Reclamation and Fertilization of Coal Mine Soils in the Southwestern Desert[1]

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Abstract

A 5-year experiment was conducted from 1978 through 1982 on the Black Mesa Coal Mine, Kayenta, Arizona, to study plant species best suited for coal mine reclamation and the effects of fertilizer on selected species. Five plant species were broadcast seeded on coal mine soil (spoils) and unmined soil. Prior to planting, 560 kg/ha of 16-20-0 fertilizer were applied on one-half of each site while the other half received no fertilizer. Immediately after planting, sprinkler irrigation water was applied on all plots, as needed, for the first two years. After two years, fertilizer and irrigation were discontinued on both soil materials and all plant species received only natural rainfall for the following three years.

Coal mine soil contained more total soluble salts, nitrogen, potassium, sodium, and organic matter than did unmined soil; however, unmined soil had a higher pH and contained more phosphorous than did coal mine soil.

Plant growth measurements were recorded for each plant species in October of each year. In general, plants grew better and produced more forage in unmined soil than they did in coal mine soil. All plant species grew better, yielded more forage, and produced a more satisfactory ground cover when they were fertilized than they did when they were not fertilized. Plant species differed greatly in general growth, forage yield, and percent ground cover within soil materials and within fertilizer treatments. Crested wheatgrass (*Agropyron cristatum* L.), western wheatgrass (*Agropyron smithii* Rydb.), and vernal alfalfa (*Medicago sativa* L.) grew better, yielded more forage, and produced a more complete ground cover than did Indian ricegrass (*Oryzopsis hymenoides* Ricker) or fourwing saltbrush (*Atriplex canescens* Pursh). In general, the reclamation of unmined soil with fertilizer and a combination of natural rainfall and sprinkler irrigation during the first two years and with perennial grasses was more successful than the reclamation of coal mine soil with no fertilizer and with legumes or shrubs in the semiarid environment in the southwestern United States.

Additonal Index Words: Disturbed land, mine spoils, revegetation, stabilization, environmental pollution.

Introduction

A number of states in the western United States contain large coal deposits that may be surface-mined to satisfy future energy requirements. The Black Mesa Coal Mine near Kayenta in northern Arizona is the site of one such coal deposit. Regraded coal mine soils (spoils) at this location range from 10 to 25 m in depth with a gently sloping topography that blends in well with the surrounding natural landscape. The primary objective of revegetation at this location is to return the coal mined areas to their premining use, which was livestock grazing.

Literature Review

Stabilization of coal mine soil material from mining operations to prevent it from being moved by winds and flash floods is the primary purpose for reclaiming disturbed lands (Powell et al., 1980). The enactment of the Surface Mined Land Conservation and Reclamation Act in 1971 and the amendments to this act in 1975 have radically changed the post-mining uses and capabilities of reclaimed lands. The amended act insures that a nearly equal amount of land will be reclaimed to its potential that existed prior to mining (Christy et al., 1979).

Productive reclamation of disturbed lands may involve many steps to insure survival and growth of vegetation. These steps may include topsoil stockpiling, supplemental irrigation, mulches, and fertilizers. Chemical and physical properties of overburden may vary greatly with depth and even within a mined area. Therefore, reclamation problems frequently differ greatly from one area to another (Schroer, 1976). Power et al. (1977) reported that mining spoils are highly variable in porosity and infiltration rates due to the vast range in size of the sedementary rock fragments and that most mine spoils in the West are deficient in plant available phosphorus. Ludeke et al. (1974) determined that the NO_3-N levels in all copper mine waste materials were too low for normal plant growth. Lanning and Williams (1980) reported that the most important loss of nitrogen in china clay sand waste is through leaching. Day et al. (1979) reported on the low phosphorus level of coal mine soils at the Black Mesa Coal Mine in northern Arizona. Nitrogen fertilizer has been shown by McGinnies and Nicholas (1980) to increase above—and below—ground growth of intermediate wheatgrass (*Agropyron intermedium* L.) in coal mine spoil while Powell et al. (1980) demonstrated the

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ability to reclaim surface-mined coal spoils with a single application of phosphate fertilizer. Luellen (1977) reported that restoration of mined lands needs heavy applications of nitrogen and phosphorus fertilizers. Nitrogen may also be supplied naturally, either from soft shale brought to the surface during mining (Power et al., 1974) or by nitrogen fixation by perennial legumes planted as part of the revegetation program (Dancer et al., 1977).

