Growth of Selected Plants on Wyoming Surface-Mined Soils and Flyash

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Highlight: This greenhouse study was initiated to determine potential plant growth on three surface-mined soils and their overburden, and on coal flyash mixtures from sites in Wyoming prior to field studies and plant establishment trials. There was no indication that either topsoil or overburden from the active mine sites in Gillette, Hanna, or Shirley Basin, was detrimental to plant growth when water and temperature were not limiting. Forage plants and range shrubs on each soil benefited from the addition of N and/or P fertilizer. The addition of sewage sludge or manure also greatly increased growth. The study indicated that certain mixtures of flyash in soil and sludge can be successfully revegetated. The application of this data may be extensive in the reclamation and revegetation of surface-mined soils in those areas tested.

During the past decade energy demands plus the necessities for environmental preservation have greatly concerned our society. The concern is that natural biological and ecological systems can only be degraded; however, the possibility of improving the vegetative cover should also be considered.

Historically, surface mining has been conducted in the eastern United States where rainfall is adequate for plant growth, and the overburden materials are acidic. Presently, surface mining has shifted to the arid and semiarid regions of the western United States, where coal seams are thick with low sulfur content. These western areas have annual precipitation ranging from 15 to 40 cm and alkaline soils with low to medium soluble-salt content.

Various groups have expressed environmental concern that has influenced legislation so that reclamation laws require that topsoil be stockpiled and returned to the overburden surface after mining is completed.

Currently, research is involved in determining the effects of disturbing these soils and reestablishing suitable plant materials by testing both introduced and native species.

To avoid the many uncontrolled variables present in field plant studies in arid regions, we initiated a greenhouse study to determine potential plant growth on three surface-mined soils, overburden materials, and flyash in Wyoming under controlled soil moisture and temperature conditions.

Literature

The literature lists species use and seeding methods for plant establishment on disturbed lands in Wyoming. Beauchamp et al. (1975) determined there was sufficient seed in the top 2 inches of soil in six surface-mined areas across Wyoming to revegetate the areas. However, the quality of vegetation would be altered as most of the seedlings were of the less desirable range species. They recommended direct seeding of preferred species. Lang et al. (1975) gave general seeding recommendations and planting practices by three rainfall zones for the establishment of forages and woody plants on disturbed lands in Wyoming. Tressler (1976) published a range seeding guide for Wyoming listing applicable areas, planning considerations, planting procedures and equipment, and range species to use in disturbed land revegetation. May et al. (1971) reported some success with deciduous tree planting, and sodding and sprigging of western wheatgrass (*Agropyron smithii*) and inland saltgrass (*Distichlis stricta*) in southwestern Wyoming.

Orr (1975) showed survival of seven woody species after 1 year in northeastern Wyoming. Power et al. (1975) surveyed some soil factors restricting revegetation of strip-mine spoils in the Fort Union geologic formation of the Dakotas, Montana, and Wyoming. Their studies showed that soluble salts and high exchangeable sodium may be limiting factors in plant establishment. In related research in the arid West, Aldon (1975) indicated the value of mycorrhizae in the establishment of fourwing saltbush (*Atriplex canescens*) on coal mine spoils in New Mexico. Aldon and Springfield (1973) in greenhouse studies found that organic matter and fertilizer amendments had no effect on seedling emergence or early growth of test plants. George (1953), Howard (1964), and Johnson (1966) summarized many years of shelterbelt research conducted by the U.S. Department of Agriculture in the Northern, Central, and Southern Great Plains embracing parts of 10 states. They determined adaptable species of trees and shrubs, and proper spacing distances for planting under clean cultivation using dryland culture. They showed that useful and effective windbreaks can be grown across all of the semiarid Great Plains of the United States by using their prescribed methods.

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Methods and Procedures

In 1974 and 1975, topsoil and newly uncovered overburden were randomly collected at three Wyoming mine sites: Wyodak Coal Mine, east of Gillette; Seminoe No. 1 Coal Mine, west of Hanna; and Utah International Uranium Mine at Shirley Basin. To ensure representative material before they were used in greenhouse studies, soils were ground and mixed thoroughly. Their electrical conductivity (EC_e) and pH were determined on a saturation paste to assess the leaching of salts and pH changes due to treatment imposed.

