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Research and Development

Reclamation and Water Relations of Strip Mine Spoils in Northern Arizona (1976 - 1978)

Interagency Energy/Environment R&D Program Report

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December 1979

RECLAMATION AND WATER RELATIONS OF STRIP MINE SPOILS IN NORTHERN ARIZONA (1976-1978)

by

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INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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DISCLAIMER

FOREWORD

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

This report is a product of the EPA planned and coodinated Interagency Energy/Environment Research and Development Program in cooperation with the United States Department of Agriculture. Surface mining of coal results in the denuding of the ground surface. Without the rapid development of a vegetative cover, accelerated erosion will occur. The report describes research to develop better reclamation methods and to better understand the physical and chemical changes occurring in the minesoil. Persons concerned with mine land reclamation should find this report of interest. For further information contact the authors or the Resource Extraction and Handling Division.

David G. Stephan
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ABSTRACT

The objectives and approach of this research project were: (1) to evaluate the properties of coal mine soil, (2) to study the germination of selected plant species in coal mine soil in the greenhouse, (3) to study the growth of selected plant species in coal mine soil on the Black Mesa Coal Mine, and (4) to study the livestock feed value of forage from selected plant species grown in coal mine soil.

The nitrogen and potassium contents were higher in coal mine soil than they were in unmined soil; however, coal mine soil contained less phosphorus than did unmined soil.

Average germination percentages for seven plant species grown in coal mine soil in the greenhouse were similar to germination percentages for the same species grown in Gila loam soil.

Seven plant species produced satisfactory germination, seedling establishment, ground cover, and forage production in unmined soil and coal mine soil on the Black Mesa Coal Mine when each soil material was supplied with optimum soil moisture and fertilizer.

The general livestock feed value of forage from seven plant species grown in coal mine soil was similar to the feed value of forage from the same species grown in unmined soil.

This report was submitted as the final report on Grant No. 684-15-1 entitled "Reclamation and Water Relations of Strip Mine Spoils in Northern Arizona (1976-1978)". This report covers the period July 1, 1976 through December 31, 1978, and work was completed as of June 30, 1979.

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SECTION 1

INTRODUCTION

Mineral wastes consist of barren overburden, submarginal grade ore, milling wastes, and strip-mine spoils. These waste materials present potential air, water, and environmental pollution hazards. The total accumulated mineral wastes in the United States was reported to be about 23 billion metric tons, which covers 2 billion hectares of land (Donovan et al., 1976). Effective stabilization and revegetation of mining wastes may reduce and/or eliminate pollution problems associated with the mining industry.

Coal mine reclamation research was conducted in Arizona with the following objectives: (1) to evaluate the properties of coal mine soil, (2) to study the germination of selected plant species in coal mine soil in the greenhouse, (3) to study the growth of selected plant species in coal mine soil on the Black Mesa Coal Mine, and (4) to study the livestock feed value of forage from selected plant species grown in coal mine soil.

SECTION 2

CONCLUSIONS

The nitrogen and potassium contents were higher in coal mine soil than in unmined soil; however, coal mine soil contained less phosphorus than did unmined soil.

Average germination percentages for seven plant species grown in coal mine soil in the greenhouse were similar to germination percentages for the same species grown in a good agricultural soil, Gila loam.

Seven plant species produced satisfactory germination, seedling establishment, ground cover, and forage production in unmined soil and coal mine soil on the Black Mesa Coal Mine when each soil material was supplied with optimum soil moisture and fertilizer.

The general livestock feed value of forage from seven plant species grown in coal mine soil was similar to the feed value of forage from the same species grown in unmined soil.

SECTION 3

RECOMMENDATIONS

Coal mine soils in the southwestern United States should be provided with supplemental irrigation sufficient to provide available soil moisture (natural rainfall + irrigation) equal to the minimum available soil moisture requirements for establishment of the plant species in the geographical area. Persistence of plant species after termination of supplemental irrigation could not be evaluated within the time frame of this study.

For effective revegetation, coal mine soils in the Southwest should be evaluated for fertility and fertilized accordingly with sufficient nitrogen (N) and phosphorus (P) fertilizers to provide the minimum N and P requirements of the plant species grown. In this region potassium (K) is usually abundant.

Whenever coal mine soils in a new area are to be revegetated, a number of plant species should be evaluated to permit the selection of species best adapted to the climatic conditions and specific soil materials being rehabilitated.

If forage from plant species grown on coal mine soil is to be used for livestock, its feed value should be compared with the feed value of forage from the same species grown on unmined soil in the area to detect potential toxic effects on livestock.

SECTION 4
LITERATURE REVIEW

The United States Bureau of Solid Waste Management estimated that by 1980 the United States mineral industries will be generating between 2 and 4 billion metric tons of solid wastes annually (Frey, 1970). Mineral wastes consist of barren overburden, submarginal grade ore, milling wastes, and strip-mine spoils. The total accumulated mineral solid wastes in the United States was reported to be about 23 billion metric tons that cover 2 billion hectares of land (Donovan, Felder, and Rogers, 1976). The most serious impact of mineral wastes on air quality occurs in semiarid and arid regions, such as the southwestern United States (Donovan et al., 1976).

The primary purpose for reclaiming disturbed lands in semiarid and arid regions is to stabilize the spoil material and prevent it from being moved by winds and flash floods, the common transporting agents in dry climates. After disturbed areas have been stabilized, a second objective for reclamation is to revegetate the barren soil materials, so that they will blend into the surrounding landscape and minimize visual pollution. The principal methods used to stabilize disturbed land areas in dry climates are: (1) physical, (2) chemical, and (3) vegetative (Donovan et al., 1976). Physical stabilization, with the use of topsoil and/or overburden soil materials, has been used successfully to control air pollution along highways and adjacent to mining operations (Janbu, 1965). Chemical stabilization has been effective in reducing wind and water erosion of mineral wastes (Struthers, 1964). Vegetative stabilization has been successfully used around mining operations where plant growth was needed for livestock and wildlife grazing (Leroy and Keller, 1972).

