Initial effects of different species treatments and fertilizer rates on a mine spoils rehabilitation
by Jerry Lee Holechek

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Science
Montana State University

Abstract:
Research was conducted on coal-mine spoils at Colstrip, Montana in the spring and summer of 1975. The purpose of this study was to determine the initial effectiveness of different species and fertilizer treatments in revegetating mine spoils.

A randomized, complete block design of five seeding treatments and two fertilizer levels was employed in the field at Colstrip, Montana.

Six species treatments and two fertilizer levels were used in. a greenhouse experiment. Thickspike wheatgrass (Agropyron dasystachyum), crested wheatgrass (Agropyron cristatum), ranger alfalfa (Medicago sativa) and fourwing saltbush (Atriplex canescens) were seeded individually and as a four species mixture. A 16 species mixture was included in the greenhouse species treatments. Experimental units from a nearby study planted to the 16 species mixture were compared to the four species mixture in the field experiment. Fertilizer was applied to both experiments at rates of 0-0-0 and 37-94-0 kg/ha of N, P2O5, and K2O.

Density, above ground biomass, and below ground biomass were estimated in both the greenhouse and field experiments. Canopy coverage data were collected for the field experiment.

Statistical analyses of the greenhouse data showed that fertilizer increased the productivity of all species treatments. The mixture of four species was superior to other species treatments in production. Analyses of data from the field experiment revealed that the species treatments did not respond uniformly to fertilizer application.

Fertilizer increased the above ground biomass of grasses but had no significant effect on legumes and shrubs. There was no significant difference between the four species mixture and a 16 species mixture in density, canopy coverage, and productivity. The ideal species and fertilizer treatment combination for good initial stabilization and high productivity on coal-mine spoils is still a reclamation problem.

The study must be continued for several years before it can be determined which species treatment and fertilizer application rate best meets the objectives of reclamation.

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Date March 23, 1976

INITIAL EFFECTS OF DIFFERENT SPECIES TREATMENTS AND FERTILIZER RATES ON A MINE SPOILS REHABILITATION

by

JERRY LEE HOLECHEK

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ABSTRACT

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A randomized, complete block design of five seeding treatments and two fertilizer levels was employed in the field at Colstrip, Montana. Six species treatments and two fertilizer levels were used in a greenhouse experiment. Thickspike wheatgrass (*Agropyron dasystachyum*), crested wheatgrass (*Agropyron cristatum*), ranger alfalfa (*Medicago sativa*) and fourwing saltbush (*Atriplex canescens*) were seeded individually and as a four species mixture. A 16 species mixture was included in the greenhouse species treatments. Experimental units from a nearby study planted to the 16 species mixture were compared to the four species mixture in the field experiment. Fertilizer was applied to both experiments at rates of 0-0-0 and 37-94-0 kg/ha of N, P_2O_5, and K_2O.

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The study must be continued for several years before it can be determined which species treatment and fertilizer application rate best meets the objectives of reclamation.

INTRODUCTION

The Montana Strip Mining and Reclamation Act of 1973 requires that coal mine spoils be revegetated with a mixture of plant species that can withstand grazing pressure to the degree that existed before mining, provide wildlife habitat, and control erosion. Certain seed mixtures may be superior to others in fulfilling the above requirements. The most appropriate combination and optimum number of plant species to use in a seeding mixture for effective stabilization and development of a permanent self-sustaining plant community still remains a question. Past reclamation research has shown that a mixture of fast growing introduced species and slower growing native species may be desirable (Sindelar *et al.*, 1973). However, since certain native species are suited to different environmental conditions than those required by introduced species, the interactions between these species groups must be considered.

The application of fertilizer has been effective in establishing a vegetational cover on coal mine spoils (Buchholz, 1972; Hodder and Sindelar, 1972; Meyn *et al.*, 1975a; Sindelar *et al.*, 1973; Sindelar *et al.*, 1974). Plant species respond differently to fertilizer application. Fertilizer rates which will encourage establishment of native species and not give a competitive advantage to fast growing introduced species must be determined.

The objectives of this research project were to:

1. Determine the rate of establishment of four species when planted individually and as a four-species mixture.

2. Determine the initial effectiveness of fertilization versus no fertilization on the four plant species individually in a mixture.

3. Compare the first-year establishment and productivity of the four-species mixture and a 16-species mixture which has been seeded in mine spoils at Colstrip.

The study was conducted in two parts: the first a field experiment on mine spoils at Colstrip, Montana; the second a greenhouse experiment at MSU in Bozeman, Montana which paralleled the field experiment to determine the effectiveness of the different treatments under controlled conditions.

LITERATURE REVIEW

Problems and Methods of Reclamation

The Issue

The revegetation of coal mined lands in the Northern Great Plains has become of great concern to government agencies and private companies in recent years. This is primarily because of increased public environmental awareness. Also, much more coal mining is planned for the future than has been done in the past. Currently little information is available on reclaiming coal mined lands in the western United States. This has resulted in a wide range of opinions on revegetation potential. Current research indicates that revegetation can be accomplished when the correct reclamation procedures are used.

Reclamation Success

Many attempts to reclaim strip-mined lands in the western United States have not been immediately successful. It took several years before any conclusions regarding vegetation success or failure could be made on strip-mined lands owned by the Knife River Coal Mining Company at Gascoyne and Beulah in North Dakota (Gwynn, 1966). Vegetational response at Soda Springs, Idaho on lands that had been strip-mined for phosphorus was positive, but not a spectacular success (Thompson,1969). Research at Colstrip, Montana showed that vegetation could be established with the use of commercial fertilizers (Hodder *et al.*, 1971). Irrigation was utilized effectively at Decker, Montana in establishing both introduced and native species (Farmer *et al.*, 1974).

Topsoiling

The lack of a developed soil profile on new strip-mine spoils is a severe limitation to revegetation. Surface mining destroys the soil structure, reduces the organic matter content, and may affect the micro-organism population (Sindelar *et al.*, 1973). The stockpiling of topsoil may retain the most important properties of a developed soil. These properties include organic matter, micro-organisms and plant nutrients. Soil structure is destroyed in topsoil salvage. At Roundup, Montana the topsoiling of mine spoils was effective (Hodder, 1974). The application of topsoil at Roundup facilitated rapid vegetation establishment which in turn reduced erosion. Studies at Colstrip, Montana indicated that 10 cm of topsoil was sufficient for successful plant establishment (Sindelar *et al.*, 1973). Topsoiling at Decker, Montana resulted in good stands of native and introduced grass mixtures (Farmer *et al.*, 1974).

