



The potential for dryland alfalfa on minesoils in southeastern Montana
by Robert Cairns Postle

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land
Rehabilitation

Montana State University

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Abstract:

Surface coal mining in southeastern Montana is disturbing areas of cropland, and in particular alfalfa fields, which are significant to local farm-ranch units. To date little research has been conducted on reestablishing alfalfa fields on minesoils. This study evaluated the potential for dryland alfalfa production on minesoils in Colstrip, Montana. Two fields, one on minesoils and one on undisturbed soils, were evaluated and compared. Alfalfa production and cover was measured at each field and alfalfa samples were analyzed for forage quality using NIR spectroscopy. Soils were characterized physically and chemically to help explain possible difference.

Alfalfa cover on the undisturbed soil was greater than on the minesoil. Production from the two fields was equal. The forage quality of the alfalfa from both fields was well within the standard range of such values for this species. In general, the soils of the two fields were similar. Based on these results the potential for dryland alfalfa production on minesoil comparable to undisturbed sites in the same area does exist.

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

of

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in

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May 1985

APPROVAL

of a thesis submitted by

Robert Cairns Postle

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

16 May 1985
Date

Frank F. Manshower
Chairperson, Graduate Committee

Approved for the Major Department

May 16, 1985
Date

Arthur Z. Linter
Head, Major Department

Approved for the College of Graduate Studies

5-20-85
Date

MS Malone
Graduate Dean

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ABSTRACT

Surface coal mining in southeastern Montana is disturbing areas of cropland, and in particular alfalfa fields, which are significant to local farm-ranch units. To date little research has been conducted on reestablishing alfalfa fields on minesoils. This study evaluated the potential for dryland alfalfa production on minesoils in Colstrip, Montana. Two fields, one on minesoils and one on undisturbed soils, were evaluated and compared. Alfalfa production and cover was measured at each field and alfalfa samples were analyzed for forage quality using NIR spectroscopy. Soils were characterized physically and chemically to help explain possible difference.

Alfalfa cover on the undisturbed soil was greater than on the minesoil. Production from the two fields was equal. The forage quality of the alfalfa from both fields was well within the standard range of such values for this species. In general, the soils of the two fields were similar. Based on these results the potential for dryland alfalfa production on minesoil comparable to undisturbed sites in the same area does exist.

INTRODUCTION

Throughout the Northern Great Plains there is concern over the environmental and economic impacts of coal development. While the total impact of coal surface mining on the region may be low, the effects on specific areas may be great. Rosebud County is one of five counties in which 50 percent of the total coal mining in the Northern Great Plains is expected to occur (NGPRP 1975). State-of-the-art reclamation technology must be applied in order to reduce environmental and economic impacts.

The current land use for most areas overlying coal deposits in Montana is the production of domestic livestock (Thornburg 1974). As a consequence of this historic and probable future land use, the 1979 Montana Stripmining and Reclamation Act requires that mined land be returned to a rangeland condition capable of supporting domestic animals. Extensive research has been carried out to determine how to restore the mined lands to premine range conditions. In addition to rangeland, small acreages of cropland have and will continue to be disturbed by mining. It is projected that five percent of the area disturbed by mining in Rosebud County will be cropland. While the loss of this cropland may be insignificant to the country or state as a whole, the impact will be very significant to individual farm-ranch units located adjacent to mine operations (NGPRP 1975). The loss of croplands, particularly alfalfa fields, could render ranching uneconomical through loss of winter feed for cattle. To date, little work has been done on restoring croplands on reclaimed mine spoils. Research dealing with reestablishment of croplands, and in particular alfalfa fields, is essential to maintain the economic viability of ranching and the integrity of ranch units in the region. The research will also provide information vital for meeting

the alternative reclamation requirements of the 1979 Montana Stripmining and Reclamation Act.

The objective of this research was to evaluate the potential for dryland alfalfa production on minesoils at Colstrip, Montana. This study was not intended to be a definitive investigation of the potential for agricultural production on Great Plains minesoils, but rather a preliminary assessment of the ability of minesoils to produce an alfalfa crop that would meet animal and economic needs of ranching interests in the study area. This was accomplished by comparing the yields and forage quality of alfalfa from two established fields, one on mined land, the other on undisturbed soils. Soil physical and chemical characteristics were examined in order to explain any major differences in yield or proximate analysis.

LITERATURE REVIEW

Alfalfa (*Medicago sativa* L.), commonly referred to as the "Queen of the Forage Crops," is a herbaceous, perennial legume. It has erect growth and a deep taproot system which enables it to utilize water from great depths under drought conditions (Miller 1984). Alfalfa is adapted to a wide range of climatic conditions and is distributed worldwide (Lowe et al. 1972). Soils best suited for alfalfa production are deep, well-drained, fertile and slightly alkaline (Miller 1984). In semiarid regions the majority of alfalfa acreage is under irrigation. The remainder of alfalfa production in semiarid regions occurs under dryland conditions, in areas where seasonal precipitation is adequate (Lowe et al. 1972). Ditterline et al. (1976) stated that 33 cm or more of precipitation are required to produce one good hay crop in areas with winter-spring precipitation patterns.

In Montana, which has a semiarid environment, alfalfa is the leading hay crop. Nationally, Montana ranked tenth in alfalfa hay production. More than half the total hay acreage in Montana in 1982 was in alfalfa (MDA 1983). Of the total acreage in alfalfa hay, approximately half is grown under nonirrigated conditions. Statewide, during the last five years, nonirrigated alfalfa production averaged from 3,001 kg/ha in 1979 to 4,077 kg/ha in 1982 (MDA 1980, 1982, 1983). Precipitation was below normal statewide in 1979 and above normal in 1982. In southeastern Montana, which has an average annual precipitation of 35.0 cm, nonirrigated alfalfa production averaged 1,971 kg/ha in 1980 and 4,278 kg/ha in 1982. Again precipitation was the controlling factor. Annual precipitation in 1980 was 29.2 cm while in 1982 it was 48.9 cm (MDA 1980, 1982, 1983). Much of the alfalfa hay raised in Montana is used by ranchers for livestock feed (Ditterline et al. 1976).

The value of alfalfa as a reclamation species has been recognized for some time. Grandt and Lang (1958) reported that alfalfa was one of the best adapted species over all the strip mine areas in Illinois. They also reported excellent hay yields on leveled spoils. More recent research on coal mine spoils in the Northern Great Plains has identified alfalfa as well suited for use in revegetation of mine soils (Holecheck et al. 1982; Nicholas and McGuinnies 1982; Depuit et al. 1978, 1977; Sindelar et al. 1973). In these studies alfalfa was included in grass-legume-shrub seed mixtures. Sindelar et al. (1973) identified Ladak alfalfa as being well adapted to both noninhibitory spoils and saline-sodic spoils. Ladak alfalfa was used in pasture seed mix at Colstrip, Montana, and yields averaged 1,800 kg/ha with a maximum yield of 3,000 kg/ha (Depuit et al. 1977). Legume trials at Colstrip indicated that both Spreader and Ranger alfalfa cultivars were suitable reclamation species (Holecheck et al. 1982; Depuit et al. 1978). However, production from the two varieties was low, averaging 1,225 and 558 kg/ha, respectively. In research performed in North Dakota, dryland alfalfa yielded an average of 2,500 kg/ha when 90 cm of topsoil and subsoil was placed over sodic spoils (Power et al. 1981). This yield was equal to that expected from undisturbed soils in the area under good management. Alfalfa has also been recognized as a species suitable for use in revegetating iron and copper tailings (Shetron 1983).