Four different soil materials (tailing, tailing-overburden, overburden, and local desert soil) were identified in copper mining wastes (Ludeke, 1973). The physical and chemical properties of the foregoing soil materials were studied and described by Ludeke et al. (1974). They also noted that straw from cereal grains planted on copper tailing with a "Hydroseeder" and incorporated into the top 15 cm of tailing with a "Sheepfoot Roller" resulted in the most desirable soil material for plant growth. Day, Tucker, and Ludeke (1975) reported that perennial grasses were more easily established and maintained than most other plants in tailing soil material from copper mines, due to their drought tolerance and low water requirement. Day and Ludeke (1973) found that giant bermudagrass (*Cynodon dactylon* L. *Pers. var. aridus* Harland et de Wet.) can be used effectively to stabilize copper mine tailing disposal-berms in southern Arizona. Day et al. (1976) suggested that forage for livestock grazing may be produced by growing spring barley (*Hordeum vulgare* L.) on copper mining wastes in Arizona if the crop is heavily fertilized with commercial, inorganic fertilizers and supplied with supplemental irrigation water throughout the growing season.

A number of states in the western United States contain large coal deposits that may be surface-mined to satisfy future energy requirements in the United States (Power, Sandoval, and Ries, 1977). Schroer (1976) found that the physical and chemical properties of coal mine spoils in Montana differ greatly with location. Edgerton, Sopper, and Kardos (1975) used municipal sewage effluent and sewage sludge to provide plant nutrients in the revegetation of coal mine spoils in Pennsylvania. Jones, Armiger, and Bennett (1975) used a two-step seeding system, successfully, to revegetate surface coal mine spoils in West Virginia. Small grain species were seeded the first year to give a quick ground cover and to produce a straw mulch into which perennial legume and grass species were interseeded the second year. Gould, Howard, and Valentine (1972) inventoried the soil characteristics and vegetation production areas leased by Western Coal Company for strip mining in New Mexico. They observed that Indian ricegrass (*Oryzopsis hymenoides* L.), fourwing saltbush (*Atriplex canescens* L.), and winterfat (*Eurotia lanata* L.) grew best on coal spoils in New Mexico. Thames and Crompton (1974) discovered that the texture of coal mine spoils in northern Arizona was similar to the texture of a clay loam soil with little structure. Thames and Verma (1975) reported that there was an urgent need to revegetate the coal spoils on the Black Mesa Coal Mine in northern Arizona. Ries, Power, and Sandoval (1976) found that supplemental irrigation water was essential in the revegetation of coal mining spoils on surface-mined land in North Dakota.

Future research involving the revegetation of coal mine soil on the Black Mesa Coal Mine in northern Arizona must be directed toward the following objectives: (1) to evaluate the physical and chemical properties of coal mine soil (spoils) on the Black Mesa Coal Mine and (2) to study the germination of plant species in the greenhouse and in the field in coal mine soil.

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SECTION 5
OBJECTIVES

The general objectives of the revegetation portion of this research study were the following:

1. To evaluate the physical and chemical properties of coal mine soil (spoils) on the Black Mesa Coal Mine.

2. To study the germination of selected plant species in the greenhouse in coal mine soil.

3. To study the seedling establishment, forage yield, and ground cover for selected plant species in coal mine soil on the Black Mesa Coal Mine.

4. To study the livestock feed value of forage from selected plant species grown in coal mine soil.

SECTION 6
EXPERIMENTAL PROCEDURES

Coal mine soil and unmined soil from the Black Mesa Mine were transported to the University of Arizona in Tucson for chemical evaluations and for greenhouse studies. Gila loam soil, which is a fertile agricultural soil found in southern Arizona, was also transported to the University of Arizona for chemical evaluations and for greenhouse studies. Gila loam is an excellent agricultural soil and it is frequently used as a "check soil" in greenhouse experiments. The chemical characteristics of the three soil materials were analyzed in the Soils, Water, and Plant Testing Laboratory at the University of Arizona.

The average germination percentages of seven plant species: (1) Indian ricegrass, (2) Fourwing saltbush, (3) Winterfat, (4) Barley, (5) Wheat, (6) Alfalfa, and (7) Yellow sweetclover were obtained when the plants were grown in Gila loam soil and coal mine soil in the greenhouse. The species were germinated in the two soil materials in metal flats in the greenhouse under near ideal conditions of temperature and humidity.

The general plan of work for the field research studies to determine the seedling establishment, forage yield, and ground cover for selected plant species in coal mine soil was as follows:

Two types of soil materials were studied:

1. Unmined soil.
2. Coal mine soil.

Two soil-moisture conditions were evaluated:

1. Natural rainfall.
2. Natural rainfall plus sprinkler irrigation.

Two fertilizer treatments were studied:

1. No additional fertilizer.
2. The addition of 500 pounds per acre of 16-20-0 commercial fertilizer.

Two soil mulch environments were evaluated:

1. No additional soil mulch.
2. The addition of barley straw as a soil mulch.

Seven (7) plant species were compared when grown on the two soil materials, with the two soil-moisture conditions, with the two fertilizer treatments, and with the two soil mulch environments:

1. Harlan II Barley (*Hordeum vulgare* L.)
2. Super X Wheat (*Triticum aestivum* L. em Thell.)
3. Crested Wheatgrass (*Agropyron cristatum* L.)
4. Western Wheatgrass (*Agropyron smithii* Rydb.)
5. Indian Ricegrass (*Aryzopsis hymenoides* Ricker.)
6. Vernal Alfalfa (*Medicago sativa* L.)
7. Fourwing Saltbush (*Atriplex canescens* Pursh.)

The following seed and/or plant characteristics were studied for each plant species when grown in each environment:

1. Number of seeds germinated in 10 square feet.
2. Number of seedlings established in 10 square feet.
3. Number of stems produced in 10 square feet.
4. Plant height at the end of the growing season.
5. Percent ground cover.
6. Forage yield in 10 square feet.
7. Forage quality estimate.

The general livestock feed value of forage from each plant species was determined by submitting forage samples to the Department of Animal Sciences, University of Arizona, for crude protein and in vitro dry matter disappearance (IVDMD) determinations.

