Effects of soil texture and salinity on the establishment and morphology of twelve range grasses
by Juanita J Lichthardt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University

Abstract:
The performance and morphology of 12 grass species were observed on soils which differed in texture and soluble salt content. Grasses were grown on experimental plots built of nine subsoils which varied in texture from clay loam to sandy loam. Half of each experimental soil was salted with a mixture of NaCl and CaCl2 to produce. 18 treatment combinations of soil texture and salt level.

Stand performance was evaluated with a first-year measure of seedling density and second- and fourth—year measures of yield. Fine textures had a negative effect on seedling emergence of Agropyron cristatum, A. inerme, Bouteloua gracilis, and Elymus junceus. Salt had a negative effect on seedling emergence of Agropyron cristatum, A. inerme, A. trachycaulum, and Bouteloua gracilis. Second-year yield measures showed better yields of Stipa viridula on fine soils. Relatively low salinities produced significant second-year yield reductions of Agropyron inerme, A. riparium, Bouteloua gracilis, Elymus angustus, E. junceus, Stipa viridula, and Triticum aestivum. The effect of texture on yield had disappeared by the fourth growing season, but salt effects were still evident for Agropyron inerme, A. riparium, A. smithii, Elymus angustus, and Stipa viridula.

To determine the magnitude of plastic morphological responses of Agropyron ("Wheatgrass") species to soil texture and salinity, 21 different morphological characteristics were measured on randomly selected specimens of 7 representative species. Sixteen characters, both vegetative and reproductive, exhibited environmental plasticity, as indicated by significant variance components due to salt, texture, or their interaction. The most common responses seen were in the number of florets per spikelet, length of rachis internodes, and spikelet lengths. Most characters (67%) exhibited plasticity in fewer than 3 species. Because of this, variation in soil quality, in the range studied, is not expected to confuse identification of these species.

EFFECTS OF SOIL TEXTURE AND SALINITY ON THE ESTABLISHMENT AND MORPHOLOGY OF TWELVE RANGE GRASSES

by

Juanita J. Lichthardt

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Biological Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

September 1986

APPROVAL

of a thesis submitted by

Juanita J. Lichthardt

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

18 Sept 1986 — Date

T. Weaver — Chairperson, Graduate Committee

Approved for the Major Department

15 September, 1986 — Date

Peter F. Brussard — Head, Major Department

Approved for the College of Graduate Studies

6 October 1986 — Date

Henry L Parsons — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Juanita J. Lichthardt

Date 15 Sept 1986

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF FIGURES

GENERAL ABSTRACT

The performance and morphology of 12 grass species were observed on soils which differed in texture and soluble salt content. Grasses were grown on experimental plots built of nine subsoils which varied in texture from clay loam to sandy loam. Half of each experimental soil was salted with a mixture of NaCl and $CaCl_2$ to produce 18 treatment combinations of soil texture and salt level.

Stand performance was evaluated with a first-year measure of seedling density and second- and fourth-year measures of yield. Fine textures had a negative effect on seedling emergence of *Agropyron cristatum*, *A. inerme*, *Bouteloua gracilis*, and *Elymus junceus*. Salt had a negative effect on seedling emergence of *Agropyron cristatum*, *A. inerme*, *A. trachycaulum*, and *Bouteloua gracilis*. Second-year yield measures showed better yields of *Stipa viridula* on fine soils. Relatively low salinities produced significant second-year yield reductions of *Agropyron inerme*, *A. riparium*, *Bouteloua gracilis*, *Elymus angustus*, *E. junceus*, *Stipa viridula*, and *Triticum aestivum*. The effect of texture on yield had disappeared by the fourth growing season, but salt effects were still evident for *Agropyron inerme*, *A. riparium*, *A. smithii*, *Elymus angustus*, and *Stipa viridula*.

To determine the magnitude of plastic morphological responses of *Agropyron* ("Wheatgrass") species to soil texture and salinity, 21 different morphological characteristics were measured on randomly selected specimens of 7 representative species. Sixteen characters, both vegetative and reproductive, exhibited environmental plasticity, as indicated by significant variance components due to salt, texture, or their interaction. The most common responses seen were in the number of florets per spikelet, length of rachis internodes, and spikelet lengths. Most characters (67%) exhibited plasticity in fewer than 3 species. Because of this, variation in soil quality, in the range studied, is not expected to confuse identification of these species.

GENERAL INTRODUCTION

Coal strip-mining in southeastern Montana disturbs extensive land areas. State law mandates reclamation of these lands and the Montana Department of State Lands is charged with overseeing the reclamation process.

This project was supported by the Department of State Lands, with the objectives of improving both the reclamation process and the reclamation evaluation process. First, to improve the reclamation process it was desirable to know whether particular soil textures and salinities commonly appearing in Ft. Union subsoils were especially good or bad for the establishment of major range grasses used in revegetation. This question is addressed in Part I of this thesis. Second, the evaluation process was improved by asking whether variability in soil texture and/or salinity, like that appearing on reclaimed mine sites, would so modify plant phenotypes as to confuse the identification of species. Significant environmentally-induced variation could make it difficult to accurately identify species. Accurate identification of species is necessary to determine whether diversity requirements, set by State law, have been met. Part II of this thesis therefore determines the degree to which levels of texture and salinity commonly found in Ft. Union subsoils modify plant characters used to identify Agropyron species used in reclamation practice.

Both projects were simultaneously conducted in an experimental garden, with soils transported to a uniform climate. As a result of the projects being jointly undertaken, they are reviewed jointly here.