Alfalfa is a valuable food source for wildlife. Egan (1957), working in Rosebud County, reported that mule deer used alfalfa fields and peak utilization occurred in August and September. Alfalfa production was not significantly reduced by deer browsing. Antelope also utilize alfalfa. Cole (1955) stated that alfalfa accounted for 14 percent of their diet and peak utilization occurred in September. Antelope depredation did reduce plant and seed production and could adversely affect second-cutting yields or seed harvest.

Alfalfa is valued as a nutritious foodstuff for livestock. Proximate analysis provides some indication of the nutritional value of this plant. Standard analysis values for alfalfa in the early bloom stage reported by the National Research Council (1971, 1982) were 18 to

20 percent crude protein (CP), 23 to 30 percent crude fiber (CF), 8.7 to 9.6 percent ash, 2.2 to 3.1 percent ether extract, 37 to 40 percent nitrogen free extract (NFE) and 51 to 59 percent total digestible nutrients (TDN). Newer techniques involved the determination of neutral detergent fiber (NDF) which represents the total plant cell wall and acid detergent fiber (ADF) which gives the lignocellulose and silica content of the plant (Miller 1984). Standard values for alfalfa plants in the first flower to mid-bloom maturity stage are 31 to 35 percent for ADF and 40 to 46 percent for NDF (Rohweder 1976; NAS 1982). Regression equations have been developed to use ADF and NDF to predict in vivo digestible matter (DDM) and dry matter intake (DMI) respectively (Rohweder 1976). Unfortunately, the correlation coefficients for these predictive equations were poor, $r = 0.71$ for DDM and $r = 0.56$ for DMI.

The chemical composition of alfalfa grown on minesoils in past revegetation efforts was similar to standard values. Grandt and Lang (1958) reported crude protein levels averaging 18.3 percent over a four-year period. Alfalfa and sweetclover grown in an improved pasture on reclaimed spoils in Montana had average values of 20 percent for CP, 2.6 percent for ether extract, 8.5 percent for ash, 28 percent for CF, 45 percent for NFE and 58 percent for TDN (Deput et al. 1977).

Recently near infrared reflectance spectroscopy (NIR) has been gaining acceptance as a technique for forage analysis. The advantage of NIR is its ability to rapidly and accurately predict forage quality (Shenk et al. 1979). This technique allows prediction of crude protein, acid detergent fiber, neutral detergent fiber, in vitro digestible dry matter and in vivo digestibility (Norris et al. 1976; Marten et al. 1983). Using multiple linear regression techniques to determine the optimum monochromatic wavelengths, prediction equations were developed for each forage parameter (Norris et al. 1976; Barnes 1981). Reflectance readings from up to nine wavelengths are used in each predictive equation. In comparing NIR to chemical analysis for forage quality, reported coefficients of determination range

from 0.99 for crude protein to 0.90 for *in vitro* dry matter digestibility for a variety of forage species (Norris et al. 1976; Marten et al. 1983). Researchers at Montana State University, working with alfalfa, have developed predictive equations for CP, CF, ether extract, NDF, ADF and *in vitro* dry matter digestibility (IVDMD) (Stivers 1984). Coefficients of determination for NIR were 0.96 for CP, 0.85 for ether extract, 0.93 for CF, 0.90 for NDF, 0.94 for ADF and 0.76 for IVDMD when the technique was compared to chemical analysis. This technique has not been applied to reclamation work to date.

Besides alfalfa's value as a high-yield, high-quality feed source, alfalfa has the potential to improve soil chemical and physical properties. Alfalfa is a legume and one of its major benefits is its ability to fix atmospheric nitrogen. Conservative estimates range from 80 to 100 Kg N/ha per year (Burton 1972). Other studies have reported to up 500 Kg N/ha added to soil following three years of growth (Brown et al. 1963; Sturkie 1960; Belyakova 1956). The major sources of this nitrogen appears to be nodule sloughing and decay of dead roots (Chamblee 1972; Brown et al. 1963; Belyakova 1956). Both nitrogen and organic matter are added to the soil when alfalfa is used in a crop rotation or as a green manure (Brown 1964; Larsen et al. 1958; Rodgers and Gidden 1975). Larsen et al. (1958) reported a 1.37 percent increase in organic matter following alfalfa use in a crop rotation scheme. Soil moisture depletions and the resultant reduction in crop yields preclude the recommendation of alfalfa as a green-manure crop for semi-arid regions.

Legumes improve the physical properties of soils. Rodger and Giddens (1957) state that cover crops, including alfalfa, have the potential to improve aggregation, reduce bulk density and increase infiltration. Alfalfa increases the number of water stable soil aggregates (Brown 1964; Klintworth et al. 1957). Alfalfa roots are able to penetrate soils with bulk densities as high as 1.90 g cm^{-3} which aids in reducing soil compaction (Gifford and Jensen 1967; Fehrenbache et al. 1965; Scott and Erickson 1964). Increased aggregation and reduced compaction tend to increase infiltration (Rodger and Giddens 1957).

The USDA land capability classification system has been used nationwide as a measure of land potential and is used to define prime agricultural land. Under current reclamation laws prime areas suited mainly for grazing showed an increase in agricultural capability class following mining (Schafer, 1982). However, prime farmlands underwent a decrease in land capability class following mining. The increases in land capability class were primarily the result of increased soil depths and reduced slopes. Decreases were caused by elevated salt and sodium in the subsoil, thin topsoil and increased erosion. Despite increases in land capability class, crop productivity generally decreases following mining (Nielsen and Miller 1980). Schafer (1981) speculated that the cause was reduced organic matter and a lack of soil structure and nutrient cycling. Schroeder and Doll (1984) stated that soil structure was necessary for good crop yield because of improved infiltration, porosity and root penetration.

Numerous researchers recommend using grass-legume mixtures prior to initiation of row crop production on reclaimed prime farmland because of their ability to improve soil physical characteristics (Ralston 1982; Nielsen and Miller 1980; Grandt 1978b). Grandt (1981) recommended the use of alfalfa in crop rotations on minesoils because it is deep-rooting and builds soil structure. Studies in West Virginia showed that 10-year-old revegetated spoils had a greater number of stable soil aggregates than nonvegetated areas, but less than undisturbed areas (Wilson 1957). Wilson also reported that the type of vegetation was an important factor in soil aggregate formation and that grass-legume mixes were most effective. Increased infiltration rates have been reported on spoils revegetated with legumes (Grandt and Lang 1958). Alfalfa also provides an economical source of nitrogen and increase soil microorganism levels in minesoils (Grandt 1978a).

