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SEEDLING WATER RELATIONS OF TWO GRASS SPECIES
ON HIGH-ELEVATION ACID MINE SPOILSLorraine K. Van Kekerix,
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ABSTRACT

*Revegetation is the most successful long-term solution to the problems caused by surface mining. However, the characteristics of mine spoils that limit natural colonization by plants often require amelioration before successful plant establishment can be achieved. High elevation disturbances in the western U.S. are particularly severe because geologic materials are often of pyritic origin resulting in lethal pH levels, poor waterholding characteristics, and toxic concentrations of heavy metals. Superimposed on these limiting site characteristics are constraints of short, cool, growing seasons and the possibility of diurnal frost action. These conditions severely limit the number of adapted vascular plant species suited for revegetation. Research was conducted at 2 925 m elevation on the McLaren Mine, near Cooke City, Montana, to determine the effects of some spoil-ameliorating treatments on water relations and growth of *Poa alpina* and *Alopecurus pratensis* seedlings. Organic matter incorporated in the spoil material together with a surface mulch reduced seedling mortality and resulted in larger plants. The effects of those treatments on plant responses under controlled conditions in a growth chamber are also discussed.*

KEYWORDS: revegetation, mine rehabilitation, Beartooth Plateau, Montana, water stress, soil amendments, grass seedlings.

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Many problems are associated with surface mine disturbances in the mountainous terrain. One of the most obvious problems is the complete destruction of both the native vegetation and the edaphic environment. In addition, various off-site concerns can develop, including damage to vegetation, deterioration of water quality, and loss of wildlife and aquatic habitats. Erosion and stream sediment loads lead to decreased water quality (Striffler 1973). Acid-water runoff from mines containing high concentrations of heavy metals can be lethal to aquatic organisms and to downslope vegetation and that along streambanks (Johnston and others 1975; Warner 1973).

The most successful long-term solution to these problems appears to be revegetation of the spoils. However, many constraints limit the success of revegetation, either by natural colonization or by artificial means. Exposed parent materials are low in essential nutrients for plant growth, and the coarse spoil texture and lack of organic matter contribute to low cation-exchange capacities. Acid is produced by the oxidation of sulfides in pyritic spoils, and the resulting low pH restricts both nutrient availability to and water absorption by plants. Toxic levels of heavy metals such as copper, iron, and aluminum can prevent plant growth and establishment (Antonovics and others 1971).

Bare spoils have a larger daily temperature fluctuation than vegetated areas (Schramm 1966). The coarse texture of the spoils and the low levels of organic matter also contribute to low water-holding capacity and to rapid drying rates. Plants must be adapted to the short growing seasons, high solar radiation loads, heavy winds, and frequent disturbances caused by congeliturbation (the turning or heaving of the soil by freezing and thawing) at high elevations. Only a relatively few vascular plant species are adapted to these conditions (Brown and others 1978; Billings 1974).

Conditions on surface mines must be improved if mined areas are to be revegetated. Other studies have demonstrated that fertilizers are essential in many areas (Brown and others 1976; Dunbar and Adams 1972; Johnston and others 1975; Vogel and Berg 1973). Applications of lime have improved plant yields on acid soils (Chadwick 1973; Dunbar 1974) and mulches have been used to improve spoil water status (Gregg 1976). Unfertilized plots established at the McLaren Mine in 1974 had a lower plant density than fertilized plots (Brown and Johnston 1976). Many seedlings on the unfertilized plots were desiccated, an indication that water stress is a severe problem in the establishment of seedlings at high elevations.

OBJECTIVES AND HYPOTHESES

The first objective of this study was to determine the extent to which soil amendments and surface mulches lessen seedling water stress on high elevation (subalpine-alpine ecotone) mine spoils. Both a field study and a growth chamber study were conducted to determine the effects of four treatments on leaf water potential. These studies tested the hypothesis that seedlings on spoils treated with an organic matter amendment and a surface mulch will be subjected to less water stress than seedlings on untreated spoils.