Compaction

Soil compaction is caused by heavy equipment in the process of reshaping and grading mine spoils (Sindelar *et al.*, 1974). This has resulted in bulk densities of 1.7 to greater than 2.0 grams per cubic cm. This produces a severe limitation to root penetration, plant development, and water infiltration (Hodder, 1974). Veihmeyer and Hendrickson (1948) found roots did not penetrate sandy soils with bulk densities over 1.75 and heavy clays with 1.46 and 1.63 grams per cubic cm. Compacted layers must be broken up to provide adequate root penetration, water infiltration, and a good seedbed. On heavy clay soils in South Dakota, ripping 30 to 35 cm deep at two meter spacings increased infiltration rates (Nichols, 1966). This resulted in a 173 percent increase in the number of western wheatgrass (*Agropyron smithii*) plants and a 444 percent increase in total grass production.

Surface manipulation treatments include chiseling, gouging and dozer basin construction. These treatments effectively increased soil moisture content, reduced soil erosion and aided vegetation establishment at Colstrip, Montana (Sindelar *et al.*, 1973).

Erosion

A vegetative cover must be established as quickly as possible on mine spoils to prevent wind and water erosion (Hodder *et al.*, 1971). Temporary stabilization with annual grasses is a potential means of erosion control.

Plantings of annual species were effective in building up organic matter and initiating soil development at Colstrip, Montana (Sindelar *et al.*, 1974). Within two years topsoiled and fertilized raw spoils returned 14,000 kilograms per hectare of organic matter to the upper 45 cm of soil in the form of roots alone.

Fertilization

The need for application of fertilizer elements in some form on strip-mined spoils has long been recognized (Hodder, 1974; Jacoby, 1969). Soil analyses of raw spoils in southeastern Montana have consistently shown deficiencies in nitrogen and phosphorus (Sindelar *et al.*, 1973). Potassium, another essential mineral, is relatively abundant in most Montana coal mine spoils.

Time, rate, placement, soil moisture, soil pH, and vegetative type are all factors important to the successful use of fertilizer (Brady, 1974; Cole *et al.*, 1963; Follett and Reichman, 1972; Lorenz and Johnson, 1953). The amount of soil moisture largely determines the effectiveness or damage of applied fertilizers (Brady, 1974). Olson and Dreier (1956) concluded that low moisture levels in conjunction with nitrogen fertilization were likely to cause poor plant response.

Additional yield increases have occurred at many locations when nitrogen was combined with phosphorus (Choriki *et al.*, 1969; Gomm, 1961; Power and Alessi, 1970; Rogler and Lorenz, 1957; Van Dyne, 1961). The use of phosphorus alone has had little effect in increasing total herbage yield on either mine spoils or native range (Buchholz, 1972; Gomm, 1961; Van Dyne, 1961). Plant production has increased with increasing amounts of nitrogen and phosphorus on mine spoils at Colstrip, Montana (Buchholz, 1972; Sindelar *et al.*, 1973). At rates over 70 kilograms per hectare of nitrogen combined with 90 kilograms per hectare of phosphorus, plant production increased at a decreasing rate.

There is evidence that fertilizer has little effect on plant density and an unpredictable effect on first-year plant production of perennial grass (Farmer *et al.*, 1974; Hodder *et al.*, 1971; Meyn *et al.*, 1975a,b; Sindelar *et al.*, 1974). Applications of 45 kilograms of nitrogen and 45 kilograms of P_2O_5 per hectare appeared to be sufficient for a first year application on raw spoils (Meyn *et al.*, 1975a). Annual plants, when planted during years of good moisture supply, had the capacity to utilize much larger applications of fertilizer than perennial plant mixtures.

Repeated nitrogen and phosphorus application may be detrimental when the goals are establishment of diverse native plant communities. A mixture of introduced grasses gave a much more pronounced response to nitrogen and phosphorus fertilization than a native grass mixture on mine spoils at Decker, Montana (Farmer *et al.*, 1974). When introduced species and native species are planted in a mixture, fertilization may give the introduced species a competitive advantage. This indicates that different species respond differently to fertilizer application.

Nitrogen fertilization on native range usually has resulted in plant compositional changes. Cool season rhizomatous grasses are usually benefited by nitrogen application, while bunchgrasses often decline (Cosper *et al.*, 1967; Johnston *et al.*, 1968; Rauzi *et al.*, 1968; Roath, 1974; Wight and Black, 1972). Warm season grasses tend to decline under nitrogen application (Choriki *et al.*, 1969; Hyder and Bement, 1972; Launchbaugh, 1962; Taylor, 1967; Weaver and Albertson, 1956). Annual grasses, however, respond quite favorably to nitrogen (Burgess and Evans, 1965; Choriki, 1969; Cline and Richard, 1973; McKell *et al.*, 1970).

Plant Community Establishment

Succession

Plant succession is the replacement of one plant community by another which can more fully utilize the available environmental resources (Daubenmire, 1968). The end product of succession is called the climax plant community. It is hoped that the successional time requirements for a permanent self-sustaining plant community capable of supporting livestock and wildlife can be compressed into a decade or less. The seeding mixture is one factor determining the rate of progression towards this type of community. Initial species selection should be given careful consideration for this reason.

The potential climax plant community on disturbed lands may not be similar to the climax plant community on sites where soil has not been disturbed (Dyksterhuis, 1949). A highly dependent relationship exists between plant succession and soil development (Daubenmire, 1968; Tansley, 1939). The revegetation of mine spoils to plant communities duplicating those that existed before mining may be a very unrealistic reclamation objective.

Monocultures versus Mixtures

The use of monocultures has proven effective when areas are under intensive management and high energy inputs are applied. Under conditions where a self sustaining plant community requiring little management is desired, diversity is essential to reduce disease, insect damage, losses from climatic fluctuations, and nutrient losses (Daubenmire, 1968). In the western United States, vast acreages have been reseeded to crested wheatgrass (*Agropyron desortorum*), an introduced species from Russia. In the last few years, the black grass bug (*Labops hesperius*) has infested and destroyed countless acres of crested wheatgrass stands in the Intermountain West (Haws *et al.*, 1973; Stoddart *et al.*, 1975; Wambolt, 1974). This may point out a danger in relying on monocultures when developing mixtures for reseeding.

Mixtures are usually more productive than monocultures (Heady, 1975; Stoddart *et al.*, 1975; Vallentine, 1971). This is because different rooting habits may result in more efficient use of soil moisture and nutrients from various soil depths. Also some plants of the mixture may have favorable influences on others. Mixtures often have greater longevity than monocultures (Stoddart *et al.*, 1975). This is because those species that are better adapted to a particular site usually replace the less suited species as they disappear from the stand.

Simple Mixtures

In designing mixtures for reseeding, simple mixtures are generally more effective than complex mixtures that use the "shotgun" approach (Vallentine, 1971). Seeding simple mixtures of not more than six species reduces species incompatibility and allows more precise site adaptation (Cox and Cole, 1960; Heady, 1975; Hull *et al.*, 1958; Idaho Agricultural Extension Service, 1961; McIlvain and Shoop, 1960; Utah Agricultural Experiment Station, 1970). The establishment of each species is more rapid and interspecific competition is reduced.

