



Suitability of an alluvial overburden material as a plant growth medium at the Berkeley Complex in Butte, Montana
by John Allen Lawson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University
© Copyright by John Allen Lawson (1984)

Abstract:

Absence of a local recoverable native soil for reclamation at Anaconda Minerals Company's Berkeley Complex in Butte, Montana, has prompted a two-phase research project initiated in 1979. Phase I identified the chemical and physical characteristics of an alluvial overburden material proposed for use as a cover-soil. Low fertility and a severe cover-soil crust were identified as the most plant limiting factors. Phase II, completed in 1982, investigated the response of three grass species (*Agropyron dasystachym*, *Festuca ovina* and *Poa compressa*) as influenced by three overburden amendments (incorporated manure, incorporated hay mulch and incorporated fertilizer). Results indicated that seedling emergence was inversely related to cover-soil crust strength and both were a function of soil moisture. Significant differences in seedling density were noted between the three amendments and the control. Crust strength increased successively and significantly in all treatments throughout the growing season when compared to incorporated manure. *A. dasystachyum* produced significantly more cover and phytomass than either *F. ovina* or *P. compressa*. Preliminary data suggested *A. dasystachyum* in the manure amendment was the most promising species-amendment combination for rapid establishment and herbage production. Percent volumetric soil water determinations, utilizing the neutron method, found no impedance to water flow at the cover-soil/spoil interface.

SUITABILITY OF AN ALLUVIAL OVERBURDEN MATERIAL
AS A PLANT GROWTH MEDIUM AT THE BERKELEY
COMPLEX IN BUTTE, MONTANA

by

John Allen Lawson

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

of

Master of Science

in

Land Rehabilitation

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 1984

APPROVAL

of a thesis submitted by

John Allen Lawson

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

11 April 1984
Date

Clayton B. Parsons
Chairman, Graduate Committee

Approved for the Major Department

April 13, 1984
Date

Arthur E. Hinton
Head, Major Department

Approved for the College of Graduate Studies

May 7, 1984
Date

Henry L. Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

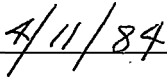
In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate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

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

Signature



Date



ACKNOWLEDGMENTS

I wish to express appreciation to the Anaconda Minerals Company for continuing to fund this project. Special recognition is due Mr. Roger Gordon, Senior Reclamationist at Butte Operations for his moral and physical support during all phases of this project; Mr. Fred Parady now with Bridger Coal Company who helped in the proposal and budget phases and who willingly gave countless advice; Dr. Clayton Marlow, my major advisor, who guided me toward the light at the end of the academic tunnel; Dr. Brian Sindelar for his evaluation of vegetation sampling procedures and editorial expertise; Dr. Douglas Dollhopf for his valuable guidance on numerous soils related matters; Mr. Eldon Ayers for his editorial expertise, moral support and knowledge of statistical analysis; Mr. Dennis Neuman for support on soil chemistry and statistics; Mr. Robert Carlson, without whom the field work for this project would have never been completed and Ms. Judy Fisher, Ms. Debby LaRue and Ms. Judy Moore for their cooperation and patience in typing.

My deepest gratitude to my parents for all their support. Finally, and most of all, I am truly indebted to my wife Dianna and our family: Keeper, Buck and Chalcedony for their undying support and affection throughout this entire ordeal.

TABLE OF CONTENTS

	Page
VITA	iv
ACKNOWLEDGMENTS.	v
TABLE OF CONTENTS.	vi
LIST OF TABLES	viii
LIST OF FIGURES.	ix
ABSTRACT	xi
INTRODUCTION	1
LITERATURE REVIEW.	4
Overburden As a Cover-soil.	4
Cultural Amendments in Reclamation.	7
Organic Mulches.	8
Fertilization.	14
Liming	18
Soil Crusting	20
Species Selection for Revegetation.	26
<u>Agropyron dasystachyum</u>	27
<u>Festuca ovina</u>	29
<u>Poa compressa</u>	31
METHODS AND PROCEDURES	35
Regional Site Description	35
Field Test Plot Descripton.	36
Incorporated Manure	38
Incorporated Hay Mulch.	39
Incorporated Fertilizer	40
Liming and pH Determinations.	41
Seeding (Spring 1981)	42
Seeding (Fall 1981)	44
Seed and Seedling Environment	45
Alluvium Crust Strength	47
Seedling Density.	47
Plant Cover	49
Production.	49
Statistical Analysis.	50

TABLE OF CONTENTS--Continued

	Page
RESULTS AND DISCUSSION	51
Seed and Seedling Environment	51
Alluvium pH	56
Time of Seeding	59
Crust Strength and Soil Moisture.	59
Crust Strength and Incorporated Amendments.	62
Crust Strength and Seedling Emergence	63
Seedling Density.	63
Plant Cover	67
Production.	68
SUMMARY AND CONCLUSIONS.	71
APPENDICES	74
Appendix A Soil Profile Hydrology.	75
Background Information	76
Experimental Approach.	76
Outcome of Field Calibration	77
Soil Profile Moisture Patterns	78
Appendix B Analysis of Variance Tables	92
LITERATURE CITED	99

LIST OF TABLES

Table	Page
1. Research plot dimensions.	39
2. Ammonium phosphate sulfate fertilizer specifics	40
3. Seed list for seeding trials.	43
4. Mean Research plot soil temperature for the 1982 growing season	52
5. Mean pH of three alluvium treatments and a control one year after liming (Summer 1982)	57
6. Plant species on research plots during 1982 growing season (plant names follow Beetle 1970)	66
7. Mean percent canopy cover in three amendments and nontreated alluvium on October 15, 1982 (all figures are in kg/ha)	68
8. Mean above and belowground phytomass production in three amendments and nontreated alluvium on October 15, 1982 (all figures are in kg/ha)	70
9. Mean values for percent volumetric soil water as measured by the neutron method and averaged over nine sample locations, 30 cm above, 30 cm below and at the alluvium/spoil interface for the driest (July 1981) and wettest (April 1982) sample dates.	80
10. Analysis of variance of percent canopy cover of three species of grasses in manure treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7).	93
11. Analysis of variance of percent canopy cover of three species of grasses in hay mulch treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7).	93

LIST OF TABLES--Continued

	Page
12. Analysis of variance of percent canopy cover of three species of grasses in fertilizer treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7).	94
13. Analysis of variance of percent canopy cover of Feov' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7)	94
14. Analysis of variance of percent canopy cover of Poco' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7)	95
15. Analysis of variance of percent canopy cover of Agda' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 7)	95
16. Analysis of variance of aboveground phytomass of three species of grasses in manure treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).	96
17. Analysis of variance of aboveground phytomass of three species of grasses in hay mulch treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).	96
18. Analysis of variance of aboveground phytomass of three species of grasses in fertilizer treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).	97
19. Analysis of variance of aboveground phytomass of Feov' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8)	97
20. Analysis of variance of aboveground phytomass of Poco' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8)	98
21. Analysis of variance of aboveground phytomass of Agda' in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8)	98

LIST OF FIGURES

Figure	Page
1. Plot design	37
2. Treatment diagram. The area between the broken lines represent amendments. The solid lines in the middle of the figure denote microplots located within each amendment. All treatments were replicated three times.	44
3. Research plot fall 1981 seeding diagram. Areas not within the broken lines are spring and fall seeded.	46
4. Example of one plot layout and sampling scheme.	48
5. Changes in average percent soil moisture in nontreated alluvium and two surface amendments, during the 1982 growing season.	54
6. Monthly precipitation averages and ranges for the Butte area (1948-1977; data acquired from the Butte airport).	55
7. Affects of liming on three alluvium treatments over a 16 month period.	58
8. Crust strength measurements of three surface amendments and nontreated alluvium, during the 1982 growing season	61
9. Seedling density of three native grass species over five dates, in three alluvial overburden (cover-soil) amendments and a control. The grass species considered were: <u>Agropyron dasystachyum</u> (Agda), <u>Poa compressa</u> (Poco), <u>Festuca ovina</u> (Feov).	64
10. Soil profile hydrology for a typical sample location on the driest (July 1981) and wettest (April 1982) sample dates. The shaded area represents the alluvium/spoil interface zone.	79

LIST OF FIGURES--Continued

Figure	Page
11. Soil profile hydrology during July 1981 and April 1982 for site number 278, North Top. The shaded area represents the cover-soil/spoil interface	83
12. Soil profile hydrology during July 1981 and April 1982 for site number 283, North Middle. The shaded area represents the cover-soil/spoil interface	84
13. Soil profile hydrology during July 1981 and April 1982 for site number 275, North Bottom. The shaded area represents the cover-soil/spoil interface	85
14. Soil profile hydrology during July 1981 and April 1982 for site number 279, Middle Top. The shaded area represents the cover-soil/spoil interface	86
15. Soil profile hydrology during July 1981 and April 1982 for site number 282, Middle Middle. The shaded area represents the cover-soil/spoil interface	87
16. Soil profile hydrology during July 1981 and April 1982 for site number 276, Middle Bottom. The shaded area represents the cover-soil/spoil interface	88
17. Soil profile hydrology during July 1981 and April 1982 for site number 280, South Top. The shaded area represents the cover-soil/spoil interface	89
18. Soil profile hydrology during July 1981 and October 1981 for site number 281, South Middle. The shaded area represents the cover-soil/spoil interface	90
19. Soil profile hydrology during July 1981 and April 1982 for site number 277, South Bottom. The shaded area represents the cover-soil/spoil interface	91

ABSTRACT

Absence of a local recoverable native soil for reclamation at Anaconda Minerals Company's Berkeley Complex in Butte, Montana, has prompted a two-phase research project initiated in 1979. Phase I identified the chemical and physical characteristics of an alluvial overburden material proposed for use as a cover-soil. Low fertility and a severe cover-soil crust were identified as the most plant limiting factors. Phase II, completed in 1982, investigated the response of three grass species (Agropyron dasystachym, Festuca ovina and Poa compressa) as influenced by three overburden amendments (incorporated manure, incorporated hay mulch and incorporated fertilizer). Results indicated that seedling emergence was inversely related to cover-soil crust strength and both were a function of soil moisture. Significant differences in seedling density were noted between the three amendments and the control. Crust strength increased successively and significantly in all treatments throughout the growing season when compared to incorporated manure. A. dasystachyum produced significantly more cover and phytomass than either F. ovina or P. compressa. Preliminary data suggested A. dasystachyum in the manure amendment was the most promising species-amendment combination for rapid establishment and herbage production. Percent volumetric soil water determinations, utilizing the neutron method, found no impedance to water flow at the cover-soil/spoil interface.

INTRODUCTION

A long history of metal mining in the Intermountain West has left permanent environmental records of previous economic enterprises (Larson 1977). One of the most extensive and lucrative mine fields in the American West was first uncovered in 1864 in Silver Bow Creek in Southwestern Montana, near present day Butte (Lewis 1963). Originally, gold and silver were the target minerals, however, by the turn of the century, copper became the most mined metal (Smith 1953).