The second objective was to determine the influence treatments had on seedling mortality. The hypothesis tested was that seedling mortality will be lower on spoil materials treated with an organic matter amendment and a surface mulch than on untreated spoils.

STUDY SITE DESCRIPTION

The field study was conducted through the 1976 growing season on the McLaren Mine (109°59' W, 45°04' N) at 2 925 m (9,600 ft) elevation near Cooke City, Montana, on the southern edge of the Beartooth Plateau. This area contains highly mineralized geologic strata that occur on the flanks of the main uplift of the Beartooth Plateau. The Cooke City ore body, which is a portion of this uplift, is a hydrothermal pyritized copper deposit (Loverling 1929). The primary minerals of economic value that were mined include gold, silver, and copper. The Cooke City area has a history of mining dating back to the 1880's (Glidden 1976). Although the McLaren Mine was operated at intervals as a shallow open pit mine until it was abandoned in the early 1950's, there is still some mineral exploration at the mine site today.

Environmental conditions at the study site are characterized by short growing seasons of 60 to 70 days, low summer temperatures, and relatively high solar radiation (Johnston and others 1975). Annual precipitation, most of which occurs during the winter (September to July), is estimated to range between 1 100 and 1 500 mm (43 to 59 in) (Johnston and others 1975). Localized summer storms cause precipitation to vary between sites in close proximity. Johnson and Billings (1962) described the plant communities of undisturbed alpine areas on the Beartooth Plateau.

METHODS

Field Study

At the McLaren Mine, snowmelt generally is not complete until August 1. Seeded plots, each 0.5 m² (19.7 by 39.4 in), were established on a nearly level portion of an abandoned roadbed on the mine July 6 and 7, 1976 (fig. 1). The physical and chemical characteristics of the spoils at the site (table 1) are representative of the majority of overburden materials on the mine (Brown and others 1976). Nonacid snowmelt streams near the site were used as a supplemental water supply.

A completely randomized block design with four blocks of eight plots was used (fig. 1). Two plant species, *Poa alpina* L. (Alpine bluegrass), a native, and *Alopecurus pratensis* L. 'Garrison' (meadow foxtail), a commercially available species, were seeded. *Poa* seed was collected on the Beartooth Plateau in 1974; *Alopecurus* seed was obtained from a commercial source in early 1976. The four spoil treatments were: (1) a control group with no treatment, (2) peat moss incorporated into the spoils, (3) a surface mulch of jute netting, and (4) peat moss plus jute netting.

We removed snow and large rocks from the site and loosened the soil with hand-tools to a depth of 10 cm (4 in). Soil pH was measured with a portable meter at several locations on the site, and, using a volumetric 1:1 mixture of soil and distilled water, we found that the pH ranged between 2.8 and 3.0. Hydrated lime was applied uniformly at the rate of 0.12 kg (0.26 lbs) per plot to raise the pH to 6.5.

Individual plots, 0.5 by 1.0 m (19.7 by 39.4 in), were staked and treatments were applied according to the completely randomized block design. All plots received an 18:46:10 N:P:K granular fertilizer at an equivalent rate of 111 kg of nitrogen per hectare (100 lbs per acre). Peat moss was applied to the selected plots at 10 percent by volume (5 000 g or 11 lbs per plot). Lime, fertilizer, and peat moss were all incorporated in the soil to a depth of 10 cm (4 in). All treatments were based on recommendations made by Brown and Johnston (1976).

Figure 1.--Plot layout for the seedling water relations study at the McLaren Mine. Plot size is 0.5 x 1.0 m. The following symbols are used: *Alopecurus pratensis* = ; *Poa alpina* = ; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J; Soil water potential measurements = S; Tensiometer measurements = T.