PART I

EFFECTS OF SOIL TEXTURE AND SALINITY ON THE ESTABLISHMENT OF TWELVE RANGE GRASSES

ABSTRACT

Performance of 12 grass species was observed, during the first 4 years of growth, on experimental plots built of soils which differed in texture and salt content. Nine subsoils varying in texture from clay to sandy loam were selected from the site of a coal strip-mine in southeastern Montana and used to construct test plots. Half of each experimental soil was salted with a mixture of NaCl and $CaCl_2$ to produce 18 treatment combinations of soil texture and salt level.

Stand performance was evaluated with a first-year measure of seedling density, and second- and fourth-year measures of yield. Texture was primarily important during seedling emergence; density data indicated that fine textures had a negative effect on emergence of *Agropyron cristatum*, *A. inerme*, *Bouteloua gracilis*, and *Elymus junceus*, and little effect on establishment of 8 other species. Yield measures made at the end of the second growing season indicated little effect of soil texture on plant performance. Two exceptions were *Agropyron inerme*, which produced significantly better yields on loams, and *Stipa viridula*, which yielded best on fine soils.

Even though salts were rapidly leached through the soils, effects on both establishment and yield were observed. Seedling densities were reduced by salinity in *A. cristatum*, *A. inerme*, *A. trachycaulum*, and *Bouteloua gracilis*. Relatively low salinities produced significant second-year yield reductions of *A. inerme*, *A. riparium*, *Bouteloua gracilis*, *Elymus angustus*, *E. junceus*, *Stipa viridula*, and *Triticum aestivum*. Negative effects of salt on yield were still evident in fourth-year measurements.

Interactions in the analyses of variance, of both density and yield data, indicated significant effects of unidentified soil properties in addition to texture and salinity.

INTRODUCTION

By legal definition, successful revegetation of strip-mined lands requires the establishment of a diverse plant cover with production equal to or exceeding that observed prior to mining (USDA Office of Surface Mining 1979). To achieve such revegetation goals, reclamation engineers must know how soil properties will affect the success of plantings in the regional climate.

Many soil properties which affect plant growth are related to texture. Among these are water and nutrient holding capacity, porosity, infiltration rate, compactability, and salinity. Soil salinity in particular is often limiting to the establishment of vegetation in dry regions.

Because it influences plant growth, and because it is easily measured, soil texture has been used to characterize plant habitat (Gates et al. 1956, Ross and Hunter 1976), evaluate sites for plant establishment (Coile 1935, Heerwagen 1958, Heerwagen and Aandahl 1961), and to predict yield (Storie 1937, Medin 1960, Clary 1964). Guidelines have been established to rate the suitability of mine soils for plant growth based on texture and other properties (Shafer 1979). However, few studies have specifically measured the effect of soil texture on grass establishment (Kilcher and Lawrence 1970, Cox and Martin 1984).

Soil textural characteristics affect plant growth and production primarily through their effects on water availability (Fribourg et al. 1982), and indirectly through the effects of water on other plant growth factors such as nutrient availability (Russell and McRuer 1927), and salinity (Richards 1969). Soil texture determines infiltration rates and permeability, and therefore water absorption (Black 1968). Soil texture is particularly important in arid regions because it determines the capacity of the soil to store absorbed water (McGinnies 1955, Clary 1964, Wollenhaupt et al. 1982). In general, loams provide the best combination of water holding capacity and permeability, and are associated with the highest forage production (Wilsie et al. 1944, Noller 1968). The relatively good infiltration and permeability associated with coarse soils sometimes offsets their low water holding and nutrient exchange capacity (Cox and Fisser 1978).

Besides texture, high levels of soluble salts also limit plant establishment and growth in semi-arid regions (Poljakoff-Mayber and Gale 1975, Smith 1978). Saline soils can severely limit the reclamation potential of proposed mine sites. When regulatory agencies choose topsoils and seed mixes they must make decisions based on existing knowledge of plant salinity tolerance. Current knowledge is largely based on observation of plants in greenhouse experiments, or on irrigated field plots in which water is not limiting. Results of these experiments are not directly applicable to field conditions where the effective salinity is dependent on the water content of the soil (Richards 1969). Field experiments are therefore needed to clarify the effects of soil salinity on plant growth under natural climatic regimes of arid and semiarid regions.

Grasses in the genus Agropyron ("Wheatgrasses") are generally considered salt tolerant (Dewey 1960). Research has related the use of salt-tolerant Agropyron species to crop breeding programs (McGuire and Dvorak 1981), forage production (Forsberg 1953, Crowle 1970) and highway plantings (Hughes et al. 1975). The highest degrees of salt tolerance appear in introduced species of poor forage quality (Dewey 1960, Hunt 1965), while among native species, A. trachycaulum and A. smithii are the most tolerant (Dewey, 1960). Different levels of salinity tolerance can also appear among varieties of the same species (McGuire and Dvorak 1981).

The closely related genus Elymus ("Wildrye") has also been the subject of research on salinity tolerance. Introduced species E. junceus and E. angustus in particular have been recommended for forage production on saline soils in Canada: in field tests, their tolerance was comparable to that of A. trachycaulum (McElgunn and Lawrence 1973).

Various other dryland forage and crop species have shown some degree of salt tolerance. Yields of Bouteloua gracilis and Triticum aestivum for example, are reduced 50% by soil solution conductivities on the order of 12 and 10 mmhos/cm respectively (Richards 1969).

Application of test results to the selection of plants for revegetation cannot be straightforward, since salinity effects are dependent on the growth stage of the plant, the form of salt, and environmental conditions (Forsberg 1953, Choudhuri 1968, Moxley et al. 1978).