Over 100 years of combined underground and open pit mining have resulted in nearly 3300 hectares of land disturbances in the Butte area (Parady 1981). The Anaconda Minerals Company administers an open pit truck and shovel operation at the Berkeley Complex in Butte, Montana. The mine extracts lowgrade copper and molybdenum ores. Currently, the mine has suspended activities in lieu of present economic conditions.

Since 1955, the open pit operation has constructed massive stockpiles of spoil material, resulting in an increased surface area requiring rehabilitation. Furthermore, the area has a critical lack of salvageable native soil, which hampers reclamation of the mine waste dumps.

In 1979 a two phase research project was initiated to identify alternate sources to native soil for covering mine waste dumps. Phase I (Parady 1981) identified the chemical and physical

characteristics of an overburden material as a potential cover-soil. The selected overburden occurs as a vast deposit of sandy loam alluvial material. Laboratory analyses indicated the alluvium is slightly acidic and lacks nitrogen (N) and phosphorus (P). Parady (1981) reported the alluvium rated "good" in a suitability classification system outlined by Schafer (1979) for topsoil, subsoil and overburden materials used as a cover-soil. Additional analyses performed in phase I reported copper, manganese and zinc concentrations were elevated in the alluvium. However, Parady (1981) recommended amendments of liming and organic matter to decrease the plant availability of these metals. Subsequent field investigations also identified a critical surface crusting problem in fallow alluvium. The mechanism of crust formation was identified in phase I as grain packing, with clays and silts filling voids between sands. Further greenhouse experiments revealed alluvium crust strength was decreased by addition of organic matter. Organic matter added to alluvium reduced crust strength by the formation of stable soil aggregates and reducing clay adhesion in the sand fraction (Parady 1981).

Based on results of laboratory and greenhouse experiments reported in phase I of this study, a second phase was initiated to further research the potential of the alluvial overburden material as a plant growth medium. A field investigation was designed for the purpose of determining the suitability of previously selected alluvium as a plant growth medium. Three surface amendments and three plant species were evaluated. Specific objectives in the second phase of this study were:

- 1.) To assess three alluvium amendments (incorporated fertilizer, incorporated manure and fertilizer and incorporated hay mulch and fertilizer) for plant growth suitability, including reduction of surface crusting in alluvium.
- 2.) To assess performance of three grass species [thickspike wheatgrass (Agropyron dasystachyum (Hook) Scribn.), Canada bluegrass (Pos compressa L.) and hard sheep fescue (Festuca ovina L.)] in each amendment as compared to non-treated alluvium.

LITERATURE REVIEW

Overburden As A Cover-soil

The use of overburden or spoil material as a plant growth medium often results from a lack of suitable existant or salvageable native soil (Kelley 1979). Brown and Johnston (1978) observed that many high elevation disturbances are frequently lacking in topsoil. The author pointed out that hardrock mining disturbances on the Beartooth Plateau in southcentral Montana, are extensive enough to dictate the use of select spoil materials for revegetation. In 1979, Schafer acknowledged that select overburden materials may be required to replace unsuitable topsoil or subsoils in the Northern Great Plains. He defines cover-soil as any earthen material used in reclamation to support plant growth. The potential of overburden materials to support vegetation was studied on surface coal mines by Byrnes et al. (1980) in southwestern Indiana. The author concluded that overburden lacked fertility and required surface amendments to establish alfalfa, small grains and tree seedlings. An extensive study was performed to analyze the chemical and physical properties of various overburden and spoil materials important to plant growth at the Jackpile uranium mine in New Mexico (Reynolds et al. 1978). Revegetation of acidic 14 year old sulfur mine spoil with tree and shrub transplants was reported to be successful in the Sierra Nevada mountains of California (Butterfield and Tueller 1980). The use of select coal spoil materials

and surface amendments for agricultural corn production was reported by Nielsen and Miller (1980). In Pennsylvania corn production was only 7-22 percent less on mine spoils when compared to native soils.

An extensive study investigating variable depths of cover-soil over select overburden materials (wedge construction) was conducted on 14 field plots at 11 coal mines in the Northern Great Plains (Barth and Martin 1982). The authors compared spoil type groups for plant performance and the chemical and physical status of cover-soil and spoil material over a five year period. Results of the strongly acid (pH 3.6 to 4.3) spoil group indicated that as cover-soil depth increased, plant production increased in a linear manner. Plant cover, however, did not vary as substantially as cover-soil depths increased. Acidification of cover-soil materials was minimal and the chemical and physical nature of the spoil did not significantly affect the cover-soil.

Successful revegetation utilizing mine waste or spoil material exclusively, is dependent upon the chemical and physical characteristics of the proposed material (Schafer 1979). Texture was reported by Sindelar and Plantenberg (1979) to be the major factor controlling plant succession on old coal mine spoils in southeastern Montana. Revegetation of metal mine spoil in the Captains Flat area of New South Wales, Australia, was solely dependent upon liming, fertilizing and the addition of organic matter (Keane and Craze 1978).

Greenhouse and laboratory experiments are often required to fully evaluate the potential of the overburden or spoil material (Butterfield and Tueller 1980, and Berg 1975). In Wyoming, Schuman

and Taylor (1978) found, through greenhouse experiments, that vegetative productivity of a native fine loamy topsoil was improved by addition of a heavy clay spoil material. However, in New Mexico, spoil from the Fruitland formation was determined to be saline and sodic and therefore, not suitable for use as a plant growth medium (Gould et al. 1976). Greenhouse studies revealed that Black Mesa coal spoil in Arizona required fertilization and irrigation to reach plant production similar to native soils (Day et al. 1979).

Accurate analysis of all potential overburden materials is critical due to the diversified nature of overburden and the subsequent spoil material after mining. In copper mining as much as 99 percent of all mined material may be waste (Imhoff et al. 1976). Furthermore, once the overburden is spoiled, the resultant dump assimilates the different chemical and physical characteristics of its components. Reynolds et al. (1978) analyzed four uranium spoils of variable age (4-20 years old) for plant growth suitabilities at the Jackpile mine. All four spoils varied in texture and chemical composition and no one spoil was superior as a plant growth medium.

In phase I of this study Parady (1981) characterized 86 alluvial overburden samples and analyzed each for plant growth potentials. A rock fragment percentage of less than 35 was utilized as the criterion for field selection of overburden to be used as a cover-soil at the Berkeley Complex. These recommendations were based on criterion outlined by Schafer (1979) for selection of suitable overburden materials to be used in the plant root zone. Although the author found the alluvium suitable for plant growth, various cultural

amendments improved the performance of this material as a plant growth medium.

Establishment of an effective plant growth medium from mine waste or spoil material is dependent upon the chemical and physical status of the soil (Schafer 1979). Although more desirable growth media may exist, in many areas there is no alternative to the use of mine spoil or overburden (Brown and Johnston 1978; Parady 1981; Schafer 1979; Byrnes et al. 1980; and Reynolds et al. 1978).

Numerous studies reported success in establishing vegetation on mine spoil (Butterfield and Tueller 1980, Nielsen and Miller 1980; and Schuman and Taylor 1978), however, cultural treatments are usually required to alter some undesirable aspect of the atypical growth media (Parady 1981; Byrnes et al. 1980; Brown et al. 1978; and Keane and Craze 1978).

Cultural Amendments in Reclamation

Revegetation of mine spoils and waste dumps is often complicated by the adverse physical nature of spoil, droughtiness, inherent low fertility, extremes in pH, salinity, sodicity, heavy metal toxicities, excessive slope gradients and uncompromising weather conditions (Troeh et al. 1980). One method of controlling and/or stabilizing mine spoil is through the establishment of permanent vegetative cover. Development of a vegetation system is dependent upon amelioration of those factors that limit plant growth. Therefore, successful rehabilitation is a process that must be initiated by man (USDA 1979). Reports of techniques to improve the plant growth environment on

native soils and mined lands exist extensively in the literature. Reclamation research regarding improvement of the plant growth environment is extensive. Only that portion of research directly pertaining to the objectives of this study is reviewed here.

Organic Mulches

The role of organic mulches in reclamation is many faceted. Generally, mulches function to increase soil fertility, decrease wind and water erosion, increase water infiltration and alter soil micro-climates to improve seed germination or improve soil aggregation (USDA 1979).

Straw and hay mulches are the most widely used of all organic mulches. In comparison, cereal grain straw is more available and economic than hay and therefore, more extensively used (Kay 1978). The presence of undesirable plant propagules is a common problem in straw and hay mulches. Annual weeds harvested with a hay crop for mulch in southeastern Montana significantly influenced subsequent vegetative cover on the mulched minesoils (Darling 1983). In addition straw and hay mulches immobilize available soil nitrogen, requiring supplemental fertilization (USDA 1979).

The use of straw or hay mulches to reduce soil erosion is widely documented. In the northern region of Bhana, Bonsu (1980), concluded that straw mulch decreased erosion loss 94 percent over bare fallow soil. An Australian study reported that three tons of hay mulch per acre maintained slope stability on mountain roadcuts during plant establishment (Wild 1979). Meyer et al. (1970) tested six rates of

straw mulch in a loam soil in Indiana and concluded that rates as low as 0.56 metric tons per hectare reduced erosion to one half that of unmulched soils. In a greenhouse experiment Singer and Blackhard (1977) found a parabolic relationship ($r^2=0.81$) between soil loss and straw mulching on a nine percent slope. The mulch reportedly reduced raindrop splash effect and soil crust formation.

Documentation of hay versus straw as a mulch is less common in the literature. However, in 1941, Wenger reported on the use of native hay for the reestablishment of deteriorated Kansas rangelands. Bergman and McKee (1976) found mulching essential for vegetation establishment on Pennsylvania coal spoil and hay was more effective than straw. At the Rosebud coal mine in southeastern Montana, native hay mulches are used exclusively over agronomic mulches. The use of native hay provides similar structural attributes as straw, but contains a valuable source of native seed (Coenenberg 1982). Ries et al. (1980) found that in North Dakota prairie hay improved the microclimate and reduced erosion for seedling establishment in addition to providing a native seed source for revegetating disturbed lands.

The application of animal wastes to improve the chemical and physical status of agricultural soils has been a common practice. Increased crop yields through the addition of manure are reported in international literature. Magdoff and Amadon (1980) reported increased yields of continuously cropped corn in Vermont through incorporation of 44 metric tons (MT) of dairy manure per acre. In Michigan, Guttay et al. (1956) reported stable manure increased the relative yield of small grain and row crops over 100 percent, two

years after application. However, small grain production decreased over ten percent six years after application while row crop production declined only slightly.

