A GREENHOUSE EVALUATION OF PLANT SPECIES FOR USE IN REVEGETATION OF BLACK MESA COAL MINE OVERBURDEN MATERIAL

by

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ABSTRACT

Greenhouse and laboratory experiments were initiated to determine chemical and physical properties of coal mine spoils from the Black Mesa, to evaluate germination of plant species in spoils, and to evaluate growth of plants in spoils with different fertilizer treatments.

Laboratory analyses showed the spoils to be slightly acidic, low in sodium, and high in nitrogen content. Unmined soil from the same area was more nearly neutral, high in sodium, and low in nitrogen content.

Seven crop and native plant species were evaluated. The species were: 'Vernal' alfalfa (*Medicago sativa* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L. um Thell.), yellow sweetclover (*Melilotus officinalis* Lam.), fourwing saltbush [*Atriplex canescens* (Pursh.) Nutt.], Indian ricegrass [*Oryzopsis hymenoides* (Roem. and Shult.) Ricker], and winterfat [*Eurotia lanata* (Pursh.) Moq.]. Germination in the spoils was not statistically different from that in the check soil. Growth data indicated that no dettrimental factors were present in the coal mining spoils. Differences in plant height, dry weight, and number of stems per pot were due to fertility differences between treatments.

CHAPTER I

INTRODUCTION

As our nation and the world face ever increasing demands on petroleum and natural gas reserves, government and industry have given greater emphasis to exploitation of coal reserves. This is especially true in the southwestern United States. United States Department of Interior studies (1974a) indicated that strippable coal reserves account for 26,306 million tons in the Western Region as opposed to 4,726 million and 7,090 million tons in the Eastern and Midwestern Regions, respectively.

As illustrated by the mining industry trends of the past twelve years (0.3 percent increase in subsurface mining of coal as compared to 6.4 percent increase in strip mining), surface extraction of coal becomes increasingly important with each passing year. Another United States Department of Interior study (1974b) showed that the total coal reserve base of Arizona (350 million short tons) is located on the Black Mesa and is suitable for strip mining. This reserve base lies beneath about 5,600 hectares (14,000 acres) of tribal land on the Black Mesa. Current operating plans of the Peabody Coal Company call for strip mining about 160 hectares (400 acres) each year for 35 years (Frank, 1977). This means, of course, that 160 hectares must also be recontoured and revegetated annually.

Peabody Coal Company is currently the only company engaged in strip mining on the Black Mesa. The 5,600 hectares under lease to Peabody Coal represents only about 0.7 percent of the coal bearing formations on the Black Mesa. It has been estimated that more than 4,800 square kilometers (3,000 square miles) have exploitable coal resources (Frank, 1977). This represents a potential of almost 800,000 hectares (two million acres) which must be revegetated.

Concurrent to the surge of surface mining and due to extensive mass media coverage, increased public awareness of environmental problems and widespread concern for their solution have been stimulated. As a direct result of this public concern, legislative pressure has been applied, almost universally, to corporations engaged in the mining industry. In general terms, they are required to return the disturbed areas to a condition capable of supporting previous use of the lands (Whetzel and Hogelin, 1977). In other areas of the United States, this problem has been dealt with successfully for a number of years and a sizeable backlog of research and experience has been accumulated. In contrast, specific information is extremely sketchy concerning techniques of economic rehabilitation of coal mining waste material under the unique climatic and soil conditions of the Southwest.

Physical Characteristics of the Area

The Black Mesa area of Arizona is located in the northeastern corner of the state. It is set in a pinyon-juniper vegetation zone (Figure 1). The elevation of the area is about 2,132 meters (7,000 feet). The annual precipitation is about 30 centimeters (12 inches) while the potential evapotranspiration rate is 160 centimeters (63 inches) on an annual basis (Verma, 1977). Approximately one-half of the annual precipitation falls during the winter months as snow. The balance of the moisture falls during convection storms of short duration and high intensity during mid- and late-summer. Unfortunately, this precipitation pattern does not lend itself to revegetation of disturbed areas. The winter moisture occurs when temperatures are too low to permit seed germination and the summer rains are too sporadic and not distributed evenly enough to allow seedling establishment.

The soils of the area originate from sandstone and shale parent material. Clay bands of variable thickness are present which separate the coal seams (Verma and Thames, 1975).

Figure 1. Pinyon-juniper vegetation of the Black Mesa. -- This view typifies the contours and vegetation of the Black Mesa. The terrain is rolling and significant numbers of pinyon pines and junipers are present. This area is used almost exclusively for grazing.

Range Conditions of the Area

Although it is difficult to believe when one first observes the area surrounding the Black Mesa and Kayenta mines, the ranges have been grazed by livestock for nearly a century. Extremes in climate, unstable soils, and gross overgrazing have reduced range production to the barest minimum. Critical observations immediately reveal a paucity of usable forage species and the dominance of snakeweed [*Gutierrezia sarothrae* (Prush.) Britt. and Rusby]. Snakeweed is considered to be a poisonous species and therefore is not suitable for grazing (Schmutz et al., 1968). Other species present in significant numbers are juniper (*Juniperus communis* L.) and pinyon pine (*Pinus cembroides* Zucc.). Sagebrush (*Artemesia tridentata* Nutt.) is also present to a limited degree but ranges are so deteriorated that most of the plants have been grazed past the recovery point and show up only as grey-colored sticks (Figure 2).

Human Concerns in Stripmining the Black Mesa

One of the most formidable barriers to improving range quality of the open range as well as in the disturbed areas is the Navajo people. According to Navajo tradition, the more animals a person has, the wealthier he is. As the Navajo nation has grown in size so have the herds of grazing animals. In addition, geographical boundaries of the tribal

Figure 2. Typical Black Mesa range site prior to strip mining. -- Most of the vegetation shown is not usable as forage. The tan species which predominates is snakeweed, a poisonous species. Another sign of poor range condition is the presence of dead sagebrush. The sagebrush appears as the grey upright sticks.

lands have forced the Navajo to abandon his traditional nomadic way of life. These two primary factors have led to severe overgrazing and total deterioration of the available ranges. The only possible solution to this problem is education of the people in sound range management practices. Unfortunately, the problem is further compounded by religious beliefs of the Navajos and Hopis. The Black Mesa is deeply woven into the fabric of the religious mythology of both tribes. By anthropromorphic extension, the Navajos consider it to be the body of a mythical woman with Navajo Mountain as the head and Balakai Mesa as the legs and feet. A related belief has given rise to tribal concerns that the surface mining is doing irreparable damage to her "heart" (Many Farms High School, 1971).