SECTION 7
RESULTS AND DISCUSSION

Physical and Chemical Properties of Coal Mine Soil

Most of the surface-mined area on the Black Mesa Coal Mine may be cultivated and seeded with modified, commercial agriculture equipment. 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 soil from the Black Mesa Coal Mine are reported in Table 1. The pH of coal mine soil was lower than the pH of unmined soil or Gila loam. This indicates that plants that grow well in an acid environment may be better adapted to this specific coal mine soil than plants that grow best under alkaline conditions. It should be pointed out that this coal mine soil was made by a scraper-type operation, instead of a dragline. Other soil tests indicate that dragline soil on the Black Mesa usually has a neutral pH. The ESP in coal mine soil was similar to the ESP in Gila loam and much lower than the ESP in unmined soil. This indicates that sodium should not present any problems in coal mine soil; however, in unmined soil sodium problems may occur. The total soluble salts in coal mine soil and unmined soil were much higher than in Gila loam; however, coal mine soil was lower in total soluble salts than unmined soil. Salt-sensitive plant species may be injured when grown in both coal mine soil and unmined soil at the levels of salt indicated. The nitrogen content of coal mine soil was much higher than the nitrogen content of unmined soil or Gila loam. This indicates that lower nitrogen fertilizer applications would be needed for plants growing in coal mine soil than would be necessary for plants produced on unmined soil. The total amount of phosphorus in coal mine soil was much lower than the phosphorus content of unmined soil. The availability of phosphorus to plants growing on coal mine soil and unmined soil is not known and should be studied in future research. Coal mine soil, unmined soil, and Gila loam contained similar amounts of potassium. There appears to be sufficient potassium in both coal mine soil and unmined soil for the growth of most plants. The sodium content of coal mine soil was much lower than the sodium content of unmined soil. From these data, it also appears that sodium should not present any problems in coal mine soil but may present problems in unmined soil.

The Black Mesa Coal Mine is located in northeastern Arizona, near the town of Kayenta, at an elevation of about 2,132 m (7,000 ft.). The annual precipitation is about 30 cm (12 in.) and approximately one-half falls during the winter months as snow. Snowmelt occurs in late winter and produces some runoff on unmined areas but very little runoff on mined areas. Most of the rainfall occurs as convection storms of short duration and high intensity during mid and late summer. These storms are spotty and occasionally result in flash floods.

Average Germination Percentages for Selected Forage Species Grown in Gila Loam Soil and Black Mesa Coal Mine Soil, in the Greenhouse, at Tucson, Arizona in 1976

Average germination percentages, 30 days after planting, for the seven (7) plant species grown in the greenhouse in Gila loam soil and in coal mine soil in a preliminary germination study are presented in Table 2. Generally speaking, the germination percentages for all plant species grown in coal mine soil were similar to germination percentages for the same species grown in Gila loam. Comparisons between native and domesticated plant species showed great differences in germination and emergence when they were planted in coal mine soil. For example, alfalfa, barley, and wheat had high rates of germination, that ranged from 84 to 93%. These species also germinated more quickly than did the other species studied. In contrast, Indian ricegrass and fourwing saltbush germinated very poorly in coal mine soil. The low germination percentage of these two species was probably due to seed dormancy. The relatively low germination percentages for yellow sweetclover may have resulted from the presence of a high percentage of hard seeds. This condition may be partially overcome by seed scarification prior to planting. Winterfat presented a germination problem that differed from that observed in all other plant species studied. The initial germination of this species was acceptable, considering the seed dormancy encountered with many indigenous plant species; however, soon after emergence, a disease similar to damping-off caused the initial leaves to drop off and the young seedlings to die. Coal mine soil did not appear to possess any undesirable characteristics that might result in lower germination percentages for the plant species studied than would be expected for the same species grown in Gila loam soil.

Average Germination Percentages for Selected Forage Species Grown in Gila Loam Soil and Black Mesa Coal Mine Soil with Different Fertilizer Treatments, in the Greenhouse, 30 Days After Planting, at Tucson, Arizona in 1976 and 1977

Average germination percentages, 30 days after planting, for the seven (7) plant species grown in the greenhouse in Gila loam soil, coal mine soil, and coal mine soil following the addition of commercial, inorganic fertilizer and/or dried sewage sludge are reported in Tables 3 and 4. The germination results obtained from the second germination and seedling growth experiment were similar to the observations made in the first germination experiment, with the exception of yellow sweetclover in 1977. Since the germination percentages for yellow sweetclover, Indian ricegrass, fourwing saltbush, and winterfat were extremely low or non-existent, meaningful germination and seedling growth data were obtained only for alfalfa, barley, and wheat. During the first 30 days of the experiment, alfalfa, barley, and wheat all germinated well and produced healthy seedlings. Thirty days after planting, there were no apparent differences in the seedling growth of each species between soil and fertilizer treatments.

Average Plant Heights for Alfalfa, Barley, and Wheat Forage Species Grown in Gila Loam Soil and Black Mesa Coal Mine Soil with Different Fertilizer Treatments, in the Greenhouse, 180 Days After Planting, at Tucson, Arizona in 1976 and 1977

The average plant heights 180 days after planting for alfalfa, barley, and wheat grown in Gila loam soil, coal mine soil, and coal mine soil following the addition of commercial fertilizer and/or dried sewage sludge are presented in Tables 5 and 6. Alfalfa and wheat plants appeared to be shorter in coal mine soil than in Gila loam. The addition of commercial fertilizer and/or dried sewage sludge to coal mine soil tended to result in taller plants of alfalfa and wheat.

Average Number of Stems Per Pot for Alfalfa, Barley, and Wheat Forage Species Grown in Gila Loam Soil and Black Mesa Coal Mine Soil with Different Fertilizer Treatments, in the Greenhouse, 180 Days After Planting, at Tucson, Arizona in 1976 and 1977

Tables 7 and 8 report the average number of stems per pot 180 days after planting for alfalfa, barley, and wheat grown in Gila loam soil, coal mine soil, and coal mine soil following the addition of commercial fertilizer and/or dried sewage sludge. Alfalfa and barley produced fewer stems per pot in coal mine soil than they did in Gila loam soil. The addition of commercial fertilizer and/or dried sewage sludge to coal mine soil resulted in an increase in the number of stems per pot from alfalfa and barley. Wheat produced the same number of stems per pot in all soil and fertilizer treatments studied in 1976. In 1977, wheat grown in Gila loam produced more stems per pot than did wheat grown in all coal mine soil and fertilizer treatments.