MATERIALS AND METHODS

Site Selection

The dryland hay field located in revegetated minesoils was chosen because of the alfalfa density and past production. Although originally seeded in the fall of 1979 with a grass-legume-shrub mixture, Ladak alfalfa seeding rates were high. This resulted in a dense stand of Ladak alfalfa, much higher than anticipated for rangeland development.

To evaluate the potential for dryland alfalfa on revegetated minesoils, a similar field on undisturbed soils had to be identified. Two main criteria were used. First, the same variety of alfalfa had to have been planted on the undisturbed dryland site. Second, the alfalfa had to have been planted at approximately the same time as that on the reclaimed site. These criteria were chosen because differences in either alfalfa variety or stand age could affect alfalfa yield and make any comparisons meaningless. A site meeting these criteria was located approximately 18 km west of the mined land study site.

Vegetation Sampling

Alfalfa Production

Alfalfa and associated grasses and forbs were clipped for production between June 18 and 20, 1983. The alfalfa was clipped when the two fields were at 1/10 bloom stage. A total of 40, 0.5 m² frames were used to sample each field. The frames were located at 20 m intervals along a transect the length of the field. All vegetation was clipped to a height of 10 cm to emulate the cutter bar height generally used in alfalfa harvesting. The clipped samples were separated into three classes: alfalfa, grasses and other species. The alfalfa, grasses and other vegetation was then oven dried at 67° C to constant weight.

Canopy Cover

Alfalfa canopy cover was recorded for both fields between June 18 and 20, 1983. Canopy cover was determined for each of the 40 0.5 m² frames prior to clipping. The alfalfa cover was estimated to the nearest percent.

Alfalfa Quality

Alfalfa was assayed for crude protein, fat, *in vitro* dry matter digestibility, crude fiber, acid detergent fiber and neutral detergent. Forage quality was determined using near infrared-reflectance spectroscopy. This method is based on techniques developed by Norris et al. (1976) and Marten et al. (1983). This technique was utilized because of the low cost of analysis and high correlation compared to wet chemical analysis. Up to six wavelengths were used to predict alfalfa quality.

Twenty dried alfalfa samples were chosen at random from the alfalfa production samples. These were ground to pass a 1 mm screen in a Udy cyclone mill. Approximately 2 g of sample were placed in a sample holder that had a quartz window and pressure pad. Samples were illuminated with monochromatic light and the reflectance was recorded with lead-sulfide detectors in a Technicon 420 NIR monochromator. Using multiple linear regression equations developed by Stivers (1984) reflectance was used to predict the percent composition of the six previously mentioned forage quality parameters.

Soil Sampling

Physical and Chemical Characteristics

Reconstructed mine soils and undisturbed soils from both dryland alfalfa fields were characterized, both physically and chemically. Ten cores were taken from each field on October 10, 1983, at 40 m intervals along a transect. The cores were divided into two increments, 0 to 30 cm (cover soil depth on the reclaimed area) and 30 to 120 cm. The

samples were frozen, returned to the lab, dried and ground to 2 mm, and analyzed (Table 1).

Bulk Density

Bulk density of the soils was determined using cores extracted with a Giddings soil sampler (Blake 1965). Five cores were taken from each field to a depth of 180 cm. Each was divided into 10 cm increments for the first 30 cm and 15 cm increments for the 30 to 180 cm intervals. These were dried, weighed and the bulk density of the soil cylinder determined.

Root Biomass

Root biomass was determined using the cores collected for bulk density determinations (Bartos and Sims 1974). Bulk density core increments were combined into 30 cm intervals and the roots were rinsed free of soil using a root washer similar to that of Brown and Thilenius (1976). Soil-free roots were dried, weighed, ashed and reweighed to get the ash-free weight. Root biomass was then calculated based on the core volume.

Infiltration

Infiltration was measured on October 10, 1983, using a rainfall simulator developed by Meeuwig (1971). Water was applied at a rate of 17.3 cm/hr for 30 minutes. Runoff was collected and measured at three-minute intervals. The procedure was repeated three times on each field. A curve showing infiltration over time was developed.

Table 1. Laboratory Procedures for Soil Analysis.

Parameter	Procedure	Reference
Particle size distribution	8 hour hydrometer	Day (1965) ASA Monograph #9 Part 1, p. 562
1/3 bar and 15 bar water	pressure plate	Klute (1965) ASA Monograph #9 Part 1, p. 273
Available water holding capacity	subtraction	Peters (1965) ASA Monograph #9 Part 1, p. 279
pH	water saturated paste extract-electrode	Peech (1965) ASA Monograph #9 Part 2, p. 914
Electrical conductivity	water saturated paste extract	USDA Handbook 60, p. 8
Ca, Mg, Na	water saturated paste extract	Sandoval and Power (1977) USDA Handbook 525
Sodium adsorption ratio	water soluble calculated $\text{Na}/[(\text{Ca} + \text{Mg})/2]^{1/2} \text{ meq/l}$	USDA Handbook 60, p. 156
Nitrate-N	chromotropic acid	Sims and Jackson (1971) SSSA Proc 35:603-606
Phosphorus	Olsen-Sodium bicarbonate extractable	Sandoval and Power (1977) USDA Handbook 525
Potassium	ammonium acetate extractable	Sandoval and Power (1977) USDA Handbook 525

Statistics

Sample size was determined for alfalfa and soil sampling based on statistics and economics. Sample size (n) was calculated using the equation

$$n = \frac{t^2 s^2}{d^2}$$

where t is the tabulated 't' value, s is the standard deviation and d is half the desired confidence interval (Steel and Torrie 1980). Standard deviations used in the tests were taken from previous studies in the area.

Comparisons of alfalfa production, alfalfa quality and soil parameters from the two fields were made using the standard "t" test. Prior to testing for differences between the two sites, the variances of the response means from the two fields were tested for equality. This was done using a F test which compares the variances from the two populations (Steel and Torrie 1980). If the variances were found equal, a test for independent samples and equal variances was used (Steel and Torrie 1980). When the variances were found unequal, a "t" test for independent samples and unequal variances was used (Steel and Torrie 1980). For the cases where the variances were unequal, it was necessary to calculate the effective degrees of freedom as described by Steel and Torrie.

The null hypothesis tested in the study was that the mean responses of the parameters examined were equal. Significance was defined as the rejection of the null hypothesis with a probability greater than 95 percent.