Simple mixtures gave the best results in Utah even when areas having a variety of soil and moisture conditions were reseeded to provide big game winter range (Plummer *et al.*, 1968). When establishing cover for small game, mixtures of not more than five species gave best results (Burger, 1973).

Aggressive Species

Jakobs (1963) found that seeding more than five species together in pasture mixes was a poor practice because certain species are always more competitive than others. Species that are aggressive when seeded in the spring are not necessarily aggressive when fall or summer seeded (Blaser *et al.*, 1956a,b). It was concluded that the ratio of species in a mixture should vary for spring and summer seedings. Aggressive species should be seeded at low rates if non-aggressive species are to be the primary species in a mixture. The growth rates of the different species should also influence mixture composition.

Warm and Cool Season Grass Relationships

Warm season grasses can seldom be seeded successfully with cool season grasses in the Northern Great Plains. The cool season grasses deplete soil moisture in the spring that otherwise would be available for summer growth of warm season grasses (Conard and Youngman, 1965).

Grass and Shrub Relationships

Unless shrub species are highly adapted to an area they are seldom compatible with grasses when seeded in a mixture. Grasses have fine, fibrous root systems which more thoroughly occupy the soil than do the tap roots of young shrub seedlings (Shultz *et al.*, 1955). Grasses use more water than the young brush seedlings, and soil moisture is exhausted before the brush roots reach the deeper depths. Sufficient soil moisture is left for developing brush seedlings only in years of exceptionally late spring rains.

Bitterbursh (*Purshia tridentata*) mortality was 57 percent under heavy competition from weeds and crested wheatgrass in the first growing season (Hubbard, 1957). Under light competition it was 21 percent. Mortality was primarily from moisture competition in both cases.

Grass and Legume Relationships

Unlike grasses and shrubs, grasses and legumes are often compatible. When crested wheatgrass and alfalfa (*Medicago sativa*) were grown together, they gave superior yields to either species grown individually (Dubbs, 1971). Aberg *et al.*, (1943) reported grasses had a higher root yield when grown in association with alfalfa. In a mixture of associated grass species, alfalfa provided nitrogen in an amount equivalent to between 45 and 90 kilograms per hectare (McLeod, 1965). Van Riper (1964) found that grasses and legumes complemented each other in using soil moisture. Grasses used more soil moisture in the first 30 cm than alfalfa, but alfalfa used more moisture from the lower depths than grasses.

Introduced and Native Species Relationships

Native species are recommended when the goal is the establishment of an ecologically stable and self-sustaining plant community (Daubenmire, 1968; McMillan, 1959). These species have had thousands of years to adapt to the climate, insects, disease, and soils of a particular area (McMillan, 1959; Suneson, 1960).

Introduced grasses are often incompatible with native grasses when planted in the same mixture (Blaser *et al.*, 1956b; Cox and Cole, 1960). Introduced species can often utilize fertilizer more efficiently than native species. In a study involving a mixture of nine native species and eight introduced species on fertilized strip-mine spoils at Colstrip, Montana, six of the introduced species accounted for 88 percent of the total production (Sindelar *et al.*, 1973).

Crested wheatgrass is often extremely competitive to native vegetation (Currie, 1969; Eckert *et al.*, 1961; Hull and Klomp, 1960; Hull, 1971). In the Northern Great Plains, crested wheatgrass seeded in mixtures with native species attained almost complete dominance and maintained stands for over forty years (Ross *et al.*, 1966). In Saskatchewan, crested wheatgrass stands from 29 to 38 years old have become a permanent part of the vegetation with almost no reestablishment of native species (Smoliak *et al.*, 1964).

Smooth brome (*Bromus inermis*) is another highly competitive introduced grass (Cooper *et al.*, 1973). It will often dominate a mixture within a very few years. Orchard grass (*Dactylus glomerata*), an introduced bunchgrass, gave good initial establishment on coal mine spoils at Colstrip, Montana (Sindelar *et al.*, 1973). It accounted for

50 percent of the first year production when planted in an eleven-species mixture of native and introduced grasses but declined rapidly in productivity during the next two years.

When a diverse plant community is the end objective, it may be a poor practice to plant introduced pasture grasses with native range grasses. Persistent introduced species, such as crested wheatgrass, may drastically slow the development of native plant communities during the natural process of succession. When introduced species are used with native species, they should be seeded at very low rates (Blaser, 1956b).

Densities of Seeding

Seedings on harsh sites are now commonly made on the basis of number of pure live seeds per square meter required to produce satisfactory stands (Vallentine, 1971). Seeding rates based on 215 pure live seeds per square meter have become somewhat standard for seeding ordinary upland sites by drilling (Burzlaff and Swinbank, 1965; McIlvain and Shoop, 1960; Rechenthin *et al.*, 1965). Seeding rates for many species should be adjusted where research and experience have shown this to be desirable (Vallentine, 1971). When broadcast seeding, the recommended seeding rates are 430 to 538 pure live seeds per square meter to compensate for uneven seeding depth (Burzlaff and Swinbank, 1965; Cook *et al.*, 1967).

THE STUDY AREA

Location

The field work for this research project was conducted near Colstrip, Montana in Rosebud County (Section 18, T4N, R42E of the Montana Principal Meridian). Colstrip is one of the primary sites of research involving strip mined land in Montana. A greenhouse experiment was conducted at MSU in Bozeman, Montana.

Climate

Cold winters and warm summers characterize the climate of the field experiment area (Sindelar *et al.*, 1974). January is generally the coldest month with temperatures down to -20° C and July is the hottest month with temperatures sometimes exceeding 40° C (Buchholz, 1972; Meyn *et al.*, 1975b). The active growing season is dependent on soil water availability but generally extends from the middle of March until the end of June with a frost free period of 100 to 140 days (Sindelar *et al.*, 1973). The average date of the last freeze is May 15 - 25 and the first fall freeze is expected about September 15 - 22 (U.S. Dept. Commerce, 1975).

The months of April, May, and June usually receive the greatest precipitation at Colstrip (Meyn *et al.*, 1975b). Most of the precipitation during these three months is rainfall. The lowest amount of precipitation occurs during December, January, and March. Mean annual precipitation for the area is 40 cm. Snow contributes approximately 12 cm to the annual total. Persistent summer winds, with average velocities up to 10 km/hr, cause potential evapotranspiration losses from spoils of about 20 cm per month during June, July, and August (D. J. Dollhopf, Montana Agriculture Experiment Station, personal communication, 1975). Plant moisture stress is usually severe in July and August. Monthly climatological data for Colstrip are presented in Table I.