Three studies were established in the spring of 1975 with various soil mixtures, amendments, and species.

Combinations of soils and fertilizers to make seven treatments of the Wyodak and Seminoe No. 1 soils and overburden and three treatments on the Utah International soils and overburden were established in a randomized, replicated greenhouse study. Critana thickspike wheatgrass (*Agropyron dasystachyum*) and Ladak and selection A741 alfalfa (*Medicago sativa*) were grown in all treatments.

The seven treatments imposed on the Wyodak and Seminoe No. 1 mine soils and overburden were: (1) untreated overburden; (2) 1:1 topsoil:overburden mixture; (3) 1:1 topsoil:overburden mixture plus 67 kg N/ha for the grass treatment, or 67 kg P/ha for the alfalfa treatment; (4) 5 cm topsoil over the overburden; (5) 5 cm topsoil over the overburden plus 67 kg N/ha for the grass treatment or 67 kg P/ha for the alfalfa treatment; (6) 1:1 topsoil:overburden mixture plus 22.4 Mt/ha sewage sludge; and (7) 1:1 topsoil:overburden mixture plus 22.4 MT/ha manure.

The three treatments for the Utah International soils and overburden were: (1) 5 cm topsoil over the overburden; (2) 5 cm topsoil over the overburden plus 67 kg N/ha for the grass treatment or 67 kg P/ha for the alfalfa treatment; and (3) 5 cm topsoil over the overburden plus 22.4 metric tons (MT)/ha sludge. The sludge and manure treatments were determined on an air dry weight basis. In these studies Critana thickspike wheatgrass and Ladak and selection A741 of alfalfa were grown in 12-cm pots and their total dry matter production determined during 1975.

Tests with woody plants used newly germinated seedlings of the native species: winterfat (*Ceratoides lanata*), rabbitbrush (*Chrysothamnus nauseous*), fourwing saltbush, and silver sage (*Artemisia cana*) and of the introduced species salttree (*Halimodendron halodendron*). These five shrubs were selected because of their adaptability to semiarid conditions and because of seed persistence after ripening. Plants were grown in 7-cm pots containing either the three topsoils from each of the mine sites or overburden or topsoil: overburden (1:1) mix in randomized, replicated plantings. Fertilizer treatments included an untreated control and 67 kg/ha of N or P alone or in equal combination for each of 45 pots in each fertilizer treatment. Plant height data were collected to evaluate growth.

Another test was conducted using coal flyash from the Dave Johnson power generating plant at Glenrock, Wyo., plus 12 topsoil, sludge, and manure combinations. These included four mixtures of flyash and soil; three mixtures of flyash, sludge and soil; one mixture of flyash and sludge; three mixtures of flyash, manure, and soil; and one mixture of flyash and manure. Rosana western wheatgrass was grown in 12-cm pots in a replicated test to evaluate the soil materials and amendments. Data obtained were oven-dried forage yield, percent germination, and oven-dried root biomass.

Pots in all experiments were hand watered to keep available soil moisture at maximum levels. Greenhouse temperatures ranged from 12°C at night to 35°C by day.

Results and Discussion

Because of the possibility of high pH or high salt values and of their changes due to leaching in disturbed Wyoming soils, both were determined prior to these plant trials. Beginning pH and EC_e values for the soil overburden materials and soil amendments used in the forage trials for the three locations are shown in Table 1. The pH values for the topsoil and overburden material ranged from neutral to slightly above neutral. Topsoil EC_e values were low and not considered a problem, whereas those for the overburden material from Wyodak and Seminoe No. 1 mine sites were moderate and could present problems in seedling development and plant growth. Beginning pH and EC_e for sludge and manure was 7.2 and 7.3, and 8.31 and 2.63 mmhos/cm respectively.

