VEGETATIVE STABILIZATION OF SPENT OIL SHALES

by
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Department of Agronomy

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Final Report, Phase II-A

to the

COLORADO DEPARTMENT OF NATURAL RESOURCES

Thomas W. Ten Eyck, Executive Director

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VEGETATIVE STABILIZATION OF SPENT OIL SHALES

(FIELD RESEARCH)

Piceance Basin study site, August 1974.

H. P. HARBERT AND W. A. BERG

DEPARTMENT OF AGRONOMY

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Phase II-A

Vegetative Stabilization of Spent Oil Shales

FINDINGS

1. In this study the bulk of the soluble salts in spent oil shales were leached to depths of several feet, however, the fine-textured spent shale was later resalinized by salt dissolved in water moving upward by capillary rise.
2. Six inches of soil cover over the leached fine-textured spent shale was also salinized.
3. The coarser-textured spent shale became resalinized at one site but not at the other. These differences are apparently due to the efficiency of the leaching procedures and possibly on the degree of compaction of the spent shale.
4. Twelve inches of soil cover over unleached spent shales was not salinized. It is believed that the salt did not move upward in these treatments because the water content of the spent shale was lower than in the leached treatment.
5. Surface temperatures on the south-facing slope of the fine-textured spent shale were cooler in the spring and much warmer in the summer than on soil. Mid-summer surface temperatures of 150° F were recorded on the fine-textured spent shale.
6. Resalinization was greater on south-facing slopes than on north-facing slopes.
7. A good cover of native species was established with intensive management on all spent shale and soil cover treatments at one study site. An adequate vegetative cover must still be established at the other site.
8. Effects of the salinity and high surface temperatures are noticeable on the vegetation and with time are expected to become more pronounced.

9. Barley plants growing in both spent shales had higher molybdenum and zinc contents than plants growing in soil.
10. Runoff from a small storm was greater from the fine-textured spent shale than from the coarse spent shale or soil.

RECOMMENDATIONS

1. If spent shales are to be used as a plant growth media they will need to be more intensively leached and managed than the plots in this study. Soil cover appears to be a more feasible approach.
2. Six inches of soil cover over leached fine-textured spent shale became salinized, twelve inches of soil cover over unleached spent shales did not. Research is needed on depths of soil cover over spent shales of various textures.
3. South and southwest facing slopes should be avoided if possible in development of spent shale disposal areas at the lower and middle elevations of the Colorado oil shale region.

INTRODUCTION

Disposal of massive amounts of spent shale will be required if an oil shale industry using surface retorting is developed. Some of the spent shale may be returned to mined-out areas; however, large amounts of spent shale would probably be disposed of by compacting it into canyons. The surface of these piles might be stabilized by establishment of vegetation directly on the spent shale or on soil cover over the spent shale.

Spent shales are too salty for plant growth and very deficient in plant available nitrogen (N) and phosphorus (P). Good stands of vegetation have been established on TOSCO spent shale after leaching, fertilization and sprinkling for seedling establishment.[1] The unanswered question on the TOSCO spent shale is: Can adequate vegetative cover, to control erosion, be maintained under natural precipitation conditions once the stand has been established by intensive management practices?

Little or no information is available on characteristics, as a plant growth media, of spent shale produced by other retorting methods. However, it is known that some processes use higher temperatures which would mean greater alkalinity (pH). Also other processes require air flow through the retort. This requires coarser feedstock than the TOSCO process and results in a considerably coarser spent shale. Thus, the suitability of spent shale as a plant growth media would depend on the physical and chemical characteristics which are, in part, a function of the retorting process. These factors plus the on-site factors of climate, aspect, elevation, slope, and management determine the potential plant cover.

With these factors in mind, this study was designed with the primary objectives of investigating surface stability of, and salt movement in, spent shales and spent shales covered with soil after vegetation had been established by intensive treatment, and then left under natural precipitation conditions. A secondary objective is to evaluate the establishment and growth of various native plant species seeded in spent shales and soil cover over spent shales.

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[1] Processed Shale Revegetation Studies, 1965-1972. M. B. Bloch and P. D. Kilborn, editors, Colony Development Operation, Atlantic Richfield Company, Operator, April 1973.

STUDY DESIGN AND METHODS

The spent shales used were from processes developed by The Oil Shale Corporation(TOSCO), and the U. S. Bureau of Mines (USBM). The TOSCO spent shale is a uniformly fine-textured (silt loam) black material[1] retorted at the Colony Development Operation near Grand Valley, Colorado. The USBM spent shale was from the waste pile at the USBM Anvil Points facility. The USBM spent shale is gray to black and contains about 60 percent coarse particles (>2mm diameter) and 40 percent soil-size particles which are a loam in texture.[1]

The basic study design consists of two sets of plots: one set at 5,700 feet (Anvil Points site) and the other at 7,300 feet (Piceance Basin site). The following seven "soil-spent shale" treatments were tested.

1. Leached TOSCO spent shale.
2. Leached TOSCO spent shale with 6 inches of soil cover.
3. Unleached TOSCO spent shale with 12 inches of soil cover.
4. Leached USBM spent shale.
5. Leached USBM spent shale with 6 inches of soil cover.
6. Unleached USBM spent shale with 12 or 24 inches of soil cover.
7. Soil control.

Each treatment has a north and a south exposure on a 4:1 (25%) slope and is replicated (Fig. 1). Thus, there are a total of 28 individual 11 feet wide by 22 feet long plots at each site.

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[1] A literature review on these spent shales is contained in the following: Striffler, W. D., I. F. Wymore and W. A. Berg. 1974. Characteristics of spent shale which influence water quality, sedimentation and plant growth medium. In Surface rehabilitation of land disturbances resulting from oil shale development. Colo. State U. Environmental Resources Center Technical Report Series 1.

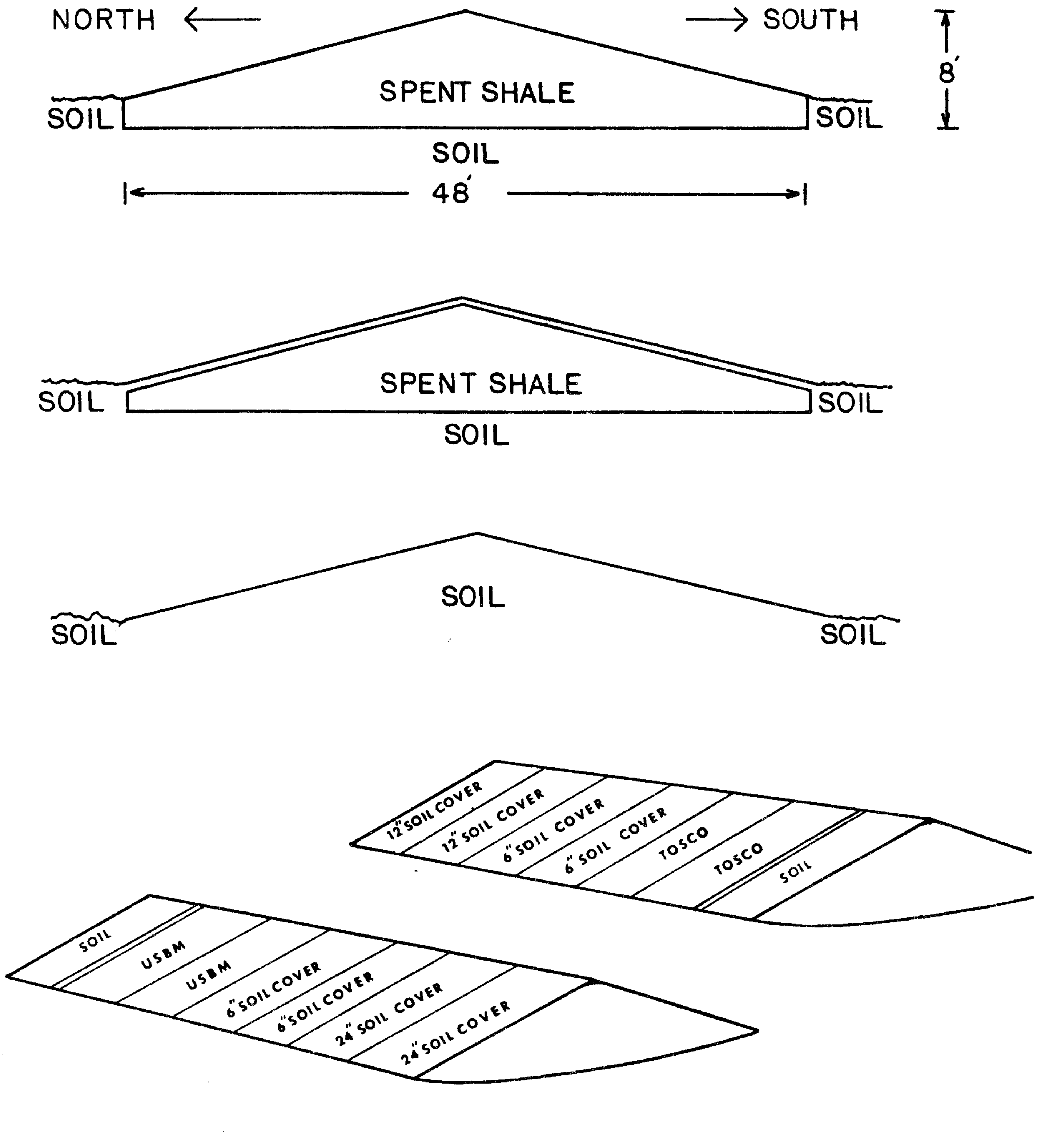

Figure 1. Schematic of spent shale and soil-covered spent shale plots. Top - Side view of cross section through plots. Bottom - Overview of north aspect of TOSCO (upper) and USBM (lower) spent shale plots showing treatments and replications.