To experimentally determine the effects of soil texture and salinity on the establishment of grasses used in revegetation, the performance of 12 grass species was observed on 9 different soils, each with 2 levels of salinity. Soils were collected and field plots were established at a mine site in southeastern Montana. Field plots were used to determine the responses of 7 *Agropyron* species: *A. cristatum* ("Crested Wheatgrass"), *A. dasystachyum* ("Thickspike Wheatgrass"), *A. inerme* ("Beardless Wheatgrass"), *A. riparium* ("Riparian Wheatgrass"), *A. smithii* ("Western Wheatgrass"), *A. trachycaulum* ("Slender Wheatgrass"), and *A. trichophorum* ("Pubescent Wheatgrass"; Barkworth and Dewey 1985). Five other species commonly included in range seedings were also tested: *Bouteloua gracilis* ("Blue Grama-Grass"), *Elymus angustus* ("Altai Wildrye"), *E. junceus* ("Russian Wildrye"), *Stipa viridula* ("Green Needlegrass"), and *Triticum aestivum* ("Spring Wheat"; Kilcher and Lawrence 1970, Hitchcock and Cronquist 1973). Plant performance on experimental soils was evaluated by measuring first-year seedling density, and second- and fourth-year maximum standing crops.

METHODS

The experiment was conducted at a site selected to represent Fort Union Formation surface coal mining, which will occur over extensive areas of southeastern Montana (USDI 1974). The site is located at the Spring Creek Coal Mine, 10 km north of Decker, in southeastern Montana. Elevation at the mine is 1050 m (3500 ft). Precipitation here averages 37 cm (14 in) annually, of which 45% falls between 1 April and 30 June (Table 1). Natural vegetation of the area is an open Ponderosa Pine woodland with semiarid grassland, and is included in Kuchler's Eastern Ponderosa Forest (Küchler 1964).

To examine the effects of soil texture on plant establishment, grasses were grown on different soils laid out in "pads", constructed on a site adjacent to the mine (Figure 1). Previous mining operations had created a level site with a compacted surface of gravel and porcelanite and without topsoil. Scrapers were used to collect nine diverse soils, haul them to the study site, and build nine, 27 X 4 m pads, approximately 0.5 m deep. Three soils were chosen in each of 3 textural categories: 1) coarse, sandy soils; 2) medium-textured loamy soils; and 3) fine, clay-rich soils. Each soil consisted of subsoil material taken from a previously undisturbed site. Pre-mine soil inventory data and soil maps were used to select the nine soils from those present on mine property.

Table 1. Monthly precipitation at the experimental site. Monthly totals (cm) for the 4 years of the study are given, with the mean, standard deviation, and range of monthly normals based on 20-year (1965-1985) precipitation records at Birney, Montana, located 40 km (25 mi) to the northeast of the experimental site.

	J	F	M	A	M	J	J	A	S	O	N	D	Total[1]
						cm							
Normal						Birney, MT							
Mean	1.96	1.50	2.03	3.71	6.02	7.21	2.82	2.11	3.07	2.74	1.78	2.03	36.98
SD	1.68	1.50	1.50	2.41	3.96	3.21	1.98	1.85	2.08	2.31	1.67	1.57	
Low	0.51	0.18	0.36	0.36	2.57	1.52	0.33	0.08	0	0	0.28	0.36	
High	8.33	6.60	6.20	7.72	19.58	13.06	6.07	7.42	7.59	6.15	4.72	3.05	
						Spring Creek Coal Mine							
1982	0.25	0.25	2.54	1.52	2.54	4.06	3.81	1.27	5.84	0.25	0.00	1.27	
1983	0.25	0.00	0.51	0.76	2.54	1.78	1.78	1.52	1.78	0.51	1.27	0.51	
1984	0.25	0.05	1.52	2.79	2.03	7.62	1.52	1.02	2.54	0	1.52	1.52	
1985	0.25	0.25	1.02	2.29	1.52	4.06	3.56	3.05	2.03	0.51	1.78	0.51	

[1]Total for water year (Sept.-Aug.); 1982 not given because data is not available for Sept.-Dec. 1981.