Phase I of this study utilized a greenhouse experiment to test variable rates of stockyard manure incorporated into the alluvium. Results indicated that increasing levels of manure produced significant differences in aerial biomass of spring wheat plants. However, the greatest differences in plant production were noted with initial addition of low levels of manure, incorporated to a depth of 8 cm (Parady 1981). In addition, crust strength was measured in alluvium mulched with manure at a 1:4 volumetric rate. The 1:4 (manure to alluvium) ratio was based on previous studies of optimum plant performance. It was concluded that alluvium with incorporated manure had significantly less crust strength than either the control or straw mulched plots. These results are similar to a study on soil crusting of native soils in eastern Nebraska. Mazurak et al. (1975) also found that stockyard manure applied at a rate of 360 MT/ha incorporated to a depth of 10 cm, significantly reduced surface soil crusting.

Modest applications of manure have been noted to reduce soil erosion (Kohlman 1978 and Free 1949), increase soil pH and nitrogen concentration (Long et al. 1975), increase soil aggregate stability (Guttay et al. 1956), increase soil cation exchange capacity (Lund and Doss 1980) and soil water holding capacity (Olsen et al. 1970).

In Vermont, Magdoff (1978) reported that manure applied to well drained soil produced more corn than the same amount of manure applied

to a heavier clay soil. The benefit of manure additions results from a more rapid release of N in the more coarse textured soil. However, these data indicate subsequent additions of manure will be necessary to sustain production. Magdoff (1980) hypothesized that an increase in cation exchange capacity (CEC) corresponding to addition of manure produces an increase in soil organic matter as well as an increase in soil pH.

In Alabama Long et al. (1975) disclosed that nitrate-nitrogen ($\text{NO}_3\text{-N}$) was elevated to a depth of 90 cm in the soil profile when 45 MT/ha of dairy manure was incorporated to a depth of 15 cm in a sandy loam soil. Nearly 35 years ago Free (1949) stated that low rates of farm yard manure applied as a top-dressing was more effective in reducing erosion than heavier rates incorporated into the soil. In addition relative crop yields were 11 percent higher in the top-dressed systems when compared to the incorporated treatments.

The increase in soil pH and CEC reported in many manure studies can be attributed to the elevated number of available cations in the manure. Lund and Doss (1980) reported that an initial surge in pH was due to the release of NH_3 cations when manure was incorporated into the soil. However, the authors felt that soil texture was important in interpreting changes in pH and CEC. The sandy loam soil had larger increases in pH when compared to the loamy sand. The differences were explained by the higher buffering capacity of the heavier soil. Concurrently, CEC increased four fold in the coarser texture loamy sand, due to the lower relative availability of cations

in coarse soil when compared to the loamy sand, which had less substantial changes in CEC.

The use of manure to improve the plant growth potential of mine soils is less common than in agricultural environments. However, on the Beartooth Plateau in Montana, Brown and Johnston (1978) reported a substantial increase in plant production on orphaned mine spoil through addition of 4480 kg/ha of dried steer manure. The addition of organic matter in the phase I of this study increased water holding capacity, nutrient availability, aeration, reduced evaporation and modified surface temperature fluctuations (Parady 1981).

In Wyoming, coal spoil was mulched with variable rates of a feedlot manure compost which contained 50 percent sawdust (Mason et al. 1980). It was concluded that the feedlot compost was less effective in producing vegetative cover than the non-treated plots. A wide carbon:nitrogen ratio created by sawdust seemed to contribute to the failure of compost. In addition the cost associated with manure application was substantially higher than the more conventional cereal grain mulches.

Both native hay mulches and animal waste mulches contain undesirable weed species. Weed seed passed through animals and deposited in manure may present difficulties in establishment of desirable plants during initial reclamation phases (Bloomfield and Ruxton 1977). However, manure contains many standard plant nutrients and microorganisms (Magdoff 1978) that may be difficult to maintain in infertile mine spoil. In 1975, Long et al. found the chemical composition of dairy cattle manure provided more N than any other

element (807 kg of N/45 MT of manure). Potassium (K), calcium (Ca) and magnesium (Mg) levels were also elevated in manure but in less than half the amount of that reported for N.

The value of animal manure based on relative nutrient amounts was calculated for five farm animals by Walsh and Hensler (1971). Prices per ton of cattle manure in this study varied according to nutrient value and ranged from \$2.00 to \$2.44/ton depending upon cattle varieties and manure availability.

Organic mulching to reestablish vegetation on mine spoil is commonplace in the western United States. Organic mulches are usually waste or by-products of agricultural systems. Most techniques were originally employed in agricultural systems and many new methods are currently being tested for agriculture in variable climates and edaphic conditions worldwide.

Straw and hay mulches are the most widely used of all organic mulches. Many uses are documented for straw and hay, however, their use in soil loss or erosion control is most widespread. Throughout the world, straw or hay incorporated into soil systems is reported to reduce erosion. Additional benefits include creating favorable microclimates for plant growth by: reducing wind velocity at the soil surface, reducing raindrop impact, reducing the velocity of overland water flow, modifying soil temperatures, increasing water infiltration, creating shade for seedlings and preventing soil crusting (Kay 1978). However, straw and hay mulches may introduce troublesome weed seed into a new environment or even wick water from the soil system (Darling 1983, and USDA 1979).

Animal wastes or manure can function to alter soil chemical and physical status and add essential microorganisms. Many studies report increased crop yields through the addition of manure to agricultural soils (Guttay et al. 1956). Benefits to the plant environment can come through additions of vital plant nutrients (especially N, K, Ca and Mg; Long et al. 1975), higher CEC levels and improved soil water status (Lund and Doss 1980, and Parady 1981). The increase in pH and CEC was documented in soils cropped continuously for corn in Vermont (Magdoff 1978). Increased grain production and decreased erosion was noted in New York (Free 1949). In Alabama Long et al. (1975) found elevated levels of N, K, Ca and Mg when manure was applied to soils. On reclaimed land in the Montana Rockies, total vegetation productivity was increased by additions of manure (Brown and Johnston 1978). However, in Wyoming feedlot compost decreased plant yields (Mason et al. 1980). Parady (1981) reported that manure decreased crust strength of alluvium cover-soil and increased wheat production under greenhouse conditions.

Fertilization

The process of revegetating mine spoil is often hampered by absence of nutrients critical to establishing and maintaining plant growth. Bauer et al. (1978) found that most spoil materials inherently lack sufficient fertility and require supplemental fertilization to support plant growth. Without the aid of cultural amendments, Omodt et al. (1975) calculated that mine spoil in North Dakota would require 350 years to build up organic matter levels comparable to

those found on native soils. Furthermore, the author determined that nearly 300 MT of manure /ha would need to be added annually for 40 years, to reach a one percent organic matter level in mine spoil. While these figures seem exceptional, they suggest the need for establishing adequate fertility and an organic matter base in mine spoil. The major nutrients required for revegetation can be supplied through addition of commercial fertilizers (Michaud 1981).

In order to determine fertilizer requirements, various factors must be assessed: plant nutrient requirements, available nutrient status of growth media, fertilizer effect on growth media, re-fertilization estimates, soil water availability and cost (USDA 1979).

The most common nutrient elements lacking in spoil materials in the West are N and P. Phosphorus is often more deficient than N (Sandoval et al. 1973) in the Northern Great Plains. In the same region DePuit and Coenenberg (1979) found P more limiting than N and K generally nonlimiting in the majority of mine soils. The authors reported increasing amounts of N and P increased plant cover of introduced grasses. However, during the initial phase of seedling establishment, variable rates of N showed no differences in plant density. In a greenhouse study of coal mine spoil Holechek (1982) found two Agropyron species increased in above and belowground biomass through low applications of N and P.

Several studies have shown that plant uptake of P is affected by N fertilization. Various rates of N and P fertilization produced greater overall yields on native range in western Canada when compared to an unfertilized condition (Johnston et al. 1968). When N and P

were applied separately and together on mixed grass prairie in North Dakota, Lorenz and Rogler (1973) found increased plant performance from variable rates of N with P, when compared to single applications of each. A laboratory study found thickspike wheatgrass yields nearly doubled in sodic coal spoil, when N was included with P. However, in the same study, nitrogen fixing yellow sweetclover only required P fertilization (Safaya and Wali 1979). In the Upper Teesdale region of England, sheep fescue benefited more from P than from N fertilization on shallow well drained soils. However, angiosperms required both N and P for increased shoot growth (Jeffrey and Pigott 1973). Revegetation of New Hampshire roadcuts with bluegrass and fescue grass species required only low rates of N and P fertilization to promote growth (Palazzo and Graham 1981). Analyses indicated that N and P in the soil were limiting to leaf growth prior to fertilization. In a southeastern Montana study of mine soil fertilizer requirements, Hertzog (1983) found fertilization produced the only significant vegetational responses when compared to N and P. However, the author concluded that indigenous N levels were sufficient in the mine soils to meet the first year growth requirements of the predominately native grass seed mixture.

Fertilization requirements in disturbed areas of higher elevations with coarse textured soils are much different than those of lower elevations that commonly have heavier soils (i.e., Northern Great Plains). Subalpine and alpine ecosystems typically have coarse textured cold soils where N is the limiting nutrient, probably resulting from low rates of microbial activity (Nishimura 1974).

Therefore, most high altitude revegetation efforts will begin with additions of N and P, but maintenance N fertilization is often required (Berg and Barrau 1978). These authors found that grasses established on two revegetated sites in the Colorado Rockies were extremely nitrogen deficient within three years after establishment. Due to the decreased organic matter level in high elevation coarse textured spoils and subsoils as well as elevated precipitation levels, 25-35 kg of N/ha is recommended every two or three years to maintain vegetative productivity on disturbed sites (USDA 1979). Working on spoil at the McLaren mine in Montana, Brown et al. (1976) found that fertilization with primarily N and P was imperative to rapid plant establishment. Specifically, the authors reported plant cover values 100 times higher, over a three year period on plots fertilized with 111 kg N/ha than non-fertilized spoils. At the end of the initial year of plant establishment, plant density was three times greater on fertilized spoil and topsoiled plots when compared to non-treated mine spoil or topsoiled plots.

The use of chemical fertilizers to improve plant growth on mine soils is well documented. Although fertilizer requirements are site specific, the basic criteria for establishing macro- and micro-nutrient needs are the same (USDA 1979). A review of the literature demonstrated that overall, mine spoil fertility is essentially quite low. The amount and grade of fertilizer used depends upon revegetation goals which are dictated by the type and location of the disturbance. In the Northern Great Plains P was found to improve plant performance (Deputt and Coenenberg 1979, Hertzog 1983, Sandoval et al. 1973,

Holechek 1982 and Safaya and Wali 1979), while in high elevation disturbances, N fertilization initially and often in repeated applications is necessary to achieve revegetation success (USDA 1979, Brown et al. 1976, Nishimura 1974 and Berg and Barrau 1978).

Liming

The creation of a suitable plant growth medium from acidic mine spoil is dependent upon the chemical characteristics of the material. Failure of many plants to survive in a low pH growth medium is rarely the result of the increased hydrogen ion (H^+) concentration (USDA 1979). Rather, decreased plant yields are most frequently due to increased and often toxic concentration of plant available aluminum (Al), manganese (Mn) and iron (Fe) (Tisdale and Nelson 1975). Furthermore, as these metals become more soluble, they form insoluble compounds with phosphates and create a phosphate fixation condition. Other macro-nutrients adversely affected by an acidic soil chemistry (i.e., decrease availability) are N and K, therefore, pH may be the most plant limiting chemical reaction in spoil materials (Vandevender and Sencindiver 1982, and Michaud 1981).

