation water is available, much greater confidence in successful plant establishment is justified despite drought conditions. Supplementary water can be applied by overhead sprinklers, trickle irrigation, or subsurface irrigation.

Improving the efficiency of natural precipitation by shaping the seedbed in specific ways is another method of increasing soil moisture. Contour furrowing, pitting, gouging, or the creation of imprinted patterns (Dixon and Simanton 1977) can conserve precipitation and direct it to where it is needed most. The erection of snow fences can result in several times as much snow buildup over local areas than would normally occur. Water harvesting techniques may be effective. Aldon and Springfield (1975a, 1975b) reported increased survival and growth of fourwing saltbush and western wheatgrass transplants where ground paraffin or polyethylene were applied over small basins around the plants. Such techniques partially or entirely seal the soil surface against evaporation and concentrate water immediately surrounding the plant.

FOREST SERVICE STUDIES AT THE ALTON COAL FIELD, UTAH

New Forest Service Studies in Utah, which began in the autumn of 1976, were designed to provide further guidelines and criteria for the revegetation of coal spoils on semi-arid lands, including the use of nonmine wastes as soil amendments. Four separate studies are summarized in this report.

Revegetation Techniques on Disturbed Overburden from Simulated Mining

The objectives of this study were: (1) to evaluate three different soil surface cultural treatments following severe site disturbance termed "simulated mining," and (2) to compare effects of simulated mining and no simulated mining on plant establishment and growth.

An 8-acre (3.2 ha) site (464 x 800 feet or 139 x 240 m) covered by an old-growth juniper-pinyon stand was cleared and fenced to exclude deer and rabbits. Simulated mining involved stockpiling topsoil, ripping the subsoil to a depth of 30 inches (76 cm), smoothing the furrows with a dozer blade, and replacing the topsoil. Topsoil was stockpiled into two windrows by pushing it inward from the top and bottom edges and outward from the middle with a dozer blade (Figure 6).

Figure 6. Topsoil stockpiled in windrows was respread following ripping of the subsoil.

The surface cultural treatments following simulated mining were: (1) contour furrowing with three ripper teeth on the back of a D-6 caterpillar tractor; (2) pitting or gouging with a machine specially designed to leave a waffle-like surface (gouger); and (3) rotovating grass hay at 2-1/2 tons per acre (0.9 metric tons/ha) to a depth of 8 inches (20.3 cm) into the soil surface. The fourth treatment involved leaving topsoil in place but gouging it to loosen the surface. This treatment occupied the two 32-foot- (9.6 m) wide strips on which topsoil had been stockpiled, plus two small areas of about 1/2 acre (0.2 ha) each, one on each end of the long axis of the study site.

A seed mixture of the species shown in Table 6 was broadcast over all four treatments using hand-operated cyclone seeders:

TABLE 6. SEED MIXTURE USED ON LARGER STUDY AREAS AT ALTON COAL FIELD

	Lbs/ac	Kg/ha
Intermediate wheatgrass	4	4.50
Pubescent wheatgrass	4	4.50
Fairway wheatgrass	4	4.50
Russian wildrye	4	4.50
Nomad alfalfa	1	1.10
Yellowblossom sweetclover	1	1.10
Bitterbrush	2	2.25
Fourwing saltbush	2	2.25
Winterfat	0.5	0.55
Green ephedra	1	1.10
Cliffrose	1	1.10
Total	24.5	27.45

The severe drought during the autumn of 1976 and first 4-1/2 months of 1977 precluded normal early spring germination and emergence of seeds sown the previous autumn. However, fair to good germination and emergence occurred on all treatments following a rainy period in the latter half of May 1977.

The most striking difference among these treatments was higher frequency and numbers of grass seedlings on the area where hay was rotovated into the soil surface. At the end of the 1977 growing season, presence of grass seedlings on square-foot (0.09 m^2) plots showed 92 percent frequency on the area treated with grass hay compared to 52 percent frequency on the areas not treated with hay. Frequency of forbs was 40 percent and 21 percent on hay and non-hay areas, respectively. Comparable shrub frequencies were 4 percent and 2-1/2 percent. The most prominent shrubs were fourwing saltbush, winterfat, and bitterbrush, in that order. Mean maximum numbers of grass seedlings per square foot (0.09 m^2) was 12.8 for hay treated plots compared to 5.2 on plots not treated with hay.