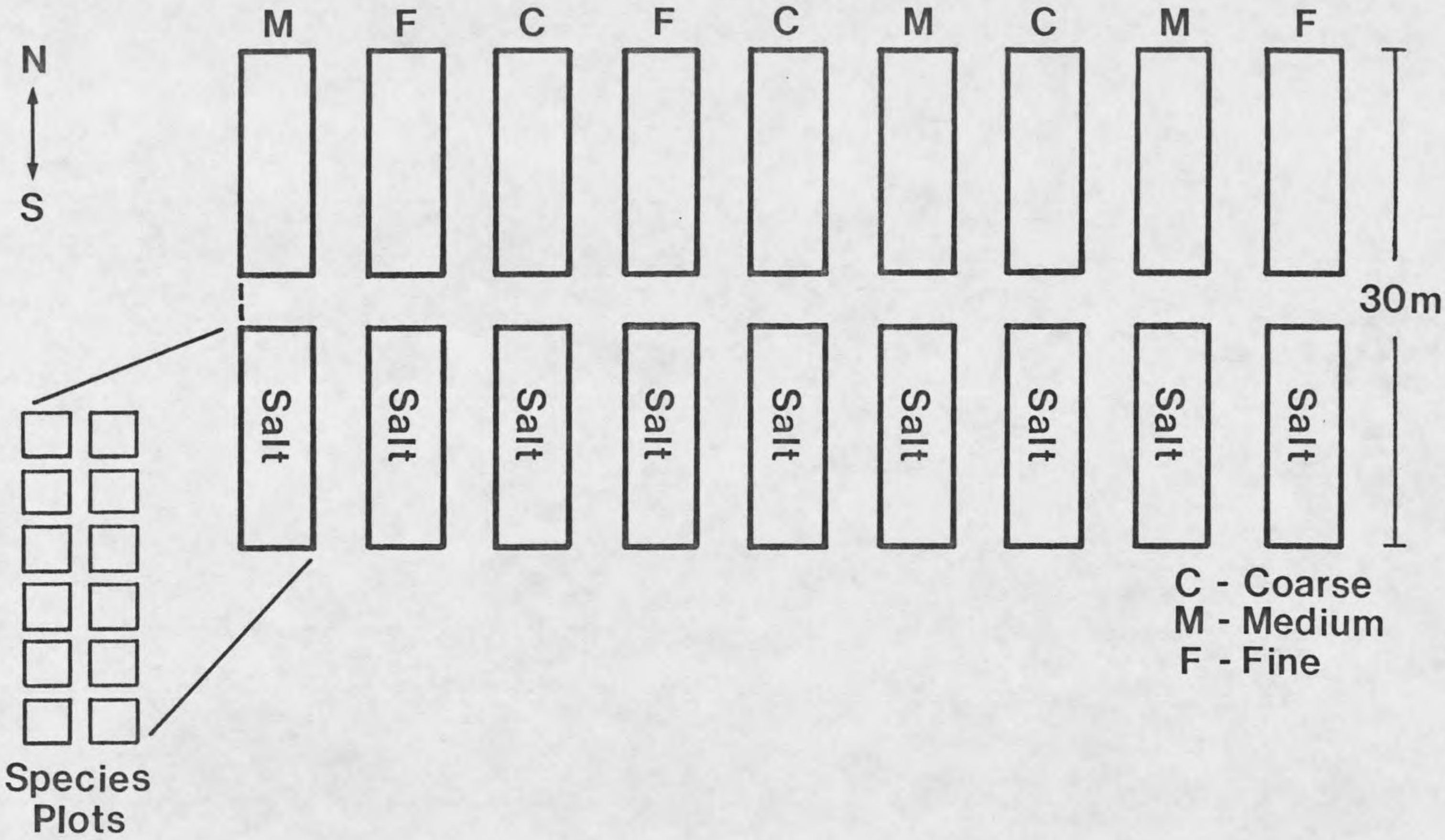

Figure 1. Lay-out of experimental plots. Plots consisted of 9 soil pads, approximately 4 X 27 m, separated by truck-width paths. Each plot in the lower half of the diagram was salt treated (see text). Each of the 18 treatment combinations of texture and salinity was subdivided into twelve, 1.5 X 1.5 m plots, in each of which the responses of an individual grass species were observed.

All soils were initially low in salts (Table 2) so, to determine the effect of moderate salinity, half of each soil pad was salt-treated with a 4:1 mixture of $CaCl_2$ and NaCl (meq $CaCl_2$: meq NaCl). This mixture of salts was used to avoid either excessive aggregation or dispersion. Salt was applied to the pads in amounts expected to produce electrical conductivities of 5 mmhos/cm, expressed as the conductivity of the saturation extract (EC_e). Amounts of salt added varied from 150 to 743 g/m^2 depending on the original conductivity of the soil (Table 2). Salt was hand broadcast and incorporated to a depth of 30 cm with a chisel plow. In this manner, 18 treatment combinations of texture and salinity were produced.

Table 2. Salinity[1] of plots before and after salt application. Electrical conductivities were measured at the end of the first growing season (Nov. 1982).

Texture	Rep.	Conductivity of unsalted plot	Amount of salt applied[2]	Conductivity obtained
		mmhos/cm	g/m^2	mmhos/cm
Fine				
	1)	2.1	732	6.1
	2)	3.0	743	7.0
	3)	2.8	743	10.0
Medium				
	1)	0.8	377	4.1
	2)	0.9	377	5.2
	3)	0.9	377	6.4
Coarse				
	1)	2.4	150	4.1
	2)	1.9	205	3.6
	3)	1.0	205	4.3

[1]mmhos/cm of a saturated paste extract.
[2]Salt was applied as a 1:4 mixture of NaCl to $CaCl_2$ (measured in milliequivalents) to prevent soil dispersion. The salt applied was therefore 20% NaCl by weight.

Plots were fertilized differentially with ammonium nitrate and ortho-phosphate to create a nearly uniform level of fertility (Table 3). Amounts of fertilizer added were based on pre-treatment soil analyses. This approach seemed valid since none of the soils contained significant amounts of organic matter which might release nutrients through decomposition.

Twelve species were planted in subplots on each pad. To maximize the genetic purity of the species grown, "breeder" or "foundation" seed was obtained for *Agropyron dasystachyum*, *A. inerme*, *A. riparium*, *A. smithii*, *A. trachycaulum*, *A. trichophorum*, *Elymus angustus*, and *E. junceus*. This seed was supplied by Soil Conservation Service Plant Material Centers at Bridger, Montana; Pullman, Washington; and Aberdeen, Idaho (Table 4). Because breeder quality seed was unavailable for *Agropyron cristatum*, *Bouteloua gracilis*, and *Stipa viridula*, less pure, locally adapted types were acquired from commercial centers (Table 4).

The soil pads were seeded in May of 1982 and, due to that summer's drought, again in November of 1982. Each soil pad, representing a texture-salinity combination, was divided into twelve, 1.5 X 1.5 m species plots separated by walkways (Figure 1). A single species was assigned randomly to each plot and seed was hand-broadcast. The surface was raked before seeding, and was raked and lightly packed afterwards to provide good contact. A seeding rate of 1080 pure live seed/m^2 (100 PLS/ft^2) was used; this corresponds to 25 kg/ha (22 lbs/A) PLS for a species such as *A. cristatum*. In order to insure stand establishment the following year, all plots were reseeded in November, 1982 at half the original rate, or 540 PLS/m^2 (50 PLS/ft^2).