Environmental extremists have also joined the controversy surrounding the Black Mesa. Gordon and Copeland (1973) express strong concern that the mining operations will use virtually all the fossil water contained in the aquifers of the area. Peabody Coal Company was pumping water from the 900 meter (3,000 feet) level. Peabody Coal maintained that the water being utilized will have no impact on the wells of the surrounding area. This evaluation is based on hydrologic research indicating that the Peabody wells are drawing from a reservoir which is deeper and noncontiguous with the reservoir providing water to the inhabitants of the area.

Description of Surface Mining Operations

In order to understand the problems of revegetation of areas disturbed by strip mining, one must first have some idea of the basic methods used in the extraction of the coal. Strip or surface mining, by definition, means the extraction of a particular mineral of interest by removing the overlying earth and rock.

In the case of coal, the "mineral of interest" is found in layers or seams ranging from 0.3 meters (one foot) to more than six meters (20 feet) thick (Figure 3). The amount of soil and rock which must be moved in order to reach the seams of coal varies widely also. It is economic, however, to remove as much as 39 meters (130 feet) of the overlying material (Frank, 1977).

The coal on the Black Mesa is mined using the conventional furrow technique. The overburden is removed by digging a furrow to expose the coal seam using huge machines called "draglines" (Figure 4). As the overburden is removed, it is placed beside the furrow. After stripping the exposed coal in the first furrow, a second furrow is started adjacent to the first. Overburden from the second furrow is placed in the first furrow (Verma and Thames, 1975). Roughly speaking, this places the various strata in reverse order from their original positions in the unmined state. The final result of the mining operation is steep-sided

Figure 3. Exposed coal seam on the Black Mesa. -- The dark material near the center of the picture is the coal seam. This seam is about 20 feet thick. The lighter colored material above the coal is the overburden.

Figure 4. Peabody Coal Company dragline removing overburden to expose a coal seam. -- This huge machine removes the strata overlying the coal. The cab surrounding the engine and operator's controls is as large as a small house.

mounds of spoils material (Figure 5). This material must then be recontoured to a configuration similar to the original contours and stabilized to prevent erosion.

Figure 5. View illustrating recontoured and non-recontoured coal mining spoils banks. -- The foreground of this view depicts an area which has been leveled and recontoured. The steep-sided rows of spoil banks in the background show how the spoils look immediately after the coal is removed.

CHAPTER II

REVIEW OF LITERATURE

One of the earliest investigations into the problems of revegetation of coal mining spoils was made by Croxton (1928). He was among the first to recognize that strip mining presents a difficult problem in resource conservation. As a point of historical interest, Croxton noted that the concept of surface mining had been conceived as early as 1866. It was not, however, until 1911, when the stripping shovel was invented, that strip mining began to gain in importance. Croxton's early characterizations of eastern mining spoils suggested great variability in the material comprising the spoil banks. Almost 50 years later, Schroer (1976) came to a similar conclusion about the physical and chemical properties of coal mine spoils in Montana. During the years that followed Croxton's initial work, little research was conducted to develop answers to the environmental questions posed by the increasing number of hectares disturbed by surface coal mining. Guccione (1974) reported that during the 41-year period from 1930 to 1971 some 1.46 million hectares (3.65 million acres) have been strip mined in the United States.

A 1976 United States Department of Interior report outlined some of the history and projections with regard to strip mining in the United States. It emphasized the need for increased research and technology with regard to rehabilitation of disturbed areas. It also cited the lack of knowledge as the single most important limiting factor in the needed reclamation pursuits.

With the impetus of this and other reports, public concern was stimulated to the extent that action was initiated in terms of legislative controls and funding for research. Since that time, considerable funding, effort and time have been devoted to learning how to effectively reclaim disturbed areas. Leroy and Keller (1972) described the successful use of plants to stabilize disturbed areas as well as to provide feed for livestock and wildlife. Edgerton et al. (1975) reported success in the use of municipal wastewater and sewage sludge to revegetate stripmine spoils in Pennsylvania. Higgins (1973) reported on mined land use in Illinois. In addition, there is an abundance of literature which recounts successful methods of revegetation in the eastern and southern United States. Unfortunately, the vast majority of this research has very little application in the arid Southwest.

In recent years, research has been reported originating in the Northern Great Plains. Thilenius and

Glass (1974) outlined the needs and progress of spoil bank rehabilitation in Wyoming. Hodder (1973) suggested that, as in other areas of pursuit, proper management, planning and preliminary studies are the key factors in determining the success of a revegetation program. He also described a number of methods of water concentration and conservation appropriate to areas of low rainfall and found to be of value in eastern Montana. Ries et al. (1976) reported that supplemental irrigation water was essential in the revegetation of coal mining spoils in North Dakota. This research sheds some light on reclamation techniques to be used in the Southwest but has limited application because of the acid nature of the Great Plains spoils.

Fortunately, parallel research has been initiated to solve the reclamation problems peculiar to the Southwest. The earliest research in the area was started in 1968 at Utah International's Navajo Mine near Farmington, New Mexico (Jackson, 1977). Gould et al. (1972) inventoried soils, vegetative and animal life on an area in northwestern New Mexico. They also estimated the impact of surface mining in the areas. Aldon and Springfield (1973) conducted one of the first greenhouse trials of plant species grown on coal mining spoils in the Southwest. Two years later, Gould and Howard (1976) and Rai et al. (1975)

conducted detailed investigations into the chemical, physical and biotic characteristics of another area in northwestern New Mexico scheduled to be stripmined. Additionally, Thames and Crompton (1974) reported the initiation of reclamation studies on the Black Mesa in northeastern Arizona. Verma (1977) reported that quality of runoff on recontoured, unrevegetated watersheds is within the proposed Environmental Protection Agency standards. Verma also feels that vegetative rehabilitation is essential to avoid future adverse impacts on quality of runoff from mined areas. Miyamoto et al. (1977) reported that coal mine spoils from the Fruitland formation near Farmington, New Mexico are poorly wettable or water repellant. The authors indicated that this condition was due to the strongly sodic nature of the spoils.

Various researchers have conducted studies on coal mining spoils using varying rates of organic and inorganic fertilizers. Peterson and Gschwind (1973) reported applications of 200-250 tons of digested sewage sludge result in the establishment of vigorous, permanent stands of grass cover on Illinois mining spoils. In a growth chamber study of barley grown on mining spoils from the Great Plains area, Sandoval et al. (1973) found very little response to varying levels of phosphorous fertilizers. The effectiveness of municipal sewage effluent and sewage sludge in providing plant nutrients was tested in revegetation research on Pennsylvania coal mining spoils (Edgerton et al., 1975). Jones et al. (1975) used a two-step seeding system to successfully revegetate spoils banks in West Virginia. This method involved seeding of small grains the first year to cover the disturbed area quickly and to provide a base of organic matter on which permanent legumes and grasses were established the second year.