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 Soil with Different Fertilizer Treatments, in the Greenhouse, 180 Days After Planting, at Tucson, Arizona in 1976 and 1977

The average dry weights per pot for the above-ground protions of alfalfa, barley, and wheat forage grown in Gila loam soil, coal mine soil, and coal mine soil following the addition of commercial fertilizer and/or dried sewage sludge are presentedin Tables 9 and 10. Alfalfa and barley produced more dry forage when grown in Gila loam than in coal mine soil in 1976. In 1977, wheat produced more dry forage when grown in Gila loam that it produced in coal mine soil. The addition of commercial fertilizer and/or dried sewage sludge to coal mine soil tended to increase the production of forage from alfalfa, barley, and wheat; however, a number of the yield differences were not statistically significant under the conditions present in this experiment.

Summary of Greenhouse Experiments With Black Mesa Coal Mine Soil in 1976 and 1977

Plant growth data from forage species grown in the greenhouse indicate that coal mine soil from the Black Mesa Mine has a lower fertility level than does Gila loam soil. When supplied with optimum soil moisture and plant nutrients, coal mine soil produced approximately the same yields of forage from alfalfa, barley, and wheat as were produced in Gila loam soil under the same soil-moisture and fertility conditions. Forage production from plant species grown on unmined soil on the Black Mesa is not known at the present time; however, it will be studied in future experiments.

Establishment of Field Research Sites on the Black Mesa Coal Mine

Field research sites were established in the J-7 area of the Black Mesa Coal Mine, adjacent to a source of irrigation water, in March, 1977. One 2-acre area, on surface-mined coal lands from a dragline operation, and one 2-acre area on unmined land were selected and fenced for field research during 1977. A Sprinkler Irrigation System was installed on one acre on each research site to permit the comparison of plant species grown on each soil material with natural rainfall and with natural rainfall plus sprinkler irrigation.

Physical and Chemical Evaluation of Soil Materials at the Field Research Sites on the Black Mesa Coal Mine

The physical characteristics of the soil materials at the two field research sites on the Black Mesa Coal Mine were observed and the future potential of each site for field experiments were evaluated. The unmined soil appeared to have a higher clay content and a lower rate of soil-moisture penetration than did the coal mine soil. The general slope of the unmined site was less than the slope of the surface-mined site. The texture of the soil material at the unmined site was more suitable for the use of commercial agricultural field equipment than was the texture of the soil material at the surface-mined site.

Fifty (50) soil samples were taken at random from the surface 15 cm of the soil material at each research site, composited, and sent to the Soils, Water, and Plant Testing Laboratory at the University of Arizona for chemical evaluation. Values for pH, $EC_e \times 10^3$, ESP, total soluble salts, nitrogen (N), phosphorus (P), potassium (K), sodium (Na), and organic matter (OM) in unmined soil and coal mine soil from the Black Mesa Coal Mine are reported in Table 11. The pH of coal mine soil was lower than the pH of unmined soil. The total soluble salts in coal mine soil were about four times higher than they were in unmined soil. The nitrogen and potassium contents were much higher in coal mine soil than they were in unmined soil; however, coal mine soil contained much less phosphorus than did unmined soil. Sodium was not a problem at either site as indicated by ESP. Coal mine soil contained three times as much organic matter as did unmined soil. Some differences were noted between chemical properties of soil samples from the field site and earlier samples taken from the materials used in the greenhouse experiment. These differences reflect variations in the unmined soil as well as mined soil from different specific locations.

The foregoing chemical evaluations of unmined soil and coal mine soil suggest that plants that grow well in an acid environment may be better adapted to this specific coal mine soil than plants that grow best under alkaline conditions. Salt-sensitive plant species may be more subject to injury when grown in coal mine soil than when grown in unmined soil. The nitrogen and potassium needs for plants growing in coal mine soil may be less than needs of the same fertilizer elements for plants growing in unmined soil; however, plants growing in coal mine soil may have a greater requirement for phosphorus fertilizer than plants growing in unmined soil. The possibility of sodium problems appears to be greater in coal mine soil than in unmined soil. It is believed that the addition of liberal amounts of organic matter to both coal mine soil and unmined soil would be beneficial in the preparation of these soil materials for the establishment of perennial grasses and legumes.

Germination of Harlan II Barley Grown on Unmined Soil and on Coal Mine Soil With Fertilizer, Without Fertilizer, With Optimum Soil-moisture, and With Insufficient Soil-moisture on the Black Mesa Coal Mine

The average germination of Harlan II Barley grown on unmined soil, and on coal mine soil with fertilizer, without fertilizer, with optimum soil-moisture, and with insufficient soil-moisture was studied on the Black Mesa Coal Mine in 1977. The fertilized plots received 500 pounds per acre of 16-20-0 commercial, inorganic fertilizer at planting time. The optimum soil-moisture treatment received sufficient sprinkler irrigation to permit optimum germination in the specific soil material. The insufficient soil-moisture treatment received 50% as much sprinkler irrigation as did the optimum irrigation treatment. Average germination counts for the four replications of each treatment were recorded as the number of seeds germinated in 10 square feet.

Barley grown on unmined soil had a higher germination percentage than did barley grown on coal mine soil (Table 12). Barley that was fertilized had a higher germination percentage than did barley that was not fertilized (Table 12). Barley that received optimum soil-moisture had a higher germination percentage than did barley that received insufficient soil-moisture (Table 12).

Average Germination, Seedling Establishment, Number of Stems Produced, Plant Height, Green Forage Yield, and Green Forage Moisture Content for Seven Plant Species Grown on Unmined Soil Without Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on unmined soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 13.

Barley, wheat, crested wheatgrass, western wheatgrass, and alfalfa had the highest germination, seedling establishment, and number of stems per unit area of the seven plant species studied. Barley produced the highest yield of green forage per acre, followed by wheat, alfalfa, fourwing saltbush, crested wheatgrass, western wheatgrass, and Indian ricegrass, in decreasing order.

Average Germination, Seedling Establishment, Number of Stems Produced, Plant Height, Green Forage Yield, and Green Forage Moisture Content for Seven Plant Species Grown on Unmined Soil With Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on unmined soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 14.