Table 3. Characteristics[1] of surface (0-15 cm) soils in the experimental plots, November, 1982.

Treatment	#	Texture: Sand	Silt	Clay	Class	PAWC	Sat.	OM	CEC	EC	SAR	pH	Nutrients: N	P	K
		%				%	%	%	me/100g	mmhos			ppm		
Coarse															
	1)	51	31	18	1	10.9	32.6	1.8	22.2	2.5	1.1	7.8	28.8	1.4	102.2
	2)	52	29	19	sl	11.0	32.9	1.7	21.3	1.9	1.4	8.0	27.6	3.8	102.8
	3)	63	27	10	sl	12.5	34.8	2.0	25.2	1.0	1.0	7.8	12.8	1.8	212.0
Coarse with Salt															
	1)	46	34	20	1	-	33.8	1.9	21.6	4.1	1.8	7.7	36.4	1.4	108.8
	2)	53	27	20	scl	-	32.4	1.9	23.5	3.6	2.3	7.8	35.6	3.8	111.2
	3)	51	36	13	1	-	36.6	2.3	25.4	4.3	1.8	7.6	15.2	1.4	184.0
Medium															
	1)	39	41	20	1	12.0	35.5	2.4	21.5	0.8	1.1	8.0	12.8	1.8	89.0
	2)	38	46	16	1	16.8	37.8	2.7	29.7	0.9	1.1	7.8	16.4	0.7	200.0
	3)	36	48	16	1	15.8	38.8	2.6	31.2	0.9	0.7	7.8	18.8	2.0	204.0
Medium with Salt															
	1)	34	45	21	1	-	35.7	2.3	21.9	4.1	4.7	7.8	23.6	1.1	94.6
	2)	31	53	16	sil	-	39.8	2.5	31.1	5.2	2.4	7.5	14.0	0.9	152.0
	3)	40	43	17	1	-	52.8	2.9	30.5	6.4	2.3	7.4	25.6	2.0	232.0
Fine															
	1)	19	51	30	sicl	16.0	52.9	0.6	25.2	2.1	11.6	8.4	22.4	0.7	86.2
	2)	18	50	32	sicl	16.9	52.7	1.2	27.7	3.0	12.8	8.3	26.0	2.0	92.4
	3)	20	40	40	c	14.2	51.7	1.3	23.4	2.8	14.5	8.2	32.8	1.4	72.0
Fine with Salt															
	1)	16	51	33	sicl	-	47.7	1.8	22.3	6.1	13.2	7.9	24.8	1.4	74.6
	2)	19	49	32	sicl	-	51.2	0.9	25.6	7.0	13.0	7.9	20.4	3.6	79.6
	3)	23	40	37	cl	-	47.3	1.0	25.8	10.0	18.2	7.9	23.6	1.6	70.0

[1] Soil texture (% sand, silt, or clay); texture class (USDA 1962); plant available water capacity (by weight, 15 bar-0.33 bar, %); % water at saturation; % organic matter; cation exchange capacity (meq/100g); electrical conductivity of the saturation extract (mmhos/cm); SAR = $Na^+/\sqrt{(Ca^{++} + Mg^{++})/2}$; soil pH; NO_3-nitrogen; Olsen phosphorus, and AB-DTPA extractable potassium (ppm); - = data not available.

Table 4. Sources and varieties used in the study and abbreviations of scientific names.

Species	Abrev.	Variety	Source[1]
Agropyron cristatum (L.) Gaertn.	AGCR	Parkway	Bridger
A. dasystachyum (Hook) Scribn.	AGDA	Critana	Bridger
A. inerme (Scribn. and Smith) Rybd.	AGIN	Whitmar	Pullman
A. riparium Scribn. and Smith	AGRI	Sodar	Aberdeen
A. smithii Rydb.	AGSM	Rosana	Bridger
A. trachycaulum (Link) Malte.	AGTRA	Primar	Pullman
A. trichophorum (Link) Richt.	AGTRI	Luna	Bridger
Elymus angustus Trin.	ELAN	Prairieland	Bridger
E. junceus Fisch.	ELJU	Vinall	Bridger
Bouteloua gracilis (HBK) Lag. ex Steud.	BOGR	locally collected	Shelby
Stipa viridula Trin.	STVI	Lodorm	Bridger
Triticum aestivum L.	TRAE	Cheyenne/spring	Belgrade

[1]Soil Conservation Service Plant Materials Centers at Bridger, MT, Aberdeen, ID, and Pullman, WA; Peavey Co., Belgrade, MT, and Big Sky Wholesale Seeds, Shelby, MT.

Precipitation and soil water were monitored during the first 2 years of the experiment. Soil moisture tension was measured with gypsum blocks (Taylor et al. 1961), buried at a depth of 25 cm in all plots of A. smithii, A. cristatum, Bouteloua gracilis, Stipa viridula, Elymus junceus and Triticum aestivum. Precipitation was monitored at an on-site weather station with a cumulative rain gauge for the duration of the experiment. The plots were never irrigated.