Response of species native to the coal mining areas of the Southwest have also been studied. Williams and O'Connor (1973) reported significant increases in dry weight yield of fourwing saltbush [*Atriplex canescens* (Prush.) Mutt.] with the application of the equivalent of 22.8 kg/ha of nitrogen, 10 kg/ha phosphorous, and 18.75 kg/ha of potassium in a greenhouse situation and on native soils. Hull (1962) observed a significant response of winterfat [*Eurotia lanata* (Pursh.) Moq.] and fourwing saltbush with the application of 22.5 kg/ha of nitrogen and 45 kg/ha of P_2O_5 in conjunction with 60 tons of peat per hectare. Aldon and Springfield (1973) observed that applications of the equivalent of 360 and 720 kg of 10-5-5 commercial fertilizer per hectares had no significant effect on germination and early growth of mountain rye (*Secale montanum* Smith) and fourwing saltbush when grown in coal mine spoils from New Mexico.

The forage characteristics of some of the native species are well established. United States Department of Agriculture Forest Service (1937) rates Indian ricegrass [*Oryzopsis hymenoides* (Roem. and Shult.) Ricker], as being highly palatable to livestock and good to very good for tolerance of alkalinity. Fourwing saltbush was described as one of the most valuable forage shrubs in an arid situation. Winterfat was shown as being drought tolerant, palatable, and good forage.

Germination and establishment of various potentially valuable revegetation species has also been widely studied. Doran (1951) conducted dryland reseeding trials in a pinyon-juniper area of Colorado and found Indian ricegrass, fourwing saltbush, and yellow sweetclover (*Melilotus officinalis* Lam.) to be good performers with regard to germination and establishment, drought tolerance, and seed set. He also reported that he was unable to obtain a stand of winterfat. Springfield (1970) gave a detailed description of the germination requirements for fourwing saltbush. He indicated optimum planting depth of 12.5 mm and germination temperatures of 13 to 24°C. Emergence was usually complete by 21 days.

Stoddart and Wilkinson (1938) studied the germination of Indian ricegrass and reported that about one-half of the seeds contained undeveloped embryos and therefore would not germinate. They outlined a flotation method for separating the seeds according to density, and indicated that germination of the seed with the developed embryos can be increased by soaking in concentrated sulfuric acid for 15 to 45 minutes to break dormancy.

Toole (1940) ran more exhaustive studies of the germination requirements of Indian ricegrass and concluded that 71 percent sulfuric acid was more effective for acid scarification of the seed than concentrated sulfuric acid as had been suggested by earlier studies. Rogler (1960) conducted further studies on breaking dormancy in Indian ricegrass and concluded that long-term storage increases germination significantly. His studies also suggested that cold soaking of the seed in water at 2° to 4°C for 40 days had an equally beneficial effect.

CHAPTER III

MATERIALS AND METHODS

Experiments were conducted in the laboratory and greenhouse at The University of Arizona, Tucson, Arizona. The objectives of this study were: (a) to evaluate the physical and chemical properties of selected samples of coal mine spoils from the Black Mesa Coal Mine and from adjacent unmined areas, (b) to determine the effect of coal mine spoils on the germination of selected species, (c) to compare growth response of selected plant species when grown in coal mine spoils and a check soil (Gila loam), and (d) to evaluate the effect of commerical, inorganic fertilizers and/or dried sewage sludge on the growth of selected species on Black Mesa Coal Mine spoils.

Soils Analyses

Soil samples were collected randomly from mined, graded spoils banks, unmined areas, and from the site where the Gila loam check soil was obtained. Gila loam was chosen because of proximity and fertility considerations. Gila loam is a fertile agricultural soil which is often used as a "check" soil in greenhouse experiments at the University of Arizona. It is native to southern Arizona and therefore readily available without incurring a great expense for its procurement. The chemical properties of the three soil materials were analyzed in the Soils, Water and Plant Testing Laboratory at the University of Arizona. Nitrogen, potassium and sodium values were obtained by water extraction procedures. Phosphorus values were obtained by CO_2 extractions.

Germination Experiment

On December 18, 1975, a study was initiated in which seven plant species were evaluated. The species were: 'Vernal' alfalfa (*Medicago sativa* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L. um Thell.), yellow sweetclover, fourwing saltbush, Indian ricegrass, and winterfat. Each of the above species were germinated in sterile, metal flats in raw coal mining spoils and Gila loam (check). The experiment was conducted in the greenhouse under near-ideal conditions of temperature and moisture.

The experiment was replicated four times with each replication consisting of four flats. Two flats of each replication were partitioned into four compartments each and into three compartments each. The compartments were lined with aluminum foil in a manner to prevent leachate from one species moving laterally in the soil to adjacent compartments. For each replication of four flats, one set of two (one three-compartmented and one four-compartmented) were filled with coal mining spoils and one set was filled with

Gila loam. Each compartment in the flats was then planted with 100 seeds of a species. The seven species were randomly arranged in each set of flats.

Seed was obtained from varying sources. Harlan II barley and Siete Cerros wheat seed were obtained from the Arizona Crop Improvement Association. Hand-collected Vernal alfalfa and yellow sweetclover seed was obtained from Peabody Coal Company reclamation personnel on the Black Mesa. The remaining three species were hand-collected. Fourwing saltbush and Indian ricegrass seed were collected from an area between Kayenta and Tuba City, Arizona. The winterfat seed was collected from a site between Willcox, Arizona and the Chiricahua National Monument in a vegetation zone similar to the Black Mesa.

The native seed was hand processed. It was rubbed between two corrugated rubber surfaces to loosen the glumes. Then, the chaff was removed with a South Dakota seed blower. The seed was then separated into 100 seed lots. Care was taken to exclude broken seed.

After planting, the flats were placed on benches in the greenhouse. The flats were irrigated with an automatic, mist-type system which provided 45 seconds of mist once each hour during the daylight hours. An approximate temperature of 25°C (75°F) was maintained with a thermostatically controlled forced-draft heater. The experiment was designed as a Randomized Complete Block with four replications. Germination was checked every other day for two weeks, weekly thereafter, and terminated at the end of 30 days.