Acidity associated with many western hardrock spoils is generated by the oxidation of pyritic and sulfide minerals. Upon oxidation, these minerals produce acids and ferrous and ferric sulfates (Richardson and Farmer 1981). Sulfuric acid is a product of the oxidation of pyritic materials and is mainly responsible for spoil acidification. The rate of oxidation is dependent upon the size and shape of pyritic minerals (Richardson 1980).

Liming acidic soil and spoil materials to aid in the establishment of vegetation is well documented in reclamation literature. Revegetation of spoil at a western hardrock mine was found by Nielson and Peterson (1972) to be contingent upon liming. In Pennsylvania, researchers reported lime was more effective in establishing crownvetch in coal-breaker refuse than either fertilization or mulching. Lime rates of 2.3 and 4.5 MT/ha had maintained near neutral pH over a seven year period. Other benefits from liming found in this study were increased soil exchangeable Ca and Mg, as well as CEC and percent base saturation (Czopowskyj and Sowa 1976). In Australia, toxic heavy metal mine wastes were limed, buried and covered with a more suitable cover-soil medium. Successful mine dump revegetation required 6.3 MT of lime /ha (Keane and Craze 1978).

Hydrated lime was applied at a rate of 4 MT/ha on coal mine spoil in West Virginia and found to significantly increase spoil pH, the neutralization potential and Ca levels. However, the authors suggested the neutralizing potential of hydrated lime may not be permanent and may require additional applications to prevent reacidification (Vandevender and Sencindiver 1982). In Arkansas, acidic bauxite minesoil was limed with six rates of hydrated lime ranging from 18-63 MT/ha. One month after liming minesoil pH was near neutral for lower rates of lime application, however, at the heavier rates soil pH was high enough to preclude plant growth. Further analyses indicated that minesoil pH decreased in all treatments two years after liming. The author concluded that hydrated lime was initially effective in elevating minesoil pH, but control must be taken to

assess the proper lime rate (Harper and Spooner 1982). Reacidification of a copper-cobalt mine spoil at the Blackbird mine in southeastern Idaho occurred two years after initial application of ground limestone (CaCO_3) at a rate of 3.2 MT/ha/30.5 cm (1.4 tons/acre/foot). Further analysis suggested a rate of 44.9 MT/ha/30.5 cm (20 tons/acre/foot) would neutralize mine spoil pH for at least 10 years (Richardson 1980). These results further exemplify the need for establishing proper lime requirements to meet revegetation goals.

The use of lime to neutralize mine spoil acidity during plant establishment is an effective tool in many revegetation programs. Adequate amounts of lime added to mine spoil will increase soil pH and reduce Al, Mn and Fe solubility which is often toxic to plants (Michaud 1981). The primary source of mine spoil acidity results from oxidation of pyritic materials in overburden, the rate of oxidation is controlled by size and shape of pyritic materials (Richardson 1980). Numerous studies proved that lime application rates must be based on accurate mine spoil chemical analysis prior to treatment (Vandevender and Sencindiver 1982, Czopowskyj and Sowa 1976, and Richardson 1980).

Soil Crusting

Prior to phase I of this study, research on mine spoil crusting was virtually nonexistent. However, given that many chemical and physical parameters of any growth medium must be similar in order to support plant life, results of agricultural research pertaining to soil crusting are valuable.

The mechanism of soil crust formation is peculiar to chemical and physical characteristics of the soil. Without exception more than one process leading to crust formation and strength was described in each study that identified a mechanism. A sequence of crust formation as outlined by McIntyre (1958a) occurred in three phases:

- 1) soil breakdown, slaking or dispersion due to raindrop impact,
- 2) translocation of fine particles to the upper 1-2 mm soil layer,
- 3) cementation of the translocated particles upon drying.

Further research on the affect of soil splash on surface crust formation concluded that washing-in of fine particles and surface compaction from raindrop impact were the main mechanisms of crust formation (McIntyre 1958b). In phase I of this study Parady (1981) identified the mechanism of alluvium crust formation as "a physical problem caused by grain packing and clay adhesion within the sand fraction."

Although crust strength is a function of the formation mechanism, several factors have been identified that contribute to increasing crust strength. Hegarty and Royle (1978) found crust strength a result of rainfall quantity, compaction as influenced by soil moisture during the compaction process and the interaction of compaction and rainfall quantity. Using the modulus of rupture technique of quantifying crust strength, Lemos and Lutz (1957) found crust strength increased by: long hot dry periods, slow drying at low temperatures, compaction, raindrop impact and puddling. The authors also considered soil texture, clay type and bulk density.

In similar studies conducted by Gerard et al. (1972), soil moisture was included as a critical component affecting crust

strength. An inverse relationship between crust strength and soil moisture is a well documented phenomenon (Hanks 1960, Arndt 1965, Lemos and Lutz 1957, Holder and Brown 1974). Parady (1981) found a very high positive correlation ($r^2 = 0.97$) between declining percent gravimetric soil moisture and increasing crust strength. Holder and Brown (1974) reported that soil crust strength increased with decreasing soil moisture and was also related to drying time. A north-central Montana soil with a long history of grain production was found to have an inverse relationship between crust strength and soil moisture (Moe et al. 1971). The authors also found that below ten percent soil moisture when crust strength was high, soil water tensions exceeded 15 bars, a level beyond the plant wilting point for this soil. Therefore, soil water (below ten percent) was more limiting than crust strength for overall plant performance.

The purpose of many soil crust research projects identified crusting characteristics that influenced seedling emergence or impedance. Mechanical impedance of emerging seedlings by soil crusts is just one of many problems associated with seedling emergence. In many areas of the world the problem is substantial. Moe et al. (1971) stated that over 60,700 hectares of Montana farmland are affected by soil crusts. Although crusting occurs in a variety of climates, soil crusts formed in semiarid or arid climates undergo rapid drying and can form quickly. Therefore, the rate of seedling emergence becomes quite critical (Taylor 1962). In the arid Negev region of Israel soil crusting is most often the cause of poor wheat yields (Hadas and Stibbe 1977). The effect of crust strength on six

important Nevada pasture grasses was reported by Frelich et al. (1973). Their research showed that pubescent wheatgrass, tall fescue and smooth brome grass were adversely affected by increasing crust strength, while emergence of tall wheatgrass, basin wildrye and Russian wildrye was less affected. Under extreme crusts, tall wheatgrass had the highest emergence percentage. In a similar study on forage seedlings Jensen et al. (1972) reported that alfalfa seedlings exhibited significantly higher emergence force when compared to narrow-leaf birdsfoot trefoil, strawberry clover and alsike clover. Furthermore, they concluded that seed weight of these legume species was positively correlated to greater seedling emergence force. However, Williams (1956) had developed the same conclusions for four legume species sixteen years previous.

Numerous techniques have been reported on chemical and physical amendments applied to crusting soil to increase seedling emergence. Mechanical methods of breaking soil crust have been reported with mixed success. Seedling damage can occur if the process is implemented during seedling emergence periods (Carnes 1934). Chemical agents used to reduce soil crusts include sulfuric acid (Johnson and Law 1967), gypsum (Dollhopf 1971) and numerous synthesized organic soil conditions (Allison and Moore 1956). Although many of these techniques have reportedly reduced soil crusting, chemical amendments are expensive and often labor intensive. Furthermore, Chaudhri et al. (1976) stated that overall, more success was achieved with physical amendments when compared to chemical additives.

Physical amendments employed to reduce soil crusting are numerous and vary from covering the soil surface with black plastic (Bennett et al. 1964) to petroleum based mulches (Ahmad and Roblin 1971). Organic mulches are more commonly used due to the wide range of available materials. Specifically, the addition of manure has shown to be effective in reducing crust strength and improving seedling emergence.

Results of a laboratory study performed by Chaudhri et al. (1976) revealed that mechanical impedance in two soils prone to crusting, was greatly reduced when manure was applied in bands. The authors found that manure facilitated cracking of the crust and thus allowed seedling emergence through cracks. Manure applications at a rate of 4.5 MT/ha improved the structural condition (i.e. greater aggregation) and allowed a higher rate of water infiltration for a sandy loam soil in India. When manured plots were compared to cultivated plots, soil crust strength was less on manured plots (Das and Chaudhri 1981). In a study on an important eastern Nebraska agricultural soil, large applications of manure (180 and 360 MT/ha/year) incorporated to a depth of 30 cm, significantly reduced soil crust strength over a three year period. Despite substantial quantities of manure applied, soil properties and corn yields were not adversely affected (Mazurak et al. 1975). Manure mulched at a 1:4 (manure: alluvium) volumetric rate into alluvium in phase I of this study, significantly ($P < 0.05$) reduced surface crusts. When compared to untreated alluvium (control) Parady (1981) found crust strength decreased up to 93 percent in manured plots under greenhouse conditions.

In addition, the manure treatment had significantly ($P < 0.05$) increased the emergence rate of sheep fescue when compared to the control.

The basis of soil crusting research results from mechanical impedance of seedlings, which is responsible for major crop losses on a world-wide scale. Many factors influence the mechanism of crust formation and all soils that form a crust do not have the same formation mechanism or sequence. A review of soil crusting literature indicates that soil crust strength for all soils decreases with increasing soil moisture (Hanks 1960, Arndt 1965, Lemos and Lutz 1957, Holder and Brown 1974, and Parady 1981). Other edaphic and environmental constituents influencing soil crust formation and strength are: temperature and length of drying time, soil texture and bulk density, raindrop impact, soil compaction and puddling (Lemos and Lutz 1957, and Hegarty and Royle 1978). In addition differences in seed size and species have been shown by several researchers to affect plant performance in crusting conditions (Williams 1956, Jensen et al. 1972, and Parady 1981).

Various cultural techniques employed to reduce soil crusting are documented in the literature. Soil amendments include additions of chemicals (Dollhopf 1971, and Johnson and Law 1967), mechanical disruption of the crust (Carnes 1934) and physical additives (Bennett et al. 1964, Ahmad and Roblin 1971, Chaudhri et al. 1975, and Mazurak et al. 1975). Organic mulches added to crusting soil such as manure were reported to be successful in reducing crust strength and improving plant performance. (Mazurak et al. 1975, and Parady 1981).

Species Selection for Revegetation

Successful revegetation of mine spoil must totally integrate all phases of the reclamation process. The establishment of vegetative cover, is in itself, a separate procedure. Many plant species are available for revegetation, however, the process of proper species selection must address several criteria. Watson et al. (1980) have developed a very thorough manual of plant characteristics and suitabilities for reclamation in Alberta, Canada. The authors present numerous selection criteria regarding the suitability of various grass, forbs and shrubs. Important parameters presented include: species origin, range, growth habit, longevity and reproductive potential, optimal ecological setting (edaphic and climatic), soil reaction tolerances, nutrient requirements, tolerance to defoliation, palatability (animal species specific), soil building and erosion control capabilities, competitive ability, availability of seed source and establishment patterns. These criteria and probably more must be considered for each potential species in a seed mixture. However, Cook et al. (1974) summarized that plant species chosen for revegetation must be adapted to the site as well as suited to the post-mine land use.