Soils were characterized by samples taken in November 1982 (Table 3). Twenty-four soil cores, 2 from each species plot, were taken from the top 15 cm and combined, to provide one composite sample for each treatment combination. Samples were analyzed by the NERCO (Northern Energy Resource Co.) environmental laboratory in Sheridan, Wyoming. Mechanical analysis (Day 1965) was used to determine texture. Plant available water holding capacity was determined, with a pressure membrane apparatus, as the difference between 1/3 bar and 15 bar water content (Richards 1965, 1969). Organic matter was measured colorimetrically after dichromate oxidation (Graham 1959). Cation exchange capacity was determined by the sodium acetate method (Richards 1969). Soil pH was measured on a saturated paste (Richards 1969). Sodium adsorption ratio (SAR) was determined on the saturated paste extract (Richards 1969). Nitrate-nitrogen was measured by the chromotropic acid method (Sims and Jackson 1971). Phosphorus was measured after extraction with sodium bicarbonate (Olson et al. 1954). Potassium and micronutrients were extracted in AB-DTPA and determined directly by atomic absorption (Soltanpour and Schwab 1977). In order to monitor salt levels, electrical conductivity was measured in November 1982, June 1983, and November 1983.

To index germination and emergence, seedling density was recorded twice during the first growing season. Rooted plants were counted in five, 2 X 2 dm quadrats within each species plot. Counts were made on 7 July, and again on 24 August. To normalize for parametric analysis density data were transformed to $(x + 0.5)^{1/2}$ as suggested by Bartlett (1947).

As an index of establishment and performance, yield was measured after the second (1983) and fourth (1985) growing seasons. Both harvests were made late in August. In the first harvest, five 2 X 5 dm frames were clipped, at 5 cm height, in each species planting. In 1985, three 3 X 6 dm (1 X 2 ft) frames were used to reduce variance. Samples were weighed after being oven-dried to constant weight.

Density and yield data were subjected to a 3-factor, nested factorial analysis of variance (ANOVA). Fixed treatments, "salt" and "texture", were crossed, with 3 random soils nested within each texture. Data were analyzed using Bio-medical Computer Programs (BMDP, Dixon 1981).

RESULTS

Soil Texture Treatments

Soil texture treatments are referred to as coarse (sandy loam and loam), medium (loam), and fine (clay loam and silty clay loam). Results of soil analyses confirm that the soils used represent three textural types ranging from moderately coarse to moderately fine (Soil Survey Staff 1962, Table 3). One soil which is technically a loam was grouped with coarse soils due to similarity of its sand content with that of sandy loams. Textural differences were quantified by calculating a mean particle diameter for each soil, using the revised textural triangle of Shirazi and Boersma (1984). In this system texture is designated by a mean particle size, which takes into account sand, silt, and clay particle size fractions, and a standard deviation indicating uniformity of texture. Mean particle diameters support the grouping of these soils into 3 textural categories, and indicate a larger range in particle size among coarse soils than among fine (Table 5).

Most other soil characteristics were sufficiently similar to allow differences in plant performance to be attributed to texture and/or salinity (Table 3). A possible exception was the relatively high sodium content of the fine soils, which approached values at which soil physical properties are affected (Richards 1969). None of the nutrient levels measured were low enough to limit plant growth markedly. Differences in end-of-season nitrate content between salted and unsalted plots may have been due to greater plant growth and nitrogen consumption on unsalted plots.

Table 5. Particle size fractions of nine soils used to create experimental plots, with corresponding mean particle diameters[1] and standard deviations (S.D.). Soils are arranged in order of decreasing mean particle size[2].

					Particle Diameter[1]	
Soil	Class	Sand	Silt	Clay	Geometric Mean	S.D. of the G.M.
			%		mm	
Coarse						
3	sl	57	32	11	.170	10.73
2	sl	52	28	20	.092	15.63
1	l	49	32	19	.085	15.38
Medium						
3	l	38	46	16	.062	7.24
1	l	36	44	20	.059	13.71
2	l	34	50	16	.054	8.25
Fine						
1	sicl	17	51	32	.020	11.18
2	sicl	18	50	32	.020	11.18
3	cl	22	40	38	.015	13.11

[1]Geometric mean particle diameter from the revised soil triangle of Shirazi and Boersma (1984).
[2]Sand fraction = 0.05-2.0 mm; silt = .002-.05 mm; clay = <.002 mm.

Salt Treatment

Untreated soils were initially low in salinity as indicated by electrical conductivities in the 0.8 to 3.0 mmho range (Table 2). Experimental addition of salts resulted in an increased but variable salt content at the end of the first growing season (Table 6). All but one of the salt-treated plots had conductivities greater than 4 mmhos/cm, the salt level used to define "saline" soils (Richards 1969).

On medium and coarse soils conductivities ranged from 3.6 to 6.4 mmhos/cm. Higher values (6-10 mmhos) for fine textured soils were due, in part, to higher initial salinity levels than anticipated.

Table 6. Changes of soil salinity with time. Electrical conductivity of the saturation extract in the top 15 cm of salt-treated (s) and control (ns) plots on 3 sampling dates.

	Nov 1982		June 1983[1]		Nov 1983	
Texture	ns	s	ns	s	ns	s
			mmhos/cm			
Coarse						
1)	2.4	4.1	-	3.0	1.0	1.0
2)	1.9	3.6	-	1.9	1.2	1.3
3)	1.0	4.3	-	1.2	0.4	0.5
Medium						
1)	0.8	4.1	-	1.4	0.5	1.0
2)	0.8	5.2	-	2.7	0.4	1.9
3)	0.9	6.4	-	3.7	0.5	2.1
Fine						
1)	2.1	6.1	-	3.2	1.1	2.1
2)	3.0	7.0	-	6.1	1.9	3.7
3)	2.8	10.0	-	6.6	1.2	4.2

[1]No data available for unsalted plots (-).

Due to leaching, the salinity of all soils decreased during the experiment (Table 6). Salt treated, coarse soils had the same conductivities as their unsalted counterparts by the end of the second growing season, and both were lower than they had been at the start of the experiment. Medium and fine textured soils retained salts longer, but the salinity of salt-treated plots had still dropped markedly by the end of the second growing season. Salinity of untreated plots dropped to a lesser degree.