Table 1.--Analyses of spoils collected on the McLaren Mine at the end of the field season, September 1976

Sample location	pH	EC _e ¹	Estimated texture	Percent coarse fragments	NH ₄ OAC Extract			Percent P total	Available phosphorus	SO ₄
					K	Ca	Mg			
					-- meq/100 g --				p/m	meq/liter
Roadbed	1.7	9.4	Clay loam	72	0.1	1.4	3.3	0.05	6.7	523
Seedling plot	1.7	13.4	Clay loam	73	.09	3.4	3.0	.04	7.2	414

Sample location	Fe	Soil analysis (DPTA)			H ₂ O soluble		NO ₃ -N	Cation exchange capacity	Saturation percent	Percent N
		Zn	Mn	Cu	Al	Cu				
		p/m						meq/1,000 g		
Roadbed	1250	7.4	10.8	26.5	390	53.3	0.3	13.3	32.7	0.02
Seedling plot	916	5.2	12.0	27.9	430	59.0	.1	13.3	32.8	.02

¹Electrical conductivity, mmhos/cm.

Seeding rate was established from laboratory germination results and previously observed emergence rates at the McLaren Mine (Brown and others 1976). Germination of *Alopecurus* and *Poa* seeds on filter paper was 60 and 27 percent, respectively. On the basis of previous observations, it was expected that only 25 percent of the seedlings germinating in the laboratory would emerge in the field. To produce 1,200 seedlings per plot, 5.0 g (0.01 lb) of *Alopecurus* seeds (1,600 seeds per g) or 5.1 g (0.01 lb) of *Poa* seeds (3,300 seeds per g) were used. Seeds were broadcast uniformly over the surface, raked into the soil to a depth of 1 cm (0.3 in), and packed. Jute netting was laid over the appropriate plots and anchored outside the plot boundaries with rocks. Approximately 27 cm (10.6 in) of snow was reshoveled onto the plots to simulate natural conditions. Since there was little precipitation in July 1976, plots were sprinkled daily with snowmelt water until plants reached the second leaf stage.

Sampling began on August 9, when plants reached the second leaf stage. Leaf water potential was estimated from leaf samples collected daily between 1400 and 1600 hours, the time of maximum water stress. Several seedlings from each plot were sealed in a thermocouple psychrometer equilibration chamber and then placed in an insulated reservoir where water temperature was kept at approximately 25° C. The samples were allowed to equilibrate for 2 hours before readings were taken.

Seeding development, plant density, and seedling mortality were determined within a 10 by 40 cm (4 by 16 in) subplot centered within each plot. Measurements of leaf water potential were not taken from the subplots because such measurements required destructive sampling. At weekly intervals, the numbers of live plants, dead plants, and leaves and the range of plant heights within the subplots were recorded.

All psychrometers used in this study were Peltier double-junction thermocouple psychrometers (Van Havern and Brown 1972). Psychrometers were attached to stainless steel Swagelok-brand² tube fittings to form small watertight equilibration chambers. Psychrometer output was measured with an SB-600 psychrometer readout meter.

Growth Chamber Study

McLaren Mine spoils were sieved to 2 mm (0.078 in) and then lime and fertilizer were added at the same rates used in the field study. Peat moss was added to half the spoils also at the rate used in the field study. The mixtures were then placed in 1 liter plastic pots with no drainage holes. The seeding rate needed to produce 100 seedlings per pot was calculated to be 0.1 g of *Poa* or *Alopecurus* seeds. The seeds were covered with 0.5 cm (0.2 in) of sieved spoils. A single layer of jute netting was applied to the appropriate pots. There were four replications of each species-treatment combination.

In the greenhouse, the pots received a 14-hour photoperiod by extending the day length with supplemental fluorescent and incandescent lighting in the evenings. Pots were irrigated with deionized water and kept in a nonstressed condition until seedlings reached the second leaf stage. At this stage of growth, the plants were placed in a Sherer-Gillett CL-37-14 growth chamber. Plants were allowed to equilibrate to growth chamber conditions for 48 hours before sampling started. The growth chamber was programed for a 14-hour light period at 27° C and a 10-hour dark period at 21 ° C. Relative humidities for the light period ranged from 25 to 35 percent and for the dark period from 43 to 68 percent.

²Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

A drying cycle was initiated after the 48-hour equilibrated period by withholding water from the plants. Daily leaf water potential was measured using the same technique described in the field study methods. A 10-cm² (1.55-in²) in the center of each plot was reserved for measurements of seedlings at the beginning and end of the drying cycle. Measurements taken were similar to those described in the field study methods.

RESULTS

Field Study

Mean leaf water potentials of both species for both the entire field season and for periods of more than 2 days without precipitation were lower (drier) on control (untreated) plots (table 2). Leaf water potentials of plants grown on plots with jute netting or peat moss-plus-jute netting amendments had the highest (wettest) means. The *Poa* control group had the lowest mean leaf water potential, -19.6 bars. Analysis of variance was not conducted on the means because of the wide differences in sample sizes.

Table 2.--Mean leaf water potentials of field study data for each species-treatment combination.
The number of replicates for each mean varies from 22 to 91

Species	Treatment	Variable	All season	More than 2 days without precipitation
			Bars	
<i>Alopecurus pratensis</i>	Control	Mean	-15.3	-22.7
		Std. error	.8	2.8
		± std. error	-14.5 to -16.1	-19.9 to -25.5
<i>Alopecurus pratensis</i>	Peat moss	Mean	-13.3	-16.0
		Std. error	.7	2.6
		± std. error	-12.6 to -14.0	-14.4 to -18.6
<i>Alopecurus pratensis</i>	Jute netting	Mean	-12.2	-19.8
		Std. error	.7	3.0
		± std. error	-11.5 to -12.9	-16.8 to -22.8
<i>Alopecurus pratensis</i>	Peat moss + jute netting	Mean	-11.0	-13.3
		Std. error	.7	2.8
		± std. error	-10.3 to -11.7	-10.5 to -16.1
<i>Poa alpina</i>	Control	Mean	-19.6	-25.4
		Std. error	1.5	2.8
		± std. error	-18.1 to -21.1	-22.6 to -28.2
<i>Poa alpina</i>	Peat moss	Mean	-15.6	-22.7
		Std. error	1.0	2.1
		± std. error	-14.6 to -16.6	-24.8 to -20.6
<i>Poa alpina</i>	Jute netting	Mean	-11.3	-14.5
		Std. error	1.0	4.9
		± std. error	-10.3 to -12.3	-9.6 to -19.4
<i>Poa alpina</i>	Peat moss + jute netting	Mean	-11.5	-18.7
		Std. error	.6	2.9
		± std. error	-10.9 to -12.1	-15.8 to -21.6

The mean daily leaf water potentials over the course of the season are presented in figures 2 and 3. The standard errors indicate the large value range of measured leaf water potential. On any day, there was usually a difference in mean leaf water potential between the control group and the peat moss-plus-jute netting treatment. The variability in the data seemed to increase from August 31 to September 6 when no precipitation occurred. Often during this period, there were not enough *Poa* seedlings to sample on the control plots.

Figure 2.--Mean daily field leaf water potentials with associated standard errors for *Alopecurus pratensis* and the precipitation record for the field season. The number of replicates for each mean varies from 1 to 4. The following abbreviations are used: *Alopecurus pratensis* = Alo; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

Figure 3.--Mean daily field leaf water potentials with associated standard errors for *Poa alpina* and the precipitation record for the field season. The number of replicates for each mean varies from 1 to 4. The following abbreviations are used: *Poa alpina* = Poa; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

Measurements of seedling mortality and growth on August 30, 1976, are presented in table 3. Analysis of variance of means for each species-treatment combination did not indicate significant difference between replications. There were significant differences between treatments for number of living plants and for species-treatment interactions. *Poa* demonstrates a response to treatments more clearly than *Alopecurus*. According to the seeding rate calculations, there should have been 96 seedlings on each subplot. However, *Alopecurus* consistently had more than 96 plants on each subplot, regardless of treatment. Fewer than 96 *Poa* seedlings per subplot survived except on plots treated with jute netting or peat moss plus jute netting. *Alopecurus* experienced significantly higher mortality than *Poa* and had more leaves and greater minimum and maximum plant heights.