Table I. Monthly climatological data for Colstrip, Montana for 1975

	Temperature (^oC)		Precipitation (cm)	
	Avg. for Month	Deviation From Norm	Total For Month	Deviation From Norm
January	-*	-	2.3**	+1.0[1/]
February	-*	-	2.0	+0.7
March	-*	-	2.5	+1.8
April	6.5	-.6[1/]	5.6	+0.8
May	12.0	-.1	8.1	+1.8
June	17.3	-.2	7.4	-0.9
July	21.9	-1.3	4.4	+1.4
August	22.2	+1.1	1.8	-1.7
September	16.2	+ .8	1.5	-2.0
October	8.8	- .4	2.0	-0.6
November	1.5	+ .2	3.6	+1.9
December	-2.3	+ .6	2.9	+1.4

1/ Average based on 46 years observation at Colstrip, Montana. (Source: Climatological Data, U.S. Dept. Commerce, N.O.A.A., Environmental Data Service.)

* Temperature data are missing for January, February, and March.

** Mean of two storage gauges located about 1 km northeast of the site.

Topography and Vegetation

Rolling prairie with alternating ridges, drainages, and sandstone bluffs formsthe primary landscape pattern of the Colstrip area. The principal drainages in the area flow generally northward to the Yellowstone River. The elevation at Colstrip and the field study site are 990 and 1070 meters, respectively.

Mixed prairie grasses with stands of ponderosa pine (*Pinus ponderosa*) characterize the local vegetation. Cool season bunchgrasses dominate the native range; however, a number of warm season species are present. Commonly found grasses include bluebunch wheatgrass (*Agropyron spicatum*), western wheatgrass, needle-and-thread (*Stipa comata*), little bluestem (*Schizachyrium scoparium*), green needlegrass (*Stipa viridula*), blue grama (*Bouteloua gracilis*), and prairie junegrass (*Koeleria cristata*) (Westinghouse Electric Corporation, 1973). Important shrubs are silver sagebrush (*Artemisia cana*), three-leaf sumac (*Rhus trilobata*), yucca (*Yucca glauca*), and big sagebrush (*Artemisia tridentata*). Snowberry (*Symphoricarpos spp.*), serviceberry (*Amelanchier alnifolia*), and chokecherry (*Prunus virginiana*) are found in the moist areas along drainage bottoms.

The field study site was located on the ridge of a mine spoils that had been shaped and topsoiled in 1974. The site was oriented to the east and west. The slope ranged from nearly level on top to approximately a 5:1 grade on the slopes. Wintergraze (*Triticum/ Agropyron* hybrid) and barley (*Hordeum vulgare*) were planted around the experimental area to stabilize the soil. The field experiment site was placed on the level part of the spoils to maximize site uniformity among treatments.

Soils

The coal in the Colstrip region is contained in the Fort Union Formation. This formation contains layers of light colored sandstone, sandy shale, carbonaceous shale, and sub-bituminous coal (Westinghouse Electric Corporation, 1973). The sandstone layers are easily fractured by the processes of weathering. Much of the coal along the outcrops has been burned (Meyn *et al.*, 1975a). This resistant porcellanite material is called scoria.

Parent materials in the Colstrip area are largely sedimentary in origin (Westinghouse Electric Corporation, 1973). The exceptions are soils formed from terrace gravel and recent alluvium. These soils are found along the river drainages and lowland areas.

Soil texture varies with location and depth (W. L. Volk, Soil Conservation Service, personal communication, 1975). The topsoil of the upland areas is usually a sandy loam. Sandy clay loams and clay loams dominate the lowland areas (Westinghouse Electric Corporation, 1973).

Poor structural development usually characterizes soils in the Colstrip area (Packer, 1974; W. L. Volk, Soil Conservation Service, personal communication, 1975). The surface horizon of local undisturbed soil is commonly granular in structure. A massive structure characterizes the subsoil.

The Colstrip area soils are usually classified as fine loamy or loamy skeletal lithic Haploborolls (Aandahl, 1972; Packer, 1974). These soils often have poor profile development. They usually lack a "B" horizon.

The application of salvaged topsoil is an important part of reclamation procedures at Colstrip. A layer of topsoil approximately 20 cm thick is usually applied over the raw spoils material. The topsoil is sandy loam in texture. It has approximately .5 percent organic matter which is relatively low. The pH averages 8.5.

Beneath the topsoil is the raw spoils material or overburden. This material is variable in texture and has no structure. The organic matter content is less than .2 percent. The pH is usually between 8.20 and 8.40.

The electrical conductivity on mine spoils at Colstrip is not high (Table II). It has not been a problem in revegetation. For most plants, four mmhos per cm is considered toxic (Soil Survey Staff, 1951).

Fertility of the mine spoils is quite low compared to undisturbed sites. Available nitrogen and phosphorus are the most limiting nutrients to plant growth (Buchholz, 1972; Meyn *et al.*, 1975a,b; Sindelar *et al.*, 1973). Other nutrients are present at acceptable levels, being neither too high nor too low. Soil analysis data are given in Table II.

Table II. Soil chemical analyses at the field study site, Colstrip, Montana.

	pH	NO_3-N ppm	PO_4-P ppm	K ppm	Ca meq/ 100g	Mg meq/ 100g	Na meq/ 100g	E.C.[1/] mmhos/ cm
*Depth								
(0-20 cm)	8.50	2.20	.60	54.17	29.36	2.18	.13	.41
(20-60 cm)	8.35	5.27	.53	56.67	21.20	2.21	.13	.75
(60-90 cm)	8.23	3.86	.45	55.83	19.78	2.32	.13	.80
(90-120 cm)	8.23	4.52	.47	56.67	19.87	2.12	.13	.80

1/ E.C. = electrical conductivity
* Mean of three replicates

METHODS AND PROCEDURES

The Greenhouse Experiment

Design

A representative sample of surface topsoil material from the field experiment area at Colstrip, Montana was taken to a 20 cm depth. The topsoil material was transported in heavy burlap bags to the USFS (United States Forest Service) greenhouse in Bozeman, Montana on March 22, 1975. At the USFS greenhouse aggregates larger than five cm in diameter were screened from the topsoil material. Approximately 88 kilograms of soil material were weighed, and placed in each of 36 rectangular test frames.

Test frames were constructed prior to obtaining soil. These experimental units were constructed by first dividing two tables lengthwise with a board 2.5 cm thick and 20 cm wide. Each half of the table was further subdivided by placing boards of the same thickness and width at right angles to the first board. The benches had holes in the bottom to facilitate aeration and drainage.

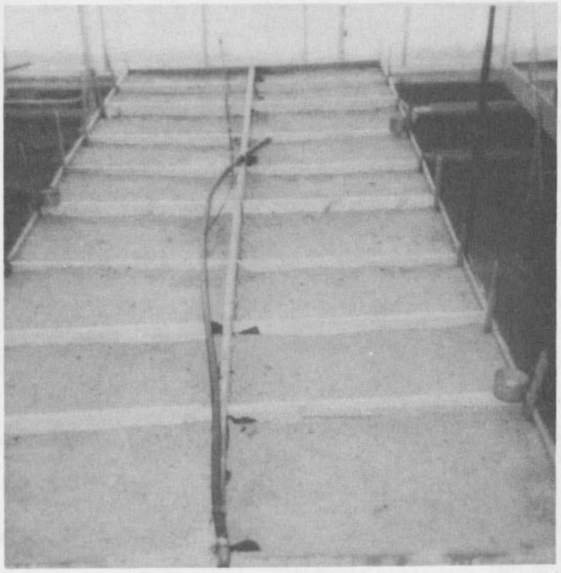

Figure 1. Table design used in the greenhouse experiment.