Soil Water

While the first growing season (1982) had only slightly sub-normal precipitation, the second growing season (1983) was exceptionally dry (Table 1). Total 1983 precipitation of 16.5 cm (5 in) at the Spring Creek Mine site was less than half the 20 year average measured at Birney, Montana, 40 km (25 mi) to the northeast (Table 1). The largest total for any month was 2.5 cm, and no more than 1 cm was ever received in a 24-hr period.

In 1982, monthly soil water measurements never indicated tensions in excess of permanent wilting point (15 bars, Table 7). In 1983 however, most soils reached wilting point in July and remained dry through October. Measurements of soil water availability paralleled differences in precipitation and plant yield between the two years.

Seedling Density

For 8 of the 12 species tested, analysis of variance (ANOVA) showed no significant effect of either salt or texture on late summer seedling density (August, Table 8). The remaining 4 species responded to salt (Agropyron trachycaulum), or to both salt and texture (A. cristatum, A. inerme, Bouteloua gracilis). Much of the variance in establishment occurred among soils within textural groups, and it was highly significant in 4 cases. This indicates that, for at least 5 species, germination and/or emergence was affected to a greater degree by some soil property or properties other than texture.

Comparison of plant density means among textures (Table 9) and between salinity treatments (Table 10) illustrates the nature of

Table 7. Soil water potentials measured over 2 growing seasons. Each entry is the mean of 5 gypsum block readings (negative bars).

Treat-ment	1982				1983				
	11 JUL	27 JUL	24 AUG	24 SEPT	8 APR	11 JUN	18 JUL	25 AUG	4 NOV
				– bars					
Coarse									
1)	–	4	8	0	0	5	>20	>20	>20
2)	–	6	7	0	0	10	>20	>20	>20
3)	0	1	3	0	0	1	>20	>20	>20
Coarse with salt									
1)	–	3	4	0	0	2	>20	>20	>20
2)	–	2	5	0	0	3	>20	>20	>20
3)	0	1	3	0	0	3	>20	>20	>20
Medium									
1)	2	2	5	1	1	1	>20	>20	>20
2)	1	2	8	0	0	10	>20	>20	>20
3)	0	1	7	0	0	7	>20	>20	>20
Medium with salt									
1)	0	1	3	0	0	3	>20	>20	>20
2)	0	1	2	0	0	1	>20	>20	>20
3)	0	0	3	0	0	5	>20	>20	>20
Fine									
1)	–	0	0	0	0	2	>20	>20	>20
2)	–	0	1	0	0	5	>20	>20	>20
3)	0	0	1	1	0	4	>20	>20	>20
Fine with salt									
1)	–	0	0	0	0	0	7	>20	>20
2)	–	0	0	0	0	0	6	>20	>20
3)	1	1	1	2	0	0	3	>20	>20

treatment effects. Although some species did not show significant responses to texture or salinity, two consistent trends appear across all species. First, mean seedling densities for coarse, medium, and fine textured soils, averaged across salt treatments, indicate fewer

Table 8. Variance components of seedling density. Mean squares, F-statistics and significance levels are given.[1] Seedling counts were given a $(x+0.5)^{1/2}$ transformation prior to analysis.

Species	Among Textures		Between Salt Treatments		Among Soils within Texture		Interactions[2] T X S		Interactions[2] S X Soil		Error
	MS	F	MS	F	MS	F	MS	F	MS	F	MS
AGDA	8.74	19.22 **	2.46	9.69	.45	.83	1.35	5.31 *	.25	.47	.54
AGDA	38.04	4.60	24.64	4.92	8.27	4.81 **	.36	.07	.25	.47	.54
AGIN	29.62	10.51 *	11.53	10.10 *	2.82	1.83	1.63	1.43	1.14	.74	1.54
AGRI	18.58	5.04	6.06	2.61	3.69	2.22	5.08	2.19	2.32	1.40	1.66
AGSM	.65	.87	5.73	3.85	.76	.74	2.29	1.54	1.49	1.46	1.66
AGTRA	6.72	.79	7.63	7.67 *	8.56	5.17 **	2.23	2.24	1.00	.60	1.65
AGTRI	8.58	2.02	6.39	2.74	4.24	3.72 **	.81	.35	2.33	2.04	1.14
BOGR	11.35	6.00 *	8.90	9.36 *	1.89	2.64 *	.80	.85	.95	1.33	.72
ELAN	1.42	.69	.92	.93	1.66	4.79 **	.44	.44	.99	2.85 *	.35
ELJU	24.55	4.81	8.25	2.56	5.10	2.92 *	3.24	1.01	3.22	1.84	1.75
STVI	2.09	5.13	2.73	1.27	.41	.59	.24	.11	2.14	3.08 **	.70
TRAE	.22	.32	.19	.34	.68	1.83	.21	.37	.56	1.50	.37

[1]Mean square deviation (MS), F-statistic (F), and significance: * = $p<0.05$, ** = $p<0.01$.
[2]Interaction between texture and salinity (TXS) and between salinity and soils within textures (S X Soil).

Table 9. Seedling density on 3 textural types averaged over 2 salt treatments. Mean density (plants/m^2); n=30.

Species	Textural Group		
	Coarse	Medium	Fine
		plants/m^2	
Agropyron cristatum	101 a	90 a	27 b
A. dasystachyum	689	477	227
A. inerme	414 a	408 a	138 b
A. riparium	541	484	253
A. smithii	83	105	78
A. trachycaulum	334	276	185
A. trichophorum	265	326	163
Bouteloua gracilis	107 ab	118 a	28 b
Elymus angustus	63	46	36
E. junceus	296	313	110
Stipa viridula	77 a	61 ab	38 b
Triticum aestivum	43	53	42

[1]Means in the same row, followed by different letters are significantly different ($p<0.05$); Tukey method of multiple comparisons.