Table 3.--Mean mortality and growth of seedlings from field plots, August 30, 1976. Abbreviations are:
Alopecurus pratensis = Alo; *Poa alpina* = Poa; Control groups = C; Peat moss = P; Jute netting = J;
 Peat moss + jute netting = P & J

	Group	Number of live plants per subplot	Number of dead plants**	Percent mortality	Minimum plant height**		Maximum plant height**		Most common num- ber of leaves**
					cm	Inches	cm	Inches	
Species	Poa	136.2	8.3	5	0.8	0.31	1.2	0.47	2.2
	Alo	176.4	38.3	18	1.3	.51	2.5	.98	2.9
Treatments	C	110.6*	20.3	16	1.0	.39	1.7	.67	2.4
	P	111.5*	25.4	19	.9	.35	1.5	.59	2.4
	J	185.5*	14.6	7	1.2	.47	2.0	.78	2.9
	P + J	217.0*	19.9	8	1.1	.43	2.1	.83	2.6
Species-treatment interactions	Poa C	47.5*	5.3*	10	.6	.23	1.0	.39	1.8
	Poa P	65.3*	8.3*	11	.8	.31	1.0	.39	2.0
	Poa J	153.5*	14.5*	9	.9	.35	1.3	.51	2.8
	Poa P + J	278.5*	5.0	2	.8	.31	1.4	.55	2.3
	Alo C	173.8*	35.3*	17	1.4	.55	2.4	.94	3.0
	Alo P	157.8*	42.5*	21	1.1	.43	2.1	.83	2.8
	Alo J	217.5*	14.8*	6	1.6	.63	2.8	1.10	3.0
	Alo P + J	156.8*	34.8*	18	1.4	.55	2.8	1.10	3.0

**Significant at the 1 percent level.

*Significant at the 10 percent level.

¹Subplots were 10 by 40 cm.

Growth Chamber Study

As in the field study, mean leaf water potentials were lower (drier) for control group plants and highest (wettest) for plants with jute netting or peat moss plus jute netting (table 4). However, unlike the field results, the *Alopecurus* control group in the growth chamber had the lowest mean leaf water potential.

Mean daily leaf water potentials during the drying cycle are shown in figures 4 and 5. Usually there were daily differences in mean leaf water potentials between the control group and the peat moss-plus-jute netting treatment. Variability in the data seemed to increase as the drying cycle progressed. Generally, leaf water potentials were drier in the growth chamber than in the field.

There were no significant differences in number of living plants or number of dead plants on the subplots at the end of the drying cycle. There were significant differences between species in number of leaves per plant and in minimum and maximum heights of plants with the most common number of leaves (table 5). *Alopecurus* plants had more leaves and were taller than *Poa* plants.

Table 4.--Mean leaf water potentials of growth chamber study data for each species-treatment combination.
The number of replicates for each mean varies from 14 to 17