For the purpose of this literature review, a brief description of the three grass species used to address specific project objectives are provided.

Agropyron dasystachyum

Thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), is a strongly rhizomatous, low to medium growing, native perennial grass species adapted to most soil textures (Long 1981).

A. dasystachyum was considered a pioneer species by Langham (1971) due in part to the wide range of adaptability to disturbed sites and excellent seedling vigor. In 1974, Dubbs et al. published results of a six year field trial where five collections of thickspike wheatgrass were tested for rangeland and pasture improvement in Montana. The document explained the variety Critana, provided good leaf production and the most vegetative cover, when compared to four other varieties. Through results of this research and numerous field trials the variety Critana was released for agronomic production in 1971 (Stroh et al. 1972). Critana was developed primarily for revegetating disturbed sites that receive minimal maintenance.

Long (1981) states that thickspike wheatgrass adapts well to eroded or well drained sites, particularly waterways and steep slopes. In Montana, he recommended the grass be seeded in areas ranging from 600-2100 m in elevation and receiving 15-50 cm of annual precipitation. However, optimum plant performance was suggested to occur in the 30-36 cm precipitation zone. Redmann (1974), concluded that thickspike wheatgrass had a wide range of physiological tolerance limits and therefore, was well suited to a variety of temperature and moisture conditions. A common Montana range species, thickspike wheatgrass provides a good forage base, increases with grazing on

most sites and is capable of withstanding heavy grazing and trampling (Yaeger et al. 1977, and Wambolt 1981).

Thickspike wheatgrass is a prevalent component in seed mixtures for Western mine spoil revegetation. A study comparing revegetative capabilities of topsoiled and non-treated spoil at the Shirley Basin mine in Wyoming, found thickspike wheatgrass produced more cover in non-treated spoil material than either Russian wildrye or western wheatgrass (Rauzi and Trester 1978). North Dakota researchers tested the growth response of thickspike wheatgrass and seven other grasses, forbs and shrubs to different textured spoil materials and variable levels of salt concentrations in spoil material. Published results indicate thickspike wheatgrass had the highest percent germination and emergence of all species considered. In addition, thickspike wheatgrass was found to produce more above and belowground biomass at all levels of salt concentration, when compared to switchgrass, Canby bluegrass, little bluestem and green needlegrass. In untreated spoil however, switchgrass produced more aboveground biomass and switchgrass and little bluestem had produced more belowground biomass. Furthermore, the authors found thickspike wheatgrass produced significantly more root biomass in a silt loam spoil when compared to a silty clay loam spoil (Ries et al. 1976).

Thickspike wheatgrass is a perennial, native, strongly rhizomatous grass species with a wide range of physiological tolerances that is adaptable to a wide range of soil textures and is commonplace in many western revegetation programs (Long 1981, Langham 1971, Dubbs et al. 1974, Stroh et al. 1972, Redmann 1974). Several varieties of

this species are commercially available, however, Critana is the most widely used (Stroh et al. 1972). Numerous studies report thickspike wheatgrass is a reliable species to use in mine spoil reclamation (Ries et al. 1976, and Rauzi and Trester 1978).

Festuca ovina

Sheep fescue (Festuca ovina L.) is a densely tufted low growing perennial bunchgrass that is well adapted to coarse textured soils (Berg 1974). Although the origin of this species has been questioned (Smoliak et al. 1975), most varieties are introduced from Eurasia (Watson et al. 1980). F. ovina has numerous varieties that are commercially available both in Europe and North America. Many reports on performance of F. ovina fail to reveal the variety of species used therefore, generalizations about plant variety performance are often difficult to interpret.

In general, however, sheep fescue is well adapted to sandy, gravelly, well drained soils and dry habitats. This plant prefers soil depths from 30 to 60 cm on 9 to 20 percent slopes (Watson et al. 1980). The species is fairly easy to establish, has weak to moderate seedling vigor (Long 1981) and may be a poor competitor initially but has been shown to be very aggressive two years after seeding (Loiseau 1974, and Schwendiman 1974).

Sheep fescue reportedly is a good soil stabilizer and improves soil structure due to the very dense mat of roots produced (Lilley and Benson 1979). The authors reported sampling an established stand that produced over 3000 kg/ha of root material in the top 20 cm of

soil. For this reason sheep fescue is widely used for soil stabilization and erosion control throughout the world.

In England, Bradshaw et al. (1978) reported good establishment of sheep fescue in a grass legume mix on sand wastes that were low in fertility. A West German researcher found F. ovina was the most dominant of 48 plant species established on xeric non-topsoiled roadcuts with south and west facing aspects (Leyer 1981). Biological methods of stabilizing fly ash and cinder waste dumps were investigated in Czechoslovakia, where Kozel (1978) found F. ovina suited to the harsh environment and provided control for fugitive dust. A study of potential plant materials for revegetation of high elevation disturbances, found sheep fescue, variety duriuscula (hard sheep fescue), performed well in a number of plantings. Several stands in Colorado were over 20 years old (Eaman 1974). In another Colorado study, hard sheep fescue was severely winter killed during the first two years of revegetation research at a molybdenum mine at an elevation above 2750 m. However, once established the author found this variety quite desirable for revegetating dry sites at this elevation (Berg 1974).

The use of F. ovina in revegetation of acidic metal mine spoil is well documented. Sheep fescue is reported to exist under a wide range of soil reactions where pH may vary from 4.5-8.0 (Long 1981). Tueller and Butterfield (1981) found sheep fescue a promising species for revegetating old mine spoil and cyanide (Cn) tailings in the Great Basin. Preliminary results indicate F. ovina expressed vigorous growth in arsenic (Ar) concentrations of 2000 ppm and toxic levels of

Al and Mn. A Belgium researcher observed that sheep fescue showed higher tolerances to cadmium (Cd), lead (Pb) and zinc (Zn) than Agrostis tenuis (a species known for heavy metal tolerance). In addition he reported that there were regional genetic differences in metal tolerance within the same species (Simon 1977). Alloway and Davies (1971) observed no toxic affects in sheep fescue growing on soil contaminated by lead mining. Concentrations of 3,680 ppm Pb, 1330 ppm Zn and 48 ppm Cu were reported in these soils.

Festuca ovina is a densely but delicately tufted low growing introduced perennial bunchgrass capable of a wide range of environmental factors. Generally, sheep fescue prefers coarse textured soils and does very well in dry habitats, on steep slopes and high elevations (Watson et al. 1980, Long 1981, Lilley and Benson 1979, Berg 1974). This circumboreal species was reported on revegetated lands throughout the world (Bradshaw et al. 1978, Leyer 1981, Kozel 1978, Eaman 1974, Berg 1974 and Watson Et al. 1980), is well adapted to a variety of soil reactions (Long 1981) and to elevated metal levels associated with metal mining (Tueller and Butterfield 1981, Simon 1977, and Alloway and Davies 1971).

Poa compressa

Canada bluegrass (Poa compressa L.) is a medium growing (15-50 cm tall), rhizomatous, perennial species with a tussock growth habit, that is adaptable to a variety of soil textures (Watson et al. 1980, Turkington et al. 1977, and Beetle and May 1971). Like sheep fescue, the origin of this species is somewhat in question. Beetle and May

(1971) refer to P. compressa as introduced from Europe; however, Canadian scientists Elliot and Baenziger (1970) characterize it as native of northern North America. Although over 24 varieties of P. compressa are recognized throughout the world (Martusewicz 1974), only the variety "Rubens" is certified in the United States (Jacklin 1975).

Canada bluegrass is known to exist in soil of variable textures and fertility levels (LICA 1978). The species was tested in Colorado and found to prefer loamy and clayey soils over lighter textured sandy soils (Varies and Sims 1977). Optimum soil depths range from 30-60 cm on 0-8 percent slopes (Watson et al. 1980), though, Canada bluegrass has been established on roadcuts in Idaho in subsoil material on a 135 percent (55 degrees) slopes (LICA 1978).

Although first year performance of P. compressa has often been recorded as poor, once established this species can be quite persistent (Watson et al. 1980). For this reason Canada bluegrass has been used for pasture improvements (Elliot and Bolton 1970) and ground cover on disturbed areas (Powell et al. 1982). In livestock pastures the species is noted for excellent palatability throughout the growing season and its resistance to trampling (Elliot and Bolton 1970). In 1982, Powell et al. reported the variety Rubens (seeded in a monoculture) produced excellent growth and after four years had effectively covered over 80 percent of test plots on a Kentucky mine spoil.

The use of Canada bluegrass for revegetation has a wide range of applications (Hafenrichter et al. 1968). The authors recommend P. compressa for erosion control and ground cover on roadcuts, barrow

pits, dam sites and recreational areas in the Pacific Northwest. However, they cautioned that when used in pastures, the species may invade other improved areas. In Poland, Ziemnicki and Fijalkowski (1975) found P. compressa the dominant species in a mixture that developed ground cover substantial enough to "afford complete protection against erosion" on sulphur (S) mine spoils four years after seeding. Revegetation efforts in the Canadian Arctic found Canada bluegrass would survive unrelenting winter conditions and become established on lands disturbed by oil and gas exploration (Bliss and Wein 1972).

The potential of P. compressa to establish on high elevation acidic mine spoil has been documented by Brown and Johnston (1978). The authors found Canada bluegrass had the highest first year survival of six introduced species tested and ranked second in performance of 12 grasses transplanted into mine spoil in Montana. In addition they reported P. compressa had the largest basal diameter, plant height, dry matter production and flowering percentage of 12 native and introduced species tested. Recognizing the preliminary nature of these results, the authors recommended further study to determine if the growth habit is suited to adverse climatic and edaphic conditions associated with high elevation hard rock disturbances. Further research on the adaptability of Canada bluegrass was conducted on lead-zinc mine tailings in northern Idaho. Three years after seeding, LICA (1978) reported the variety Rubens had higher vegetative production than hard sheep fescue and intermediate wheatgrass, to establish an almost pure stand.

Canada bluegrass is a medium growing, sodforming, perennial species with potential for revegetating a variety of disturbances (Watson et al. 1980). Although this species is adaptable to many soils, optimum performance has been reported on textures somewhat heavier than sandy (Vories and Sims 1977). Specifically, P. compressa has shown excellent production on acidic mine spoil and has superb potential for providing long term forage for livestock and wildlife (Brown and Johnston 1978, LICA 1978, Elliot and Bolton 1970, and Powell et al. 1982). The ease of establishment of Canada bluegrass is somewhat in question and may depend on localized edaphic and climatic conditions; however, once established this rhizomatous species has proven persistent (Watson et al. 1980, Powell et al. 1982, Elliot and Bolton 1970, LICA 1978, and Ziemnicki and Fijalkowski 1975).