Table 10. Mean seedling densities (plants/m^2) on 2 salt treatments averaged over all soils; n=45.

Species	No salt	Salt	Comparison[1]
	plants/m^2		
Agropyron cristatum	82	55	*
A. dasystachyum	559	340	
A. inerme	369	243	*
A. riparium	469	363	
A. smithii	113	66	
A. trachycaulum	311	216	*
A. trichophorum	290	207	
Bouteloua gracilis	108	53	*
Elymus angustus	55	41	
E. junceus	296	200	
Stipa viridula	71	45	
Triticum aestivum	48	3	

[1]An * indicates a significant difference between salt treatments ($p<0.05$); Method of Least Significant Difference (LSD).

plants emerging on fine soils for every species (Table 9). This effect was significant only for Agropyron cristatum, A. inerme, Bouteloua gracilis, and Stipa viridula ($p<0.05$). There was never a significant difference in seedling density between coarse and medium soils, although densities were higher on coarse soils for eight of the twelve species. Second, overall mean density was lower on salt-treated soils for every species (Table 10). This effect was only significant for Agropyron cristatum, A. inerme, A. trachycaulum, and Bouteloua gracilis ($p<0.05$).

Grasses established in the absence of weeds the first year. Those weeds present, consisting almost exclusively of Salsola kali and Kochia scoparia, were restricted to the sides of soil pads. Flat, smooth surfaces produced by the seeding method may have discouraged weed growth. In the second growing season annual weeds invaded those plots that had sparse grass cover.

Second-Year Yield

Because treatment response was expected to vary among species, yield data were first analyzed individually by species in order to simplify interpretation of the results. For 11 of the 12 species tested, no differences in yield could be attributed to soil texture in the range moderately-coarse to moderately-fine (Table 11). The exception was Agropyron inerme, for which yield was significantly greater on medium-textured soils than on coarse ($p<0.01$, Table 12). For 6 of the twelve species, variance in yield due to soils within texture was significant, and highly significant in several cases, as was previously demonstrated with the density data. This result indicates important

Table 11. Variance components of 1983 yield data. Mean square deviations, F-statistics and significance tests are given for a 2-factor ANOVA, soils nested within textures[1]; n=5.

	Among Textures		Between Salt Treatments		Among Soils within Texture		Interactions[2] T X S		Interactions[2] S X Soil		Error
Species	MS	F	MS	F	MS	F	MS	F	MS	F	MS
AGCR	1063.7	2.23	570.5	2.72	477.1	3.42 **	689.3	3.29	209.6	1.50	139.6
AGDA	8.0	0.09	398.2	3.92	86.1	1.76	175.1	1.72	101.6	2.07	49.0
AGIN	259.5	9.76 *	437.8	27.97	26.6	1.87	59.2	3.78	15.6	1.10	14.2
AGRI	16.6	0.25	1396.3	47.67 **	66.5	2.48 *	148.5	5.07	29.3	1.09	26.3
AGSM	157.9	1.28	215.0	4.98	123.3	5.11 **	58.8	1.36	43.2	1.79	24.1
AGTRA	244.4	1.13	38.3	0.07	216.1	2.80 *	560.5	1.09	514.4	6.67 **	77.1
AGTRI	156.4	0.70	15.7	0.07	224.7	1.98	40.1	0.19	210.3	1.85	113.6
BOGR	4.6	0.90	26.5	6.42 *	5.1	4.62 **	3.4	0.19	4.1	3.75	1.1
ELAN	24.8	.92	206.1	6.46 *	27.0	1.33	56.7	1.78	31.9	1.58	20.2
ELJU	10.5	0.20	86.4	7.97 *	53.9	4.13 **	6.5	0.60	10.8	0.83	13.1
STVI	56.1	5.05	205.5	16.43 **	11.1	1.92	79.8	6.38 *	12.5	2.16	5.8
TRAE	73.5	2.92	494.2	7.02 *	25.1	1.00	11.9	0.17	70.4	2.81 *	25.1

[1]Mean square deviation (MS), F-value (F), and significance: * = $p<0.05$, ** = $p<0.01$.
[2]Interaction between texture and salinity (T X S) and between salinity and soils within textures (S X Soil).

Table 12. Mean, second-year (1983) dry matter yield of 12 grass species. Yields are shown for each species on coarse (c), medium (m), and fine (f) textured soils and on unsalted (ns) or salted (s) conditions.

Species	Texture	Salt Level ns	Salt Level s	ave	Comparisons[1] Texture	Comparisons[1] Salt
		g/m^2				
AGCR	c	145	205	175		
	m	220	120	170		
	f	125	14	70		*
	ave	163	113	-		
AGDA	c	90	104	97		
	m	122	53	88		
	f	125	54	90		
	ave	112	70	-		
AGIN	c	41	24	33	A	
	m	109	66	88	B	*
	f	78	6	42	AB	*
	ave	76	32	-		**
AGRI	c	110	33	72		*
	m	90	54	72		
	f	147	22	85		*
	ave	116	36	-		**
AGSM	c	23	24	23		
	m	61	18	40		
	f	94	43	69		
	ave	59	28	-		
AGTRA	c	96	157	127		
	m	175	183	179		
	f	226	118	172		
	ave	166	153	-		
AGTRI	c	120	140	130		
	m	161	184	173		
	f	176	158	167		
	ave	152	161	-		