Barley, wheat, crested wheatgrass, western wheatgrass, and alfalfa had the highest germination, seedling establishment, and number of stems per unit area of the seven plant species studied. Wheat produced the highest yield of green forage per acre, followed by barley, fourwing saltbush, alfalfa, western wheatgrass, crested wheatgrass, and Indian ricegrass, in decreasing order.

Average Germination, Seedling Establishment, Number of Stems Produced, Plant Height, Green Forage Yield, and Green Forage Moisture Content for Seven Plant Species Grown on Coal Mine Soil Without Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on coal mine soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 15.

Barley, wheat, crested wheatgrass, western wheatgrass, and alfalfa had the highest germination, seedling establishment, and number of stems per unit area of the seven plant species studied. Barley produced the highest yield of green forage per acre, followed by wheat, fourwing saltbush, crested wheatgrass, alfalfa, western wheatgrass, and Indian ricegrass, in decreasing order.

Average Germination, Seedling Establishment, Number of Stems Produced, Plant Height, Green Forage Yield, and Green Forage Moisture Content for Seven Plant Species Grown on Coal Mine Soil With Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on coal mine soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 16.

Barley, wheat, crested wheatgrass, western wheatgrass, and alfalfa had the highest germination, seedling establishment, and number of stems per unit area of the seven plant species studied. Barley produced the highest yield of green forage per acre, followed by wheat, fourwing saltbush, western wheatgrass, crested wheatgrass, alfalfa, and Indian ricegrass, in decreasing order.

Average Plant Establishment, Number of Stems Produced, Plant Height, Forage Yield, and Ground Cover for Seven Plant Species Grown on Unmined Soil Without Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average plant establishment, number of stems produced, plant height, forage yield, and ground cover for seven plant species grown on unmined soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978 are reported in Table 17.

Alfalfa, crested wheatgrass, barley, western wheatgrass, and wheat produced the highest number of plants per unit area. Alfalfa, crested wheatgrass, fourwing saltbush, and barley produced the highest yields of dry forage per acre. Alfalfa produced the most complete ground cover, followed by crested wheatgrass, barley, wheat, western wheatgrass, fourwing saltbush, and Indian ricegrass, in decreasing order.

Average Plant Establishment, Number of Stems Produced, Plant Height, Forage Yield, and Ground Cover for Seven Plant Species Grown on Unmined Soil with Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average plant establishment, number of stems produced, plant height, forage yield, and ground cover for seven plant species grown on unmined soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978 are reported in Table 18.

Alfalfa, barley, wheat, and crested wheatgrass produced the highest number of plants per unit area. Barley, western wheatgrass, crested wheatgrass, and fourwing saltbush produced the highest yields of dry forage per acre. Alfalfa produced the most complete ground cover, followed by barley, wheat, crested wheatgrass, western wheatgrass, fourwing saltbush, and Indian ricegrass, in decreasing order.

Average Plant Establishment, Number of Stems Produced, Plant Height, Forage Yield, and Ground Cover for Seven Plant Species Grown on Coal Mine Soil Without Fertilizer and With Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average plant establishment, number of stems produced, plant height, forage yield, and ground cover for seven plant species grown on coal mine soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978 are reported in Table 19.

Crested wheatgrass, alfalfa, western wheatgrass, wheat, and barley produced the highest number of plants per unit area. Fourwing saltbush, crested wheatgrass, alfalfa, and barley produced the highest yields of dry forage per acre. Fourwing saltbush produced the most complete ground cover, followed by crested wheatgrass, western wheatgrass, alfalfa, barley, wheat, and Indian ricegrass, in decreasing order.

Average Plant Establishment, Number of Stems Produced, Plant Height, Forage Yield, and Ground Cover for Seven Plant Species Grown on Coal Mine Soil with Fertilizer and with Natural Rainfall Plus Sprinkler Irrigation on the Black Mesa Coal Mine

The average plant establishment, number of stems produced, plant height, forage yield, and ground cover for seven plant species grown on coal mine soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978 are reported in Table 20.

Crested wheatgrass, alfalfa, western wheatgrass, and barley produced the highest number of plants per unit area. Fourwing saltbush, crested wheatgrass, barley, and western wheatgrass produced the highest yields of dry forage per acre. Western wheatgrass produced the most complete ground cover, followed by alfalfa, fourwing saltbush, crested wheatgrass, barley, wheat, and Indian ricegrass, in decreasing order.

In Vitro Dry Matter Disappearance (IVDMD) and Crude Protein for Plant Species Grown on Unmined Soil Without Fertilizer

In vitro dry matter disappearance (IVDMD) and crude protein in forage from seven plant species grown on unmined soil without fertilizer and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 21.

The IVDMD in forage from the seven plant species studied ranged from 56.4 to 71.7%. Forage from alfalfa had the highest and forage from Indian ricegrass had the lowest IVDMD percentage.

The crude protein in forage from the seven plant species ranged from 8.1 to 16.3%. Forage from crested wheatgrass had the highest and forage from wheat had the lowest protein percentage.

In Vitro Dry Matter Disappearance (IVDMD) and Crude Protein for Plant Species Grown on Unmined Soil with Fertilizer

In vitro dry matter disappearance (IVDMD) and crude protein in forage from seven plant species grown on unmined soil with fertilizer and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 22.

The IVDMD in forage from the seven plant species ranged from 64.9 to 74.3%. Forage from crested wheatgrass had the highest and forage from fourwing saltbush had the lowest IVDMD percentage. With one exception, the addition of fertilizer increased the IVDMD percentage of the forage from all plant species (Table 21 and 22).

The crude protein in forage from the seven plant species ranged from 10.1 to 20.9%. Forage from crested wheatgrass had the highest and forage from wheat had the lowest protein percentage. With one exception, the addition of fertilizer increased the protein percentage in the forage from all plant species (Tables 21 and 22).

In Vitro Dry Matter Disappearance (IVDMD) and Crude Protein for Plant Species Grown on Coal Mine Soil Without Fertilizer

In vitro matter disappearance (IVDMD) and crude protein in forage from seven plant species grown on coal mine soil without fertilizer and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 23.

The IVDMD in forage from the seven plant species ranged from 59.1 to 77.6%. Forage from alfalfa had the highest and forage from wheat had the lowest IVDMD percentage.

The crude protein in forage from the seven plant species ranged from 12.5 to 26.3%. Forage from crested wheatgrass had the highest and forage from wheat had the lowest protein percentage.