METHODS AND PROCEDURES

Regional Site Description

The Berkeley Complex is located in southwestern Montana on the western slope of the Continental Divide. The area is bordered by steep bedrock ridges to the north and east, the Summit Valley to the south and smooth rounded mountain slopes to the west. Total related mining disturbances encompass well over 3200 ha, where elevations range from 1750 to 2000 m.

The Butte area experiences long cold winters and short cool summers. The average annual temperature is 3.7°C while average monthly extremes range from -9.3°C in January to 17.1°C in July. The average frost free period is 60 days; however, frost can occur in any month (National Oceanic and Atmospheric Administration 1977).

The average annual precipitation for the area is 283 mm, 30 percent of which comes as snow. The wettest months are May and June when over one-third of the total precipitation falls (National Oceanic and Atmospheric Administration 1977). Thornwaite's (1941) Precipitation-Evapotranspiration index (a relative measure of effective precipitation), classifies the Butte area as a semi-arid province which indicates effective precipitation is deficient year-round.

Additional description of the geology, soils and vegetation, both on and adjacent to the site, can be found in the final report of phase I of this study (Parady 1981).

Field Test Plot Description

The study site was located within the mine permit boundary, on a westsouthwest sloping mine waste dump. The average elevation on the site is 1860 m and slope angles range from 26° (south end) to 20° (north end). Construction of the research plots began in April of 1981. Approximately 7,650 m³ of alluvial overburden (alluvium) was veneered over the surface (2.23 ha) of the waste dump. Selection of the alluvium was based on test results and recommendations from phase I of this study. Alluvium application depth varied greatly throughout the research area; cover-soil depths averaged 2.0 m on the crest of the slope, 1.8 m in the middle and an average of 1.2 m at the toe of the slope. Total average thickness of the alluvium over all twelve plots was determined from nine drill holes and found to be 1.8 m.

The study design included three replicates of three amendments and three control replicates (Figure 1). Surface amendments incorporated into the alluvium were:

- A) Stockyard manure incorporated at a rate of 190 MT/ha (1:4 manure to overburden; volumetric rate) + fertilizer* + lime†.
- B) Mulched grass hay incorporated at a rate of 1786 kg/ha + fertilizer* + lime†.
- C) Chemical fertilizer* incorporated at a rate of 269 kg/ha + lime†.
- D) Control; non-treated alluvium.

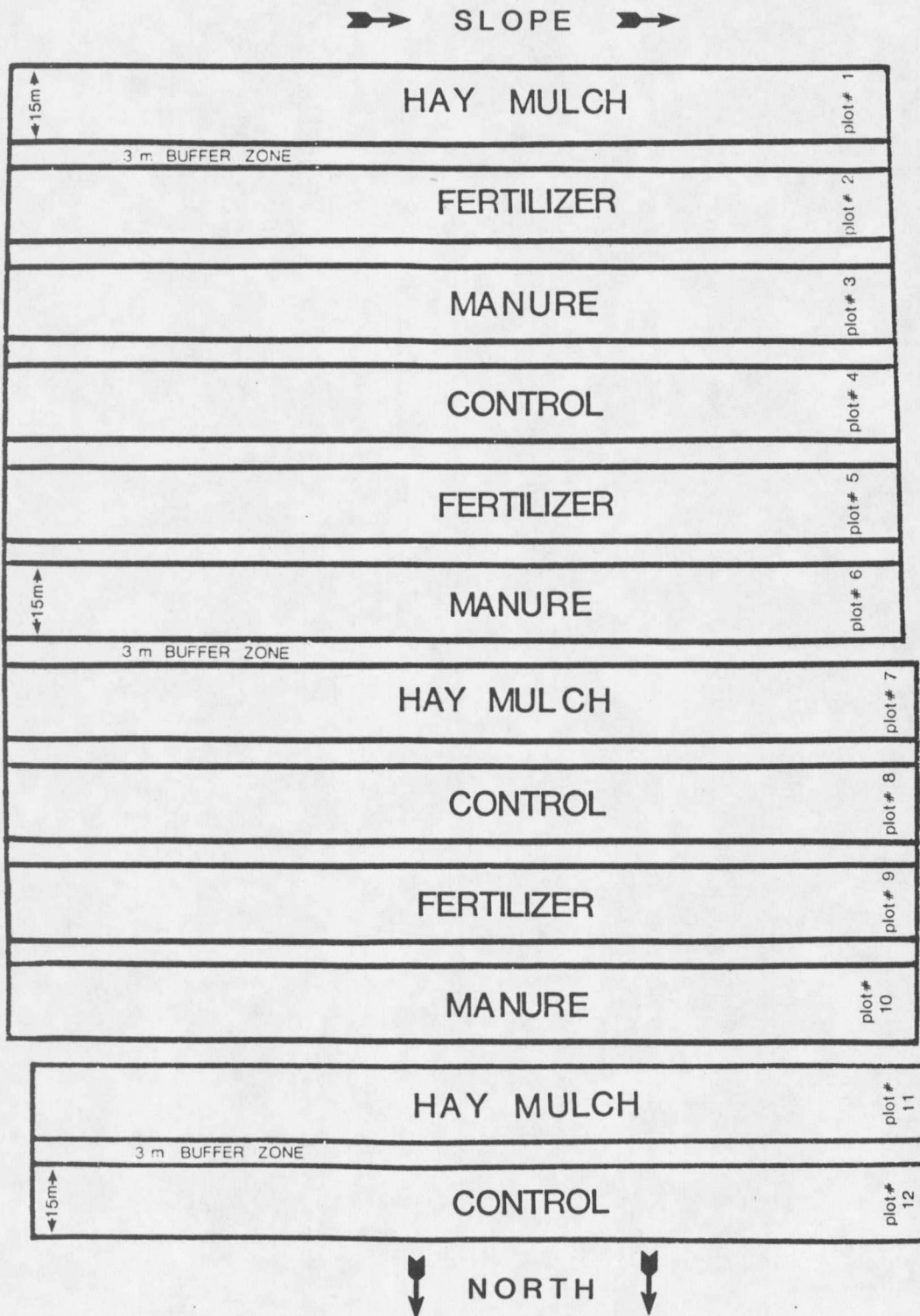


Figure 1. Plot design.

- * fertilizer = ammonium phosphate sulfate (16-20-0) incorporated at a rate of 269 kg/ha.
- † lime = a quick or hydrated lime ($\text{Ca}(\text{OH})_2$) incorporated at a rate of 1545 kg/ha. Lime used was type S construction grade lime which conforms to these specifications: A.S.T.M. C206-49 and C207-49 Types, and federal specification number SSL-351.

The use of lime and fertilizer in Berkeley Pit alluvium were reported by Parady (1981) as management techniques that were critical to plant growth in this medium. Therefore, following results and recommendations from phase I, all treated plots were limed and fertilized and are considered equal except for additional amendments (e.g., incorporation of hay or manure).

Dimensions, slope and treatment of each plot are provided in Table 1. A 3.0 m buffer zone was created between each plot to limit confounding between treatments. All amendments were incorporated to a depth of 20-30 cm with a vibrashank chisel plow. A brief description of each amendment follows.

Incorporated Manure

Manure used for this amendment was obtained from the Butte Livestock Yard and originated primarily from feedlot beef cattle. The manure had been stockpiled for one year prior to application. Approximately 190 MT of manure/ha (90 m^3) was applied to each of the three manure replicates (Figure 1). The application rate (one part manure to four parts alluvium) was based on results from phase I and

Table 1. Research plot dimensions (aspect = 256° WSW).

Plot Number	Treatment	Length*	Slope†	Width*	
				Top	Toe
1	Hay	52.4	26	15.2	15.2
2	Fertilizer	52.4	24	15.2	15.2
3	Manure	57.0	25	15.2	15.2
4	Control	59.1	24	15.2	15.2
5	Fertilizer	59.7	24	15.2	15.2
6	Manure	62.5	23	15.2	13.7
7	Hay	67.7	23	15.2	12.2
8	Control	67.7	21	15.2	13.7
9	Fertilizer	67.7	20	15.2	15.2
10	Manure	67.1	21	15.2	15.2
11	Hay	67.1	23	15.2	15.2
12	Control	67.7	23	15.2	12.2

*Length and width in meters

†Slope in degrees

was found to be the optimum amount for plant performance and crust strength reduction (Parady 1981). Application rate and incorporation of manure varied greatly throughout each plot, due to the slope of the terrain, variable plot surface area and the heavy equipment required to distribute the massive amount of manure.

Incorporated Hay Mulch

The hay mulch treatment was designed to test the affect of coarse organic matter incorporation on plant response and alluvium crust strength.

Hay was obtained from an early second cutting on a tame grass pasture near Bozeman, Montana. Primary components of the hay were smooth brome grass (Bromus inermis), common timothy (Phleum pratense) and alfalfa (Medicago sativa). The early, second cutting hay was choosen for the lack of fertile seed in the hay. Hay was chopped to an average length of 10 cm in a tub-type hay grinder, applied by hand

at a rate of 1786 kg/ha and incorporated to a depth of 20-30 cm with a vibrashank chisel plow.

Incorporated Fertilizer

Fertilization as a treatment is designed to test the ability of the alluvium as a plant growth medium when soil fertility is not limiting. Chemical fertilizer applied during seedbed preparation allows for a more direct incorporation of each compound in the fertilizer into the plant growth medium (Tisdale and Nelson 1975).

The fertilized plots were treated with an ammonium phosphate sulfate (16-20-0) fertilizer ($\text{NH}_4 \text{H}_2\text{PO}_4 (\text{NH}_4)_2 \text{SO}_4$), which is a mixture of 16% nitrogen (all ammonium form), 20% $\text{P}_2 \text{O}_5$ (8.8 available P) with no additional potassium (K) added (previous alluvium analysis indicated substantial levels of K were present; Parady 1981). The mixing agent for this fertilizer is combined S compound at a rate of 14%. A breakdown of the major fertilizer components is provided in Table 2.

Table 2. Ammonium phosphate sulfate fertilizer specifics.

<u>Applied Nutrient</u>	<u>%</u>	<u>kg/ha</u>
N	16	54
P	8.8	24
K	0	0
S	14	38

The fertilizer was applied at a rate of 269 kg/ha, with a 4.3 m wide fertilizer spreader. Fertilizing is considered a separate treatment; however, all treated plots were fertilized.

Liming and pH Determinations

In addition to the various amendments, all but the control plots were treated with a liming agent to increase pH prior to seeding. Parady (1981) concluded that over 30 percent of the Berkely Pit alluvium samples have a pH lower than 5.6. Soil pH in the range of 4.5 to 5.6 is considered limiting to a plant growth.