A randomized complete block design with a factorial arrangement of two variables (six species treatments and two fertilizer rates) in three replicates was used in the greenhouse experiment. Table III presents a description of the different treatments for the greenhouse experiment and Figure 2 outlines the experimental design.

The amount of fertilizer applied was calculated on the standard kilograms per hectare basis (Brady, 1974). The relatively low rate of 37, 94, and 0 kg/ha of N, P_2O_5, and K_2O respectively were selected so that species which are more responsive to fertilizer inputs would not be given a competitive advantage. The rate of P_2O_5 was selected high enough to eliminate any phosphorus deficiencies in the fertilized treatments.

Table III. Treatment descriptions for the greenhouse and field experiments.

SPECIES	PLS/m^2 [1]	Kg/ha
Species Seeded as Monocultures		
*Critana thickspike wheatgrass (*Agropyron dasystachyum*)	538	16.24[2]
Fairway crested wheatgrass (*Agropyron cristatum*)	538	12.19
Ranger alfalfa (*Medicago sativa*)	538	11.61
*Fourwing saltbush (*Atriplex canescens*)	108	6.97
Four Species Mixture		
*Critana thickspike wheatgrass	162	4.87
Fairway crested wheatgrass	162	3.70
Ranger alfalfa	162	3.08
*Fourwing saltbush	54	3.48
Total	540	15.13
16 Species Mixture (SEAM)[3]		
Fairway crested wheatgrass (*Agropyron cristatum*)	172	3.85
*Critana thickspike wheatgrass (*Agropyron dasystachyum*)	131	3.85
*Western wheatgrass (*Agropyron smithii*)	140	5.13
Tall wheatgrass (*Agropyron elongatum*)	86	5.13
Lincoln smooth brome (*Bromus inermis*)	118	3.85
Orchard grass (*Dactylis glomerata*)	301	2.55
*Green needlegrass (*Stipa viridula*)	86	2.09
Cicer milkvetch (*Astragalus cicer*)	86	2.55
Ladak alfalfa (*Medicago sativa*)	65	1.28
*Prairie sandweed (*Calamovilfa longifolia*)	75	1.25
*Greasewood (*Sarcobatus vermiculatus*)	5	1.25
*Antelope bitterbrush (*Purshia tridentata*)	5	1.28
*Big sagebrush (*Artemisia tridentata*)	215	.38
*Indian ricegrass (*Oryzopsis hymenoides*)	32	.75
Sweetclover (*Melilotus officinalis*)	75	1.25
Eski sainfoin (*Onobrychis vaciafolia*)	11	1.25
Total	1603	37.69

Fertilizer Rates

0-0-0 Kg/ha available N-P_2O_5-K_2O

37-94-0 Kg/ha available N-P_2O_5-K_2O

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[1] PLS/m^2 is pure live seed per square meter.

[2] (Source of conversion from PLS/m^2 to Kg/ha: Vallentine, J. F. 1971. Range development and improvements. Brigham Young University, Provo. 515 p.

[3] 16 species mixture seeded in the field was part of the SEAM study.

* Native Species

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Treatment Codes
1 = Thickspike wheatgrass
2 = Crested wheatgrass
3 = Ranger alfalfa
4 = Fourwing saltbush
5 = Four species mixture
6 = 16 species mixture

F0 = 0-0-0 Kg/ha $N\text{-}P_2O_5\text{-}K_2O$

F1 = 37-94-0 Kg/ha $N\text{-}P_2O_5\text{-}K_2O$

Experiment unit dimensions = 76cm X 44cm X 18cm

Figure 2. Design of the experiment conducted in the USFS Greenhouse, Bozeman, Montana

Fertilizer was manually applied as a top dressing. Irrigation was used to leach the fertilizer into the soils material.

Experimental units were seeded on the basis of pure live seed per square meter. All seed used in the study had been recently tested for germination. Crested wheatgrass, thickspike wheatgrass, and ranger alfalfa in the monoculture plantings were planted at 538 pure live seeds per square meter. This seeding rate was used to compensate for the uneven depth of broadcast seeding (Vallentine, 1971). The four species mixture was also planted at this rate. Fourwing saltbush (*Atriplex canescens*) was seeded at a reduced rate to lower intraspecific competition. The 16 species mixture was seeded at a rate of 1603 pure live seeds per square meter to correspond to the rate commonly used in revegetation at Colstrip, Montana.

The watering system was manual, with three permanently mounted sprinklers used on each bench. Approximately .4 cm of water was applied every other day in March, April, and May. In June this same rate of water was applied every third day. Frequent small applications of water were used to prevent soil material from washing out of the test frames. The total water application for each month approximated the long term average monthly precipitation at Colstrip.

Evaluation

The plant density in each treatment was measured after seedling emergence on April 20 and again on July 1. All the plants were counted in each experimental unit and were separated into four categories. These four categories were perennial grasses, legumes, shrubs, and weeds.

All the above ground biomass except for plant crowns was clipped in each experimental frame on July 2. Grass, legume, and shrub components were also separated from each other and placed into an individual paper bag. The herbage samples were dried at 60° C for five days before being weighed.

Immediately after clipping, below ground biomass samples were collected with the use of an oakfield tube. Twenty-five 1.90 cm diameter cores were removed randomly from each experimental frame. These cores spanned the entire depth of the frame and were placed in groups of five. The roots were extracted by placing the soil in screens and flushing the roots with water. Screens of 20, 40, and 60 mesh were used. Forceps were used to remove the roots from each screen. Below ground biomass samples were dried at 60° C for five days before weighing. Immediately after weighing, the below ground biomass samples were put into porcelain crucibles and placed in a muffle furnace at a temperature of 550° C for 16 hours. After cooling, the ashes were weighed and subtracted from the oven dry weights. This was done to reduce error from mineral particles attached to the roots. Plant crowns were included in below ground biomass data.

The Field Experiment

Design

An area of 5,500 square meters of graded, ripped, and topsoiled mine spoils lying east of the SEAM (Surface Environment and Mining) planting was chiseled on March 25, 1975 to prepare a seedbed for the field experiment. Individual experimental units, nine meters by ten meters, were used. These units were broadcast seeded after they were chiseled. Immediately after seeding, the area was cultipacked to provide seed coverage and a firm seedbed (Figure 3). The SEAM planting, located next to the field experiment, received identical preparation except that seeding was accomplished in both fall and spring.