In Vitro Dry Matter Disappearance (IVDMD) and Crude Protein for Plant Species Grown on Coal Mine Soil With Fertilizer

In vitro dry matter disappearance (IVDMD) and crude protein in forage from seven plant species grown on coal mine soil with fertilizer and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977 are reported in Table 24.

The IVDMD in forage from the seven plant species ranged from 65.3 to 81.9%. Forage from alfalfa had the highest and forage from wheat had the lowest IVDMD percentage. With one exception, the addition of fertilizer increased the IVDMD percentage in the forage from all plant species (Tables 23 and 24).

The crude protein in the forage from the seven plant species ranged from 13.8 to 23.8%. Forage from crested wheatgrass and alfalfa had the highest and forage from wheat had the lowest protein percentage. The addition of fertilizer to coal mine soil did not influence the protein content in forage from plant species as much as did the addition of fertilizer to unmined soil (Tables 21, 22, 23, and 24).

Special Features of the 1978 Black Mesa Coal Mine Revegetation Research Program

Approximately 8 inches of natural rainfall were obtained during the growing season (May 1 through November 30, 1978) on the Black Mesa Coal Mine in 1978. The foregoing amount of natural rainfall was not sufficient to permit any of the adapted plant species to produce enough dry forage for harvest and yield estimates on coal mine soil.

Approximately 2 acre-feet of irrigation water were applied to the irrigated research plots during the growing season (May 1 through November 30, 1978). The cost of the foregoing amount of irrigation water would be $50 per acre (assuming a value of $25 per acre-foot).

The fertilized research plots received 500 pounds per acre of 16-20-0 commercial, inorganic fertilizer. The cost of the foregoing amount of fertilizer would be $44 per acre (assuming a value of $176 per ton).

SECTION 8
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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 soil 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 soil	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.

TABLE 2

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

Forage species	Gila loam soil	Coal mine soil
	Germination %	
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 o	5.7 o

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

‡ Mean seedling survival rates for winterfat were 5.0% in Gila loam soil and 7.3% in coal mine soil.

TABLE 3

Average germination percentages for selected forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 30 days after planting, at Tucson, Arizona, in 1976.

Soil and fertilizer treatment	Barley (%)	Wheat (%)	Alfalfa (%)	Yellow sweetclover (%)	Indian ricegrass (%)	Fourwing saltbush (%)	Winterfat (%)
Gila loam (check)	100 a +	92 a	67 b	0 a	0 a	7 a	0 a
Coal mine soil (check)	100 a	92 a	93 a	0 a	0 a	0 a	7 a
Coal mine soil plus 12.0 g sewage sludge	100 a	92 a	87 a	0 a	7 a	0 a	0 a
Coal mine soil plus 1.8 g 10-10-10 fertilizer	100 a	92 a	80 a	13 a	0 a	0 a	0 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	93 a	87 a	87 a	7 a	0 a	0 a	0 a

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

TABLE 4

Average germination percentages for selected forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 30 days after planting, at Tucson, Arizona, in 1977.

Soil and fertilizer treatment	Barley (%)	Wheat (%)	Alfalfa (%)	Yellow sweetclover (%)	Indian ricegrass (%)	Fourwing saltbush (%)	Winterfat (%)
Gila loam soil (check)	100 a+	40 a	67 a	53 a	13 a	7 a	0 a
Coal mine soil (check)	100 a	67 a	87 a	87 a	0 a	13 a	0 a
Coal mine soil plus 12.0 g sewage sludge	100 a	27 a	87 a	53 a	0 a	7 a	0 a
Coal mine soil plus 1.8 g 10-10-10 fertilizer	100 a	40 a	93 a	53 a	0 a	20 a	0 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	93 a	13 a	80 a	60 a	7 a	20 a	0 a

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

TABLE 5

Average plant heights for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	Plant height in cm		
Gila loam soil (check)	43 a+	68 a	63 ab
Coal Mine soil (check)	23 a	61 a	48 b
Coal mine soil plus 12.0 g sewage sludge	26 a	56 a	63 ab
Coal mine soil plus 1.8 g 10-10-10 fertilizer	38 a	58 a	61 ab
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	29 a	63 a	64 a

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

TABLE 6

Average plant heights for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1977.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	Plant height in cm		
Gila loam soil (check)	26 a+	50 a	63 a
Coal mine soil (check)	18 a	57 a	42 b
Coal mine soil plus 12.0 g sewage sludge	25 a	51 a	54 ab
Coal mine soil plus 1.8 g 10-10-10 fertilizer	29 a	52 a	65 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	31 a	50 a	61 a

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

TABLE 7

Average number of stems per pot for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	Number of stems		
Gila loam soil (check)	34 a +	13 ab	3 a
Coal mine soil (check)	5 b	6 b	3 a
Coal mine soil plus 12.0 g sewage sludge	15 ab	14 ab	3 a
Coal mine soil plus 1.8 g 10-10-10 fertilizer	20 ab	17 a	3 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	21 ab	18 a	3 a

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

TABLE 8

Average number of stems per pot for alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1977.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	Number of stems		
Gila loam soil (check)	18 a +	15 a	6 a
Coal mine soil (check)	9 b	7 a	3 b
Coal mine soil plus 12.0 g sewage sludge	20 a	12 a	2 c
Coal mine soil plus 1.8 g 10-10-10 fertilizer	21 a	12 a	4 b
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	25 a	12 a	4 b

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

TABLE 9

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 soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1976.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	g/pot		
Gila loam soil (check)	7.1 a +	13.0 a	4.2 a
Coal mine soil (check)	0.3 b	5.1 b	1.2 a
Coal mine soil plus 12.0 g sewage sludge	2.6 ab	10.0 a	2.7 a
Coal mine soil plus 1.8 g 10-10-10 fertilizer	4.9 ab	11.0 a	3.5 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	3.6 ab	12.8 a	3.4 a

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

TABLE 10

Average dry weights for the above-ground portions of alfalfa, barley, and wheat forage species grown in Gila loam soil and Black Mesa Coal Mine soil with different fertilizer treatments, in the greenhouse, 180 days after planting, at Tucson, Arizona, in 1977.