DESCRIPTION OF STUDY SITES

Location

The minesoil study site was located in Area A of Western Energy Company's Rosebud Mine at Colstrip, Rosebud County, Montana (Figure 1). The legal description for this site was NE $\frac{1}{4}$, S5, T.1N R.41E of the Montana Principal Meridian. The field covered approximately 57 acres. The study site on undisturbed soil was located 18.4 kilometers west of Colstrip, Rosebud County, Montana. The legal description for this site was the E $\frac{1}{2}$, SW $\frac{1}{4}$, S.34, T.2N, R.39E of the Montana Principal Meridian. It covered approximately 50 acres.

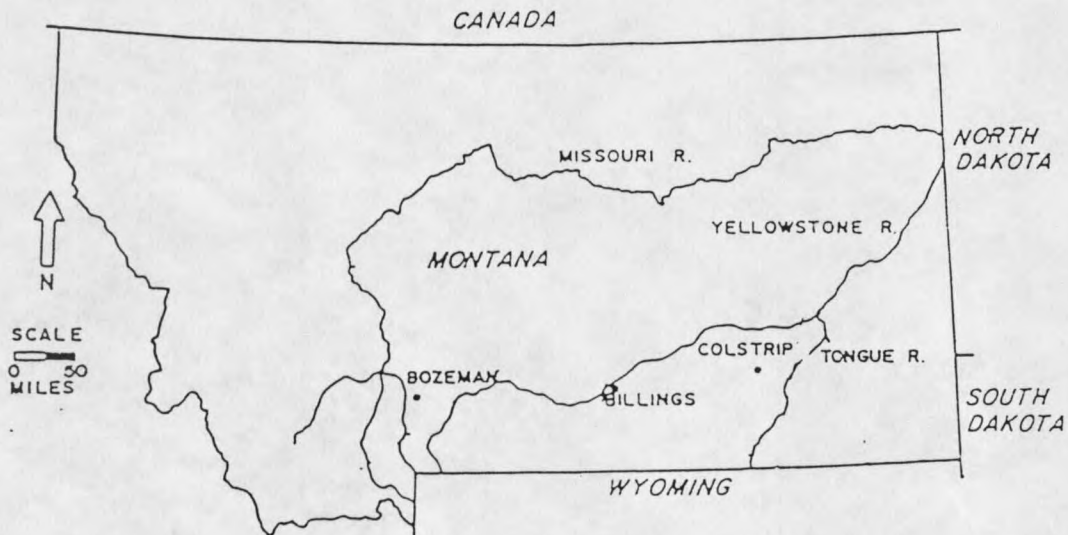


Figure 1. Map showing location of Colstrip, Montana.

Topography and Geology

Resistance of geologic strata to erosion largely determines the topography of the Colstrip area (Skilbred 1979). The landscape is dominated by gently rolling, wide, shallow valley and broad, flat divides with occasional outcrops of remnant sandstones and clinker beds forming ridges and buttes (Veseth and Montagne 1980). Streams generally drain northward, flowing into the Yellowstone River.

The geology of eastern Montana is dominated by soft, nonmarine sediments laid down during the late cretaceous and early tertiary (Veseth and Montagne 1980). The sediment source was the uplifting mountains of western Montana. The Colstrip area geology is dominated by the Tongue River member of the Fort Union Formation. The Tongue River member is composed of soft interbedded lenticular sandstones; gray claystones and shales; thin, dark, carbonaceous shales; coal seams; and clinker beds. Clinker beds, formed by the baking of sediments, form resistant caps on buttes and ridges of the area.

Climate

Colstrip has a continental climatic regime characterized by cold winters and warm summers (Meyn et al. 1976). July is usually the warmest month; January is the coldest (Munshower and Depuit 1976). Colstrip is in a semiarid region with an average annual precipitation of 40.1 cm (N.O.A.A. 1981). The majority of the precipitation occurs in April, May and June.

Long-term average monthly precipitation, monthly precipitation for the 1982-1983 growing season and the deviation from the averages of 1983 monthly precipitation are presented in Table 2. Precipitation was below normal for the entire year. During the critical months of April, May and June, precipitation was 11.9 cm less than the average.

Table 2. Average Long Term Monthly Precipitation, Actual Monthly Precipitation and the Deviation from the Monthly Average for Colstrip, Montana 1982-1983.

Month	Average Precipitation (cm)	1982-1983 Precipitation (cm)	Deviation
October	2.6	3.3	+0.7
November	1.7	1.0	-0.7
December	1.7	1.5	-0.2
January	1.4	0.7	-0.7
February	1.4	0.1	-1.3
March	1.9	0.6	-1.3
April	4.7	0.1	-4.6
May	6.3	4.1	-2.2
June	8.4	3.3	-5.1
July	3.0	4.2	+1.2
August	3.5	3.4	-0.1
September	3.5	3.6	+0.1
Annual	40.1	25.9	-14.2

History of the Sites

Stockpiled coversoil was applied to the study site on reclaimed land in the spring and summer of 1979. The site was broadcast seeded in the fall of 1979 with Western Energy's approved rangeland seed mix. The fertilization rate varied across the field but between 144 and 225 lbs/acre of 11-55-0 fertilizer was applied in the fall of 1979. The mix included Ladak alfalfa, numerous wheatgrass species (*Agropyron* spp.), green needlegrass (*Stipa viridula*), fourwing saltbrush (*Atriplex canescens*) and several forbs. At that time, alfalfa was an accepted legume in Western Energy's seed mix. Since, alfalfa has become the dominant species in the field. The field was cut once prior to this study, in July 1982 a local rancher cut and baled this field.

The study site on undisturbed soils was seeded to Ladak alfalfa in the spring of 1980. It had been cut in subsequent years at approximately 1/10 bloom. During years in which seed set was adequate, alfalfa seed was harvested in September.

Soils of the Study Sites

Soil profiles typical of the study sites were described according to *Soil Taxonomy* (Soil Survey Staff, 1975), with modifications for mine soils suggested by Schafer (1979a). The two profile descriptions are given in Table 8 of Appendix A. The mine soil was classified as a fine-loamy, mixed Typic Ustorthent. Using unofficial soil series names from Schafer (1979), the mine soil study site was placed in the Cow Creek Series. The undisturbed soil was classified as a fine-loamy, mixed Aridic Haploboroll. Using recognized soil series names, the study site on undisturbed soil was placed in the Kremlin Soil Series. Also present in this field were Borollic Camborthids and Ustic Torripsamments which were placed in the Busby-Yetull complex and the Yamac Series (SCS 1985).

Using criteria developed by Klingebiel and Montgomery (1961) and Schafer (1979), both study sites were classified as land capability Class IV. This class is suitable for cultivated pasture and rangeland. The major limitation of the mine soils was a mean EC above 2 mmhos/cm for the spoil material (30 to 120 cm). The major limitations of the undisturbed soil was inadequate available water-holding capacity in the topsoil.

Soil physical data by depth and location for the two study sites are presented in Table 3. Particle size distribution and texture was similar for the 0 to 30 cm zone. Both sites had a sandy clay loam texture. For the 30 to 120 cm zone, particle size analysis revealed that the mine soil had significantly less sand and more silt and clay than the undisturbed soil. The mine soil was classified as a clay loam while the undisturbed soil was a sandy clay loam. The texture of the soils of the two sites varied widely across the field (Table 9, Appendix B).