Figure 3. The field experiment after seeding and cultipacking on March 26, 1975.

A randomized complete block design with a factorial arrangement of two variables (five species treatments and two fertilizer rates) was used in the field experiment. Treatment descriptions are given in Table III. The experimental design for the field experiment is given in Figure 4. Figure 5 shows the treatments from the SEAM study used for comparison with the four species mixture in the field experiment.

Two levels of fertilizer (0-0-0 and 37-94-0 kg/ha of N, P_2O_5, and K_2O) were applied to each species treatment on June 9, 1975 with a hand operated broadcast spreader. The portion of the SEAM planting used for comparison with the four species mixture in the field experiment received the same fertilizer rates.

Eight neutron tubes were randomly located at the site for measurement of soil water content. The tubes were read monthly for the SEAM investigation in the period March to September, 1975. The reader is referred to Schultz (1966) for detail on the theory behind the neutron method for estimating soil water content.

Analysis

Plant density samples were collected on June 8 and August 15 using 20 by 20 cm square frames. Three transects were randomly selected for sampling from eight possible transects one meter apart on each experimental unit. Seven seedling counts were taken at one meter intervals on each transect for a total of 21 samples per experimental unit. No

5F0	4F1	3F1	2F1	3F0	Rep 1
2F0	5F1	1F0	1F1	4F0	

5 meter buffer area

2F1	4F1	3F1	1F1	1F0	Rep 2
4F0	5F1	2F0	3F0	5F0	

5 meter buffer area

4F1	5F1	1F0	5F0	3F0	Rep 3
2F1	1F1	2F0	4F0	3F1	

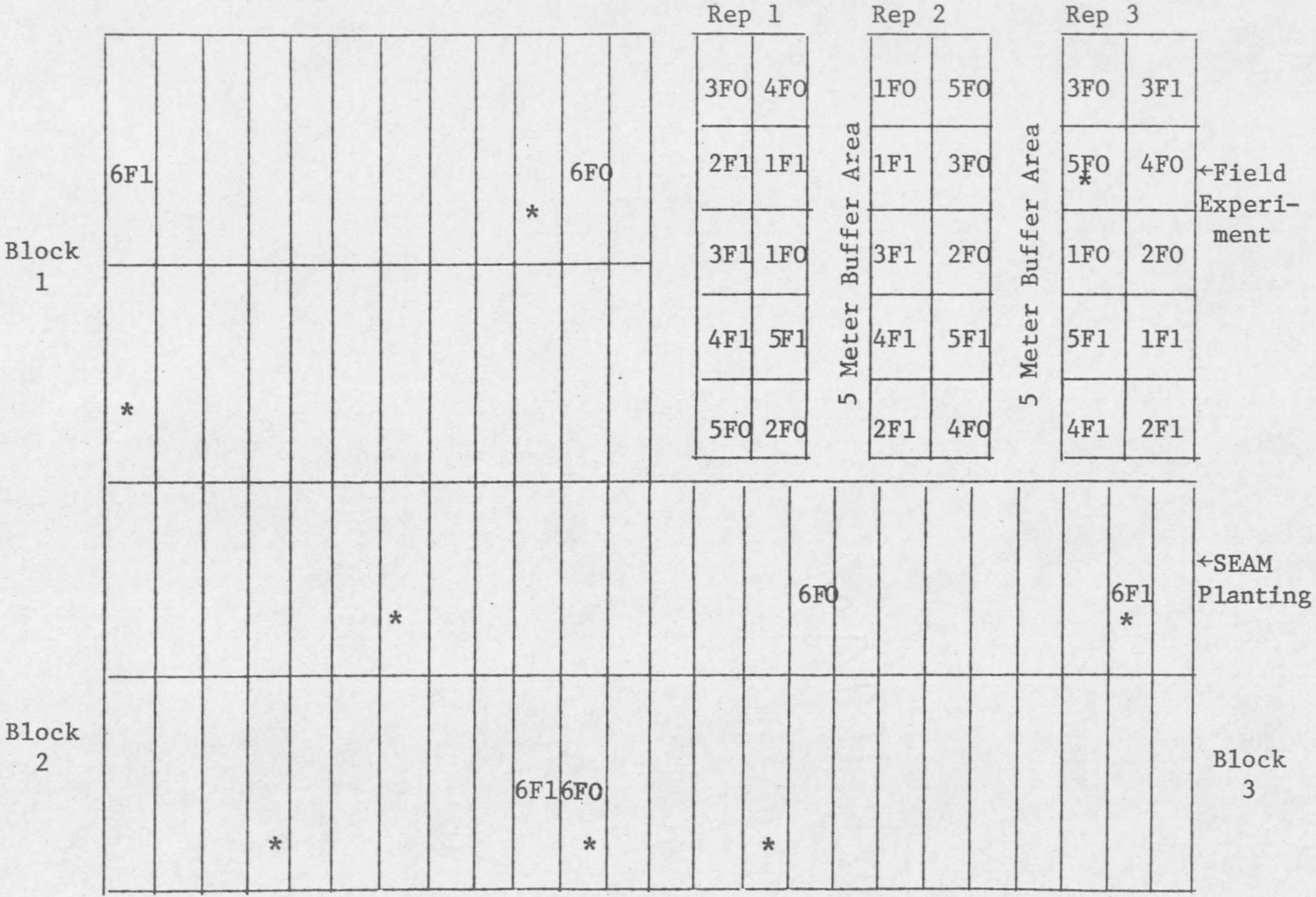
Experimental Unit Dimension = 10 meters X 9 meters

Treatment Codes:
1 = Thickspike wheatgrass
2 = Crested wheatgrass
3 = Ranger alfalfa
4 = Fourwing saltbush
5 = Four species mixture

F0 = 0-0-0 Kg/ha available $N-P_2O_5-K_2O$

F1 = 37-94-0 Kg/ha available $N-P_2O_5-K_2O$

Figure 4. Plot design of field experiment, Colstrip, Montana.



F0 = 0-0-0 Kg/ha available $N-P_2O_5-K_2O$
F1 = 37-97-0 Kg/ha available $N-P_2O_5-K_2O$
1 = Thickspike wheatgrass
2 = Crested wheatgrass
3 = Ranger alfalfa
4 = Fourwing saltbush
5 = Four species mixture
6 = 16 species mixture
*Neutron probe location

Figure 5. Plot design of field experiment and SEAM planting, Colstrip, Montana.

samples were taken in a one meter buffer strip around each experimental unit. The same transects were used on the second sampling date as on the first so survival could be estimated directly between the two periods.

Canopy coverage was estimated on August 17 by using a modification of the Daubenmire method (Daubenmire, 1959). Twenty-one frames were taken per experimental unit at the same points used for density data.