Table 1. Pretreatment pH and EC_e of the topsoil and overburden from Wyodak, Seminoe, and Utah International mines.

	pH		EC_e (mmhos/cm)	
Mine	Topsoil	Overburden	Topsoil	Overburden
Wyodak	7.0	7.3	1.00	6.60
Seminoe No. 1	7.5	7.4	0.14	3.95
Utah International	7.4	7.3	2.60	0.16

The intent of revegetation research is to find methods for revegetating disturbed lands that will restore range productivity to equal or higher levels than those which existed prior to mining. Hence, forage yields were studied with the soils and amendments under test. Total oven-dried forage yield for the grass and alfalfa for the seven soil and fertilizer treatments and the final pH and EC_e for Wyodak and Seminoe No. 1 coal mine site soils and overburden are shown in Tables 2 and 3,

Table 2. Oven-dried yields, final pH, and EC_e on Wyodak Coal Mine soils and overburden for seven treatments using 12-cm pots under greenhouse culture.

	Forage yield[1] (g)		Final pH[1]		Final EC_e[1] (mmhos/cm)	
Treatments	Alfalfa[2]	Grass[3]	Alfalfa	Grass	Alfalfa	Grass
(1) Untreated overburden	13.4[c 4]	1.03[d]	7.3	7.3	2.8	2.9
(2) Topsoil:overburden (1:1 mix)	14.6[c]	1.90[cd]	7.2	7.2	2.6	2.2
(3) Topsoil:overburden (1:1 mix) +						
67 kg N/ha	—	3.90[ab]	—	7.2	—	2.2
67 kg P/ha	21.2[a]	—	7.2	—	2.7	—
(4) 5-cm topsoil over overburden	16.3[bc]	1.43[cd]	7.1	7.4	2.9	2.7
(5) 5-cm topsoil over overburden +						
67 kg N/ha	—	4.65[a]	—	7.2	—	2.7
67 kg P/ha	19.4[ab]	—	7.3	—	2.2	—
(6) Topsoil:overburden (1:1 mix) +						
22.4 MT/ha sludge	22.4[a]	3.28[b]	7.2	7.2	2.7	3.0
(7) Topsoil:overburden (1:1 mix) +						
22.4 MT/ha manure	19.5[ab]	2.20[c]	7.3	7.5	3.1	3.1

[1] Single plot means from 4 reps.
[2] Sum of five 1975 harvests on 4/14, 5/21, 6/26, 7/28, 9/2 of Ladak alfalfa (seeded 2/14/75).
[3] Sum of three 1975 harvests on 4/14, 5/21, 9/2 of Critana thickspike wheatgrass (seeded 2/14/75).
[4] Column yields followed by same letter do not differ at 5% level of probability by Fisher's method.

Table 3. Oven-dried forage yields, final pH and EC_e for Seminoe No. 1 Coal Mine soils and overburden for seven treatments using 12-cm pots under greenhouse culture.

Treatment	Forage yield[1] (g)		Final pH[1]		Final EC_e[1]	
	Alfalfa[2]	Grass[3]	Alfalfa	Grass	Alfalfa	Grass
(1) Untreated overburden	13.3[d 4]	2.93[c]	7.2	7.6	1.3	1.0
(2) Topsoil:overburden (1:1 mix)	18.9[c]	2.40[c]	7.2	7.4	1.3	1.0
(3) Topsoil:overburden (1:1 mix) +						
67 kg N/ha	—	4.83[ab]	—	7.5	—	0.8
67 kg P/ha	31.8[a]	—	7.1	—	1.7	—
(4) 5-cm topsoil over overburden	17.3[c]	3.35[bc]	7.2	7.5	2.0	1.0
(5) 5-cm topsoil over overburden +						
67 kg N/ha	—	6.48[a]	—	7.4	—	0.9
67 kg P/ha	25.2[b]	—	7.3	—	1.3	—
(6) Topsoil:overburden (1:1 mix) +						
22.4 MT/ha sludge	24.6[b]	5.13[a]	7.3	7.3	1.7	0.9
(7) Topsoil:overburden (1:1 mix) +						
22.4 MT/ha manure	25.4[b]	6.00[a]	7.6	7.4	1.4	1.5

[1] Single plot means from 4 reps.
[2] Sum of six 1975 harvests on 3/18, 4/23, 5/21, 6/26, 7/28, 9/2 of A741 alfalfa (seeded 2/17/74).
[3] Sum of three 1975 harvests on 3/18, 5/21, 9/2 of Critana thickspike wheatgrass (seeded 12/18/74).
[4] Column yields followed by same letter do not differ at the 5% level of probability of Fisher's method.