Growth and Development Study

The previously listed seven species were also utilized in the growth and development experiment to study the influence of varying fertilizer treatments on species grown in coal mining spoils in the greenhouse. The experiment was started December 27, 1975 and was conducted in 4,000 grams of soil in 20-centimeter red clay pots using the following treatments:

1. Gila loam soil (Check)
2. Coal mining spoils with no added fertilizer (Check)
3. Coal mining spoils plus 12.0 grams of dried sewage sludge (approximate field equivalent of five tons per acre on a weight basis).
4. Coal mining spoils plus 1.8 grams of 10-10-10 commercial fertilizer (this application provided an amount of nitrogen equivalent to that supplied in treatment 3).
5. Coal mining spoils plus 12.0 grams of dried sewage sludge plus 0.9 grams of 10-10-10 commercial fertilizer.

The fertilizer was worked into the top half of the soil in the pots. Pots without fertilizer or sewage sludge treatments were also worked to maintain uniform treatment.

A Split-Plot design using the seven species as main plots and the soil-fertilizer treatments as sub-plots was employed. The experiment was replicated three times.

Each pot was planted with five seeds and thinned to three seedlings approximately 30 days later. The pots were watered as needed to maintain, as nearly as possible, optimum soil-moisture levels and identical treatment within and between replications. The experiment was harvested June 26, 1976.

On September 19, 1976, the growth and development phase of the study was replanted. The methods shown above were followed and the experiment harvested on March 18, 1977.

The following data were obtained from each pot: germination percentage 30 days after planting, plant height, number of stems per pots, and dry weight of the aboveground forage per pots. All data were analyzed using the standard analysis of variance and means were compared using the Student-Newman-Keuls' Test.

CHAPTER IV

RESULTS AND DISCUSSION

Soils Data

As previously indicated, the soil material which is found on the surface after an area has been stripmined is probably not the soil which was on the surface previously. The surface soil material after mining is an unstructured mixture of sandstone and shale rock bits, soil materials from various horizons including the surface, and bits of coal (Figure 6). Mining operators in many parts of the country are required by law to stockpile topsoil and replace it upon completion of extraction of the coal. There have been opinions expressed both supporting and condemning the concept of stockpiling. A study committee within the National Academy of Sciences expressed the opinion that mine operators should be required to stockpile topsoil or other desirable strata (National Academy of Sciences, 1974). Jackson (1977) defended the opposing position in the case of the Southwest on the basis that the native entisols and aridosols are poorly developed, saline, and lacking in organic matter and essential nutrients. He also noted that it would not be unreasonable to find that spoils materials are sometimes more responsive to revegetation than the original

Figure 6. Close-up view of coal mining spoils material. -- This picture illustrates the type of soils material which is left after mining. One may note numerous bits of rock and coal mixed into the material which is left on the surface after mining.

surface soils. The information in Table 1 supports Jackson's viewpoint. The ESP values are especially significant. The unmined soil has an ESP of more than 15 which places it in the sodic class (Barth, 1976). An apparent dilution with regard to ESP has taken place during the mining process. The ESP value of the mined soils material compared very favorably with that of the Gila loam check soil.

The fertility level of the mined soils material also compares favorably with the check soil. The nitrogen value is higher, the potassium value is sufficient to meet the needs of most plants and the sodium value is low enough that salinity should present no problems. The one exception to this comparison is phosphorus. All three soil types analyzed were low in phosphorus. The mined soils material, however, was especially low. This is probably due to a dilution effect with regard to the small amount of organic matter that was originally present on the surface (as reflected in the phosphorus level of the unmined soil and the check soil). Another contributing factor may be the large amount of unweathered material brought to the surface by the mining process.

The pH of all three soils were within the neutral range. The check soil and unmined soil tended to be slightly alkaline, while the mined soils material tended to be somewhat acid. Plant species which are well-adapted to

Table 1. Values for pH, $Ec_e \times 10^3$, ESP, total soluble salts, nitrogen (N), phosphorus (P), potassium (K), and sodium (Na) in Gila loam soil, unmined soil, and coal mine spoils from the Black Mesa Coal Mine, Kayenta, Arizona, in 1976.

Soil material	pH	$EC_e \times 10^3$	ESP	Total soluble salts (ppm)	N (ppm)	P (ppm)	K (ppm)	Na (ppm)
Gila loam soil	7.6	0.54	2	378	5.7	1.8	14	12
Unmined soil	7.5	6.56	16	4592	4.5	1.7	9	1196
Coal mine spoils	6.2	4.63	1	3241	64.0	0.3	11	147

Note: N, K, and Na were obtained by water soluble extraction and P was obtained by CO_2 extraction.

acid environments may grow more vigorously in the mined soils material than those species adapted to alkaline conditions.

Germination Data

Average germination percentages for the three native and four domesticated plant species are shown in Table 2. At the 30-day level, germination percentages for seeds grown in coal mining spoils were very similar to those in the Gila loam check. Comparisons between native and domesticated species, on the other hand, showed great differences.

Alfalfa, barley, and wheat had high rates of germination. The percentages ranged from 85 to 99 percent with little difference observed between the coal mining spoils and the check soil. These species also germinated more quickly than the other species, with emergence occuring in 72 to 96 hours.

Indian ricegrass and fourwing saltbush germinated poorly in both soil materials. The low germination was probably due to seed dormancy in these species. No attempt was made to scarify the seed beyond the mechanical action provided by the corrugated rubber threshers in order to maintain uniformity throughout the experiment.

Yellow sweetclover also germinated poorly. This may be attributed to the presence of a high percentage of

Table 2. Average germination percentages for selected forage species grown in Gila loam soil and Black Mesa Coal Mine spoils, in the greenhouse, at Tucson, Arizona, in 1976.

Forage species	Gila loam soil	Coal mine soil
	------- Germination	percent--------
Indian ricegrass	1.5 d #	1.5 d
Fourwing saltbush	1.3 d	1.5 d
Winterfat ##	32.0 b	35.0 b
Harlan II barley	99.0 a	93.0 a
Siete Cerros wheat	91.0 a	88.0 a
Vernal alfalfa	87.0 a	84.0 a
Yellow sweetclover	9.0 c	5.7 c

Means in the same column, followed by the same letter, are not different at the 5 percent level of significance, using Student-Newman-Keuls' Test.

Means seedling survival rates for winterfat were 5.0 percent in Gila loam soil and 7.3 percent in coal mine spoils.

hard seed. Again, no scarification was provided beyond the hand rubbing of the seed.

Winterfat presented a situation different from all other species. Germination percentages were quite acceptable, considering the dormancy problems encountered with other wild species. Another problem became evident as the experiment progressed. A disease similar to damping-off caused the cotyledonary leaves to shed from a majority of the plants. As a result, seedling survival rate was lowered dramatically.