All surface cultural treatments were effective in limiting runoff from high-intensity summer storms in 1977. Some sediment was deposited in the bottoms of terraces and pits, but the result was not serious. Minor repairs were made where a few small channels developed, mainly in wheel tracks left by equipment. No such storms occurred on this site in 1978.

Above average precipitation during the winter of 1977-1978 produced excellent growth of vegetation in the spring of 1978 (Figure 7). Smooth brome was a prominent component of grasses where hay was used, indicating that seed of this species was present in the hay used as organic soil amendment. Monitoring of vegetative production and ground cover will extend over the next 3 or 4 years to fully evaluate treatments.

Figure 7. A good cover of grasses, forbs, and shrubs, in the second growing season (1978), occupies area where grass hay was rotovated into soil.

Effects of Organic Amendments on Growth of Selected Grasses

This study, established on a part of the 8-acre (3.24 ha) Alton site, involved testing effects of all combinations of two soil types and three organic amendments on growth of 10 selected grasses. Soil types included: (1) topsoil replaced over subsoil after simulated mining, and (2) subsoil only. Soil amendments included: (1) grass hay spread at 2-1/2 tons per acre (0.9 metric tons/ha) and rotovated into the soil; (2) bark-woodfiber compost spread 1 inch (2.5 cm) deep and rotovated into the soil; and (3) no amendment. Seeds of 10 selected grasses were planted in small subplots on each of the six larger main plots in a randomized block design having three replications.

Seed germination and emergence of grass seedlings did not occur until late May 1977. Cursory observations in mid-June while seedlings were still small and not fully established showed more seedlings present where organic amendments had been used. At the end of the first growing season, grass seedlings were most numerous on the grass hay amendment plots and fewest on the bark-woodfiber compost plots (Table 7).

TABLE 7. MEAN MAXIMUM NUMBER OF PLANTS/SQUARE FOOT (0.09 m^2) FOR SOIL-AMENDMENT TREATMENTS*

Topsoil hay	Subsoil hay	Topsoil check	Subsoil check	Topsoil compost	Subsoil compost
5.48	5.34	4.54	4.18	4.16	3.58

*Means underscored by the same line are not significantly different at the 0.05 probability level.

Survival of streambank (Agri) and fairway (Agcr) wheatgrasses was superior among the ten species, whereas western wheatgrass (Agsm) and Great Basin wildrye (Elci) showed fewest plant numbers (Table 8).

TABLE 8. MEAN MAXIMUM NUMBER OF PLANTS/SQUARE FOOT (0.09 m^2) FOR 10 SELECTED GRASSES*

Agri	Agcr	Elju	Agin[2]	Brin	Agel	Agin	Agtr[2]	Agsm	Elci
5.99	5.79	4.97	4.84	4.54	4.46	4.42	4.14	3.22	3.08

*Means underscored by the same line are not significantly different at the 0.05 probability level.

Differences among the other six grasses were less important. Species in descending order of maximum plant numbers were Russian wildrye (Elju), intermediate wheatgrass (Agin[2]), smooth brome (Brin), tall wheatgrass (Agel), beardless bluebunch wheatgrass (Agin), and pubescent wheatgrass (Agtr[2]).

Adaptability of Selected Grasses and Shrubs on Different Profile Materials

This particular study (begun in October 1976) was designed to determine the effectiveness of different grass and shrub species in forming suitable cover on different subsoil materials as well as on topsoil.

The study was established on four different types of overburden above the coal seam on a 3-acre (1.2 ha) site having a 20 to 25 percent slope and a westerly exposure. Juniper and pinyon trees were bulldozed from the areas above and below the cut area exposing the coal seam. The high sidewall was reduced by developing two terraces each about 25 feet (7.6 m) wide and 220 feet (67 m) long in the cut area. A 4- to 5-foot-(1.2 to 1.5 m) deep layer of dark, carbonaceous shale that lay just above the coal seam was exposed on the surface on both terraces. Three additional strips, each 50 x 220 feet (15 x 66 m), two above and one below the terraces, were prepared with different types of overburden on the surface. Starting at the top of the hill, the sequence of the four treatments was as follows:

(1) A 50- x 220-foot (15.2 x 67 m) strip of topsoil was left in place but ripped with dozer teeth to prevent runoff.