The 0.3 bar and plant-available water-holding capacities for the 0 to 30 cm depth for the two soils were significantly different. The mine soil had a higher 0.3 water-holding capacity and more plant-available water. The 15 bar water-holding capacity for the two

Table 3. Mean Particle Size Distribution and Volumetric Water-Holding Capacities for Two Depths of the Two Soils.

Depth Site	0 to 30 cm		30 to 120 cm	
	Undisturbed Soil	Minesoil	Undisturbed Soil	Minesoil
Sand %	50 ^a	45 ^a	52 ^a	33 ^b
Silt %	26 ^a	28 ^a	26 ^a	39 ^b
Clay %	24 ^a	27 ^a	22 ^a	28 ^b
Texture	sandy clay loam	sandy clay loam to loam	sandy clay loam	clay loam
1/3 bar %	21.3 ^a	26.6 ^b	26.0 ^a	32.3 ^b
15 bar %	15.5 ^a	17.1 ^a	15.1 ^a	22.7 ^b
Plant available %	5.8 ^a	9.5 ^b	10.9 ^a	9.6 ^b

The same letter across columns within a soil depth indicates no significant difference at the 0.05 level.

soils was similar. Significant differences in water-holding capacities for the 30 to 120 cm zone were also present between the two sites. The minesoil had higher 1/3 bar and 15 bar water-holding capacities but the percent plant-available water was lower. The water-holding capacities of the soils at both depths for both fields varied with the texture (Table 9, Appendix B).

Infiltration rates, as measured with the Meeuwig rainfall simulator, at the two sites were similar (Figure 2). The measured infiltration rate of the minesoil was 14.1 cm/hr. The infiltration rate of the undisturbed soil was 14.6 cm/hr. These infiltration rates are similar to rates measured on minesoils and undisturbed soils in the Colstrip area by Schafer et al. (1979) and Norbeck et al. (1984). The minesoil had greater variation in infiltration rates than the undisturbed soil.

The bulk densities of the two soils are similar for the 0 to 45 cm depth (Figure 3). The bulk density of the minesoil for the 0 to 45 cm depth ranged from 1.47 g cm⁻³ to 1.70 g cm⁻³, while that of the undisturbed soil ranged from 1.44 g cm⁻³ to 1.58 g cm⁻³. The minesoil had significantly higher bulk densities for the 45 to 135 cm depth. Bulk

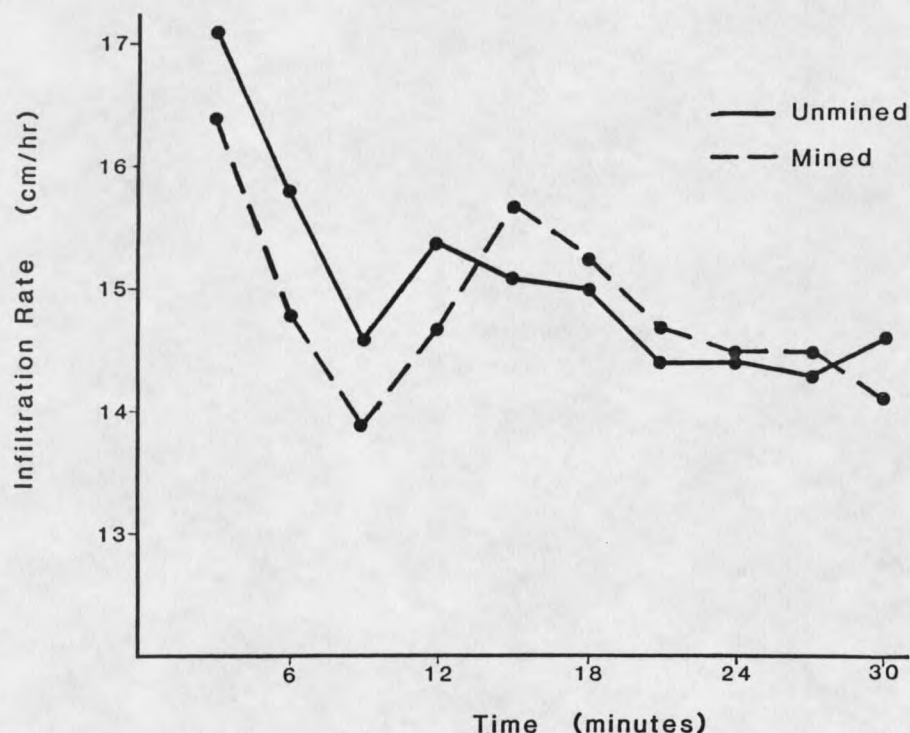


Figure 2. Infiltration rate of the two soils.

densities ranged from 1.68 to 1.80 g cm^{-3} in the minesoil. The undisturbed soil had bulk densities ranging from 1.52 to 1.60 g cm^{-3} . Below the 135 cm depth, bulk densities were similar for the two sites. The bulk densities measured in this study were similar to those reported by Schafer et al. (1979).

Generally, the chemistry of the 0 to 30 cm depth of the two soils was similar (Table 4). The pH, electrical conductivity, sodium adsorption ratio, calcium, magnesium, sodium and potassium levels were not significantly different. The undisturbed soil had significantly higher $\text{NO}_3\text{-N}$ and P levels compared to the minesoil for this depth. The nitrate nitrogen, phosphorus and potassium levels from the two sites were within the range of those reported in soils of the area (Dollhopf et al. 1978; Munshower et al. 1975). Phosphorus levels were considered very low for dryland alfalfa production (Wilson and Christensen 1978). The