The objectives of this research were to determine the effects of two soil materials and two fertilizer treatments on the seed germination, seedling establishment, number of stems produced, plant height, forage yield, and ground cover of five plant species used in coal mine reclamation in a semiarid environment.

Materials and Methods

A 5-year experiment (1978–1982) was conducted on the Black Mesa Coal Mine near Kayenta, Arizona, to study plant species best adapted to coal mine reclamation and to determine the effect of fertilizer on the germination and growth of five plant species. The Black Mesa is located in Northeastern Arizona at an elevation of about 2,132 m (7,000 ft) with an annual precipitation of approximately 25 cm (10 inches). About one-half of the precipitation occurs during the winter months producing snowmelt with some runoff in late winter. The remainder occurs as spotty storms of short duration and high intensity in mid- to late-summer.

Mined and unmined research sites were chosen for the study. The mined areas consisted of freshly contoured strip mine overburden composed of particles ranging in size from silt to crushed sedimentary rock fragments 15 cm in diameter with no vegetation. The unmined areas were located adjacent to the strip mining operations and they had a sparse vegetative cover of native grasses and sagebrush, which had been severely overgrazed. The topsoil in the unmined areas was classified as the Fruitland soil series belonging to the soil family of coarse-loamy mixed (calcareous), Mesic Typic Torieorthents.

After the seedbeds in all research sites were prepared by disking with a double disk harrow, 50 soil samples were collected at random from the surface of each site, composited, and analyzed (Table 1). All sites received 25 cm of natural rainfall plus 35 cm of sprinkler irrigation water per year for the first two years (1978 and 1979). Five plant species were broadcast seeded with a cyclone seeder in April, 1978 at a rate of 500 viable seeds per m² and covered with a spike-tooth harrow. The five plant species consisted of two introduced perennial grasses, crested wheatgrass (*Agropyron cristatum* L.) and western wheatgrass (*Agropyron smithii* Rydb.), one native perennial grass (Indian ricegrass (*Oryzopsis hymenoides* Ricker), one introduced legume (Vernal alfalfa (*Medicago sativa* L.) and one native shrub, fourwing saltbush (*Atriplex canescens* Pursh). Each research site was further divided into two areas: One was fertilized with 560 kg/ha of 16-20-0 fertilizer prior to planting and the other was left unfertilized (check treatment). Immediately after planting the plots received supplemental irrigation as needed throughout the growing season, using a sprinkler irrigation system with sprinkler heads spaced approximately 9 m apart. Irrigation was maintained for the

Table 1. 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, Kayenta, Arizona, in 1978.

Soil material	pH	$EC_e \times 10^3$	ESP	Total soluble salts (ppm)	N (ppm)	P (ppm)	K (ppm)	Na (ppm)	OM (%)
Unmined soil	7.4	2	0	1190	6	2.3	18	46	1.2
Coal mine soil	6.6	6	1	4270	78	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.

first two years (1978 and 1979) and then discontinued for the remaining three years, during which all plots received rainfall only. The experimental design was a Split-Split Plot with soil materials as main plots, fertilizer treatments as subplots and plant species as sub-subplots with four replications. The plot size was 48 m². Plant growth measurements in each plot were recorded in October of each year. All data were analyzed using the analysis of variance. The Student-Newman-Keuls' Test was used for comparison of means (Steel and Torrie, 1960).

Results and Discussion

Soil analyses for unmined soil and coal mine soil (spoils) are presented in Table 1. Unmined soil had a higher pH and contained more phosphorous than did coal mine soil; however, coal mine soil contained more total soluble salts, nitrogen potassium, sodium, and organic matter than did unmined soil. Since unmined soil had the highest pH, one might expect legumes that require an alkaline soil to grow better in unmined soil than in coal mined soil. The concentration of total soluble salts was about four times higher in coal mine soil than it was in unmined soil. This suggests that salt sensitive plant species may grow more effectively in unmined soil than they would in coal mine soil. Since the general fertility level and organic matter content of coal mine soil were higher than they were in unmined soil, there would be a greater need for fertilizer in the revegetation of unmined soil than would be necessary in the revegetation of coal mine soil.