Germination percentages for the growth and development phase are shown in Table 3. Average percentages for all species were similar to those obtained in the previous germination study. Winterfat, Indian ricegrass, fourwing saltbush, and yellow sweetclover were replanted without success. Only scattered, single plants of these species grew throughout the experiment. This resulted in meaningful data being available for alfalfa, barley and wheat but not for the other species.

There were no statistically detectable differences between the check soil, the coal mine spoils, or any of the other treatments which included coal mining spoils. This indicates there were no detrimental chemical properties contained in the spoils which might result in lower germination rates of the species tested.

Table 3. Average germination percentages for selected forage species grown in Gila loam soil and Black Mesa Coal Mine spoils with different fertilizer treatments, in the greenhouse, 30 days after planting, at Tucson, Arizona, in 1976 and 1977 (2-year average).

Soil and fertilizer treatment	Barley (pct)	Wheat (pct)	Alfalfa (pct)	Yellow sweet-clover (pct)	Indian rice-grass (pct)	Fourwing saltbush (pct)	Winter-fat (pct)
Gila loam (check)	100 a#	66 a	67 a	27 a	7 a	7 a	0 a
Coal mine spoils (check)	100 a	80 a	90 a	44 a	0 a	7 a	4 a
Coal mine spoils plus 12.0 g sewage sludge	100 a	60 a	87 a	27 a	4 a	4 a	0 a
Coal mine spoils plus 1.8 g 10-10-10 fertilizer	100 a	66 a	87 a	33 a	0 a	10 a	0 a
Coal mine spoils plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	93 a	50 a	84 a	34 a	4 a	10 a	0 a

Means in the same column, followed by the same letter, are not different at the 5 percent level of significance, using Student-Newman-Keuls' Test.

Growth Data

During the first 30 days of the experiment, barley, wheat and alfalfa germinated well and produced healthy seedlings. At this point, few differences were apparent between the various treatments. It was during this period that the wheat seedlings showed a slight susceptibility to salt damage in the pots where sewage sludge had been applied. Chemical analyses of dried sewage sludge made in connection with other experiments at The University of Arizona have shown sodium levels in excess of 1,200 ppm and $EC_e \times 10^3$ values of more than 15.00. The indication of salt damage in the wheat shows that the amount of sewage sludge applied may be near the upper level of tolerance for the seedlings. Barley also showed a small amount of tip-burn during this period but to a lesser extent than did wheat.

Sixty days after planting, differences were visibly apparent between treatments on barley and wheat but were not statistically significant. It was interesting to note that the wheat plants showing the greatest growth were those which were treated with the highest amount of total nitrogen. Wheat, at this point, had initiated reproductive growth but anthesis had not occurred.

In contrast to the grassy species, the alfalfa showed significant differences between treatments. The

Gila loam check and coal mining spoils with 1.8 grams of 10-10-10 commercial fertilizer produced the greatest amount of growth.

Approximately 70 days after planting, water was purposely withheld for a period of five days, to observe the drought tolerance of the species. Of the three species (alfalfa, barley, and wheat), alfalfa showed the least stress and barley showed the most. There were also observable differences between the Gila loam check soil and the coal spoils material. The plants growing in coal spoils showed slightly less stress than did plants in the Gila loam soil.

Two weeks prior to harvest, irrigation was terminated to prepare the plants for harvest. At time of termination, the wheat was fully mature, the barley was 75-85 percent mature, and the alfalfa was still actively growing. These maturity differences were dramatically evident when the growth responses of the three species were compared (Figures 7, 8, and 9). The alfalfa and barley growth curves indicated that these species had not reached maturity prior to harvest. The application of fertilizer to coal mining spoils increased dry matter production from all plant species studied.

Average plant heights of wheat, barley, and alfalfa at time of harvest are shown in Table 4. The values shown