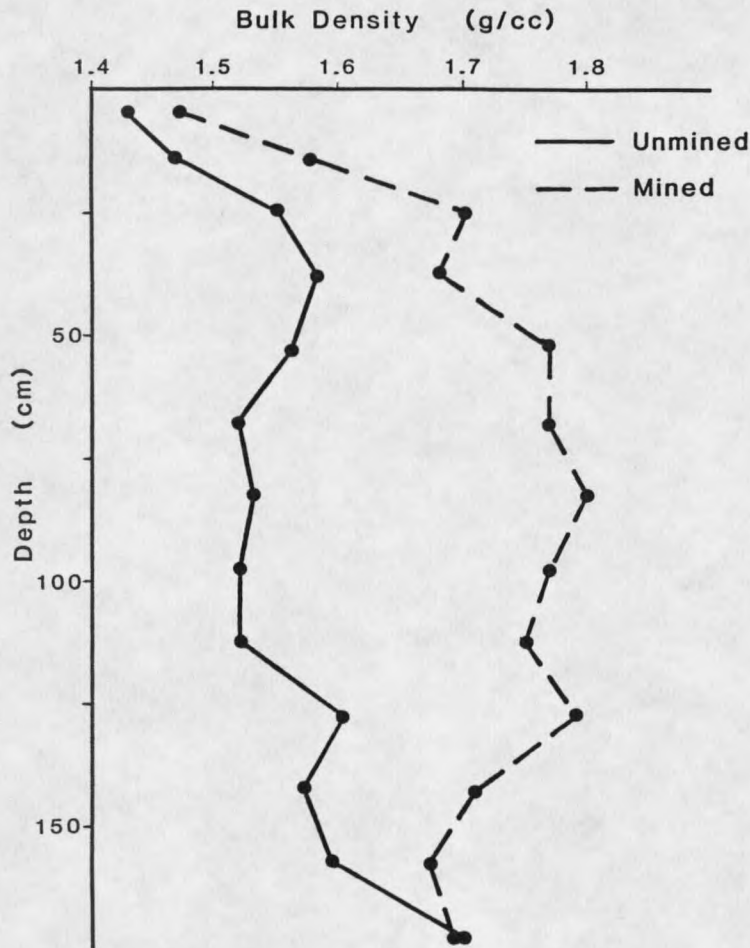


Figure 3. Bulk density of the two soil profiles.

minesoil and undisturbed soil were significantly different for most chemical parameters within the 30 to 120 cm zone. The undisturbed soil had a significantly higher pH while the minesoil had significantly higher calcium, magnesium, sodium, electrical conductivity, sodium adsorption ratio and potassium levels. The nitrate nitrogen and phosphorus levels were similar for the two fields, at this depth. Again, phosphorus levels were very low for dryland alfalfa production.

The root distribution on a dry weight basis was similar for the two fields, but variation was large (Figure 4). The only significant difference between the two soils was for the

Table 4. Mean Soil Chemistry for Two Depths of the Two Soils.

Depth Site	0 to 30 cm		30 to 120 cm	
	Undisturbed Soil	Minesoil	Undisturbed Soil	Minesoil
pH	8.2 ^a	8.2 ^a	8.2 ^a	8.0 ^b
EC (mmhos/cm)	0.8 ^a	1.0 ^a	0.3 ^a	2.8 ^b
Ca (meq/l)	109.9 ^a	101.7 ^a	27.1 ^a	238.8 ^b
Mg (meq/l)	36.8 ^a	41.0 ^a	29.0 ^a	62.7 ^b
Na (meq/l)	3.4 ^a	49.0 ^a	4.6 ^a	211.1 ^b
SAR	0.1 ^a	0.8 ^a	0.1 ^a	3.2 ^b
NO ₃ -N (ppm)	21.9 ^a	11.1 ^b	1.0 ^a	1.0 ^a
P (ppm)	9.9 ^a	5.9 ^b	2.2 ^a	1.8 ^a
K (ppm)	172.7 ^a	177.2 ^a	68.4 ^a	131.5 ^b

The same letter across columns within a soil depth indicates no significance difference at the 0.05 level.

150 to 180 cm depth where there were significantly more roots in the undisturbed soil. The minesoil had 59 percent of the total plant roots present in the minesoil profile in the top 30 cm and 77 percent in the top 60 cm. This was similar to values reported by Baur et al. (1978). Only 1.1 percent of the roots in the minesoil profile were below 120 cm. In the undisturbed soil, 63 percent of the total roots were in the top 30 cm of the soil profile and 79 percent in the top 60 cm. The undisturbed soil had 15 percent of the roots present in the 120 to 180 cm zone.

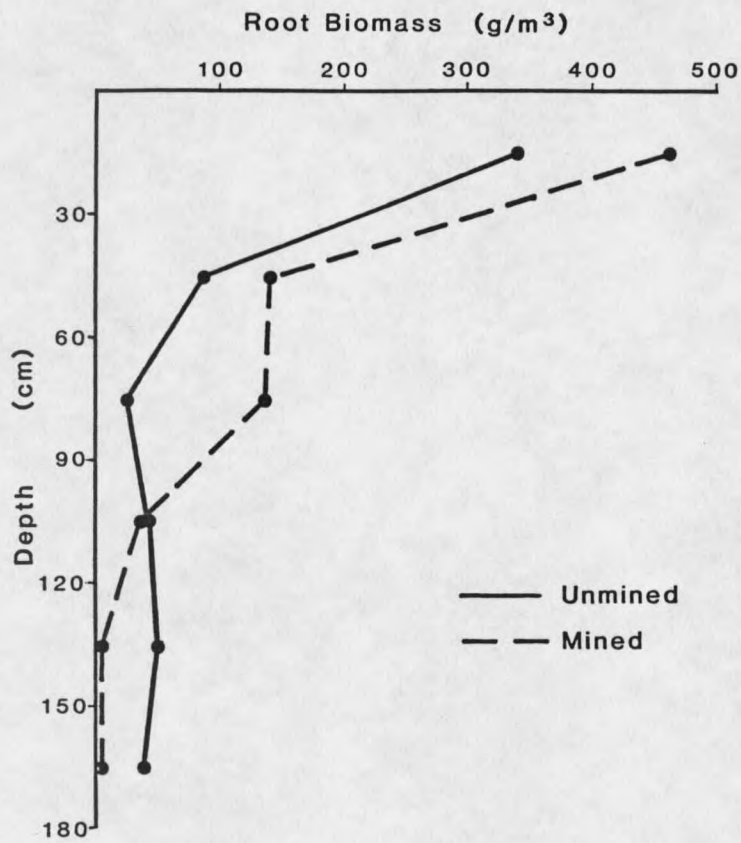


Figure 4. Root biomass distribution in the two soil profiles.

RESULTS AND DISCUSSION

Alfalfa Cover and Production

Alfalfa canopy cover on the minesoil was significantly lower than alfalfa canopy cover on the undisturbed soil (Table 5). This is not unexpected. The minesoil was originally seeded with a rangeland seed mix with included alfalfa. Since seeding, alfalfa has become the dominant species but the other seeded species have remained present on the site. The undisturbed soil was seeded only with alfalfa. Under such conditions one would expect close to 100 percent cover of the seeded species. Weedy species have reduced this somewhat.

Table 5. Percent Alfalfa Canopy Cover at 1/10th Bloom of Alfalfa Grown in Undisturbed and Minesoil Sites Near Colstrip, Montana, 1983.

	Undisturbed Soil	Minesoil
Canopy cover %	92*	76

Asterisk (*) indicates significant differences at the 0.05 level.

Alfalfa production on the minesoil was not significantly different from alfalfa production on the undisturbed soil (Table 6). In 1983, nonirrigated alfalfa production in Rosebud County averaged 2328 kg/ha and production for other hay averaged 1202 kg/ha on a dry-weight basis (MDA 1984). The low productivity on the study sites and throughout the county compared to previous years was caused by the dry conditions in 1983. Precipitation was 16 percent below normal in Forsyth and 35 percent below normal in Colstrip for that year. While alfalfa cover was lower on the minesoil, visual observation indicated that the plants were also taller on the minesoil. This may account for the similar production.