Soil and fertilizer treatments	Alfalfa	Barley	Wheat
	g/pot		
Gila loam soil (check)	4 a +	8 b	5 a
Coal mine soil (check)	2 a	6 b	1 b
Coal mine soil plus 12.0 g sewage sludge	2 a	9 b	1 b
Coal mine soil plus 1.8 g 10-10-10 fertilizer	4 a	9 b	4 a
Coal mine soil plus 12.0 g sewage sludge plus 0.9 g 10-10-10 fertilizer	3 a	13 a	3 a

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

TABLE 11

Values for pH, EC_e X 10^3, ESP, total soluble salts, nitrogen (N), phosphorus (P), potassium (K), sodium (Na), and organic matter (OM) in unmined soil and coal mine soil from the Black Mesa Coal Mine, Kayenta, Arizona, for the field study initiated in 1977.

Soil material	pH	EC_e X 10^3	ESP	Total soluble salts (ppm)	N (ppm)	P (ppm)	K (ppm)	Na (ppm)	OM (%)
Unmined soil	7.4	2	0	1190	6.0	2.3	18	46	1.2
Coal mine soil	6.6	6	1	4270	78.0	0.5	38	208	3.4

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

TABLE 12

Average germination of Harlan II Barley grown on unmined soil and on coal mine soil with fertilizer, without fertilizer, with optimum soil-moisture, and with insufficient soil-moisture on the Black Mesa Coal Mine, Keyenta, Arizona in 1977.

Soil material	Fertilizer treatment	Soil-moisture	Germination (seeds/10 sq. ft.)
Unmined soil	Fertilized	Optimum	143
		Insufficient	69
	Not Fertilized	Optimum	130
		Insufficient	39
Coal mine soil	Fertilized	Optimum	135
		Insufficient	24
	Not Fertilized	Optimum	55
		Insufficient	17

Comments

1. Planted on 5/25/77.
2. Germination counts taken on 6/22/77.
3. The fertilized treatments received 500 pounds per acre of 16-20-0 commercial fertilizer at planting.
4. The optimum soil-moisture treatment received sufficient sprinkler irrigation to permit optimum germination in the specific soil material.
5. The insufficient soil-moisture treatment received 50% as much sprinkler irrigation as did the optimum irrigation treatment.
6. Field data were presented in U.S. Common Units because this system of measurement was most easily understood on the Navajo Indian Reservation where the research was conducted.

TABLE 13

Average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on unmined soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	Seeds germinated in 10 ft^2 (no.)	Seedlings established in 10 ft^2 (no.)	Stems produced in 10 ft^2 (no.)	Plant height (inch)	Green forage yield (lb./acre)	Green forage moisture (%)
Harlan II Barley	218	188	510	12	3632	71
Super X Wheat	212	207	413	11	3496	70
Crested Wheatgrass	276	142	627	5	839	45
Western Wheatgrass	214	123	260	7	360	37
Indian Ricegrass	26	23	69	12	204	61
Vernal Alfalfa	479	252	383	8	1223	51
Fourwing Saltbush	93	76	86	6	1160	55

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.
5. The forage was harvested on 10-4-77.

TABLE 14

Average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on unmined soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	Seeds germinated in 10 ft^2 (no.)	Seedlings established in 10 ft^2 (no.)	Stems produced in 10 ft^2 (no.)	Plant height (inch)	Green forage yield (lb./acre)	Green forage moisture (%)
Harlan II Barley	171	166	610	12	4858	70
Super X Wheat	221	216	728	11	5176	72
Crested Wheatgrass	345	204	1361	5	875	33
Western Wheatgrass	263	163	654	9	1211	46
Indian Ricegrass	21	10	65	12	192	50
Vernal Alfalfa	619	372	829	8	1774	35
Fourwing Saltbush	86	70	70	12	1875	55

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.
5. The forage was harvested on 10-4-77.

TABLE 15

Average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on coal mine soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	Seeds germinated in 10 ft^2 (no.)	Seedlings established in 10 ft^2 (no.)	Stems produced in 10 ft^2 (no.)	Plant height (inch)	Green forage yield (lb./acre)	Green forage moisture (%)
Harlan II Barley	96	91	248	11	3768	86
Super X Wheat	291	286	350	6	2588	86
Crested Wheatgrass	312	196	594	4	1007	52
Western Wheatgrass	153	119	171	6	240	42
Indian Ricegrass	7	3	6	5	48	64
Vernal Alfalfa	227	148	173	4	456	40
Fourwing Saltbush	52	48	51	6	1913	55

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.
5. The forage was harvested on 10-4-77.

TABLE 16

Average germination, seedling establishment, number of stems produced, plant height, green forage yield, and green forage moisture content for seven plant species grown on coal mine soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	Seeds germinated in 10 ft^2 (no.)	Seedlings established in 10 ft^2 (no.)	Stems produced in 10 ft^2 (no.)	Plant height (inch)	Green forage yield (lb./acre)	Green forage moisture (%)
Harlan II Barley	116	111	558	11	5403	85
Super X Wheat	286	281	466	7	4358	84
Crested Wheatgrass	506	796	1346	5	1151	39
Western Wheatgrass	295	163	442	6	1187	41
Indian Ricegrass	12	7	15	7	96	45
Vernal Alfalfa	304	154	430	5	1055	34
Fourwing Saltbush	68	61	61	7	2117	55

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.
5. The forage was harvested on 10-4-77.

TABLE 17

Average plant establishment, number of stems produce, plant height, green forage yield, dry forage yield, and ground cover for seven plant species grown on unmined soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978.

Plant species	Plants established in 10 ft^2	Stems produced in 10 ft^2	Plant height	Green forage yield	Dry forage yield (12% moisture)	Ground cover
	(no.)	(no.)	(inch)	(lb/acre)	(lb/acre)	(%)
Harlan II Barley	144	289	8	3044	1093	55
Super X Wheat	115	169	10	2661	925	53
Crested Wheatgrass	198	1243	9	3165	1604	56
Western Wheatgrass	117	560	10	1271	539	51
Indian Ricegrass	19	501	12	1391	632	25
Vernal Alfalfa	319	1600	10	10597	2707	88
Fourwing Saltbush	75	75	7	4507	1532	36

Comments

1. The perennial plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 18

Average plant establishment, number of stems produced, plant height, green forage yield, dry forage yield, and ground cover for seven plant species grown on unmined soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978.