Species	Treatment	Variable	All data	More than 2 days without precipitation
----- Bars -----				
<i>Alopecurus pratensis</i>	Control	Mean Std. error ± std. error	-20.6 2.9 -17.7 to -23.7	-25.1 3.9 -21.2 to -29.0
<i>Alopecurus pratensis</i>	Peat moss	Mean Std. error ± std. error	-18.5 2.1 -16.4 to -20.6	-21.9 2.8 -19.1 to -24.7
<i>Alopecurus pratensis</i>	Jute netting	Mean Std. error ± std. error	-13.7 2.6 -11.1 to -16.3	-16.3 5.0 -11.3 to -21.3
<i>Alopecurus pratensis</i>	Peat moss + jute netting	Mean Std. error ± std. error	-14.1 2.2 -11.9 to -16.3	-19.3 2.7 -16.7 to -22.0
<i>Poa alpina</i>	Control	Mean Std. error ± std. error	-18.5 1.7 -16.8 to -20.2	-21.3 2.2 -19.1 to -23.5
<i>Poa alpina</i>	Peat moss	Mean Std. error ± std. error	-16.1 2.7 -13.4 to -18.7	-21.0 3.5 -17.5 to -24.5
<i>Poa alpina</i>	Jute netting	Mean Std. error ± std. error	-12.5 1.9 -10.6 to -14.4	-14.3 2.7 -11.6 to -17.0
<i>Poa alpina</i>	Peat moss + jute netting	Mean Std. error ± std. error	-13.8 1.7 -11.1 to -15.5	-15.0 2.0 -13.0 to -17.0

Figure 4.--Mean daily growth chamber water potentials with associated standard errors for *Alopecurus pratensis* during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreviations are used: *Alopecurus pratensis* = Alo; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

Figure 5.--Mean daily growth chamber water potentials with associated standard errors for *Poa alpina* during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreviations are used: *Poa alpina* = Poa; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

Table 5.--Mean mortality and growth of seedlings in the growth chamber at the end of the drying cycle.
Abbreviations are as follows: *Alopecurus pratensis* = Alo; *Poa alpina* = Poa; Control group = C;
Peat moss = P; Jute net = J; Peat moss + jute net = P + J

Species	Group	Number of		Dead/ live + dead	Minimum plant		Maximum plant		Most common num- ber of leaves
		live plants	dead plants		cm	Inches	cm	Inches	
Species	Poa	9.3	3.8	0.29	1.2	0.47	2.0	0.78	1.9
	Alo	5.4	1.5	.21	3.9	1.53	6.3	2.48	2.4
Treatment	C	6.1	3.8	.38	1.8	.71	2.9	1.14	1.9
	P	6.0	1.0	.14	1.9	.75	2.8	1.10	2.0
	J	7.6	2.8	.27	3.3	1.29	5.4	2.13	2.4
	P + J	9.6	3.4	.26	3.4	1.34	5.7	2.24	2.5
Species-treatments interactions	Poa C	8.5	5.5	.39	1.3	.51	2.1	.83	2.0
	Poa P	5.8	1.3	.18	1.1	.43	1.3	.51	2.0
	Poa J	9.5	3.5	.27	1.1	.43	2.0	.78	1.8
	Poa P + J	13.3	4.8	.26	1.6	.63	2.9	1.14	2.0
	Alo C	3.8	1.3	.25	2.6	1.02	3.8	1.49	1.8
	Alo P	6.3	.8	.11	2.8	1.10	4.3	1.69	2.0
	Alo J	5.8	2.0	.26	5.5	2.16	8.8	3.46	3.0
	Alo P + J	6.0	2.0	.25	5.3	2.08	8.5	3.34	3.0

**Significant at the 1 percent level.

DISCUSSION

The leaf water potentials measured in 1976 may not reflect the true levels of water stress that plants could experience on the McLaren Mine because the 1976 field season was considerably wetter than the previous year. Approximately 9.7 cm (3.8 in) of precipitation was recorded from August 1 to mid-September 1976, compared to 1.1 cm (0.43 in) of precipitation for the same period in 1975. Spring snowmelt in 1976 began approximately 2 weeks earlier than it had the previous 3 years (1972-1975). However, despite the early snowmelt, frequent rainfall throughout the field season maintained a relatively high soil water content. In a year with less precipitation, soil water potentials probably would be lower. The analyses of predicted leaf water potentials do give an indication of the general effects of the treatments. The lower mean leaf water potential for the *Alopecurus* control group in the growth chamber could be attributed to larger plant size. Both peat moss and jute netting appear to maintain soil water potentials at higher levels than untreated spoils.