Above ground biomass was clipped on August 19. Three transects different from those used for density were selected for each experimental unit. Five 0.25 square meter quadrats were clipped per transect (Figure 6). The clip quadrats were placed on alternating sides of the transect line. Seeded species were separated from other plants. The primary weed species were Russian thistle (*Salsola kali*), annual sunflower (*Helianthus annuus*), and cheatgrass brome (*Bromus tectorum*). Crested and thickspike wheatgrass were pooled together in the four species mixture because of the difficulty in identifying these two species in the early stages of growth. The seeded species in the 16 species mixture were separated into perennial grasses, legumes, and shrubs. Samples were dried at 60° C for five days before weighing.

Figure 6. Above ground biomass for the field experiment was estimated by the clipping method on August 19, 1975.

The methods used in collecting below ground biomass were modified slightly from those used by Bartos and Sims (1974). Below ground biomass samples were taken from each experimental unit with a portable gas operated soil sampler on August 26, 1975 (Figure 7). The three transects not used for density or above ground biomass data collection were used for sample collection in each experimental unit. Two cores, five cm in diameter, were removed per transect from randomly selected points one meter apart. The cores were separated into depths of 0-15, 15-30, and 30-60 cm. Below ground biomass was separated, dried, weighed, and ashed using the same processes employed in the greenhouse experiment.

Figure 7. The collection of below ground biomass in the field experiment, Colstrip, Montana on August 29, 1975.

RESULTS AND DISCUSSION

The Greenhouse Experiment

Phenology

Phenological data (vegetative versus reproductive growth stage) were collected throughout the period of study for crested wheatgrass, thickspike wheatgrass, ranger alfalfa, and fourwing saltbush. These data showed that fertilizer application hastened plant maturity of crested wheatgrass, thickspike wheatgrass, and ranger alfalfa. These three species flowered in the fertilized treatments but only crested wheatgrass produced seedheads in the unfertilized treatments. In all cases crested wheatgrass was the first to flower.

Plant numbers

Germination data for the six species treatments were collected on April 20, 1975 (Table IV). Fourwing saltbush planted as a monoculture had the highest mean germination (92 percent) while the 16 species mixture had the lowest (29 percent).

Table IV. Percent germination for the six seeding treatments in the greenhouse experiment

Treatment	PLS/m^2	Number of Seeds Germinating/m^2	Percent Germination
Sixteen species mixture	1603	452[1/]	29
Crested wheatgrass	538	409	77
Thickspike wheatgrass	538	366	68
Four species mixture	538	362	67
Ranger alfalfa	538	296	55
Fourwing saltbush	108	99	92

[1/] Main effects for species treatment

The low germination of the 16 species mixture was probably due to a number of factors. Research has shown that different species often require different light, temperature, and soil water regimes for optimal germination (Daubenmire, 1968; Knipe and Herbel, 1960; Smoliak and Johnston, 1968; Weaver and Rowland, 1952). Some species with rapid germination produce chemical substances which are inhibitory to species with delayed germination (Evenari, 1949; Garb, 1961; Muller, 1966; Van Sumere, 1960). The seeding rate of the 16 species mixture was approximately three times the application rate of the four species mixture. Harper (1960, 1961) found that species with rapid germination can often reduce the number of more slowly germinating species by limiting space, light and moisture.

The legume component had a higher percent germination in both seeding mixtures than the grass component (Table V). The legumes germinated three to four days earlier than the grasses in each mixture. This may have affected the germination of the grasses.

Table V. Percent germination for the components of the two mixtures in the greenhouse experiment on April 20, 1975.

Treatment	PLS/m^2	Number of Seeds Germinating	Percent Germination
Four species mixture			
grasses	324	193[1/]	60
legumes	162	129	80
shrubs	54	40	74
Sixteen species mixture			
grasses	1141	330	29
legumes	237	115	49
shrubs	225	14	6

[1/] Main effects for species treatments

Shrub germination was much different between the two mixtures. Greasewood and bitterbrush plants were observed in equal numbers on experimental units planted to the 16 species mixture. Big sagebrush (*Artemisia tridentata*) did not occur in any of the 16 species mixture treatments although it was seeded to represent 95 percent of the shrub component in this mixture.

Only species treatments had a significant effect on plant density (numbers per unit area) results (Appendix Table I; Table IV). Fertilizer had no effect on density or survival. The interaction between seeding and fertilizer treatments was not significant.

Mortality between seedling emergence on April 20 and completion of the experiment on July 1 was statistically significant for crested wheatgrass as a monoculture and the 16 species mixture (Table VI). These two species treatments had the highest densities at emergence. Seedling competition for soil water may have been responsible for the significant mortality rate.

Table VI. Seedling mortality between emergence and completion of the greenhouse experiment on July 1, 1975.

Treatment	Plants/m^2 April 20	Plants/m^2 July 1[1/]	Difference	% Survival
Sixteen species mixture	459^{a} [2/]	395^{a}	-64**	86.1
Crested wheatgrass	409^{a}	346^{a}	-63**	84.6
Thickspike wheatgrass	366^{a}	334^{a}	-32	99.4
Four species mixture	362^{ab}	343^{a}	-19	94.7
Ranger alfalfa	296^{b}	246^{b}	-50	83.1
Fourwing saltbush	99^{c}	113^{c}	+14	114.1

1/ Statistical comparisons and significance valid only within each column.
2/ Means followed by the same letter or letters are not significantly different ($P < .05$) according to Newman-Keuls Test.
* Significant at $P < .05$ using *t* test.
** Significant at $P < .01$ using *t* test.

The percent survival was quite high for grasses in both the four and 16 species mixture between April 20 and July 1 (Table VII). The number of grass seedlings actually increased in the 16 species mixture. The temperature in the greenhouse increased rapidly between the two sampling dates which may have improved germination conditions for some species. Seedcoat hardness often retards germination (McKell, 1974; Whalley and McKell, 1967). This is a possible reason for the delayed germination of some grass seedlings in the 16 species mixture.

The 16 species mixture had considerable reduction in the shrub and legume components. This mixture was seeded at a very high rate. Harper (1967) found that self-thinning increases with increasing seed density. The grasses were evidently better adapted to greenhouse conditions than the shrubs and legumes in the 16 species mixture. The tap root systems of the legumes and shrubs may not have been able to utilize available moisture and nutrients as well as the fibrous root systems of the grasses. Root penetration was definitely restricted by the shallow depth of the test frames. This may have given the grasses a competitive advantage.

Table VII. Seedling mortality for the mixture components in the greenhouse experiment.

Treatment	Plants/m^2 April 20	Plants/m^2 July 1	Difference	% Survival
Four species mixture				
grasses	193	192	-1	99.5
legumes	129	113	-16	87.6
shrubs	40	38	-2	95.0
Sixteen species mixture				
grasses	330	348	+18	105.4
legumes	115	44	-71**	38.3
shrubs	14	3	-11**	21.4

*Significant at $P < .05$ using *t* test.
**Significant at $P < .01$ using *t* test.