(2) A 50- x 220-foot (15.2 x 67 m) plot was stripped of approximately 1 foot (30 cm) of topsoil and 2 feet (61 cm) of gravelly clay subsoil leaving a light-colored, clay-shale surface exposed. This plot was also ripped to a depth of about 2 feet (61 cm) and furrows were left to prevent runoff and erosion.

(3) Two 25-foot- (7.6 m) wide terraces were formed where dark carbonaceous shale was exposed on the surface.

(4) A 50-foot- (15.2 m) wide strip of "fill" material consisted of the gravelly clay subsoil from (2) above.

On each of these four soil types, 11 grasses were seeded in separate plots, 10 feet wide and 50 feet long (3 m x 15 m), in two replications.

The drought during the autumn and winter of 1976-1977 prevented early spring seed germination, but seedling emergence occurred in late May 1977. By the end of the first growing season, survival of the seeded grasses could only be considered as fair to good. Ranking of the above four treatments in descending order of plant establishment and growth was: 1, 4, 3, 2. All grass species exhibited fair to good growth, but some were superior to others.

Excellent winter precipitation and the relatively cool spring of 1978 was conducive to abundant growth of grasses. Smooth brome and several of the wheatgrasses grew particularly well.

In early May 1978, container-grown plants of the following 10 shrub species were planted on one replication of the study: fourwing saltbush, Bonneville saltbush, winterfat, curlleaf mountainmahogany, true mountain-mahogany, green ephedra, prostrate summer cypress (two varieties), skunk-bush sumac, and bitterbrush.

A single row of each shrub species was planted across all 11 grass plots on each of the four types of soil. Shrubs were planted approximately 5 feet (1.5 m) apart so that in any single row, two plants occurred in each 10-foot-wide (3 m) grass plot. Rows were also spaced approximately 5 feet (1.5 m) apart so that all 10 shrub species occurred on each of the four types of soil.

All shrubs survived well during the 1978 growing season. Growth of shrubs and grasses will continue to be monitored for at least 3 to 4 more years to evaluate compatibility of shrub species with grass species on different types of overburden.

Establishment and Longevity of Several Plant Species on Various Topsoils and Shaley Overburden

Utah International Incorporated is a major holder of coal leases in the Alton Coal Field of southern Utah. The company considers that in a strip mining operation, carbonaceous shale directly overlying coal seams would be most readily available as revegetation media.

Study objectives were: (1) to test the possibility of establishing vegetation on the carbonaceous shale without topsoil and on carbonaceous shale covered with three different kinds of topsoil, (2) to monitor soil moisture and salinity regimes in topsoils and shale, and (3) to determine the physical and chemical properties of the three topsoils and carbonaceous shale.

An 0.5-acre (0.2 ha) area approximately 7 miles (11.2 km) southeast of Alton, Utah, was fenced to exclude deer, livestock, and rodents. Within the exclosure, four soil materials were placed in plots 10 x 30 feet (3m x 9m) in size that had been excavated to a depth of 40 inches (100 cm), replicated four times. Soil materials included: (1) shale overburden taken from directly above a coal seam, (2) sandy loam topsoil, (3) loam topsoil, and (4) silty clay topsoil. Each topsoil common to a part of the coal field was spread to a depth of 10 inches (25 cm) over a 30-inch (76 cm) layer of the shale overburden that had been placed first in the excavated pits. Sensors for monitoring soil moisture and salinity were placed at depths of 8, 18, and 30 inches (20, 46, 76 cm) in each plot. One-half of each plot was fertilized with 80 lb/acre (90 kg/ha) of both elemental nitrogen and phosphorous, and all plots were broadcast-seeded with a mixture of six grasses, six forbs, and six shrubs, in November 1976. Differences in plant density and ground cover will be determined and analyzed over the next 3 years.

Seed germination was delayed by lack of soil moisture until late May 1977. Although seedling establishment appeared adequate on the sandy loam topsoil and on the shale overburden for satisfactory vegetative cover, all plots were reseeded in November 1977 in an effort to obtain better vegetative stands.