Plant species	Plants established in 10 ft^2	Stems produced in 10 ft^2	Plant height	Green forage yield	Dry forage yield (12% moisture)	Ground cover
	(no.)	(no.)	(inch)	(lb/acre)	(lb/acre)	(%)
Harlan II Barley	158	555	16	14265	4881	90
Super X Wheat	139	457	13	8631	2925	85
Crested Wheatgrass	131	1392	15	8511	3613	85
Western Wheatgrass	81	1536	13	10717	4066	85
Indian Ricegrass	21	623	16	2709	1263	28
Vernal Alfalfa	343	2741	10	9902	2843	94
Fourwing Saltbush	41	41	12	9374	3594	70

<u>Comments</u>

1. The perennial plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 19

Average plant establishment, number of stems produced, plant height, green forage yield, dry forage yield, and ground cover for seven plant species grown on coal mine soil without fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978.

Plant species	Plants established in 10 ft^2	Stems produced in 10 ft^2	Plant height	Green forage yield	Dry forage yield (12% moisture)	Ground cover
	(no.)	(no.)	(inch)	(lb/acre)	(lb/acre)	(%)
Harlan II Barley	57	398	10	2781	1064	20
Super X Wheat	79	159	8	1601	614	17
Crested Wheatgrass	227	2726	10	2656	1371	43
Western Wheatgrass	94	517	9	1966	710	36
Indian Ricegrass	19	123	9	767	422	5
Vernal Alfalfa	134	268	7	3759	1199	29
Fourwing Saltbush	19	19	13	11124	4450	55

<u>Comments</u>

1. The perennial plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 20

Average plant establishment, number of stems produced, plant height, green forage yield, dry forage yield, and ground cover for seven plant species grown on coal mine soil with fertilizer and with natural rainfall plus sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1978.

Plant species	Plants established in 10 ft^2	Stems produced in 10 ft^2	Plant height	Green forage yield	Dry forage yield (12% moisture)	Ground cover
	(no.)	(no.)	(inch)	(lb/acre)	(lb/acre)	(%)
Harlan II Barley	140	702	14	6070	2623	50
Super X Wheat	79	269	12	4094	1554	43
Crested Wheatgrass	266	3856	14	7864	3371	87
Western Wheatgrass	144	2118	15	5706	2445	93
Indian Ricegrass	29	386	12	1055	515	9
Vernal Alfalfa	164	790	11	5111	1563	91
Fourwing Saltbush	23	23	15	13570	5569	89

Comments

1. The perennial plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 21

In vitro dry matter disappearance (IVDMD) and crude protein for seven plant species grown on unmined soil, without fertilizer, and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	IVDMD	Crude protein
	(%)	(%)
Harlan II Barley	69.2	9.4
Super X Wheat	60.0	8.1
Crested Wheatgrass	69.8	16.3
Western Wheatgrass	68.5	10.6
Indian Ricegrass	56.4	13.1
Vernal Alfalfa	71.7	15.6
Fourwing Saltbush	57.1	10.0

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 22

In vitro dry matter disappearance (IVDMD) and crude protein for seven plant species grown on unmined soil, with fertilizer, and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	IVDMD	Crude protein
	(%)	(%)
Harlan II Barley	70.8	10.6
Super X Wheat	65.5	10.1
Crested Wheatgrass	74.3	20.9
Western Wheatgrass	71.5	14.3
Indian Ricegrass	66.3	13.7
Vernal Alfalfa	71.7	14.1
Fourwing Saltbush	64.9	15.6

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 23

In vitro dry matter disappearance (IVDMD) and crude protein for seven plant species grown on coal mine soil, without fertilizer, and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	IVDMD	Crude protein
	(%)	(%)
Harlan II Barley	68.9	16.9
Super X Wheat	59.1	12.5
Crested Wheatgrass	70.0	26.3
Western Wheatgrass	66.1	19.4
Indian Ricegrass	72.0	21.3
Vernal Alfalfa	77.6	22.5
Fourwing Saltbush	62.9	18.8

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. No fertilizer was used.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

TABLE 24

In vitro dry matter disappearance (IVDMD) and crude protein for seven plant species grown on coal mine soil, with fertilizer, and with natural rainfall and sprinkler irrigation on the Black Mesa Coal Mine, Kayenta, Arizona in 1977.

Plant species	IVDMD	Crude protein
	(%)	(%)
Harlan II Barley	72.1	15.6
Super X Wheat	65.3	13.8
Crested Wheatgrass	75.2	23.8
Western Wheatgrass	73.3	18.1
Indian Ricegrass	68.9	20.0
Vernal Alfalfa	81.9	23.8
Fourwing Saltbush	69.7	20.0

Comments

1. The plant species were planted on 5-25-77 at the suggested planting rate.
2. The experimental design was a Randomized Complete Block with 4 replications.
3. Five hundred (500) pounds per acre of 16-20-0 fertilizer were applied at planting.
4. Irrigation was applied to insure that plants were never stressed for soil moisture.

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15. SUPPLEMENTARY NOTES

This project is part of the EPA-planned and coordinated Federal Interagency Energy/Environmental R&D Program.

16. ABSTRACT

The objectives and approach of this research project were: (1) to evaluate the properties of coal mine soil, (2) to study the germination of selected plant species in coal min soil in the greenhouse, (3) to study the growth of selected plant species in coal mine soil on the Black Mesa Coal Mine, and (4) to study the livestock feed value of forage from selected plant species grown in coal mine soil. The nitrogen and potassium contents were higher in coal mine soil than they were in unmined soil; however, coal mine soil contained less phosphorus than did unmined soil. Average germination percentages for seven plant species grown in coal mine soil in the greenhouse were similar to germination percentages for the same species grown in Gila foam soil. Seven plant species produced satisfactory germination, seedling establishment, ground cover, and forage production in unmined soil and coal mine soil on the Black Mesa Coal Mine when each soil material was supplied with optimum soil moisture and fertilizer. The general livestock feed value of forage from seven plant species grown in coal mine soil was similar to the feed value of forage from the same species grown in unmined soil.

17. KEY WORDS AND DOCUMENT ANALYSIS

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