With a hot dry summer climate and sparse natural vegetation, the Anvil Points site represents one of the more difficult areas to revegetate within the oil shale region. The average annual precipitation is about 12 inches. The surrounding natural vegetation is the low elevation pinyon-juniper woodlands as described by Ward _et al_.[1] This site is located on the northwest corner of the housing area of the U. S, Bureau of Mines Oil Shale Research Facility, 8 miles west of Rifle.

The Piceance Basin study site has an average annual precipitation of about 17 inches, and the natural vegetation types are high elevation big sagebrush shrubland, and high elevation pinyon-juniper woodland. This site was selected because its climate, elevation, and vegetation is representative of the federal oil shale lease sites (Colorado a&b) located within the Piceance Basin. The study site is located on federal land (BLM) along Wagonroad Ridge. Access to the site is up Black Sulfur Creek (7 miles) to the Equity Oil Company field camp, then turning right and following the road (2 miles) to the top of the ridge next to the Equity Oil Company radio repeater tower. The plots are across a small valley on a sagebrush flat about 1/2 mile west of the repeater station (SE1/4, NE1/4, S30, T2S, R98W).

The development of both study sites was carried out in five phases:

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[1] Ward, R. T., W. Slauson, R. L. Dix, 1974: Natural Vegetation in the Landscape of the Colorado Oil Shale Region pp 30-66. In _Surface Rehabilitation of Land Disturbances Resulting from Oil Shale Development_, Colorado State University Environment Resources Center Technical Report Series No. 1.

1. Construction of spent shale piles, soil covering certain treatments, and application of phosphorus fertilizer.
2. Installation of salinity and moisture monitoring equipment within each plot.
3. Leaching of soluble salts by sprinkler irrigation.
4. Installation of individual runoff plots and runoff collection systems.
5. Seeding, mulching, sprinkler irrigation for establishment of seedlings, fertilization with nitrogen, and construction of a deer-proof fence.

The construction phase for each site started with the excavation of 2 feet of soil in an area 48 feet wide and 66 feet long and then filling the center of the excavation with spent shale to a depth of 6-8 feet depending upon the depth of soil cover. The sites were then sloped to 25% and the excavated soil was used for the soil cover treatments. Construction of the plots was completed in April 1973 on the Anvil Points site, and in August 1973 on the Piceance Basin site.

Following construction, each plot was fertilized with triple super phosphate at the rate of 400 pounds P per acre. Each plot was then instrumented with a neutron probe access tube for moisture determinations and two salinity sensors. The access tubes were installed to a depth of 5 feet, and the salinity sensors were buried at depths of 7 and 20 inches.

The spent shale leaching at Anvil Points consisted of applying a total of 40 inches of water by sprinkling (.16 in/hr) for two 5-day periods in May 1973.

The Piceance Basin site was leached with 20 inches of water during August and September 1973, and was leached again the following June with an additional 40 inches of water. A low application rate (.16 in/hr) automated sprinkler irrigation system was used; this applied approximately 1 inch in the 6 hours of the day the system was in operation. However, there was some variation in daily application rates because of the logistics of hauling water to the site.

Runoff plot dividers and catchment containers were completed in April 1974 at Anvil Points and in July 1974 at the Piceance site. A sheet-metal collector and steel culvert catchment container is shown in Fig. 2. The catchment container has a concrete bottom and serves as an overflow container in case the 32 gallon plastic can inside becomes full.

Soil moisture and salinity data were collected at Anvil Points through the growing season in 1973 and 1974, and at Piceance Basin through the 1974 growing season. Soil moisture data collection for both sites consisted of measuring the moisture by depth in each plot with the neutron (soil moisture) probe. Salinity data collection consisted of periodically reading the salinity sensors; however, the sensor is accurate only at high moisture levels. Thus, selected treatments at both sites were core sampled for laboratory salinity measurements in 1973 and 1974. Only the results of the core sampling are given in this report.

Surface temperatures were recorded continuously during the 1973 and 1974 growing season at Anvil Points using Lambrecht 30-day recording thermographs. The sensors were buried approximately 1/4 inch under the surface of the TOSCO spent shale and 6 inches of soil cover

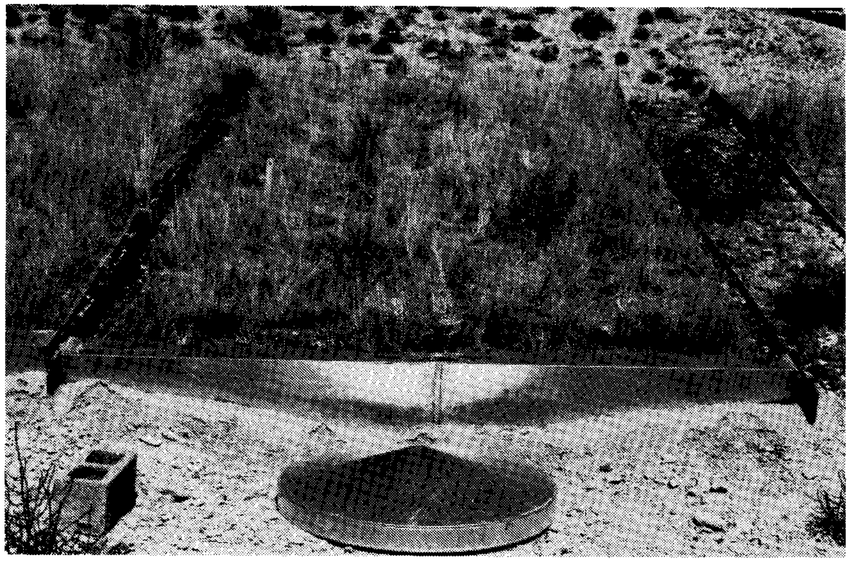


Figure 2. Runoff plot (11' x 22' - 25% slope) with sheet metal collector and 42" diameter x 36" deep catchment basin, with sheet metal lid. (USBM spent shale treatment, south aspect, Anvil Points study site - August, 1974).

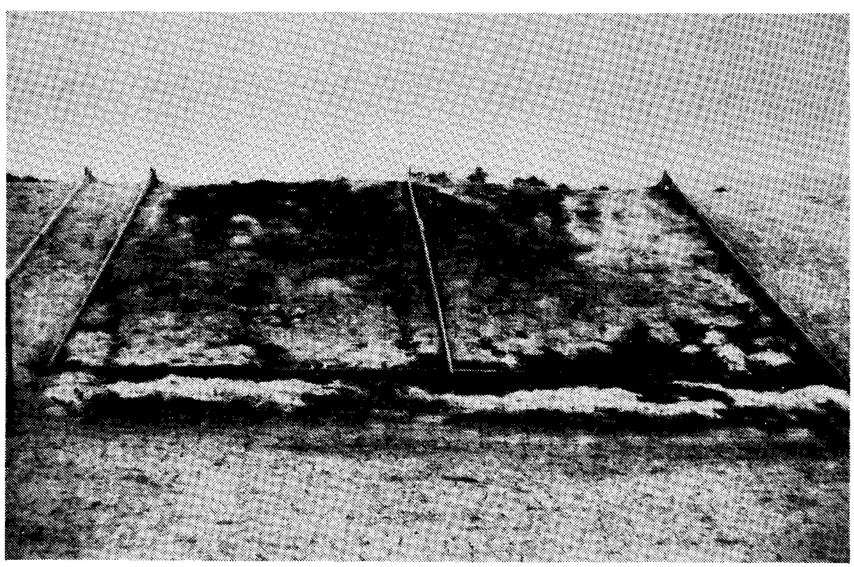


Figure 3. Salt crust on TOSCO spent shale treatments south aspect, April 28, 1974, following application of 20 inches of leach water (August, 1973) and 4.5 inches of winter precipitation. (Piceance Basin study site.)

over TOSCO spent shale treatments on both north and south slopes.

The Anvil Points site was seeded on June 11, 1973, with a mixture of native grasses and shrubs (Table 1). The plots were then raked lightly and mulched with hay which was held in place with cotton netting. The plots were sprinkler irrigated with a total of 18.5 inches of water during June and July 1973. In addition, a total of 120 lb/a of nitrogen was applied in June and August 1974.

Table 1. List of species seeded and rate of seeding (lb/a) on the oil shale research plots at the Anvil Points study site, June 11, 1973.

Species	Rate (lb/a)
Grasses	
Bluebunch wheatgrass (*Agropyron spicatum*)	2
Indian ricegrass (*Oryzopsis hymenoides*)	2
Western wheatgrass (*Agropyron smithii*)	1
Shrubs	
Big sagebrush (*Artemisia tridentata*)	1/2
Fourwing saltbush (*Atriplex canescens*)	1
Rabbitbrush (*Chrysothamnus* spp.)	1/2
Winterfat (*Eurotia lanata*)	1

The Piceance Basin plots were seeded on June 26, 1974, with a mixture of species (Table 2), raked lightly and then mulched with straw held in place with cotton netting. These plots were sprinkler irrigated until July 19. A total of 11.0 inches of water was applied for establishment. Following germination, 80 lb/a of nitrogen was applied.

Table 2. List of species and rate of seeding (lb/a) on the oil shale research plots at Piceance Basin study site June 26, 1974.

Species	Rate (lb/a)
Grasses	
Bluebunch wheatgrass (Agropyron spicatum)	1/2
Beardless wheatgrass (Agropyron inerme)	1/2
Indian ricegrass (Oryzopsis hymenoides)	1
Western wheatgrass (Agropyron smithii)	1/2
Forbs	
Lupine spp. (Lupinus spp.)	1
Utah sweetvetch (Hedysarum boreale utahensis)	3/4
Arrowleaf balsamroot (Balsamorhiza sagittata)	1/2
James penstemon (Penstemon jamesii)	3/4
Rocky Mt. penstemon (Penstemon montanus)	3/4
Shrubs	
Antelope bitterbrush (Purshia tridentata)	2
Big sagebrush (Artemisia tridentata)	1
Fourwing saltbush (Atriplex canescens)	1
Rabbitbrush (Chrysothamnus spp.)	1/2
Serviceberry (Amelanchier utahensis)	1
Mountain mahogany (Cercocarpus montanus)	1
Winterfat (Eurotia lanata)	1/2

In September 1973 and 1974 plant density by species and estimated percent ground cover were determined for each of the treatments at Anvil Points. Plant density measurements were made at the Piceance study site in September 1974. Plant density measurements were made by randomly placing four 8 x 16 inch rectangular quadrats in each plot, and counting the number of plants of each species. Percent ground cover was estimated as the total amount of ground cover (litter and plant cover).