On site alluvium analyses indicated the untreated alluvium had an average pH of 5.3 ranging from 6.18 to 4.28 (36 samples). Alluvium pH determinations utilized a 1:1 saturated paste with a glass probe pH instrument (Peach 1965). Samples were allowed to equilibrate in paste form for four hours prior to pH measurements. A regression equation developed for Berkeley Complex alluvium, correlating lime rate and pH (Parady 1981) indicated a requirement of 4303 kg/ha of agricultural lime (CaCO_3). The lime used was a commercial grade, quick or hydrated lime (Ca(OH)_2). Evaluation of the physical characteristics (percent coarse rock fragments) of the alluvium and the chemical nature of the lime (molecular weight of Ca(OH)_2 vs. CaCO_3) produced a net reduction in liming amounts of 55 percent. Therefore, the actual lime requirement was 1545 kg/ha. The lime was applied by hand from 23 kg bags.

Seeding (Spring 1981)

Incorporation of the above amendments and the preparation of an adequate seedbed were delayed by unsuitable weather conditions. Seeding on the research plots began June 22, 1981, and was completed on June 24, 1981. Each of the 12 plots (Figure 1) was divided into five microplots for the purpose of testing three grass monocultures and two grass/forb mixtures (Table 3 and Figure 2). Therefore, each microplot was seeded with a different species or mixture of species (Table 3).

Prior to seeding, the seedbed was loosened with a spike-toothed harrow and five microplots were located within each plot and marked with string. The seeding order of each microplot was randomly selected to reduce bias within the system. The size and variable order of the microplots required seeding to be accomplished by hand broadcasting. The seeding rate was 435 pure live seed (PLS) per square meter for the grass monocultures and grass forb mixtures. Once sown the rough seedbed was cultipacked with an empty Brillion seeder (Vallentine 1980).

Numerous difficulties were experienced with this seeding, most of which were weather related. The first recorded seed germination was 33 days after seeding and emergence was recorded 22 days later (August 18, 1981). During the period between seeding and emergence (55 days), 41 mm of precipitation were recorded onsite and a substantial surface crust had formed. Seed germination and subsequent emergence were delayed as the first phase of germination required ample moisture for imbibition or hydration (Salisbury and Ross 1978). Average soil surface temperatures for this period were over 20°C.

Table 3. Seed list for seeding trials.

Single species seeded		
<u>Scientific Name</u>	<u>Common Name/Cultivar</u>	<u>rate/meter^{2*}</u>
<u>Agropyron dasystachyum</u>	thickspike wheatgrass/Critana	435 PLS
<u>Poa compressa</u>	Canada bluegrass/Ruebens	435 PLS
<u>Festuca ovina</u>	hard sheep fescue/Durisicula	435 PLS
Mixtures seeded		
<u>Mix A</u>		
<u>Agropyron dasystachyum</u>	thickspike wheatgrass/Critana	65 PLS
<u>Festuca ovina</u>	hard sheep fescue/Durisicula	65 PLS
<u>Sporobolus cryptandrus</u>	sand dropseed	65 PLS
<u>Linum lewisi</u>	Lewis flax/Appar	65 PLS
<u>Oryzopsis hymenoides</u>	Indian ricegrass/Nezpar	65 PLS
<u>Elymus junceus</u>	Russian wildrye	65 PLS
<u>Mix B</u>		
<u>Agropyron riparium</u>	steambank wheatgrass	65 PLS
<u>Festuca ovina</u>	sheep fescue/Covar	65 PLS
<u>Calamovilfa longifolia</u>	prairie sandreed/Gosen	65 PLS
<u>Achillea millifolium</u>	western yarrow	65 PLS
<u>Poa compressa</u>	Canada bluegrass/Reubens	65 PLS
<u>Agropyron trachycaulum</u>	slender wheatgrass/Revenue	65 PLS
<u>Astragalus cicer</u>	cicer milkvetch/Lutana	65 PLS

*Fall 1981 seeding are double these rates.

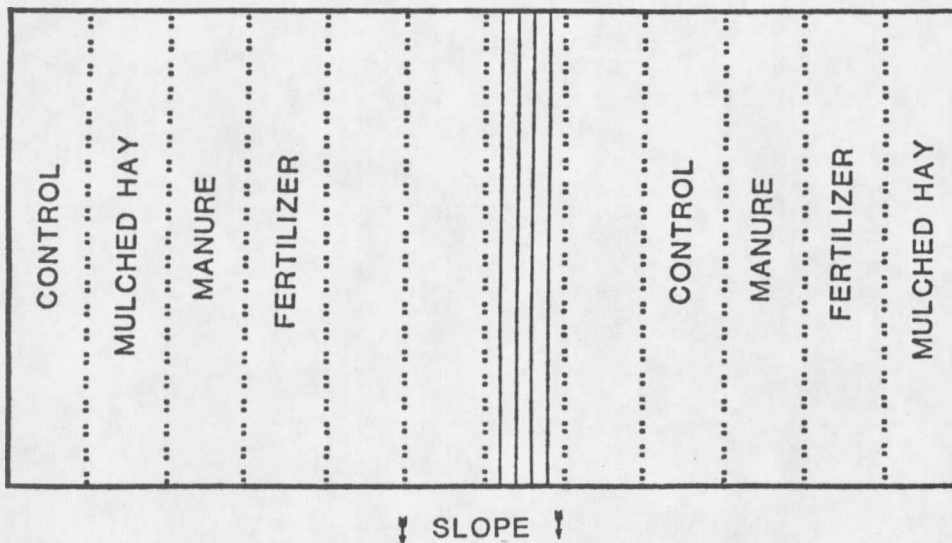


Figure 2. Treatment diagram. The area between the broken lines represent amendments. The solid lines in the middle of the figure denote microplots located within each amendment. All treatments were replicated three times.

These conditions resulted in total seeding failure, therefore, preparations were initiated for fall seeding.

Seeding (Fall 1981)

The resolution to initiate another seeding created an entirely new set of variables. To perform an adequate vegetation analysis, the seeding rate must be known. Due to the severe crusting problem and the subsequent variable rate of seedling mortality, the residual seed available for establishment could not be accurately determined. Therefore, prior to the fall seeding, a method of quantifying the combined (fall and spring) seeding rates was developed.

Following seed bed preparation subplots were sterilized (thereby killing residual seed and seedlings) using methyl bromide gas (CH_3Br).

An area 4.5 x 15.25 m, (15.25 m = the width of one plot) was randomly selected in plots 1 through 4, for sterilization. A plastic tarp was placed over the entire 4.6 x 15.25 m (68.6 m^2) plot and secured by burying the ends in trenches. On October 26, 1981, six, 227 gram canisters of methyl bromide gas were released under each of the four tarps. The tarps remained in place for two days to allow complete penetration of the gas, whereupon the tarps were removed to allow any residual methyl bromide time to dissipate, prior to seeding.

All plots employed the same seeding methodology as the previous spring seeding. However, due to the previous seeding failure, the fall seeding rate was doubled to a rate of 870 PLS per square meter. For the basis of comparison, an area the same size as the sterilized zones was left unseeded in all plots (Figure 3). This design served as a check for comparison of the variable seeding rates.

Seeding was completed November 8, 1981, utilizing the same hand broadcast technique applied in the spring seeding. The following day the seed was covered by the cultipacking action of the Brillion seeder. Seeding was intentionally delayed to initiate a late fall seeding.

Seed and Seedling Environment

At the onset of germination and emergence, soil temperature and percent moisture was recorded for each amendment. In addition, precipitation data were recorded throughout the entire study period.

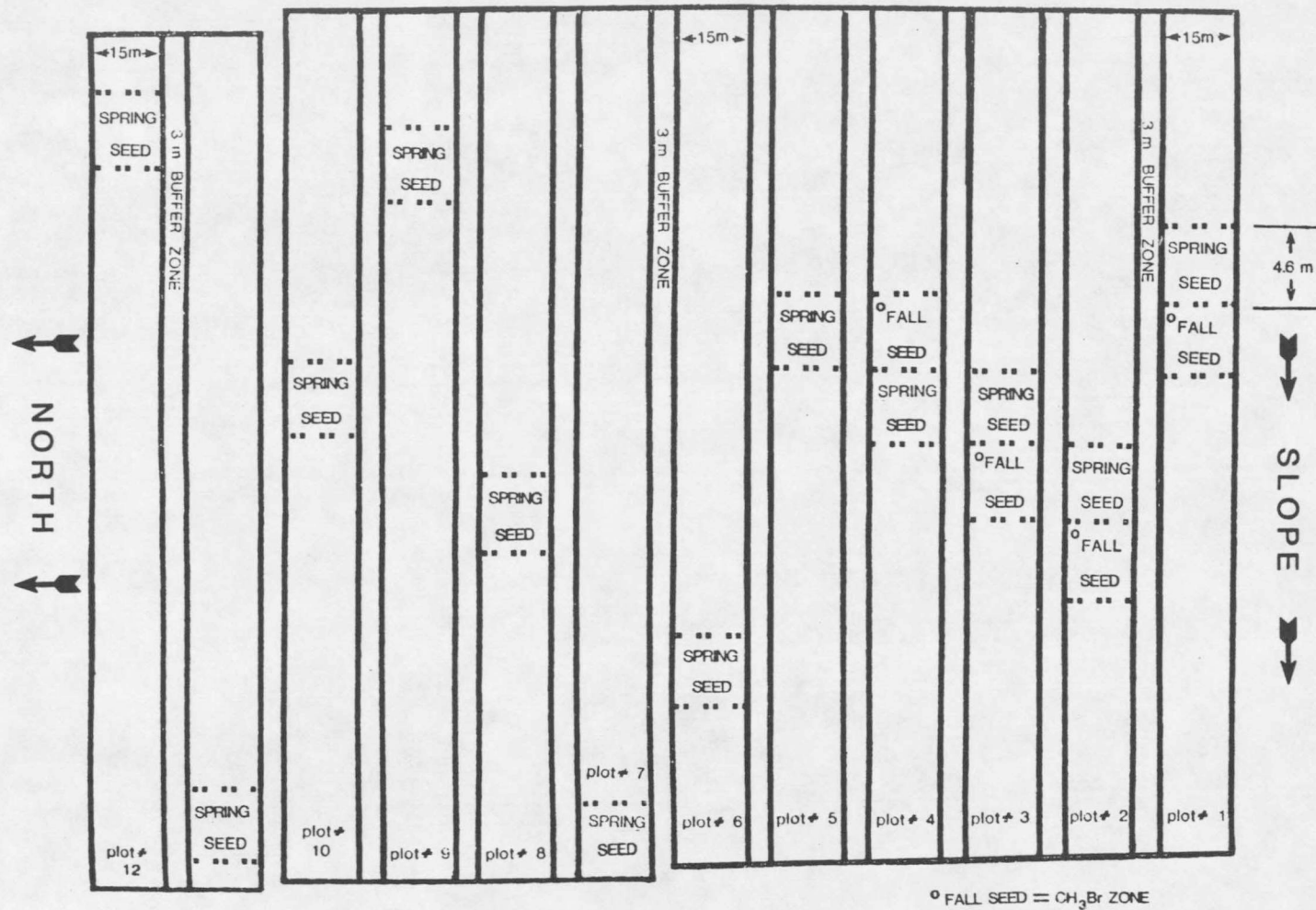


Figure 3. Research plot fall 1981 seeding diagram. Areas not within the broken lines are spring and fall seeded.