Table 6. Mean Alfalfa, Grass and Total Production [kg/ha(lb/acre)] at 1/10th Bloom of Alfalfa Grown on Undisturbed and Minesoil Sites Near Colstrip, Montana, 1983.

	Undisturbed Soil	Minesoil
Alfalfa (kg/ha) (lb/ac)	2089 ^a (1864)	1958 ^a (1747)
Grass	416 ^a (372)	416 ^a (371)
Total	2507 ^a (2237)	2427 ^a (2165)

The same letter across columns indicates no significant difference at the 0.05 level.

Plant-available water may have played a role in controlling alfalfa production. The minesoil held 40 percent more plant-available water in the top 30 cm. Plant-available water content in the 30 to 120 cm depth for both sites was only slightly different. Approximately 60 percent of the plant roots were located in the surface zone at both sites. Bauer et al. (1978) found that a grass-legume mixture on minesoils removed 46 percent of the total water depleted from the minesoil profile from the top 30 cm. The combination of a higher plant-available water content in the top cm of the minesoil profile and concentration of roots in the upper 30 cm may have resulted in the high alfalfa production on the minesoil, even though cover was less. Jensen et al. (1967) reported that as available soil moisture increased, alfalfa yields increased. However, the plant-available water content for the entire soil profiles at both sites was similar. Therefore, available water may not have affected production.

An alternative reason for the high alfalfa production on the minesoil was the higher levels of potassium in 30 to 120 cm depth of the minesoil. Increased soil potassium levels have been shown to increase alfalfa yield and persistence (Rhykerd and Overdahl 1972; Gerwig and Ahlgreen 1958). Adequate soil potassium also gives alfalfa a competitive advantage over grasses which may explain its dominance in the minesoil field (Chamblee 1972).

Grass production on the two sites was similar (Table 6). Cheatgrass (*Bromus* spp.) and beardless goatgrass (*Aeglops cylindrica*) were present in large amounts on the undisturbed soil, resulting in the high grass production at that site.

Total production on the minesoil was also similar to total production on the undisturbed soil (Table 6). Apparently the minesoil was capable of alfalfa and total production equal to that of the undisturbed soil in this study. Total minesoil production was also similar to countrywide production levels.

Alfalfa Forage Quality

Generally, the forage quality of alfalfa grown on the undisturbed soil was significantly better than the alfalfa grown on the minesoil (Table 7). The alfalfa grown on the undisturbed soil had a significantly higher crude protein level and significantly lower amounts of fat, crude fiber, neutral detergent fiber and acid detergent fiber. The differences in crude protein content and fiber content between the two fields may have been the result of differences in soil moisture. Jensen et al. (1967) found that as soil moisture decreased, crude protein increased and acid detergent fiber and lignin content decreased.

Table 7. Mean Alfalfa Forage Quality Determined by NIR Spectroscopy.

	Undisturbed Soil	Minesoil
Crude protein %	21.1 ^a	19.2 ^b
Fat %	1.4 ^a	1.6 ^b
Crude fiber %	27.1 ^a	30.4 ^b
NDF %	39.8 ^a	44.0 ^b
ADF %	32.1 ^a	35.4 ^b
IVDMD %	73.4 ^a	71.1 ^a

The same letter across columns indicates no significant difference at the 0.05 level.

The percent *in vitro* dry matter digestibility was similar for the two fields. While significant differences in alfalfa quality do exist between the two fields, the determined values fall within the range of standard values reported by the National Research Council (see Literature Review) and should meet the nutritional needs of livestock.

SUMMARY AND RECOMMENDATIONS

Alfalfa production was similar on both sites. Grass and total production were also similar. Alfalfa forage quality exhibited significant differences between the two fields. Crude protein content was lower and fiber content higher in the alfalfa from the minesoil field. Digestible dry matter was similar for both sites. Regardless of the significant differences, the forage quality values from the two fields fell well within the range of standard forage quality values of alfalfa.

The two soils were generally similar, although some significant differences did exist. A soil factor which may have had an effect on plant growth was plant-available water-holding capacity, which was greater in the surface of the minesoil. Potassium may have affected alfalfa dominance and production in the minesoil.

Based on these results, it is apparent that the potential for dryland alfalfa on mine-soils does exist and should be capable of meeting the requirements of the Montana Strip and Underground Mining Act of 1979.

To definitively ascertain the potential for dryland alfalfa on minesoils, a paired experiment is recommended. Two fields should be established, one on minesoils and one on undisturbed soils. The following criteria should be employed in establishing the two fields:

1. Soils with similar physical and chemical characteristics,
2. Similar optimum soil nutrient levels, adjusted through fertilization,
3. The same alfalfa variety,
4. The same seeding rate and date, and
5. The same management practices.

Use of these criteria would provide the basis for a definitive comparison of alfalfa production and forage quality from the two fields similar to the use of reference areas for rangeland establishment.

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LITERATURE CITED

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APPENDICES

APPENDIX A

SOIL PROFILE DESCRIPTIONS

Table 8. Soil Profile Descriptions.

<u>Soil Series:</u>	Kremlin
<u>Classification:</u>	Aridic Haploboroll, fine-loamy, mixed
<u>Location:</u>	Rosebud County, MT. Alfalfa field, E½, SW¼, S.34, T.2N, R.39E.
<u>Physiographic Position:</u>	Upland
<u>Topography:</u>	Northeast aspect, 0-4% slope
<u>Drainage:</u>	Well drained, moderately permeable
<u>Erosion:</u>	Uneroled
<u>Parent Material:</u>	Alluvium
<u>Sampled By:</u>	R. C. Postle and T. Byron, September 15, 1983
<u>Remarks:</u>	Weak platy structure in surface 2 cm may be evidence of compaction. No coarse fragments encountered, soils very dry when characterized. Colors are for dry soils.
A1p 0-14 cm	(0-6 in.). Brown to pale brown (10YR 5.5/3) sandy clay loam; moderate medium blocky parting to strong coarse granular; slightly hard, friable, slightly sticky and nonplastic; many very fine to coarse roots; mildly effervescent; abrupt smooth boundary.
B2+ 14-30 cm	(6-12 in.). Brown (60YR 4.5/3) sandy clay loam; strong medium subangular blocky (weak prismatic) parting to strong medium granular; slightly hard, firm, slightly sticky and slightly plastic; common very fine to medium roots; mildly effervescent; abrupt smooth boundary.
B3k 30 to 58 cm	(12 to 23 in.). Light brownish gray to light yellowish brown (2.5YR 6/3) sandy clay loam; strong medium subangular blocky; hard, firm, slightly sticky and slightly plastic; common very fine to fine roots; strongly effervescent; gradual smooth boundary.
C1 58-85+ cm	(23+ in.). Light gray to light brownish gray (2.5YR 6.5/2) sandy clay loam; massive; slightly hard, friable, slightly sticky and slightly plastic; few very fine to fine roots; effervescent.