Rainstorms caused measurable runoff on some plots at both study sites in August of 1974. Following the storm, runoff data was collected at both sites. Percent runoff, water quality, and sediment yields were determined. Analysis of the runoff samples was made by the Soil and Water Testing Laboratory at Colorado State University.

Precipitation data was recorded at Anvil Points during 1973 and 1974 with a standard U.S. Weather Bureau weighting rain gauge. A total of 3.7 inches of rainfall was received during the 1973 growing season (June-September). An additional 5.0 inches was received over the winter (October 13, 1973, through April 28, 1974). In 1974 only 1.85 inches was received during the growing season (May-September). Precipitation data was also recorded at the Piceance Basin study site; however, a 4 ft. long by 4 inch diameter steel pipe, capped at one end and then buried 12 inches in the ground, was used. A total of 4.6 inches was received between October 13, 1973, and May 10, 1974. An additional 1.5 inches was recorded during the 1974 growing season (June-September).

A weighting rain gauge with automatic event recorder will be installed at each study site in 1975.

RESULTS AND DISCUSSION

Salinity Measurements (Anvil Points, 1973-74)

Soluble salts were reduced to low levels by leaching the Anvil

Points spent shale plots with 40 inches of water in May 1973. However, the TOSCO spent shale was later resalinized by salts dissolved in water carried upward by capillary rise.

Soluble salts in soils are measured by the electrical conductivity (EC) of a solution extracted from the soil. In soil analyses the EC determinations are usually made on saturation extracts as was the procedure in this study; an EC value of 4 mmhos and greater indicates a saline soil, whereas, EC values of 16 mmhos and greater indicate extremely saline soil in which many species will not grow.

The EC of unleached TOSCO spent shale is about 15 mmhos. After leaching, the Anvil Points spent shale plots were sampled and found to have EC values of less than 2 mmhos to a depth of 4 feet. The plots were again core sampled on October 13, 1973. At this time the EC had risen to about 5 mmhos in the top 4 feet (Fig. 4a,b). By the following spring (1974) it appears that some leaching of salts had occurred during the winter from the 5 inches of precipitation received between October and April. However, there was no indication of leaching of the TOSCO spent shale south aspect (Fig. 4b) during this period. The September 1974 sampling indicated resalinization of the TOSCO profiles to EC values greater than 10 mmhos (Fig. 4a,b). The sampling results from the USBM spent shale plots (Fig. 4c,d) indicated no significant resalinization during the 1974 growing season.

The 6 inches of soil cover over leached TOSCO spent shale on both the north and south aspects was salinized by salts dissolved in water carried upward by capillary rise (wick action) from the underlying spent shale. EC values of greater than 10 mmhos were measured in the surface 2 inches on September 6, 1974 (Fig. 5a,b). In contrast, the

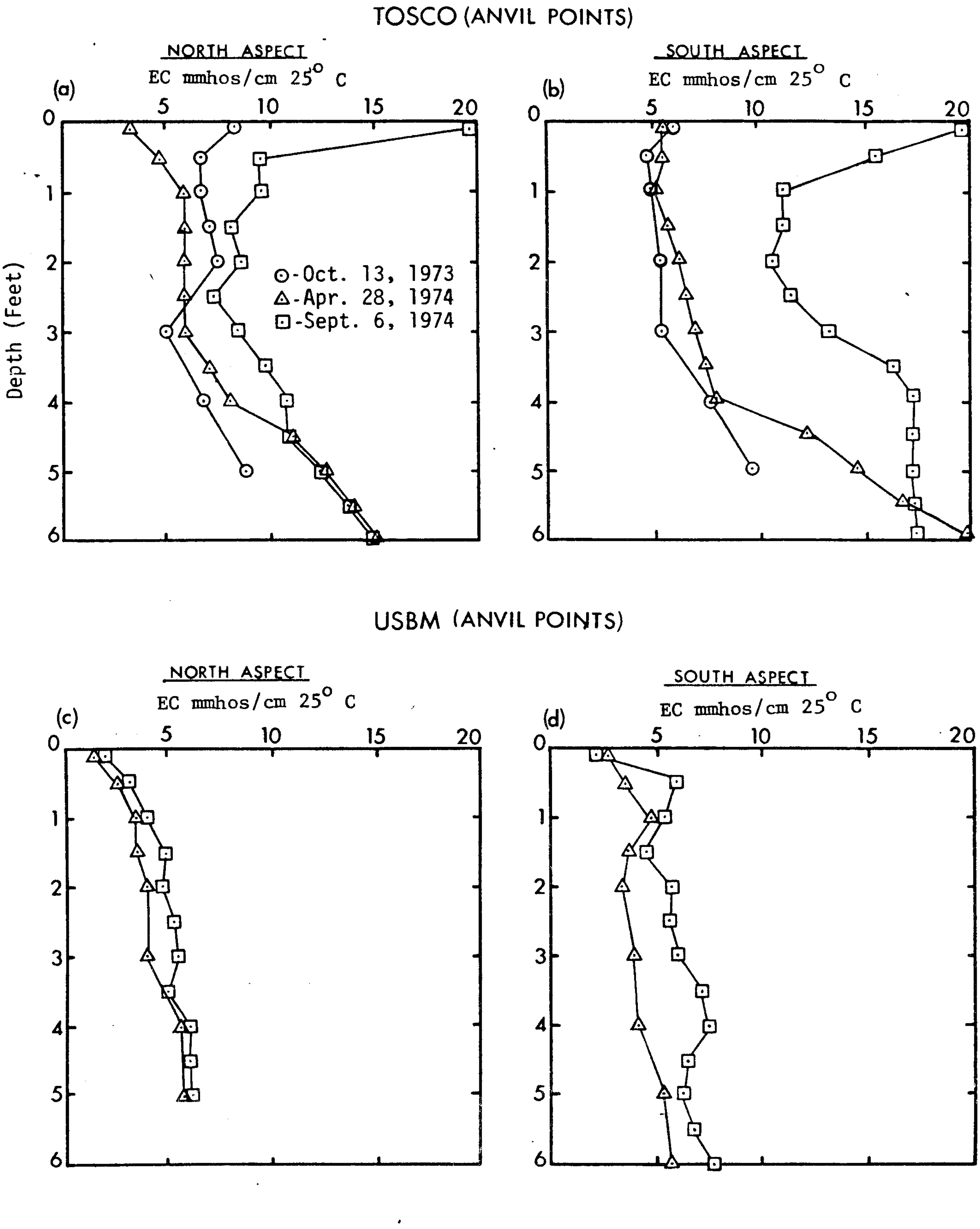


Figure 4 (a, b, c, d). Salinity profiles in TOSCO and USBM spent treatments showing the effect of winter leaching and capillary rise during the summer (Anvil Points, 1973-74).