Table 4. Oven-dried forage yields, final pH and EC_e for Utah International Uranium Mine soils and overburden for three treatments using 12-cm pots under greenhouse culture.

Treatments	Forage yield[1] (g)		Final pH[1]		Final EC_e[1] (mmhos/cm)	
	Alfalfa[2]	Grass[3]	Alfalfa	Grass	Alfalfa	Grass
(1) 5-cm topsoil over overburden	19.1[b 4]	4.57[c]	7.0	7.5	1.35	0.66
(2) 5-cm topsoil over overburden +						
67 kg N/ha	—	11.10[a]	—	7.3	—	0.70
67 kg P/ha	28.7[a]	—	7.0	—	1.36	—
(3) 5-cm topsoil over overburden +						
22.4 MT/ha sludge	26.0[ab]	6.73[b]	7.2	7.4	1.63	0.78

[1] Single plot means from 4 reps.
[2] Sum of six 1975 harvests on 3/18, 4/23, 5/21, 6/26, 7/28, 9/2 on alfalfa (seeded 12/17/74).
[3] Sum of three 1975 harvests on 3/18, 5/21, 9/2 on thickspike wheatgrass (seeded 2/18/74).
[4] Column yields followed by same letter do not differ at the 5% level of probability by Fisher's method.

respectively. Similar data are presented in Table 4 for the Utah International Uranium Mine site soils with three soil and fertilizer treatments.

Of all the treatments with Wyodak soils and overburden, treatments with fertilizer amendments gave significantly higher alfalfa yields whether the fertilizer was 67 kg (P/ha or 22.4 MT/ha of sludge or manure (Table 2). Wheatgrass yields were significantly greater in the two treatments having 67 kg/ha of N. The pH values did not change during the experiment, while the EC_e of the overburden alone and in combination was decreased by leaching from 6.6 to 3.1 mmhos/cm or lower during the experiment (Tables 1 and 2).

Of the treatments with Seminoe No. 1 soils and overburden, the addition of 67 kg P/ha had a significantly higher alfalfa yield response in the 1:1 mix while thickspike wheatgrass had a significant yield response for the four treatments having either

Table 5. Preplant and final pH and EC_e and mean height of five woody plant species grown on topsoils, overburden, and mixtures from three Wyoming mine sites with fertilizer treatments combined.

Mine and treatment	Height (cm)						pH		EC_e (mmhos/cm)	
	Winter-fat	Salt-tree	Rabbit-brush	Fourwing saltbush	Silver sage	Mean	Preplant	Final	Preplant	Final
Seminoe No. 1										
Topsoil	14.3[1]	26.2	28.8	20.4	5.0	18.9[a 2]	7.5	7.5	0.14	0.55
Overburden	11.9	5.4	14.5	7.0	5.4	8.8[f]	7.4	7.4	3.95	0.43
1:1 mix	12.3	18.6	20.2	9.6	4.5	13.0[cde]	—	7.9	—	0.55
Wyodak										
Topsoil	14.2	36.3	22.4	11.3	4.6	17.7[ab]	7.0	8.0	1.00	0.55
Overburden	8.5	8.9	16.1	8.2	4.6	9.3[f]	7.3	8.3	6.60	1.70
1:1 mix	10.9	20.9	26.5	8.5	5.8	14.5[bcd]	—	7.5	—	2.80
Utah International										
Topsoil	9.3	18.9	22.3	17.0	5.1	14.5[bcd]	7.5	7.7	0.14	0.39
Overburden	7.0	13.0	14.4	6.7	5.7	9.4[ef]	7.4	7.2	3.95	0.30
1:1 mix	7.0	35.8	23.0	8.7	5.3	16.0[abc]	—	7.4	—	0.25
Mean	10.6[b]	20.4[a]	20.9[a]	10.8[b]	5.1[c]					

[1] Single plot means from 4 reps.
[2] Means followed by the same letter do not differ at the 5% level of probability by Fisher's method.