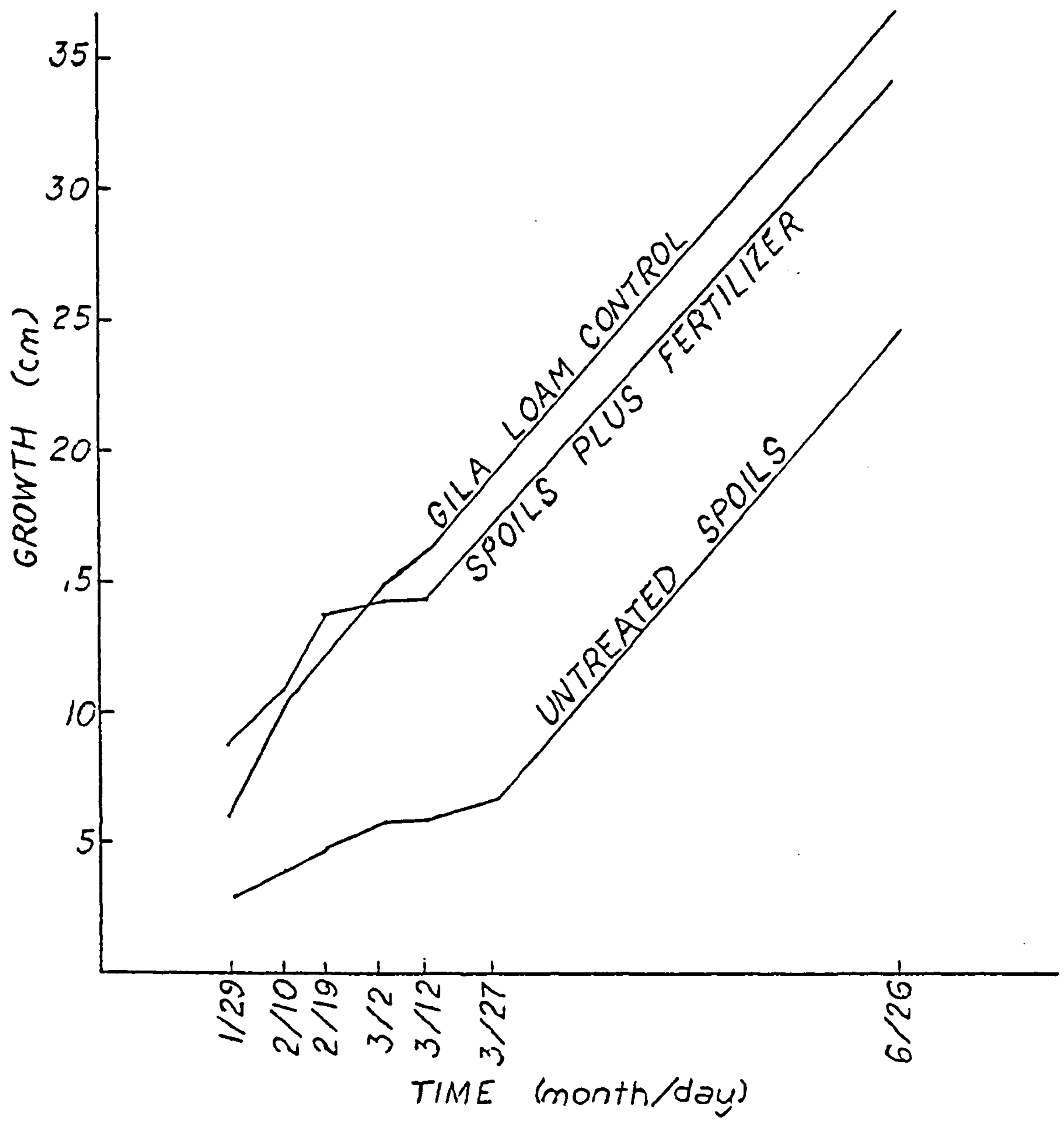

Figure 7. Growth curves of alfalfa grown under varying soil and coal mine spoils treatments in the greenhouse in 1976.

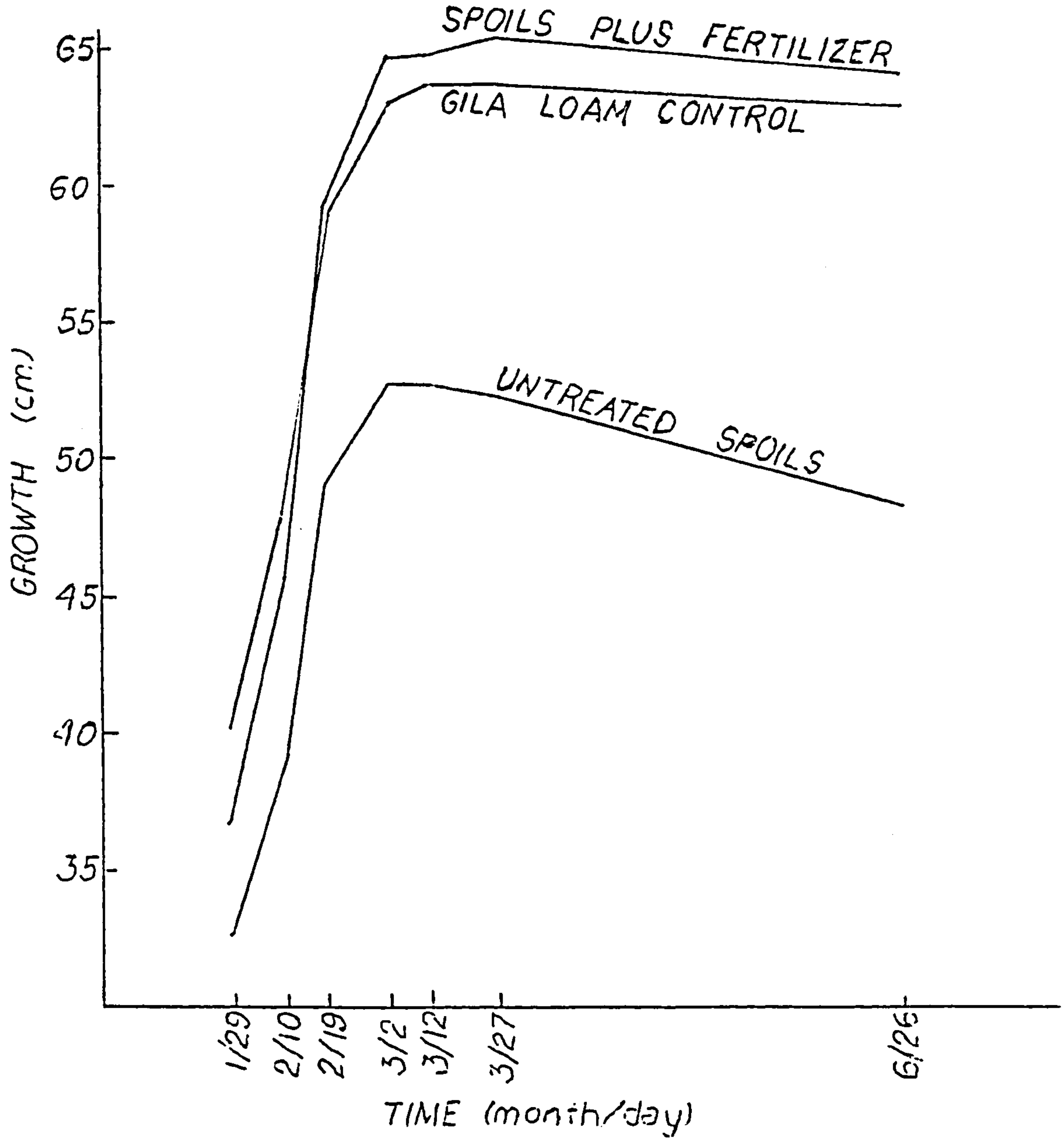

Figure 8. Growth curves of wheat grown under varying soil and coal mine spoils treatments in the greenhouse in 1976.

