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

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by

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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, P_2O_5, and K_2O.

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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.

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 microorganism 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 desertorum*), 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 (^{o}C)		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 forms the 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.