Table 6. Mean height of combined shrub species grown on topsoil, overburden and mixture from three Wyoming mine sites under four fertilizer treatments.

Mine and treatment	Height (cm)			
	Control	67 kg N/ha	67 kg N/ha + 67 kg P/ha	67 kg P/ha
Seminoe No. 1				
Topsoil	13.9[1]	23.2	23.3	15.4
Overburden	5.3	12.0	10.0	8.0
1:1 mix	11.2	14.2	15.9	10.7
Wyodak				
Topsoil	14.9	24.4	19.0	12.6
Overburden	5.8	11.2	13.6	6.5
1:1 mix	10.7	14.0	17.4	16.0
Utah International				
Topsoil	7.7	19.9	18.3	12.1
Overburden	5.6	8.3	12.2	11.3
1:1 mix	14.2	20.3	19.4	10.1
Mean	9.9[b2]	16.4[a]	16.6[a]	11.6[b]

[1] Single plot means from 5 reps.
[2] Means followed by same letters do not differ at the 5% level of probability by Fisher's method.

Table 7. Mean height (cm) of five shrub species under four fertilizer treatments with reps. and soil combined.

Treatments (kg/ha)	Winter-fat	Salt-tree	Rabbit-brush	Fourwing saltbush	Silver sage
Control	6.0[b 1,2]	16.1[a]	17.4[a]	5.9[b]	4.1[a]
67 N	18.5[a]	19.9[a]	25.6[a]	13.4[ab]	4.6[a]
67 N + 67 P	12.0[ab]	22.9[a]	24.1[a]	16.2[a]	7.8[a]
67 P	5.9[b]	23.0[a]	16.5[a]	7.7[ab]	3.9[a]

[1] Single plot means.
[2] Column means followed by same letter do not differ within a species at the 5% level of probability by Fisher's method.

67 kg N/ha, sludge, or manure added to the soil mixtures (Tables 3). The pH values did not change while salt levels were decreased by leaching for both test species.

Of all the treatments on Utah International soils and overburden, the P fertilized or amended with sludge had significantly higher alfalfa yields while only the N fertilizer treatment was significantly higher in grass yield (Table 4). Soil pH changed little and the originally low EC_e levels were further decreased by leaching.

Shrubs form an integral part of the native range in Wyoming. Their reintroduction on disturbed lands seems desirable for holding drifted snow and for furnishing forage to livestock and wildlife. However, numbers of shrubs per unit area in many parts of the state may well be reduced. The growth response of both native and introduced species was studied. The mean height growth of four native and one introduced range shrubs by species and soils from the three mine sites is shown in Table 5. Because first-year seedlings produced little or no lateral growth, height was used as the measure of their growth response. Shrubs grew significantly taller in topsoil from the Seminoe No. 1 and Wyodak sites and in the 1:1 mix from the Utah International site. Mean height values for salttree and rabbitbrush were significantly greater than those of the other three species, which indicates their growth habit. The preplant and final pH and EC_e response were similar to those for the forage pots.

Fertilizer effects on shrub growth was determined for each of the mine soils and mixtures under test. The mean combined shrub growth by fertilizer treatments on each of the three mine topsoils, overburden, and mixtures is presented in Table 6. Growth was significantly greater with the 67 kg N/ha and 67 kg N/ha + 67 kg P/ha fertilizer treatments. However, the combined fertilizer treatment did not significantly increase shrub growth over that with 67 kg N/ha alone.

Some of the interaction means for fertilizer treatments by shrub species were significant (Table 7). The meaningful comparison is response to fertilizer treatments within a species. Winterfat responded significantly to N or a N/P combination but not to P alone. Salttree, rabbitbrush, and silver sage had no significant differences in growth in any fertilizer treatment. Fourwing saltbush significantly responded to the fertilizer treatments, the greatest amount seeming to be from N. This response may indicate some species for use in revegetation that do not need additional fertilizer for establishment.