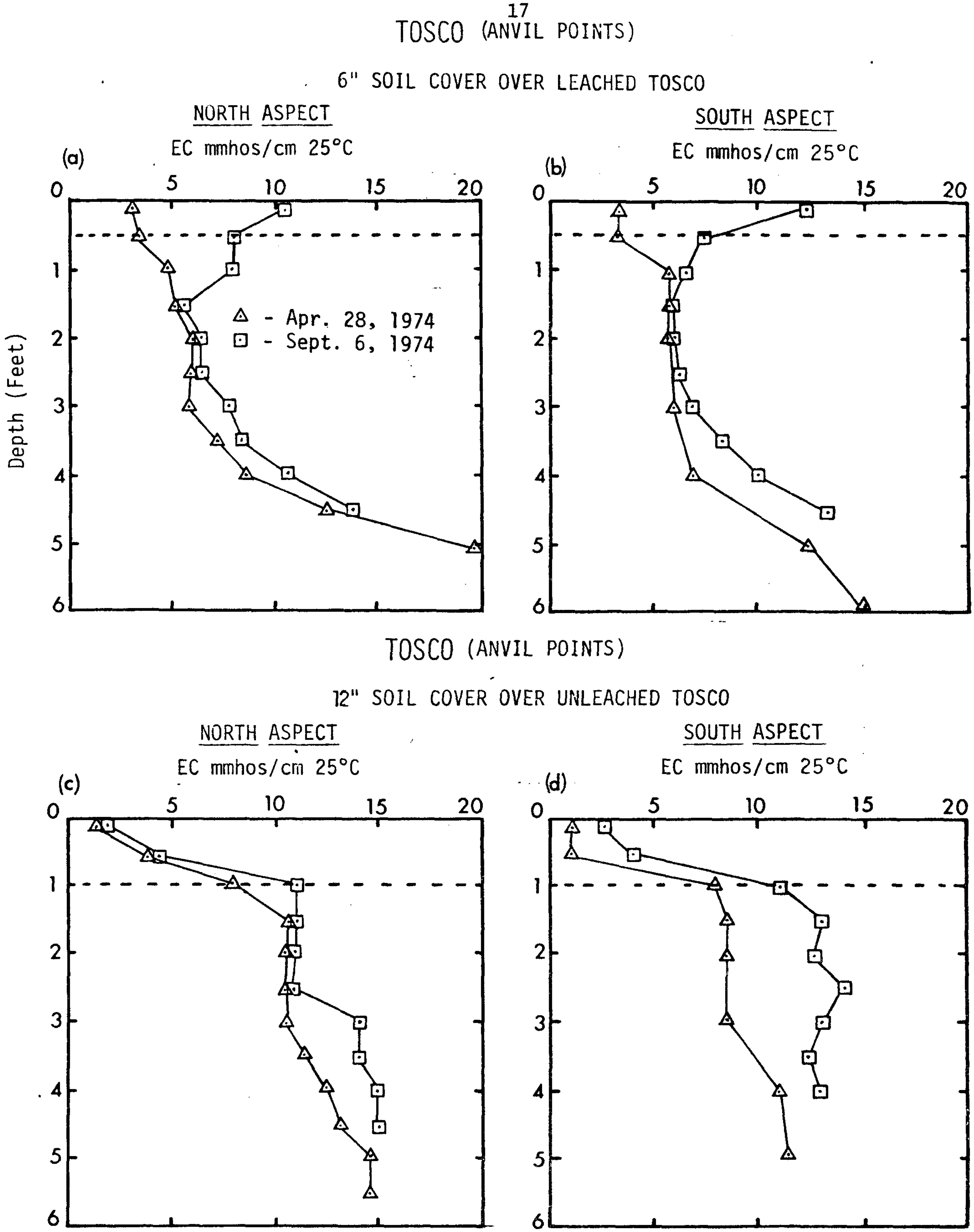


Figure 5 (a, b, c, d). Salinity profiles in treatments of 6" and 12" soil cover over TOSCO spent shales. 12" soil cover treatments were unleached. Salinization of the 6" soil cover is shown (Anvil Points study site, 1974).

12 inches of soil cover over unleached TOSCO spent shale was not salinized; however, there appears to be some salt movement upward from the spent shale into the soil (Fig. 5c,d). Little if any movement of salts into the 6 and 24 inch soil cover over USBM spent shale occurred (Fig. 6).

The salinization of the TOSCO spent shale treatments can be attributed to the following factors:

1. The uniform silty texture develops small capillary pores. The capillary pores in turn conduct water and dissolved salts upward in response to a potential developed by evaporation at the spent shale surface.
2. The silty material also has a high moisture-holding capacity which provides sufficient water for evaporation and the resulting upward salt movement after leaching.

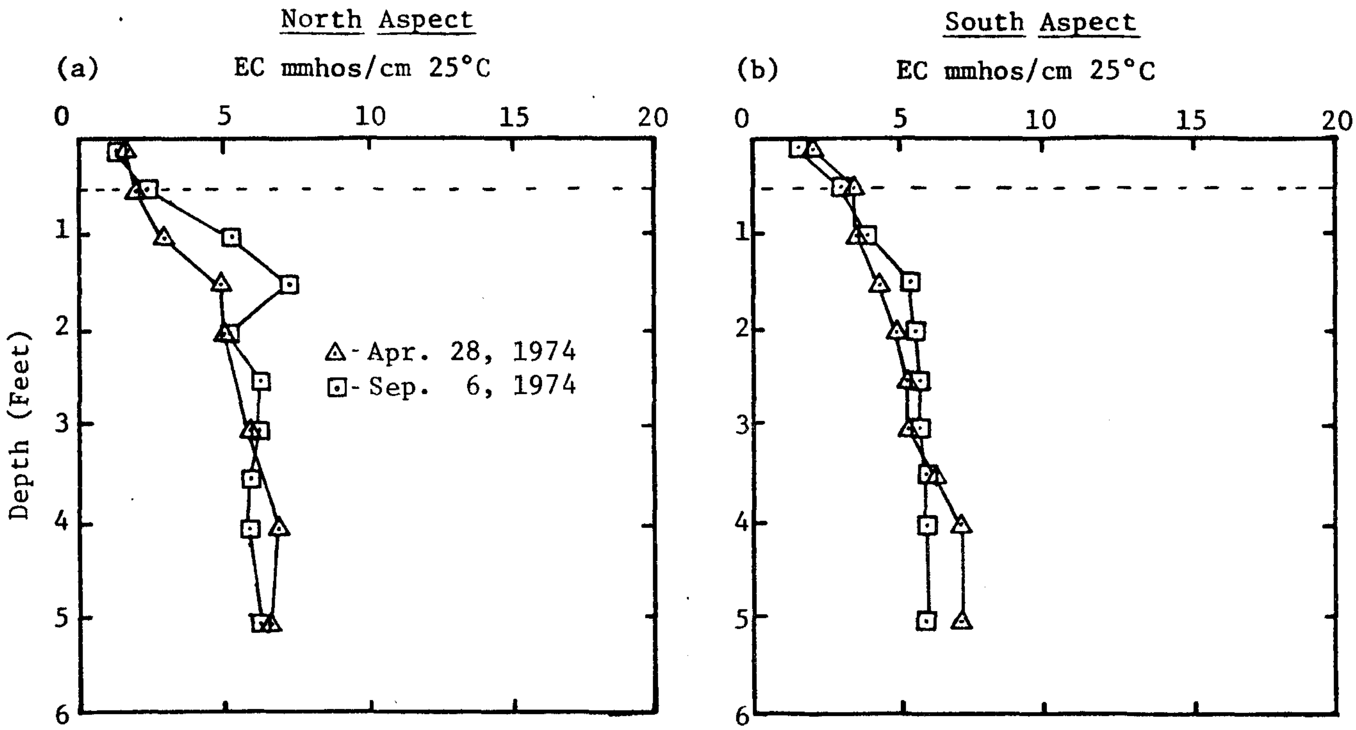
The salinization of 6-inch soil cover over leached TOSCO spent shale can also be attributed to capillary rise, both in the underlaying spent shale and in the soil cover. Apparently there is not adequate textural differences between the loam soil cover and the silt loam TOSCO spent shale to prevent the development of capillary pores across the spent shale-soil interface.

The lack of salinization of the 12 inches of soil cover over unleached TOSCO spent shale can be attributed to the lower moisture content of the unleached spent shale.

The USBM spent shale and soil cover over USBM spent shale treatments on the Anvil Points plots were not salinized in either 1973 or 1974. The lack of salinization can be attributed to the coarser texture of the USBM spent shale.

USBM (ANVIL POINTS)

6" SOIL COVER OVER LEACHED USBM



USBM (ANVIL POINTS)

24" SOIL COVER OVER UNLEACHED USBM

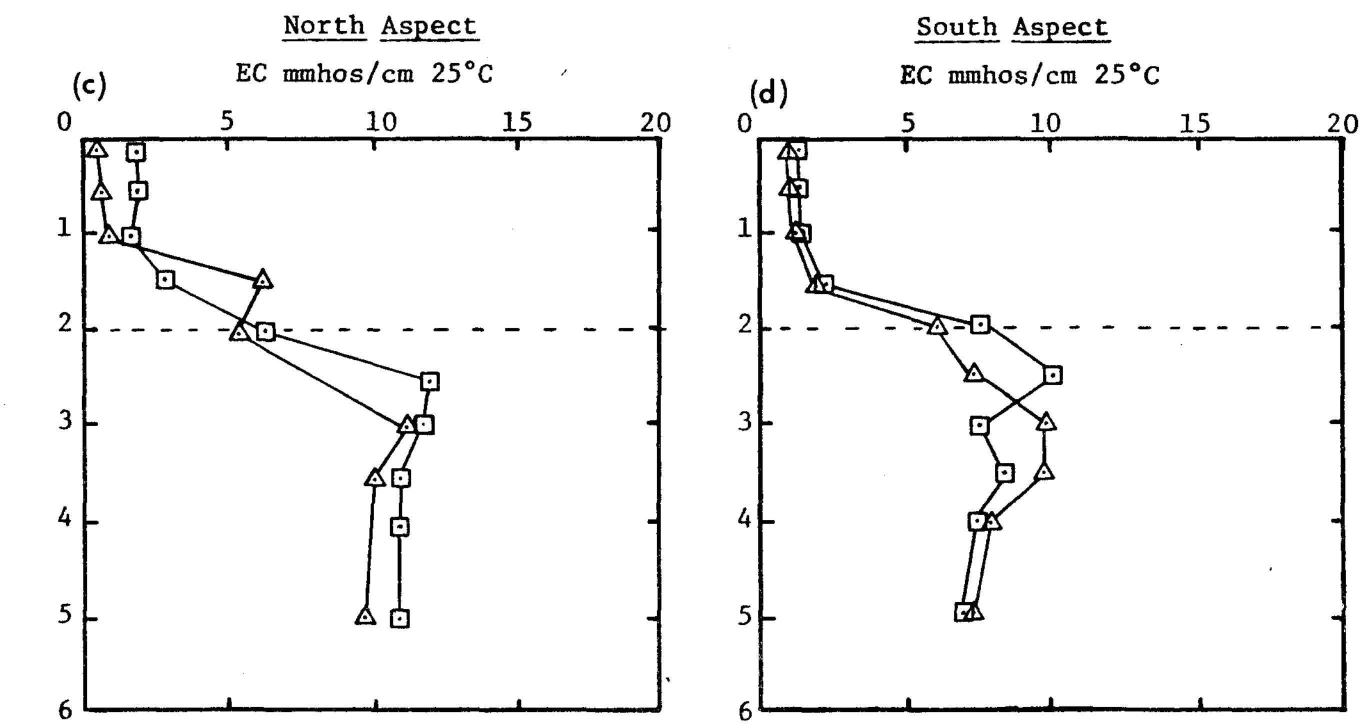


Figure 6 (a, b, c, d). Salinity profiles in treatments of 6" and 24" of soil cover over USBM spent shale, 24" soil cover was not leached (Anvil Points study site, 1974).

Salinity Measurements (Piceance Basin 1973)

The Piceance Basin study site was initially leached with 20 inches of water during a four-week period in August and September 1973. Analysis of core samples obtained from the TOSCO spent shale in October 1973 indicated high levels of soluble salts remained in the spent shale (Fig. 7a,b).