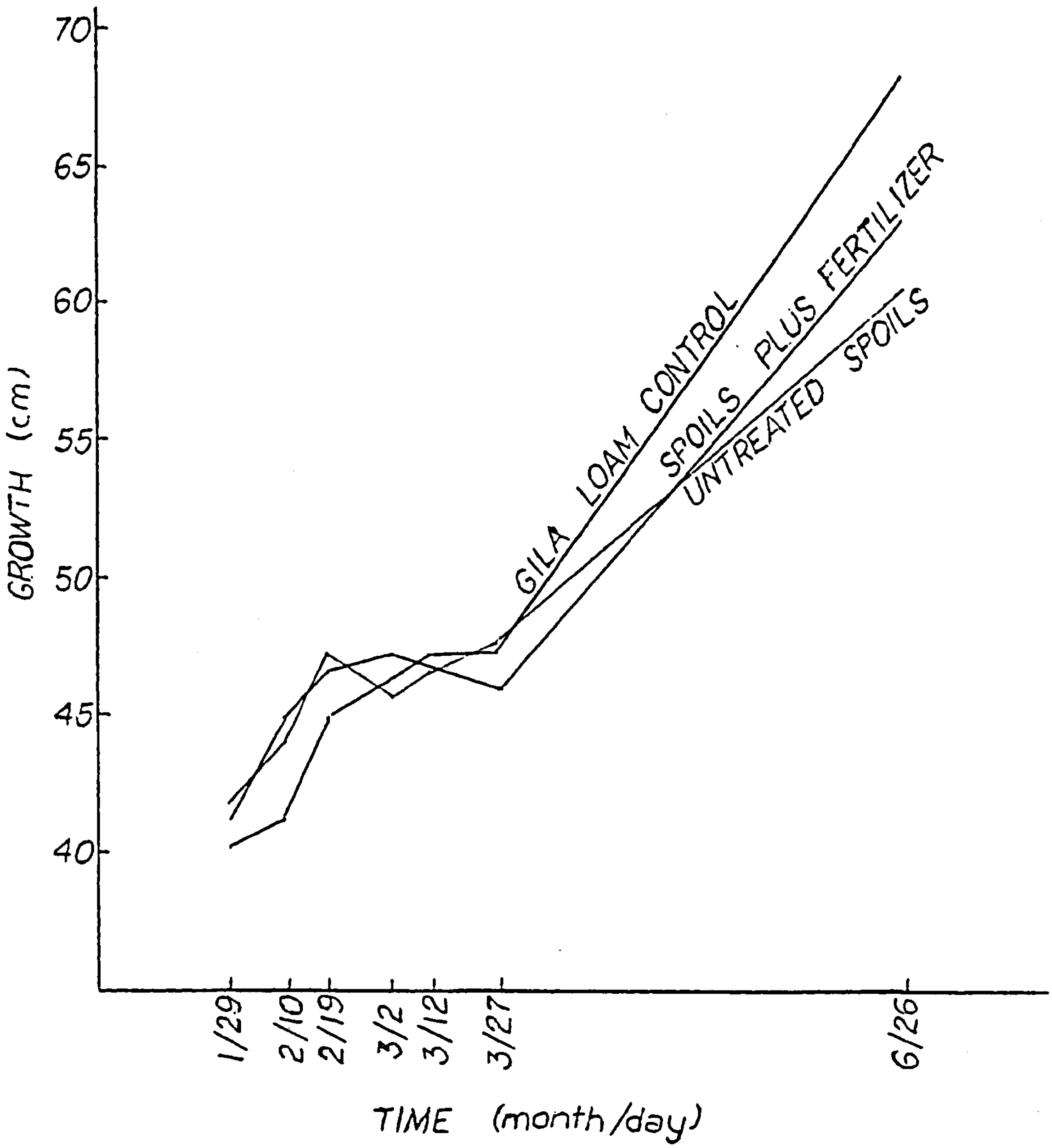

Figure 9. Growth curves of barley grown under varying soil and coal mine spoils treatments in the greenhouse in 1976.

Table 4. Average plant heights for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine spoils with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976 and 1977 (2-year average).

Soil and fertilizer treatments	Plant height (cm)		
	Alfalfa	Barley	Wheat
Gila loam soil (check)	35 a#	59 a	63 a
Coal mine spoils (check)	21 b	59 a	45 b
Coal mine spoils plus 12.0 g sewage sludge	26 a	54 a	59 a
Coal mine spoils plus 1.8 g 10-10-10 fertilizer	34 a	55 a	63 a
Coal mine spoils 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	30 a	57 a	63 a

Means in the same column, followed by the same letter, are not different at the 5 percent level of significance, using the Student-Newman-Keuls' Test.

here represent a two-year average. The plant heights for wheat and alfalfa grown in the untreated coal mine spoils are the only ones showing a statistical difference. Differences in barley plant height were not significant. It may be postulated that plant height response in barley is less sensitive to fertility levels than the other two species.

Average number of stems per pot was another parameter which was evaluated (Table 5). The values shown in Table 5 also represent two-year averages. These data reveal two responses of significance. The first was exhibited by both alfalfa and barley. In both instances, the average number of stems per pot was significantly lower when the two species were grown on untreated coal mining spoils. Additionally, although there were no detectable differences, the pots treated with sewage sludge, commercial fertilizer, and a combination of the two showed step-wise increases in stem numbers which appeared to be related to total amount of available nitrogen. The wheat plants showed no statistically detectable response to any of the five treatments.

Average dry weights for the above-ground portions of alfalfa, barley and wheat forage were similar between treatments (Table 6). All species tested did, however, produce significantly less dry matter on the untreated spoils material.

Table 5. Average number of stems per pot for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine spoils with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976 and 1977 (2-year average).

Soil and fertilizer treatments	Number of stems		
	Alfalfa	Barley	Wheat
Gila loam soil (check)	26 a#	14 a	5 a
Coal mine spoils (check)	7 b	7 b	3 a
Coal mine spoils plus 12.0 g sewage sludge	18 a	13 a	3 a
Coal mine spoils plus 1.8 g 10-10-10 fertilizer	21 a	15 a	4 a
Coal mine spoils plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	23 a	15 a	4 a

Means in the same column, followed by the same letter, are not different at the 5 percent level of significance, using Student-Newman-Keuls' Test.

Table 6. Average dry weights for the above-ground portions of alfalfa, barley, and wheat forage plants grown in Gila loam soil and Black Mesa Coal Mine spoils with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976 and in 1977 (2-year average).

Soil and fertilizer treatments	Dry Matter (g/pot)		
	Alfalfa	Barley	Wheat
Gila loam soil (check)	5.6 a#	10.5 a	4.6 a
Coal mine spoils (check)	1.2 b	5.6 b	1.1 b
Coal mine spoils plus 12.0 g sewage sludge	2.3 b	9.5 a	1.9 b
Coal mine spoils plus 1.8 g sewage sludge	4.5 a	10.0 a	3.8 a
Coal mine spoils plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	3.3 a	12.9 a	3.2 a

Means in the same column, followed by the same letter, are not different at the 5 percent level of significance, using Student-Newman-Keuls' Test.

Alfalfa and wheat treated with sewage sludge only showed numerical but not statistically significant increases in dry weight when compared to the untreated spoils.

Summary and Conclusions

The major conclusions which may be drawn from this research are as follows:

1. Preliminary results reveal that recontoured Black Mesa spoils are probably superior in fertility and have fewer undesirable characteristics than native undisturbed soils of the area.
2. No toxic compounds were present in the coal mine spoils material which were detrimental to germination of the species tested.
3. Differences in plant height, dry weight of above ground portions, and numbers of stems per pot were closely related to levels of available nitrogen and phosphorus.
4. A more extensive physical and chemical characterization of the Black Mesa spoils needs to be initiated to determine degree of variability and to develop baseline data for fertilizer applications.
5. On-site studies need to be expanded to confirm the trends shown in the greenhouse studies.