In general, plants grew better and produced more forage in unmined soil than they did in coal mine soil (Table 2). The higher concentration of total soluble salts and sodium in coal mine soil may be a partial explanation. All plant species grew better, yielded more forage, and produced a more complete ground cover when they were fertilized prior to planting than they did when they were grown without fertilizer (Table 2). This indicates that the natural fertility levels of the coal mine soil materials on the Black Mesa was not sufficient for optimum seed germination and effective seedling establishment in either unmined soil or coal mine soil. Plant species differed greatly in general growth, forage yielded, and percent ground cover within soil materials and within fertilizer treatments (Table 2). The number of seeds germinated per unit area is important in the revegetation of disturbed mining areas because a high germination percentage usually results in a high seedling establishment. High seedling establishment is accompanied by the development of many separate roots which

Table 2. Average seed germination, seedlings established, stems produced, plant height, dry forage yield, and ground cover for five plant species grown on unmined soil and coal mine soil with two fertilizer treatments on the Black Mesa Coal Mine, Kayenta, Arizona from 1978 through 1982 (5-year average).

Soil Material	Fertilizer Treatments	Plant Species	Seeds Germinated/m² (no.)	Seedlings Established/m² (no.)	Stems Produced/m² (no.)	Plant Height (cm)	Dry Forage Yield/m² (g)	Ground Cover (%)
Unmined soil	No Fertilizer	Crested Wheatgrass	202 b+	119 a	1130 a	28 a	189 b	50 a
		Western Wheatgrass	156 b	99 b	985 a	19 a	186 b	40 a
		Indian Ricegrass	27 c	19 c	341 b	23 a	67 c	15 c
		Vernal Alfalfa	416 a	189 a	409 b	10 b	81 c	15 c
		Fourwing Saltbush	71 c	89 b	89 c	23 a	389 a	25 b
	Fertilizer	Crested Wheatgrass	371 b	126 b	1272 a	33 b	212 b	60 a
		Western Wheatgrass	283 b	119 b	1199 a	30 b	233 b	50 a
		Indian Ricegrass	22 c	20 c	363 b	25 b	73 c	25 b
		Vernal Alfalfa	453 a	225 a	533 b	12 c	117 c	25 b
		Fourwing Saltbush	92 c	72 c	82 c	66 a	403 a	30 b
Coal mine soil	No Fertlizer	Crested Wheatgrass	236 a	104 a	1022 a	25 b	147 b	40 a
		Western Wheatgrass	104 b	87 a	938 a	16 b	171 b	30 a
		Indian Ricegrass	8 c	11 b	267 b	18 b	39 c	10 c
		Vernal Alfalfa	225 a	91 a	226 b	7 c	62 c	10 c
		Fourwing Saltbush	56 c	41 b	51 c	47 a	321 a	20 b
	Fertilizer	Crested Wheatgrass	445 a	121 a	1114 a	30 b	173 b	50 a
		Western Wheatgrass	318 b	100 a	1047 a	23 b	206 b	40 b
		Indian Ricegrass	13 c	15 b	289 b	23 b	52 c	20 b
		Vernal Alfalfa	328 b	153 a	317 b	12 c	85 c	20 b
		Fourwing Saltbush	73 c	64 b	64 c	57 a	366 a	25 b
Significance of differences:								
Between Soil materials			*	*	*	ns	*	*
Between fertilizer treatments			*	*	*	*	*	*
Between plant species			**	*	**	*	*	*

**=Significant at 1% level; *=Significant at 5% level; ns=Not significant the 5% level.

+Means followed by the same letter, within a soil material, for the same fertilizer treatment, are not different at the 5% level of significance, using the Student-Newman-Kuels' test.

develop a more compact root community below the soil surface. A more compact root community stabilizes the soil surface more effectively and makes it more resistant to the effects of erosion and trampling by animal life than does a sparse root population. A high seedling establishment and a high percent ground cover protect the soil surface against wind and water erosion and produce a more pleasing appearance of the disturbed area than do a low seedling establishment and sparse ground cover. The general eye-appeal of an area increases as the percent ground cover increases. Crested wheatgrass, western wheatgrass, and vernal alfalfa grew better, yielded more forage, and produced a more complete ground cover than did Indian ricegrass or fourwing saltbrush.

In general, the reclamation of fertilized unmined soil with a combination of natural rainfall and sprinkler irrigation during the first two years and with perennial grasses was more successful than the reclamation of unfertilized coal mine soil and with legumes and shrubs in the semiarid environment in the southwestern United States.

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