Table 8 (continued).

<u>Soil Series:</u>	Cow Creek*
<u>Classification:</u>	Typic Ustorthents, fine-loamy, mixed (calcareous), mesic
<u>Location:</u>	Rosebud County, MT. Area A, Rosebud Mine, Western Energy Co. NE¼, S.5, T.1N, R.41E.
<u>Physiographic Position:</u>	Upland
<u>Topography:</u>	East aspect, 0-3% slopes
<u>Drainage:</u>	Moderately well drained, moderately permeable
<u>Erosion:</u>	Uneroded
<u>Vegetation:</u>	<i>Medicago sativa</i> , <i>Agropyron</i> spp., <i>Bromus</i> spp., <i>Stipa viridula</i> , <i>Atriplex canescens</i> , forbs
<u>Parent Material:</u>	Mine spoil and salvaged topsoil/subsoil
<u>Sampled By:</u>	R. C. Postle and T. Byron, September 15, 1983
<u>Remarks:</u>	Mine spoils covered with coversoil in 1979. Weak platy structure in surface 5 cm (also soil tended to break out in weak plates throughout profile) may be evidence of compaction. Only one coarse fragment encountered. Soil was very dry and digging was extremely difficult. Roots tended to occur in horizontal layers.
A1 0-30 cm	(0-12 in.). Grayish brown to light brownish gray (2.5YR 5.5/3) sandy clay loam to loam; stringer of dark grayish brown to grayish brown (2.5YR 4.5/2) loam; massive; hard, firm, slightly sticky and slightly plastic; many very fine to medium roots; mildly effervescent; abrupt smooth boundary.
C1 30-80+ cm	(12-32+ in.). Light gray to light brownish gray (2.5YR 6.5/2) clay loam, with siltstone (2.5YR 8/2) fragments, shale (7.5YR 6/8) fragments and coal (7.5YR 2.5/0) fragments; massive; slightly hard, firm, slightly sticky and slightly plastic; few very fine to medium roots; effervescent.

*Based on unofficial soil series from Schafer (1979).

APPENDIX B

STATISTICAL ANALYSIS OF SOILS AND
VEGETATION DATA

Table 9. Statistical Analysis of Soils Data.

Site	Depth (cm)		pH	EC (mmhos/ cm)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	SAR	NO ₃ -N (ppm)	P (ppm)	K (ppm)	% Sand	% Silt	% Clay	Soil Water		
															-3 bar (% by volume)	-15 bar	AW- HC
Undis- turbed soil	0-30	$\bar{x}$	8.1	0.78	109.9	36.8	3.4	0.1	21.9	9.9	172.7	50	26	24	21.3	15.5	5.8
		s	0.1	0.22	39.8	10.0	1.6	0.0	9.0	2.6	83.1	14.1	7.2	6.2	4.6	3.0	1.8
		range	8.0-8.4	0.46-1.14	52.8-175	19.7-52.9	2.0-7.1	0.1	13-14	6-14	89-388	27-70	18-41	16-33	15.8-27.9	11.0-19.7	4.2-8.8
Mine- soil	0-30	$\bar{x}$	8.2	0.95	101.7	41.0	49.0	0.8	11.1	5.9	177.2	45	28	27	26.6	17.1	9.5
		s	0.1	0.82	96.0	13.2	40.5	1.1	4.7	1.8	54.7	12.5	8.5	4.7	5.9	2.8	3.8
		range	8.0-8.4	0.44-3.21	46.1-361	26.1-67.0	3.6-304	0.1-3.9	6-21	3-9	84-256	27-68	14-39	18-36	18.3-37.3	11.5-18.6	6.3-16.1
		t ¹	0.88	0.63	0.25	0.80	1.59	2.01	3.37*	4.00*	0.14	0.86	0.40	1.09	2.24*	1.23	2.78*
		d.f. ²	18	~10	~12	18	~9	~9	18	18	18	18	18	18	18	18	18
Undis- turbed soil	30-120	$\bar{x}$	8.2	0.30	27.1	29.0	4.6	0.1	1.0	2.2	68.4	52	26	22	26.0	15.1	10.9
		s	0.1	0.05	7.4	6.2	1.3	0.1	0.8	1.4	18.8	13.5	7.9	5.8	3.9	4.3	1.4
		range	8.0-8.3	0.24-0.39	13.2-37.4	16.4-36.8	3.0-7.4	0.1-0.2	0.3-3.0	0.5	47-107	33-82	9-37	9-30	18.4-31.3	6.1-19.6	9.1-13.6
Mine- soil	30-120	$\bar{x}$	8.0	2.76	238.8	62.7	211.1	3.2	1.0	1.8	131.5	33	39	28	32.3	22.7	9.6
		s	0.1	0.95	119.8	20.3	104.4	1.4	0.6	1.2	17.1	8.1	5.3	3.4	2.3	2.0	1.1
		range	7.8-8.3	1.54-3.96	44.1-426	61.7-75.0	101.0-405	1.4-5.4	0.5-0.2	0.4	99-162	25-52	26-44	22-32	28.0-35.0	19.8-25.4	7.5-10.8
		t	3.42*	8.18*	5.58*	5.02	6.25	6.98	0.97	0.87	7.84*	3.85*	4.46*	2.72*	4.40	4.62	2.31
		d.f.	18	~	~9	~11	~9	~9	18	18	18	18	18	18	18	~12	18

Asterisk (*) indicates significant differences at the 0.05 level.

Table 10. Statistical Analysis of Vegetation Data.

Site		Alfalfa Cover (%)	Production (Kg/ha)			Forage Quality (%)					
			Alfalfa	Grass	Total	Crude Protein	Fat	Crude Fiber	IVDMD	NDF	ADF
Undisturbed soil	$\bar{x}$	92	2089	416	2507	21.1	1.4	27.1	73.4	39.8	32.1
	s	11	777	257	789	0.98	0.2	2.0	3.9	3.3	2.4
	range	55-100	735-3874	45-879	1171-4100	19.1-22.6	0.9-1.6	24.5-32.3	80.5-68.0	33.4-47.8	28.5-38.1
Minesoil	$\bar{x}$	76	1958	416	2427	19.2	1.6	30.4	71.1	44.0	35.4
	s	21	1070	211	1097	1.4	0.2	2.2	6.6	4.0	3.2
	range	1-100	17-4540	101-884	695-5466	16.9-21.6	1.2-1.9	27.5-37.0	78.5-58.9	38.7-54.7	32.3-45.4
	t	4.27*	0.63	0.01	0.38	5.23*	3.39*	4.97*	1.35	3.67*	3.74*
	d.f.	78	~72	~75	~71	38	38	38	~31	38	38

Asterisk (*) indicates significant differences at the 0.05 level.

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Postle, R. C.

The potential for dryland alfalfa on minesoils...

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