LITERATURE CITED

Aldon, E. F., and H. W. Springfield. 1973. Revegetating coal mine spoils in New Mexico: a laboratory study. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Note RM-245. 4p.

Barth, R.C. 1976. Saline and sodic spoils-what are they and how are they reclaimed. Mining Congress J. 62: 51-55.

Croxton, W. C. 1928. Revegetation of Illinois coal stripped lands. Ecology 9:155-175.

Doran, C. W. 1951. Reseeding trials in a sagebrush-pinyon-juniper area in western Colorado. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Note RM-9 3p.

Edgerton, B. R., W. E. Sopper, and L. T. Kardos. 1975. Revegetating bituminous strip-mine spoils with municipal wastewater. Compost Sci. 16:20-25.

Frank, H. J. 1977. Arizona energy inventory: 1977. University of Arizona, Tucson. 100p.

Gordon, S., and A. Copeland. 1973. Black Mesa, the angel of death. The John Day Co., New York. 113p.

Gould, W. L., and V. W. Howard. 1975. Biotic composition and soil characteristics of an area to be surface mined in San Juan County by El Paso Natural Gas Company. New Mexico State University Agricultural Experiment Station, Special Report No. 24-2. 31p.

Gould, Q. L., V. W. Howard, and K. A. Valentine. 1972. Soil characteristics, biotic composition, and vegetative production of areas leased by Western Coal Company for strip mining near Fruitland, New Mexico. New Mexico State University Agricultural Experiment Station, Special Report No. 20. 49p.

Guccione, E. 1974. U.S. Mining Industry reclaims 80 percent of surface acreage used in 1971. Mining Engineering 26:59-60.

Higgins, T. 1973. The planning and economics of mined-land use for agricultural pruposes. In J. R. Garvey (ed.) Research and applied technology symposium on mined-land reclamation. Bituminous Coal Research, Inc. Pittsburg, Pennsylvania. 287-293.

Hodder, R. L. 1973. Surface mined land reclamation research in eastern Montana. In J. R. Garvey (ed.) Research and applied technology symposium on mined-land reclamation. Bituminous Coal Research, Inc. Pittsburg, Pennsylvania. 82-97.

Hull, A. C., Jr. 1962. Growth in the greenhouse of grasses and shrubs on soils from shadscale and sagebrush areas. J. Range Manage. 15:262-266.

Jackson, D. 1977. Western coal is the big challenge to reclamation experts today. Coal Age 82:90-108.

Jones, J. N., Jr., W. H. Armiger, and O. L. Bennett. 1975. A two-step system for revegetation of surface mine spoils. J. Environ. Qual. 4:233-235.

Leroy, J. C., and H. Keller. 1972. How to reclaim mined areas, tailing ponds and dumps into valuable lands. World Mining 8:34-41.

Many Farms High School. 1971. Environmental and economic issue: the strip mining on Black Mesa and the coal burning power plants in the southwest. Unpublished Research Paper. 25p.

Miyamoto, S., A. Bristol, and W. L. Gould. 1977. Wettability of coal mine spoils in northwestern New Mexico. Soil Sci. 123:258-263.

National Academy of Sciences. 1974. Rehabilitation potential of western coal lands. Ballinger Pub. Co. Cambridge, Massachussetts. 189p.

Peterson, J. R., and J. Gschwind. 1973. Amelioration of coal mine spoils with digested sewage sludge. In J. R. Garvey (ed.) Research and applied technology symposium on mined-land reclamation. Bituminous Coal Research, Inc. Pittsburg, Pennsylvania. 187-196.

Rai, D., P. J. Wierenga, and W. L. Gould. 1975. Chemical and physical properties of soil samples from a coal bearing formation in San Juan County, New Mexico. New Mexico State University Agricultural Experiment Station, Research Report No. 294. 24p.

Ries, R. E., J. F. Power, and F. M. Sandoval. 1976. Potential use of supplemental irrigation for establishment of vegetation on surface-mined land. North Dakota Farm Research 34:21-22.

Rogler, G. A. 1960. Relation of seed dormancy of Indian ricegrass (Oryzopsis hymenoides (Roem. and Schult.) Ricker) to age and treatment. Agron J. 52:470-473.

Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis. 1973. Lignite mine spoils in the northern Great Plains-characteristics and potential for reclamation. In J. R. Garvey (ed.). Research and applied technology symposium on mined-land reclamation. Bituminous Coal Research, Inc. Pittsburg, Pennsylvania. 117-133.

Schmutz, E. M., B. N. Freeman, and R. E. Reed. 1968. Livestock-poisoning plants of Arizona. University of Arizona Press, Tucson. 176p.

Schroer, F. W. 1976. Chemical and physical characterization of coal overburden. North Dakota Farm Research 34:5-11.

Springfield, H. W. 1970. Germination and establishment of fourwing saltbush in the southwest. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-55. 48p.

Stoddart, L. A., and K. J. Wilkinson. 1938. Inducing germination in Oryzopsis hymenoides for range seeding. J. Amer. Soc. Agron. 30:763-768.

Thames, J. L., and E. J. Crompton. 1974. Reclamation studies on the Black Mesa. Progressive Agriculture in Arizona 26(1):14-16.

Thilenius, J. F., and G. B. Glass. 1974. Surface coal mining in Wyoming: needs for research and management. J. Range Manage. 27:336-341.

Toole, V. K. 1940. The Germination of seed of Oryzopsis hymenoides. J. Amer. Soc. Agron. 32:33-41.

U.S. Department of Agriculture, Forest Service. 1937. Range Plant Handbook. 538p.

U.S. Department of the Interior. September, 1974a. Prospective regional markets for coal conversion products projected to 1980 and 1985. Office of Coal Research and Development. Report No. 102. 664p.

U.S. Department of the Interior. November, 1974b. Federal energy administration project independence blueprint: Final task force report-coal. Inter-agency Task Force on Coal. 175p.

Verma, T. R. 1977. Strip mining and hydrologic environment on the Black Mesa. In J. L. Thames (ed.) Reclamation and use of disturbed land in the southwest. University of Arizona Press, Tucson, Arizona 161-166.

Verma, T. R., and J. L. Thames. 1975. Rehabilitation of land disturbed by surface mining of coal in Arizona. J. Soil and Water Cons. 30:129-131.

Whetzel, J., and C. Hogelin. 1977 Revegetation in the Rockies. Soil Cons. 43:4-5.

Williams, S. F., and G. A. O'Connor. 1973. Chemical fertilization of fourwing saltbush. J. Range Manage. 26:379-380.