The TOSCO spent shale plots were core sampled again on May 23, 1974, and the results show a decrease in EC throughout profiles on both the north and south aspects. The decrease in salinity between October 1973 and May 1974 was a result of leaching from winter snow melt. There was more effective winter-leaching on the south aspect than on the north aspect (Fig. 7a,b). The increase in EC values in the upper 12 inches of the TOSCO south aspect (Fig. 7b) on May 23 indicates that movement of water and dissolved salts to the surface by capillary rise had already occurred; however, on the north aspect (Fig. 7a), capillary rise had not occurred by the May sampling date. The photograph in Figure 3 shows the salt crust on the south aspect of TOSCO spent shale treatments on May 23, 1974. The corresponding north aspect TOSCO spent shale did not have a salt crust on May 23.

The difference between the more effective leaching and yet the development of a salt crust by May 23 on the TOSCO south aspect was apparently the result of heavy snow accumulation on the south aspect during the winter and rapid melting in early spring. Snow drifts with an average depth of 30 inches were measured on November 23, 1973, across the south aspect of the TOSCO spent shale pile. While the corresponding north aspect only had 6 to 8 inches of snow cover.

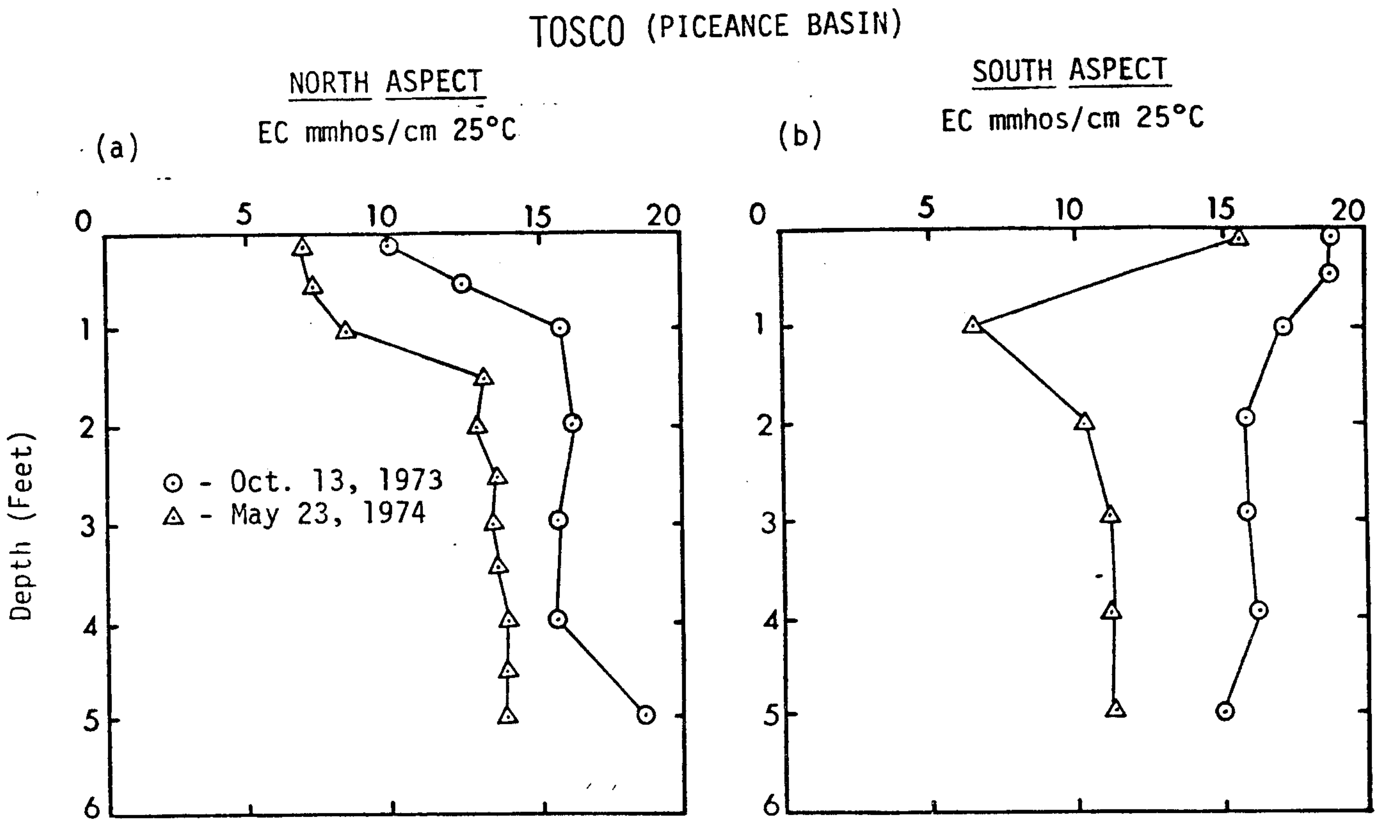


Figure 7 (a, b). Salinity profiles in TOSCO spent shale treatments, showing the leaching by snow melt (Piceance Basin study site, 1973-74).

Salinity Measurements (Piceance Basin 1974)

The Piceance plots were leached with an additional 40 inches of water in June 1974. Following leaching, the plots were core sampled on June 26, and the results show more effective leaching on the north aspect (Fig. 8a) than on the corresponding south aspect (Fig. 8b) for TOSCO spent shale. The USBM spent shale on both north and south aspects (Fig. 8c,d) were more effectively leached than the TOSCO spent shale treatments.

Both spent shale plots were core sampled again on September 10, 1974, and the results show that the TOSCO and USBM spent shales were resalinized and had EC values of 15 mmhos and greater at the surface (Fig. 8a,b,c,d). In addition, the results of the September sampling indicated that the 6 inches of soil cover over both TOSCO and USBM spent shales was becoming salinized (Table 3). There is no indication of the 12-inch soil cover on the USBM spent shale becoming salinized. There is an indication of some salt movement up into the 12-inch soil cover on the TOSCO spent shale (Table 3).

Table 3. Salinity measurements for soil control and soil cover over spent shales. Values are EC mmhos/cm 25° C, saturated paste. (Piceance Basin study site, September 10, 1974).

	SOIL		TOSCO				USBM			
			6"*		12"		6"		12"	
Depth	North	South	North	South	North	South	North	South	North	South
Surface	.9	.9	3.0	4.5	1.3	1.0	1.2	2.5	.5	.7
6"	.6	1.0	1.4	3.1	.9	1.0	.6	1.4	.4	.5
12"	.7	.8	-	-	3.0	3.5	-	-	1.0	.5

* Depth of soil cover over spent shale.

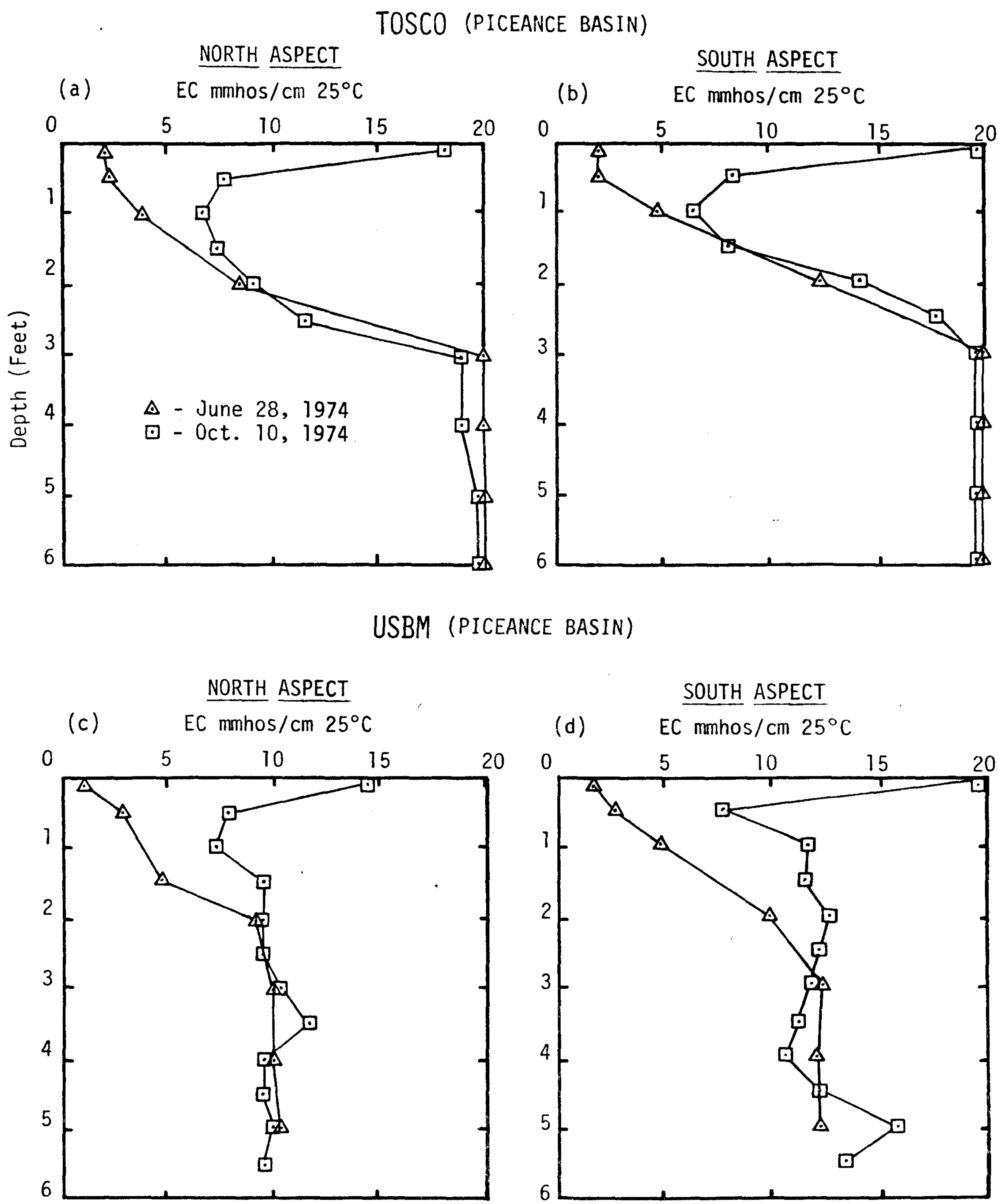


Figure 8 (a, b, c, d). Salinity profiles in TOSCO and USBM spent shale treatments showing resalinization of the leached spent shales (Piceance Basin study site, 1974).