Coal-fired electric generating plants produce large amounts of flyash. When plants are at a distance from the coal mines disposition of the flyash becomes a problem. This trial was initiated to determine whether flyash mixtures could be successfully revegetated under controlled moisture and temperature conditions. Of Rosana western wheatgrass grown in 12 soil, flyash, and sewage sludge combinations, Table 8 shows germination rate, preplant and final pH and EC_e, oven-dried biomass, and forage yield. The soil used was five parts greenhouse soil

Table 8. Quantitative data for Rosana western wheatgrass grown in 12-cm pots containing 12 soil, flyash, sludge and manure combinations.

Media	Ratio	Germination[1] (%)	pH[2] Prelant	pH[2] Final	EC_e[2] (mmhos/cm) Preplant	EC_e[2] (mmhos/cm) Final	Root biomass[2,3] (g)	Forage yield[2,3] (g)
Flyash:soil	1:1	60	12.0	8.9	1.55	1.00	0.35	0.27[e 4,5]
	1:2	67	11.5	8.1	1.51	1.34	2.92	2.14[cde]
	1:4	73	11.3	8.0	2.56	0.97	3.99	2.92[cde]
	1:6	78	11.0	8.1	2.57	1.04	4.53	4.54[bc]
Flyash:sludge:soil	1:1:1	78	10.9	8.2	5.60	3.20	4.03	6.11[b]
	1:2:2	92	10.2	7.9	5.70	2.87	7.37	9.19[a]
	1:3:3	92	9.6	7.8	5.90	2.37	8.57	10.43[a]
	1:1:0	62	10.7	7.9	5.80	1.82	1.77	4.47[bc]
Flyash:manure:soil	1:1:1	60	11.4	8.3	4.00	1.62	1.12	1.63[de]
	1:2:2	72	11.0	7.9	5.00	1.94	2.49	3.03[cde]
	1:3:3	77	11.0	8.1	4.20	1.42	2.09	2.31[cde]
	1:2:0	60	11.0	8.2	6.50	0.95	2.68	3.32[bcd]

[1] 20 seed/pot; 3 rep. means.
[2] Single pot means from 3 reps.
[3] Oven-dried weights.
[4] Sum of three 1975 harvests on 8/22, 10/29, 12/26 (seeded 4/10/75).
[5] Means followed by same letters do not differ at 5% level of probability by Fisher's method.

(Pachic Argustoll) added to one part sand. All pH values were high at the start of the experiment and most were decreased to near 8.0 during the tests. Preplant EC_e values were at the upper limits for good plant growth. Through leaching, the EC_e was decreased to acceptable levels during the experiment. The 1:2:2 and 1:3:3 flyash-sludge-soil mixtures had significantly higher forage yields, greater percent germination of any of the combinations, and the lowest pH values throughout the study. Western wheatgrass growth in these two mixtures was outstanding and seemed to demonstrate a synergistic effect within the media used.

When we calculated a correlation coefficient between the amount of root growth and forage yield for the western wheatgrass in the 12 mixtures the value was .931 and highly significant. An r^2 calculation indicated that 86.7% of herbage yield in each mixture may be accounted for by its dependence on its corresponding amount of root development.

Thickspike wheatgrass planted in 3, 6, or 9 cm of soil over powdered coal flyash or over 1-to-3 cm flyash chips showed little or no root penetration into the flyash. When powdered flyash was wetted and dried it hardened like concrete and the plants and soil could be lifted from the flyash with no root attachment. However, some grass roots were able to reach the bottom of the pots by growing between the pots and the flyash inside.

Summary and Conclusions

This study showed no indication that either topsoil or overburden, from the active mine sites in Gillette, Hanna, or Shirley Basin was detrimental to plant growth. Forage plants grown on each of the soils benefited from the addition of N more than P fertilizer. The addition of sewage sludge greatly increased growth. As a group the woody shrubs significantly responded in growth to N treatment while winterfat and fourwing saltbush had a significant species response to N.

The study indicated that certain mixtures of coal flyash in soil and sludge can be successfully revegetated with irrigation.

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