Crested and thickspike wheatgrass were easily identified by the presence of seedheads in the fertilized four species mixture treatment. There was no significant difference in density between the two species (Table VIII).

Table VIII. Crested and thickspike wheatgrass numbers in the fertilized four species mixture on July 1 in the greenhouse experiment.

Crested wheatgrass plants/m^2	Thickspike wheatgrass plants/m^2	Difference
93	99	6[1/]

[1/] No significant difference at $P < .05$ using *t* test.

Production

The main effects of species and fertilizer treatments were significant for above and below ground biomass (Figure 8 and Appendix Table II). A significant interaction indicated the different species did not respond uniformly to fertilizer application. Table IX presents the mean above and below ground biomass for the six species treatments.

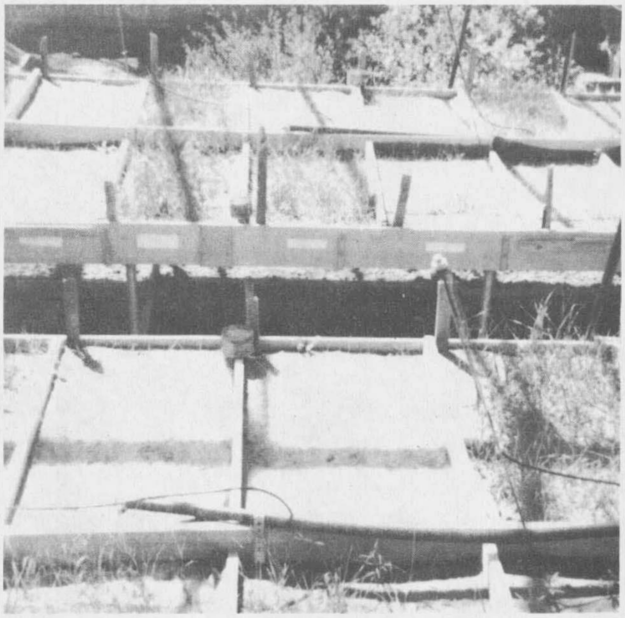


Figure 8. A section of the benches in greenhouse study showing the difference between fertilized and unfertilized treatments on June 5, 1975.

Table IX. The main effects of species treatments on plant production in the greenhouse experiment on July 3, 1975.

Treatment	Above Ground[1/] Biomass Kg/ha	Below Ground Biomass Kg/ha
Four species mixture[2/]	2221^{a} [3/]	3066^{a}
Sixteen species mixture	876^{b}	1496^{b}
Crested wheatgrass	732^{b}	1340^{b}
Thickspike wheatgrass	695^{b}	1299^{b}
Ranger alfalfa	448^{b}	503^{c}
Fourwing saltbush	408^{b}	474^{c}

1/ Main effects for species treatments.

2/ Above and below ground biomass means were ranked separately.

3/ Means followed by the same letter or letters are not significantly different ($P < .05$) using Newman-Keuls Test.

The four species mixture produced significantly more above and below ground biomass than the other species treatments (Figures 9 and 10). This mixture had vigorous initial vegetative growth which may have resulted in more shading at the soil surface. In the last 45 days of the experiment, the four species mixture test frames in both fertilized and unfertilized treatments were visibly more damp at the soil surface than the other test frames. The apparent shading effect could have offset the greater use of water by the four species mixture.

The above and below ground production of each species treatment were tested separately for each fertilizer treatment (Table X and XI). Fertilizer significantly increased above and below ground biomass for all species treatments.

Figure 9. The fertilized four species mixture treatment in the greenhouse on June 15, 1975

Figure 10. Fertilized 16 species mixture treatments in the greenhouse on June 15, 1975.

Table X. The effects of fertilizer on above ground biomass in the greenhouse experiment.

Treatment	Fertilized[1/] Kg/ha	Unfertilized Kg/ha	Difference Kg/ha	% Increase
Four species mixture	2937^{a} [2/]	1506^{a}	+1431**	95.2
Sixteen species mixture	1078^{b}	663^{b}	+415*	62.4
Crested wheatgrass	1151^{b}	315^{c}	+836**	265.4
Thickspike wheatgrass	1074^{b}	316^{c}	+758**	239.9
Ranger alfalfa	569^{c}	327^{c}	+242**	74.0
Fourwing saltbush	535^{c}	280^{c}	+255**	91.1

1/ Statistical comparisons and significance valid only within each column.

2/ Treatments with different letters are significantly different ($P < .05$) using the Newman-Keuls Test.

* Significant at $P < .05$ using *t* test.

** Significant at $P < .01$ using *t* test.

Table XI. The effects of fertilizer on below ground biomass in the greenhouse experiment.

Treatment	Fertilized[1/] Kg/ha	Unfertilized Kg/ha	Difference Kg/ha	% Increase
Four species mixture	3683^a [2/]	2448^a	1235**	50.5
Crested wheatgrass	2178^b	420^c	1758**	418.6
Thickspike wheatgrass	2054^b	627^c	1427*	227.6
Sixteen species mixture	1827^b	1165^b	622**	56.8
Fourwing saltbush	744^c	204^c	540**	264.7
Ranger alfalfa	683^c	325^c	358**	110.2

[1/] Statistical comparisons and significance valid only within each column.

[2/] Treatments with different letters are significantly different ($P < .05$) using the Newman-Keuls Test.

* Significant at $P < .05$ using *t* test.

** Significant at $P < .01$ using *t* test.

The legume and shrub components contributed more to the total above ground biomass in the four species mixture than in the 16 species mixture (Table XII). This indicates the species in the four species mixture were better able to use the environmental resources available in the greenhouse than those in the 16 species mixture. It also suggests that the species in the four species mixture were highly compatible under greenhouse conditions. This may mean that a mixture seeded with equal numbers of grasses, shrubs and legumes is more productive than one in which the three components are unbalanced.

Table XII. Above ground biomass of the mixture components in the greenhouse experiment on July 2, 1975.

Treatment	Fertilized Kg/ha	Unfertilized Kg/ha	Difference Kg/ha	% Increase
Four species mixture				
grasses	1617	557	+1060**	+190.3
legumes	793	497	+296*	+59.6
shrubs	527	452	+75	+16.6
Sixteen species mixture				
grasses	967	597	+370**	+62.0
legumes	108	66	+42	+63.6
shrubs	3	-	3	-

*Significant at $P < .05$ using *t* test.
**Significant at $P < .01$ using *t* test.

The Field Experiment

Soil Water

Precipitation at Colstrip, Montana in the spring of 1975 was much higher than average (Table I). This resulted in more favorable conditions for plant establishment than in a normal year.

Soil water data were collected at the field experiment site on a monthly basis using the neutron scatter method. Figure 11 shows the average percent soil moisture at different depths for March through September in 1975. In July soil water dropped sharply and low soil water conditions prevailed through September. Plants were only subjected to severe moisture stress in the middle and latter part of August. The