The more effective leaching on the spent shales at Anvil Points then at the Piceance Basin site can be attributed to the following:

1. The use of moderately saline water (EC .7 to 1.0 mmhos) at the Piceance Basin site and high quality water at Anvil Points.
2. The USBM and the TOSCO spent shales at Piceance Basin site were compacted to higher bulk densities during construction to minimize settling--this results in creation of smaller pores and a greater capillary rise potential.
3. The sprinkler irrigation system design used at both sites was identical. However, the leach water was applied continuously for two 5-day periods at Anvil Points but was only applied intermittently (1.0 inch/day with approximately 6 hours required to apply) at the Piceance Basin site.
4. The sprinkler irrigation efficiency was reduced at the Piceance Basin site by the prevailing south-southwest wind (10-15 mph) during leaching. In addition, relative humidities were low and daily maximum temperatures were between 85 and 95° F.

Moisture Measurements (Anvil Points 1973-74)

Upon completion of leaching and seedling establishment in late July of 1973, the spent shales were at field capacity (approximately 35% by volume). However, by October 13, 1973, the moisture content in the spent shale was depleted to 28 percent by volume.[1]

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[1] The percent moisture values given in Figure 9 were obtained from a calibration curve developed for soils and, therefore, the values do not report the actual moisture content for the spent shales; however, the relative differences as plotted in Figure 9 are valid. Calibration curves are presently being developed for both the TOSCO and USBM spent shales.

Moisture readings were made every 15 days between April 18 and July 1, 1974, at Anvil Points; by June 15 available plant moisture was depleted to a depth of 30 inches in all treatments. The September 1974 soil moisture readings show the available plant moisture was depleted throughout the entire profile in each spent shale (Fig. 9). In general the results in Figure 9 are representative of the results obtained from all the plots at Anvil Points. There was no significant difference in plant available moisture depletion patterns between the spent shale plots and the soil control plots.

Moisture Measurements (Piceance Basin 1974)

Plant available moisture was depleted in both spent shales to a depth of 18 inches and was depleted to a depth of 30 inches in the soil control plots by September 1974 on the Piceance Basin site. The difference in moisture depletion between the spent shales and soil control was due to excellent plant growth on the soil control plots and only moderate plant growth in the spent shales.

Surface Temperature Measurements (Anvil Points 1973-74)

Extremely hot surface temperatures (150^{o} F) were recorded in the summer of 1974 on the TOSCO spent shale surface. In contrast, maximum surface temperatures of 118^{o} F were recorded on the soil. The mean maximum monthly temperatures for 1973 and 1974 are shown in Table 4. The surface temperatures for 1973 were cooler than the surface temperatures in 1974 because the plots were leached, mulched and irrigation water was applied almost daily in June and July 1973.

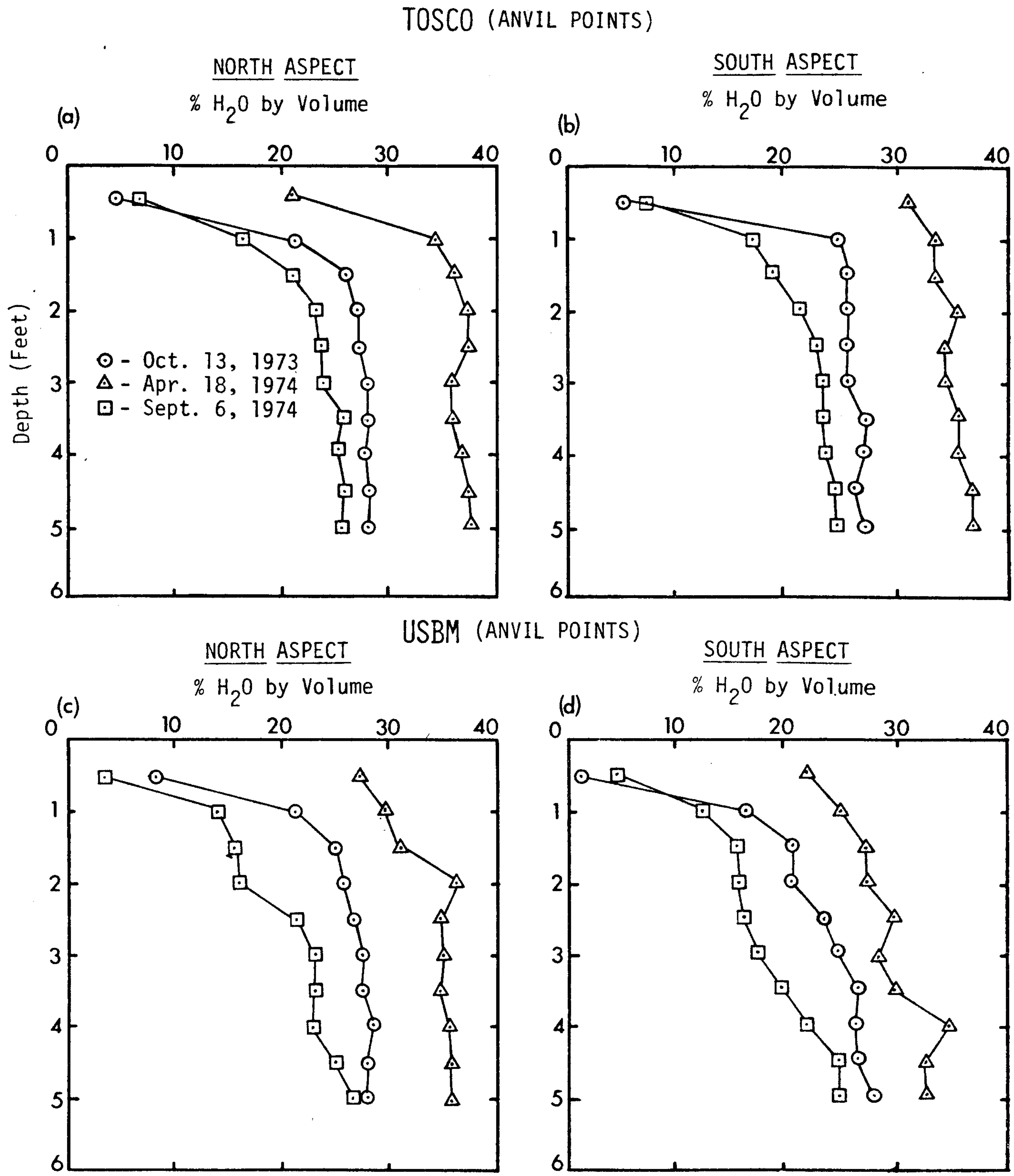

Figure 9 (a, b, c, d). Moisture profiles in TOSCO and USBM spent shale treatments showing profile recharge over the winter and use during the growing season (Anvil Points study site, 1973-74).

Table 4. Mean maximum monthly surface temperatures (^{o}F) for TOSCO spent shale and 6" soil cover over TOSCO spent shale, north and south aspect. Anvil Points study site, 1973 and 1974.

Treatment	Aspect	April 73	April 74	May 73	May 74	June 73	June 74	July 73	July 74	Aug. 73	Aug. 74	Sep. 73	Sep. 74
TOSCO	North	-	50	-	71	79	88	83	88	79	80	74	64
TOSCO	South	-	48	-	80	74	104	81	131	88	108	86	113
Soil	North	-	50	-	70	80	88	86	104	80	86	75	75
Soil	South	-	60	-	72	86	104	93	118	88	100	84	104

In April 1974 the TOSCO south aspect plot was 12^{o} (F) cooler than the corresponding soil cover south aspect, however there was no difference in the surface temperatures between these treatments on the north aspect. In May 1974 the TOSCO south aspect temperatures averaged 8^{o} (F) cooler than the soil cover temperatures. By July the maximum temperatures on the TOSCO south aspect was averaging 131^{o} (F) per day with 150^{o} (F) maximum temperatures recorded during June, July and August. The cooler spent shale surface in May was caused by surface evaporation of stored water from the spent shale profile. Once the moisture available for evaporation was depleted the temperature increased rapidly.

A typical summer diurnal temperature curve for surface temperatures on the TOSCO spent shale and soil cover is shown in Figure 10.