Jute netting appears to be more effective than peat moss in reducing the levels of plant water stress. This could be caused by several microclimatic changes brought about by a jute netting surface mulch. For example, surface mulches lessen the effects of raindrop impact and allow more water to penetrate into the soil (Rickert 1974). The jute netting is a rough barrier to airflow and it creates a larger boundary-layer (pocket) of still air that reduces the rate of evaporation from the soil (Hanks 1967). Also, it may increase the air temperature of the seedling environment. The jute itself absorbs water and evaporation from the fiber provides a higher relative humidity for the seedlings, decreasing the daily depth of soil water loss (Hanks and Woodruff 1958).

The variability in the data collected may be due in part to the genetic variation within the seedling population. The genetic variability is probably high while selective forces are acting upon unadapted organisms in the seedling population (Saraukhan and Harper 1973; Canfield 1957). Another source of variability in the data could be plant response to microsite differences (Harper and others 1965).

In the field, there was a high degree of variability in numbers of plants within a species-treatment combination. Some of this variability could be explained by small differences in technique during plot establishment. The spoils are also quite variable and a higher percentage of acid-producing iron pyrite could limit plant emergence. Wind could also cause some variability, which at this location generally blows from the west. Plots treated with peat moss on the west side of the study site had fewer plants than other plots. Also, mortality rates were highest among the relatively few plants on these plots.

The higher mortality of *Alopecurus* plants (table 3) might have been caused by a lower threshold to toxic concentrations of aluminum, zinc, copper, or iron or perhaps by greater competition between plants since *Alopecurus* plants were so large. Although *Alopecurus* has been used successfully in revegetation efforts at high elevation sites in the West (Brown and others 1976; Hendzel 1976; U.S. Forest Service 1966), *Poa* is native to the study area and probably is better adapted to the climatic conditions. *Poa* could be expected to have higher survival than introduced species, such as *Alopecurus*, in these environments.

The number of leaves and heights of plants seemed to be characteristics of species and treatment had little effect. These traits are probably genetically determined.

The plant in the greenhouse and growth chamber were grown in a different environment than that to which the plants in the field were acclimated. Air and soil temperatures were higher and plants grew taller and more quickly than those grown in the field. Larger plant size and more favorable growing conditions may help to explain why there were no significant differences between treatments in the number of living plants or the number of dead plants. As reflected by larger physical size, the plants apparently were responding more to the favorable growing conditions in the growth chamber than they were to the spoil treatments. This was indicated by the larger shoots and perhaps roots of the two species under all treatments studied. Therefore, mortality under these growing conditions may not have been due to treatment conditions, but rather due to genetic variability within the population of seeds used. Total mortality, however, was much higher in the growth chamber than in the field, an indication that plants experienced more water stress during a drying cycle in the growth chamber. Apparently, periods of severe water deficit were longer and more intense from day to day in the growth chamber than in the field.

Tensiometer measurements in the field, indicated that soil water was available at a depth of 7.5 cm (2.95 in). However, plant roots may not have reached this source of water because of acidity, low spoil temperatures, and lack of plant nutrients.

Seedling water stress was reduced by the spoil treatments; treatments of jute netting or peat moss-plus-jute netting were most effective in reducing plant water stress. Treatments of jute netting or peat moss-plus-jute netting decreased rates of seedling mortality in the field, but not in the growth chamber studies.

The results of this study suggest that native species are better adapted for revegetation than are introduced species, at least for the environmental conditions on the McLaren Mine. Care must be taken to select treatments that will ameliorate spoil conditions within the physiological limitations of the plant species being used. In the case of the McLaren Mine, those treatments include: incorporation of lime, fertilizer, and organic matter into the spoil; and a surface mulch to reduce evaporation and the incidence of frost.

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