Through the early part of the second growing season (June 1978), "drylander" alfalfa from Saskatchewan provided most of the vegetative cover on all plots. However, fairway wheatgrass showed good establishment and vigor and should ultimately form a substantial portion of the stand on most plots. Excellent individual plants of Russian wildrye, Indian ricegrass, small burnet, globemallow, winterfat, and fourwing saltbush also occurred. Shrub species such as true mountainmahogany, green ephedra, and antelope bitterbrush have yet to exhibit good growth on any of the soils.

Chemical and physical analyses showed that other than being low in available nitrogen, none of the three topsoils or shale overburden were unsuited for plant growth. Although no apparent benefits resulted from the addition of inorganic fertilizer to the four soil materials, soil moisture probably was inadequate during the first growing season; by the second growing season, nitrogen might have dissipated. Further testing is necessary.

To date, best overall vegetative cover has been obtained on plots having 10 inches (25 cm) of sandy loam topsoil over the shale overburden, followed by the loam topsoil over shale overburden. The shale overburden itself currently ranks third among the four growing media in vegetative cover. After weathering over winter, the shale overburden has excellent moisture-holding capacity and has been an excellent seed germination medium. In contrast, the silty clay topsoil has proven to be the poorest material with respect to seedling germination and establishment.

CONCLUSIONS AND RECOMMENDATIONS

Grass hay spread at 2-1/2 tons per acre (0.9 metric tons/ha) and rotovated 8 inches (20 cm) deep into the topsoil increased seedling survival of grasses, forbs, and shrubs during the first growing season on a simulated mining tract at the Alton coal field. Where available at reasonable cost, use of hay is recommended to increase moisture-holding capacity and improve seedling establishment. Surface configurations such as gouging (pitting) and contour furrowing should also be used to retain precipitation in the form of snow or rain on reconstructed areas.

Plants of streambank and fairway wheatgrasses were most abundant the first year among 10 grass species broadcast-seeded at equal rates in separate plots at Alton. Other species in order of descending numbers of plants were: Russian wildrye, intermediate wheatgrass, smooth brome, tall wheatgrass, beardless bluebunch wheatgrass, pubescent wheatgrass, western wheatgrass, and Great Basin wildrye. The latter two species, plus streambank and beardless bluebunch wheatgrasses, are native; the other grasses are introduced. Two or three of the native grasses and a similar number of introduced species should be used in a mixture with selected forbs and shrubs for revegetating disturbed areas. Recommended forbs include alfalfa, sweet clover, small burnet, Utah sweetvetch, and scarlet globemallow. Recommended shrubs include fourwing saltbush, winterfat, and bitterbrush among other species now being tested.

When weathered over winter, the dark carbonaceous shale (clay loam) lying immediately above the coal seam has good water-holding capacity, but it is best suited as a growing medium for plants if covered with approximately 1 foot (30 cm) of sandy loam or loam topsoils. These two kinds of topsoils were superior to other profile materials as growing media for plants. The dark carbonaceous shale was superior to a blue-colored shale overlying the carbonaceous shale and also to a silty clay topsoil found on part of the area.

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APPENDIX

LIST OF PLANT SPECIES CITED IN THIS REPORT

GRASSES:

Scientific Name	Common Name
Agropyron cristatum	Fairway wheatgrass
A. dasystachyum	Thickspike wheatgrass
A. elongatum	Tall wheatgrass
A. inerme	Beardless bluebunch wheatgrass
A. intermedium	Intermediate wheatgrass
A. riparium	Streambank wheatgrass
A. smithii	Western wheatgrass
A. trachycaulum	Slender wheatgrass
A. trichophorum	Pubescent wheatgrass
Bouteloua curtipendula	Sideoats grama
B. gracilis	Blue grama
Bromus inermis	Smooth brome
Buchloe dactyloides	Buffalograss
Distichlis spicata var. stricta	Inland saltgrass
Elymus cinereus	Great Basin wildrye
E. junceus	Russian wildrye
Festuca ovina var. duriuscula	Hard fescue
Hilaria jamesii	Galleta
Oryzopsis hymenoides	Indian ricegrass
Sporobolus airoides	Alkali sacaton
S. cryptandrus	Sand dropseed