Vegetation Measurements (Anvil Points 1973-74)

A good vegetative cover of native species was established at Anvil Points by late July 1973 (Fig. 11a). Major shifts in the relative density of the established species occurred between September

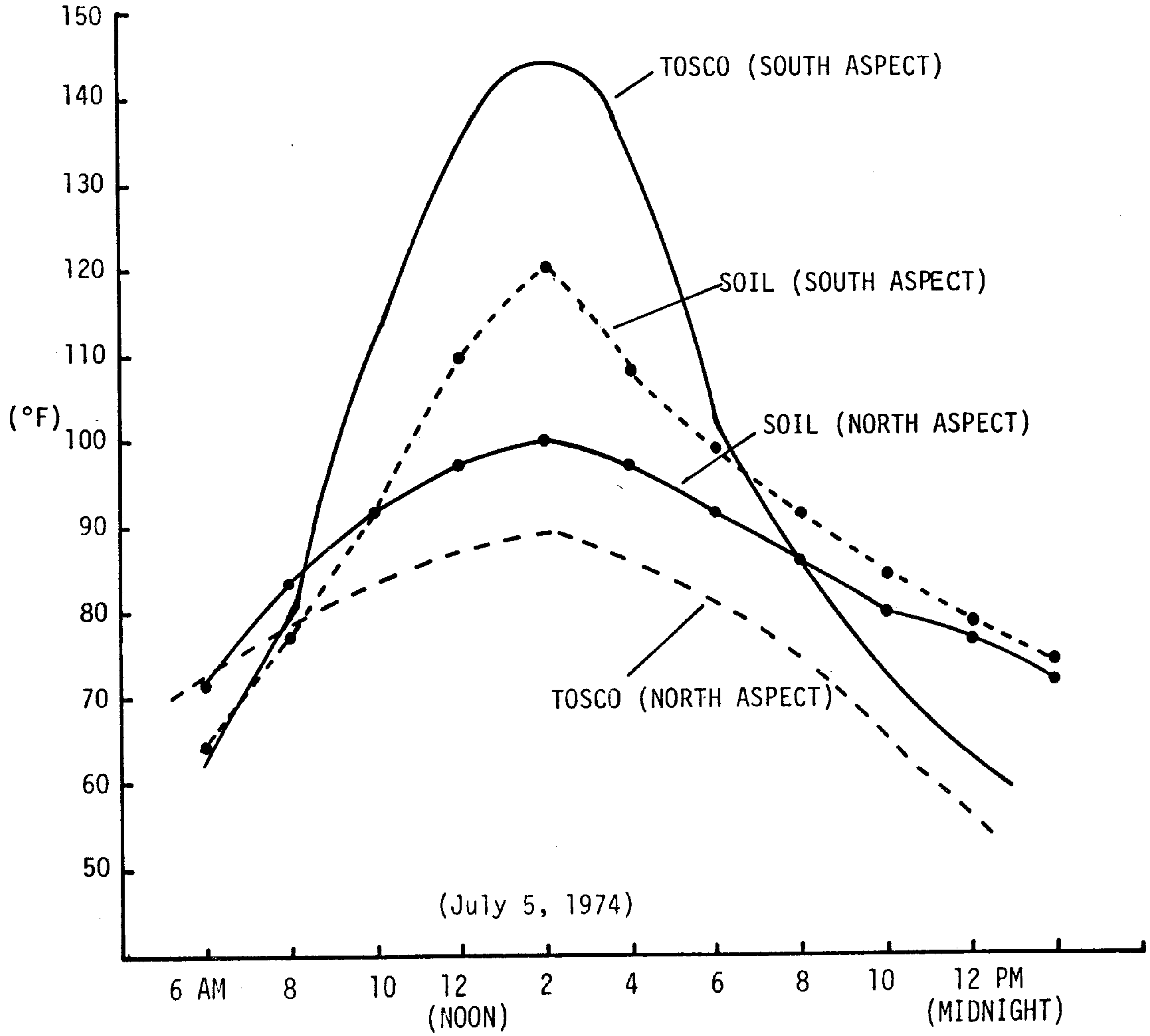

Figure 10. Surface temperatures of TOSCO spent shale and 6" of soil cover over TOSCO spent shale, north and south aspects (Anvil Points study site, July 5, 1974).

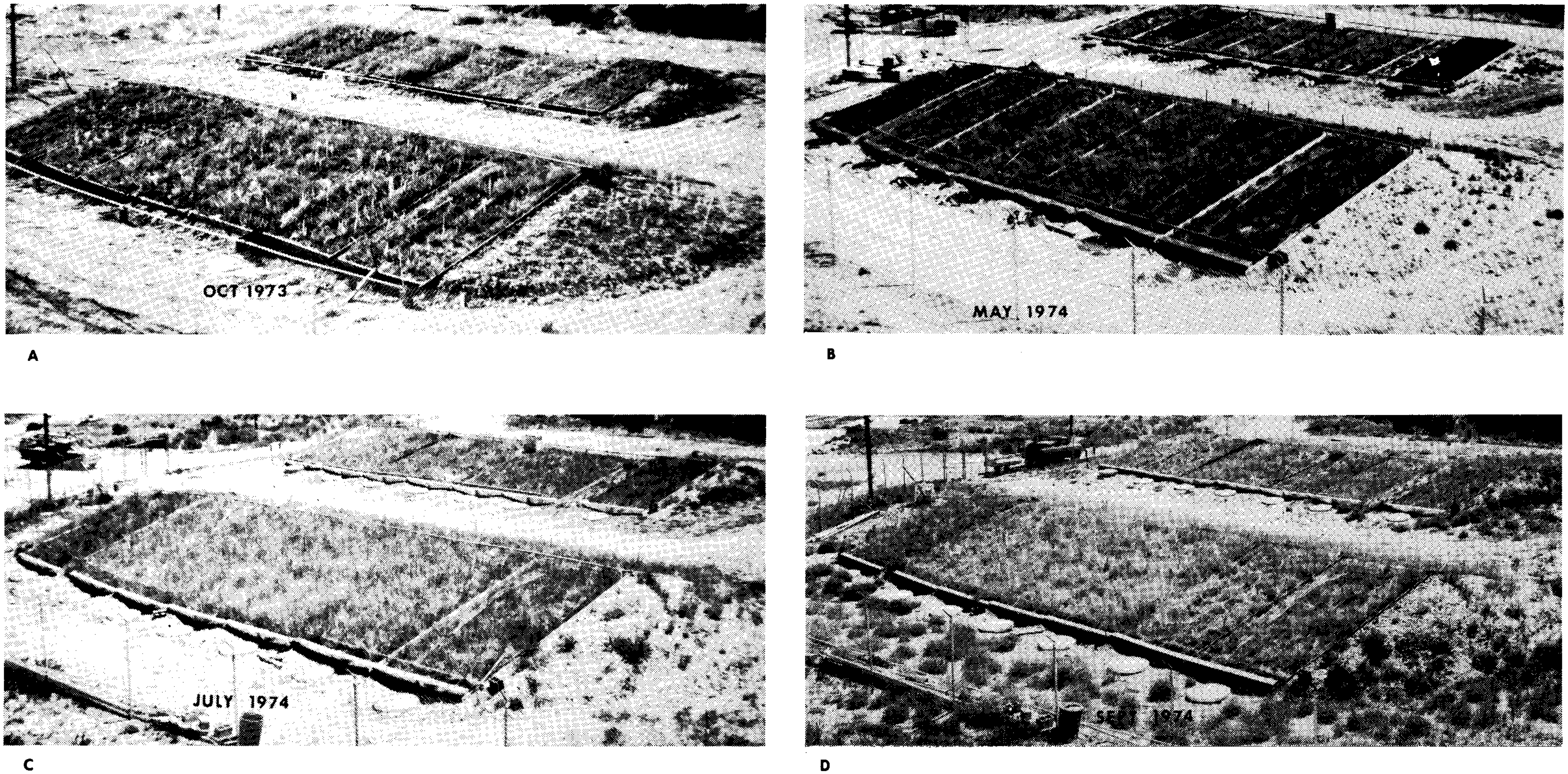

Figure 11 (a, b, c, d). Vegetative cover for the north aspect of the USBM and TOSCO research plots (Anvil Points study site - 1973-74).

1973 and September 1974 sampling dates (Table 5). The high 1973 relative density for timothy was due to timothy seed in the hay mulch and the subsequent excellent establishment under irrigation. In 1974 the plots were not irrigated and the timothy died out. Bluebunch wheatgrass increased in relative density on the north aspects and Indian ricegrass increased in relative density on the south aspects in 1974. The shrubs did not show any significant shifts between 1973 and 1974.

Table 5. Relative densities of the dominant plant species growing on the Anvil Points study site - September 1973 and 1974. Spent shale types and soil cover treatments are not differentiated.

Species	% Relative Density	
	1973	1974
Bluebunch wheatgrass	28.3	43.3
Western wheatgrass	26.9	27.2
Indian ricegrass	8.0	22.7
Timothy	33.1	1.8
Winterfat	3.0	3.4
Fourwing saltbush	0.7	1.6

Cover decreased on the TOSCO spent shale plots (Table 6) apparently in response to the high salinity and surface temperatures. Cover also decreased on the soil over TOSCO spent shale; this decrease, however, was only to cover levels comparable to those on the soil control. The original (1973) high cover values for the soil-covered TOSCO spent shale plots was due to thick stands of timothy on these plots but not on other plots.

Table 6. Percent ground cover for the north and south aspects soil control, TOSCO and USBM spent shale and soil cover over TOSCO and USBM spent shale, Anvil Points study site, 1973 and 1974.

Treatments	% Ground Cover			
	September 1973		September 1974	
	North	South	North	South
Soil Control	65	60	65	60
TOSCO spent shale	53	48	43	43
6" soil cover/TOSCO spent shale	80	80	63	58
12" soil cover/unleached TOSCO spent shale	80	80	63	60
USBM spent shale	55	57	55	55
6" soil cover/USBM spent shale	73	68	75	62
24" soil cover/unleached USBM spent shale	73	68	68	60

Observations were made in 1974 on the time of plant growth initiation for each treatment at Anvil Points. Growth began on the following treatments during the last week in April 1974: (1) TOSCO spent shale with 12 inches of soil cover, (2) USBM spent shale with 6 and 24 inches of soil cover, (3) USBM spent shale, and (4) the soil control plots (Fig. 11b). Growth on the TOSCO spent shale with 6 inches of soil cover was initiated by the second week in May; but plant growth on the TOSCO spent shale treatments did not begin until the last week in May. Figure 11b was photographed May 10, 1974. The dark color (green) of some plots represents new growth. The delay in growth initiation on the TOSCO spent shale treatment was apparently due to cooler surface temperatures caused by the evaporation of stored moisture. Once the moisture available for evaporation was depleted, the surface warmed rapidly and new growth started. (See the results section on surface temperatures at Anvil Points.)

On July 3, 1974, (Fig. 11c) only the TOSCO spent shale, TOSCO spent shale with 6 inches of soil cover, and the soil control plots contained actively growing plants. On the other treatments the plants had matured and set seed. The soil control plots in Figure 11d are darker in color, which represents new plant growth following 1 inch of precipitation received in August 1974.

The 1974 reduction in plant growth on the TOSCO spent shale can be attributed to the following factors:

1. Low surface temperatures in April and May caused by evaporation of water brought to the surface by capillary rise.
2. High salt content in the surface as a result of the movement of dissolved salt upward with the capillary water.
3. High surface temperatures (150° F) recorded during late June, July and August on the spent shales.

Even greater differences in plant cover among the spent shale and soil cover treatments are expected in the future.

<u>Vegetation Measurements (Piceance Basin 1974)</u>

Stand establishment was poor for grasses and fair to good for shrubs and forbs on the Piceance Basin plots. One reason for the thin grass stands is that very low seeding rates (Table 2) were used in an attempt to obtain stands similar in density to stands supported by the natural precipitation. Another reason is competition from barley growing from viable seeds in the mulch despite methyl bromide treatment. The barley was hand pulled in late August and data was collected on the remaining seeded species. The results of quadrat analysis show fair to poor establishment of the grasses. Establishment of big sagebrush was excellent; as many as 20 plants were counted per quadrat (8 in. x 16 in.). Mountain mahogany and bitterbrush also had good establishment; however, the other shrubs listed in Table 2 only showed fair to no establishment. Utah sweet vetch and the penstemons also had good establishment. No arrowleaf balsamroot was found.

Due to the poor to fair establishment of the grass species seeded in June 1974, the Piceance Basin plots were reseeded on October 18, 1974. At this time the plots were furrowed lightly (so as not to destroy the established plants) and seeded with western wheatgrass (7 lb/a), bluebunch wheatgrass (7 lb/a) and Indian ricegrass (7 lb/a), raked lightly and mulched. In addition, big sagebrush seedlings were hand thinned to prevent the plots from becoming dominated by this species.

To insure development of adequate vegetative cover in the spring of 1975, an additional 20 inches of leach water will be required in May and supplemental irrigation through June. The additional seeding, leaching and supplemental irrigation is required to insure adequate vegetative (approximately 60-70%) cover, similar to that obtained at Anvil Points in 1973. Once the plant cover is established, no additional irrigation water will be applied.

Analysis of Barley Plants Collected from the Piceance Basin Site 1974

Molybdenum and zinc were higher in barley grown in the spent shales than in soil (Table 8). These plant samples were collected on August 15, 1974, from the Piceance Basin plots. No discussion of the ramifications of the results given in Table 8 are made as we feel that more detailed research is needed.

Runoff Measurements (Anvil Points 1974)

The Anvil Points study site received .75 inches of rain in 30 minutes from a thunderstorm on August 14, 1974. On August 15 the total runoff was measured from each plot and samples taken for water quality analyses. In general the runoff was extremely low for all plots (Table 9). The only plots with significant runoff in comparison to the soil control plots were the TOSCO spent shale treatments. The low sediment yields are a reflection of the rather dense ground cover of living and dead vegetation and mulching residue. Runoff water from all treatments was somewhat saline. Comparison of runoff water quality between the soil and spent shale treatments must take into consideration the difference in total runoff; if this is done the quantity of soluble salts in runoff from the TOSCO spent shale was much greater than from the soil.

Runoff Measurements (Piceance Basin 1974)

A total of .50 inches of rainfall fell on the Piceance Basin study site on August 14, 1974. No information was obtained on storm duration, intensity, or wind direction. Total runoff was measured and samples were collected for water quality analyses.

The results show a significant amount of runoff from the TOSCO spent shale treatments in comparison to the soil control plots (Table 10).

Table 8. Elements found in the analysis[1/] of mature barley plants growing on spent shale and soil plots. (Piceance Basin study sites, August 15, 1974). The values given are in ppm dry weight basis, and are means of two replications per treatment.

Treatments	K	Ca	Mn	Fe	Cu	Zn	Sr	Zr	Mo	Cd
TOSCO										
North	37676	5700	56.0	82.7	15.4	58.7	23.5	0	8.6	.83
South	29490	4133	49.5	95.6	13.8	67.0	24.4	0	11.9	.86
USBM										
North	44453	6397	24.5	122.2	18.6	24.0	41.8	.70	12.9	.56
South	52831	10752	22.6	148.0	21.5	34.7	50.5	1.3	18.0	.43
SOIL										
North	32749	3532	49.6	91.0	16.5	17.5	42.2	.33	3.0	1.6
South	28343	10279	60.0	200.0	18.6	23.4	51.6	.89	2.8	.95

1/ Analyses were made in cooperation with Dr. G. M. Ward, Animal Science Department, CSU. The analyses were made by the University of Colorado in conjunction with the Transport and the Biological Effect of Molybdenum in the Environment Project.

Table 9. Runoff, sediment yield, and water quality from a .75 inch, 30-minute storm at Anvil Points study site, Aubust 14, 1974.

	TOSCO						USBM						SOIL	
	Spent Shale		6" Soil Cover		12" Soil Cover		Spent Shale		6" Soil Cover		24" Soil Cover			
	North	South	North	South	North	South	North	South	North	South	North	South	North	South
Runoff, gallons	9.4	2.3	T*	.8	T	T	.4	.4	T	T	.4	T	T	.5
Runoff, %	.82	.20		.07			.03	.03			.03			.04
Sediment lb/a	200	145		25			12	52			8			12
EC mmhos/cm 25°C	1.5	1.5		1.3			1.9	1.4			1.2			1.1
pH	7.0	7.1		7.0			7.6	7.3			7.2			7.7
Cations														
Ca ppm	147	146		100			122	123			100			75
Mg ppm	74	33		21			36	26			20			16
Na ppm	67	29		34			161	62			79			70
K ppm	22	35		70			70	64			98			69
Anions														
HCO_3 ppm	113	179		500			543	418			584			451
Cl ppm	17	36		35			198	66			34			40
SO_4 ppm	822	104		144			192	168			408			115
NO_3 ppm	3	3		5			6	6			3			4

* T denotes trace of runoff, less than .2 gallon.

Table 10. Runoff, sediment yield, and water quality from a .50 inch storm at the Piceance Basin study site, August 14, 1974

	TOSCO						USBM						SOIL	
	Spent Shale		6" Soil Cover		12" Soil Cover		Spent Shale		6" Soil Cover		24" Soil Cover			
	North	South	North	South	North	South	North	South	North	South	North	South	North	South
Runoff, gallons	2.8	7.4	.4	T*	T	T	.4	.7	.5	.5	T	T	T	.4
Runoff, %	.37	.97	.05				.05	.09	.06	.06				.05
Sediment lb/a	27	162	12				.7	8	2	5				8
EC mmhos/cm 25°C	3.0	2.2	.85				1.2	1.9	1.2	.92				.73
pH	7.1	7.5	7.4				8.0	7.5	7.9	7.6				7.6
Cations														
Ca ppm	350	301	69				89	165	57	73				67
Mg ppm	174	103	17				32	74	25	17				17
Na ppm	131	66	52				56	137	74	59				22
K ppm	12	10	9				7	22	28	6				3
Anions														
HCO_3 ppm	88	100	195				251	198	364	207				238
Cl ppm	15	10	40				35	27	40	25				12
SO_4 ppm	1584	1236	175				276	744	233	238				77
NO_3 ppm	.3	.4	.8				.8	4.4	.3	.3				1

* T denotes trace of runoff less than .2 gallon.

However, the total runoff from any one treatment was very low when compared to total rainfall received. The water quality results (Table 10) tend to show lower quality runoff water from the spent shales than from the soil control.

SUMMARY

Plots of spent oil shales (TOSCO and USBM) and soil-covered spent shales were established in 1973 at the U.S. Bureau of Mines (Anvil Points Oil Shale Research Facility, 5,700 feet) near Rifle, and in the Piceance Basin (7,200 feet). The Anvil Points plots were leached with 40 inches of water in May 1973, seeded on June 11 with a mixture of native grasses and shrubs, mulched, and fertilized. An additional 18.5 inches of water was then applied for establishment. Seedling establishment was good. The Piceance Basin plots were leached with 20 inches of water in August 1973 and 40 inches of water in June 1974. The plots were seeded with a mixture of native species on June 26, mulched and fertilized. An additional 11.0 inches of water was applied for establishment. However, seedling stands were thin, and the plots were reseeded on October 18, 1974.

Salinity data collected at both sites show resalinization following leaching of the TOSCO spent shale and salt movement up into 6 inches of soil cover over leached TOSCO spent shale. The USBM spent shale was resalinized at the Piceance site in 1974 but was not resalinized at Anvil Points in either 1973 or 1974. The 12 inches of soil cover over unleached TOSCO or unleached USBM spent shales was not salinized at either study site. Maximum surface temperatures of 150° F were recorded on the south-facing TOSCO spent shale plot in late

June, July and August 1974 at Anvil Points. Maximum surface temperature of 113^{o} F was recorded on the south-facing soil cover at the same time.

High levels of molybdenum and zinc were found in barley plants growing directly in both the TOSCO and USBM spent shale when compared to plants growing in the soil; the plants were collected from the Piceance Basin study site on August 1974.

Measureable amounts of runoff were collected from both the spent shale and soil treatments at each site in August 1974. The greatest runoff at both sites was from the fine-textured TOSCO spent shale. Water quality analyses show that moderately saline runoff water was collected from both spent shale and soil plots at each site.

Future of This Study

We hope to maintain and monitor this study for a number of years. It is expected that vegetation will become less dense and runoff will increase as the stands established by irrigation thin to stands that can be supported under the prevailing climatic and soil conditions.

Funds have been obtained from the EPA to finance the study through July of 1975 and a continuation will be requested. A more detailed report on this study will be available later this year in the thesis of the senior author.

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