FORBS:

Astragalus cicer	Cicer milkvetch
Balsamorhiza sagittata	Arrowleaf balsamroot
Hedysarum boreale	Utah sweetvetch
Medicago media	"Drylander" alfalfa
M. sativa	Alfalfa
Melilotus officinalis	Yellow sweetclover
Penstemon spp.	Penstemon
Sanguisorba minor	Small burnet
Sphaeralcea coccinea	Scarlet globemallow
Swainsona salsula	Swainsonpea

TREES AND SHRUBS:

Amelanchier alnifolia	Saskatoon serviceberry
Artemisia nova	Black sagebrush
A. pygmaea	Pygmy sagebrush
A. tridentata tridentata	Big sagebrush
A. tridentata vaseyana	Mountain big sagebrush
Atriplex aptera	Shortwinged saltbush
A. bonnevillensis	Bonneville saltbush
A. canescens	Fourwing saltbush
A. cuneata	Castle Valley clover
A. gardneri	Gardner saltbush
A. lentiformis	Big saltbush
A. obovata	Broadscale saltbush
A. polycarpa	Cattle saltbush
A. saltilloensis	Blue saltbush
Camphorosma monspeliaca	Mediterranean camphorfume
Caragana arborescens	Siberian peashrub
Ceanothus cuneatus	Wedgeleaf ceanothus
Ceratoides lanata	Winterfat
C. papposa	Plumed white sage
Cercocarpus ledifolius	Curlleaf mountainmahogany
C. montanus	True mountainmahogany
Chrysothamnus nauseosus albicaulis	White rubber rabbitbrush

C. viscidiflorus	Green rabbitbrush
C. viscidiflorus stenophyllus	Narrowleaf low rabbitbrush
Cowania mexicana	Cliffrose
Elaeagnus angustifolia	Russian-olive
Ephedra viridis	Green ephedra
Forestiera neomexicana	New Mexico forestiera
Juniperus scopulorum	Rocky Mountain juniper
Kochia prostrata	Prostrate summer cypress
Lonicera tatarica	Tatarian honeysuckle
Picea engelmannii	Engelmann spruce
Populus spp.	Cottonwood
Potentilla fruticosa	Bush cinquefoil
Purshia tridentata	Bitterbrush
Rhus glabra	Smooth sumac
R. trilobata	Skunkbush sumac
Robinia neomexicana	New Mexico locust
Rosa woodsii	Woods rose
Salix alba var. vitellina	Golden willow
Sambucus cerulea	Blueberry elder
S. racemosa pubens microbotrys	Red elder
Shepherdia argentea	Silver buffaloberry
Symphoricarpos oreophilus	Mountain snowberry
Ulmus parvifolia	Chinese elm

TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Forest Service revegetation studies on TOSCO II processed shale (beginning in 1976) at Sand Wash, eastern Utah, within the salt desert shrub zone and at Davis Gulch, western Colorado, in the upper mountain brush zone, involved the use of amendments on processed shale without leaching salts. At Sand Wash, seven species of the Chenopodiaceae family were far superior to other species on processed shale with or without supplementary water or a covering of soil. Where at least 1 foot (30 cm) of soil covered processed shale, an additional eight species showed good survival. At Davis Gulch, a covering of 8 to 12 inches (20 to 30 cm) of topsoil over processed shale greatly increased survival and growth of container-grown plants compared to a 2- to 3-inch (5 to 7.5 cm) covering of broken rock fragments or a cover of barley straw crimped into the processed shale.

On a simulated mining tract at the Alton coal field, southern Utah, grass hay rotovated 8 inches (20 cm) deep into the soil increased seedling survival. Where several overburden materials were tested as growing media for plants, sandy loams and loam topsoils gave best results while a dark-colored carbonaceous shale material (clay loam) lying immediately above the coal seam gave better results than the poorest topsoil (silty clay).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Oil Shale Coal Mining Semiarid land Spoil Grasses	Tosco Spent Shale Revegetating Utah Colorado Irrigation	2A 2B 2D 8G 8I 13B

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