Soil temperature was based on at least one thermometer measurement in each plot. Three replicates of each treatment were averaged on each respective sample date and soil temperatures were compared between treatments.

Soil moisture was measured by the Troxler model 3411 soil moisture/density gauge (Troxler 1980) at the beginning, middle and end of the summer growing season. Measurements were taken five times in each treatment block along a pre-designated transect line (Figure 4). Information on soil moisture was recorded every 10.0 m on the diagonal. Non-seeded and methyl bromide zones were not measured separately. The instrument was operated in the back scatter mode, which incorporated soil moisture data from approximately the 0-10 cm soil depth zone.

Alluvium Crust Strength

Alluvium crust formation was reported in phase I to influence seedling performance. Previous observations in phase II reported a seeding failure in 1981 due in part to excessive crust strength. Therefore, measurements of alluvium crust strength were made six times during the 1982 growing season, using a Proctor Soil Penetrator. Crust strength was measured parallel to soil moisture measurements and seedling density count on the same sample dates.

Seedling Density

Seedling density counts conducted every two weeks after initial germination were made utilizing a 50 X 30 cm (0.15 m^2) quadrat. Sampling followed the pattern shown in Figure 4 on the grass monoculture

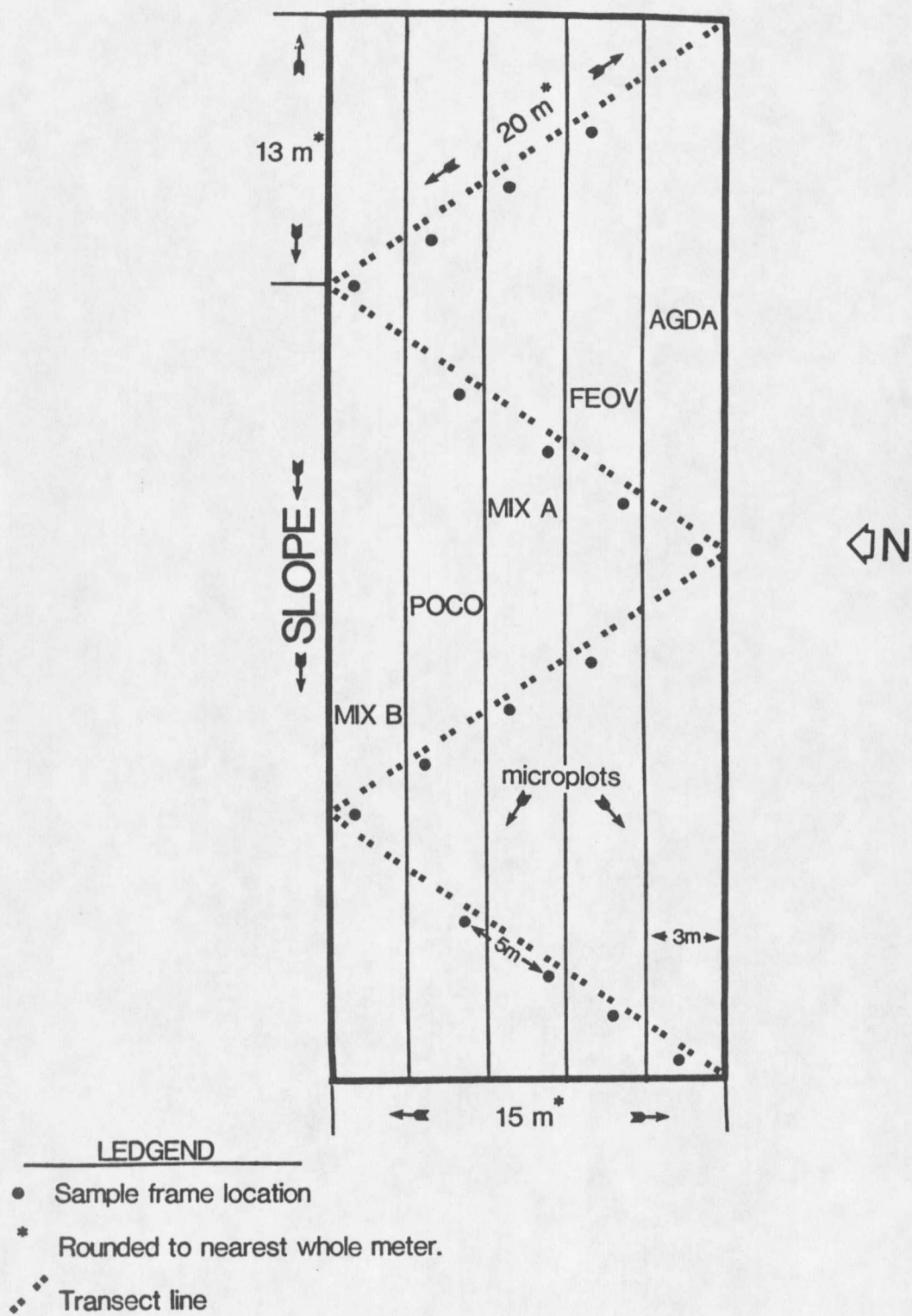


Figure 4. Example of plot lay out and sampling scheme.

plots only. All quadrats were 5.0 m apart and arranged on a diagonal (to minimize slope effect). Additional sampling was done horizontally (across plots) on each of the non-seeded and methyl bromide zones to ascertain the effect of the two seedings on plant density.

Plant Cover

Plant aerial or canopy cover was estimated on October 15, 1982, after a fall green-up period. Procedures for estimating cover, follow Daubenmire (1959). Quadrat size was 75 cm x 75 cm (0.56 m^2).

Sampling was conducted on a transect perpendicular to the slope. All species were thus compared under the same slope conditions. Each treatment contained five transect lines with a quadrat centrally located in each seeded microplot. All transects were spaced on 13.7 m intervals with the first transect line randomly selected. Cover estimates were made five times for each plant species in each replicate.

Production

Production data were obtained by harvesting accessible aboveground plant matter for each species, within the same sample frames in which canopy cover was estimated (five quadrats/species/treatment). Harvested plant material was oven dried at 70°C , weighed and species production was expressed as grams of oven dry material per unit area.

In attempt to analyze total plant performance (disregarding growth form), each species harvested for aboveground production, was sampled for belowground phytomass (roots, rhizomes and belowground shoots).

Belowground phytomass data were obtained with 100+ randomly located individual samples of each species of the feasibly attainable belowground roots and shoots. Species sampled for aboveground phytomass were also harvested for belowground phytomass. Selected samples were excavated with a shovel (to a maximum depth of one meter), taking care to obtain as much root material as possible.

Results of above and belowground yield data were compared. An above to belowground phytomass ratio was developed through harvesting an entire plant of each species in each amendment. The whole plant was separated into above and belowground portions. After the roots were completely cleaned, both fractions were then dried and weighed. Through comparison of 100 samples of each species, an above to belowground phytomass ratio was determined. Furthermore, these data were used in extrapolation from the more extensively sampled aboveground yield data to infer belowground trends.

Statistical Analysis

Statistical analysis utilized standard analysis of variance techniques provided by the Montana State University computer statistical analysis package (MSUSTAT). Comparisons of treatment means were made and those found significantly different at the 0.01 probability level (unless otherwise noted) were further compared to assess all differences.

RESULTS AND DISCUSSION

Results of this study are reported according to each separate phase of data collection and follow the format presented in the previous section. Although each phase appears separately, data pertinent to complimentary sections is provided to assist in the overall interpretation of the potential of alluvium to support plant life.

Seed and Seedling Environment

In effort to characterize edaphic conditions influencing the seed and seedling environment, measurements of soil temperature, soil moisture and precipitation were made throughout the growing season.

Soil temperature was recorded eight times throughout the 1982 growing season at 0-5 cm. Measurements were taken in all plots and averaged over each treatment. No significant differences ($P < 0.10$) in soil temperature were noted on any date among all treatments (Table 4).

The initial soil temperature measurement corresponds to the earliest seedling emergence observation. The first recorded emerged seedlings were primarily seeded wheatgrasses and cool season invading weed species (e.g., Bromus tectorum and Trifolium spp).

Analysis of temperature measurements indicates that mulching had very little effect on soil temperature in the critical seed

Table 4. Mean¹ research plot soil temperature for the 1982 growing season.

Date	Temperature in °C			
	<u>Control</u>	<u>Mulched Hay</u>	<u>Fertilizer</u>	<u>Manure</u>
4/27	1	1	1	1
5/27	4	4	4	4
6/1	9	9	9	10
7/1	16	16	16	16
7/13	25	25	25	25
7/27	30	30	30	28
8/27	28	28	28	26
10/15	10	10	10	9

¹ Each figure represents a mean of three measurements.

germination zone (0-5 cm). These results reflect the high amount of soil water initially and the subsequent elevated rate of evaporation, producing a colder soil. The fact that no significant differences were found in soil temperatures among treatments may be interpreted differently as per treatment.

The top 5 cm of soil was much less dense in the manure amendment than untreated alluvium. This condition provides more soil to air contact resulting in a drier soil, which is more affected by diurnal temperatures and may be a reflection of ambient air temperatures. The manure was also much darker than the alluvium and therefore absorbed more heat; however, the heat appeared to dissipate as air temperatures decreased. Combined, these factors appeared to contribute to mitigate much of the soil buffering capacity the manure may provide.

Soil temperature patterns in the hay mulch condition were more straightforward and related to the amount of mulch applied. Chopped hay was applied at a rate of 1786 kg/ha and incorporated to a depth of 20-30 cm. Incorporation of the hay, therefore, limited the surface

effect of the mulch as an average of only one percent of the soil surface was covered by mulch.

Soil moisture was measured on three dates during the 1982 growing season (Figure 5). Analysis of these data reveals that no significant differences ($p < 0.05$) in soil moisture occurred on the June and August sample dates in the control, fertilized or hay mulched plots. However, the mulched hay treatment had significantly ($p < 0.05$) higher soil moisture in May than the control. Soil moisture determinations for the manure treatment were disallowed because the Troxler 3411 moisture/density gauge produced unrealistic moisture values due to the elevated hydrocarbon level in the manure.

Precipitation data accumulated on site and compared to historical averages for the Butte area (Figure 6) revealed that total precipitation for the period November 1981 through October 1982 was 30.9 cm or 103 percent of normal (National Oceanic and Atmospheric Administration 1977). Historical data indicate that June received the highest average monthly precipitation (6.2 cm). However, during the critical seedling emergence period (May and June), an average of 10.3 cm of precipitation can be expected to occur. During the same period in 1982, 11.0 cm of precipitation was recorded (107 percent of normal).

No differences in soil moisture was found over all treatments for the last two sample dates and therefore moisture was not regarded as plant limiting. Soil temperature was surprisingly low at germination based on recommended optimum germination conditions for

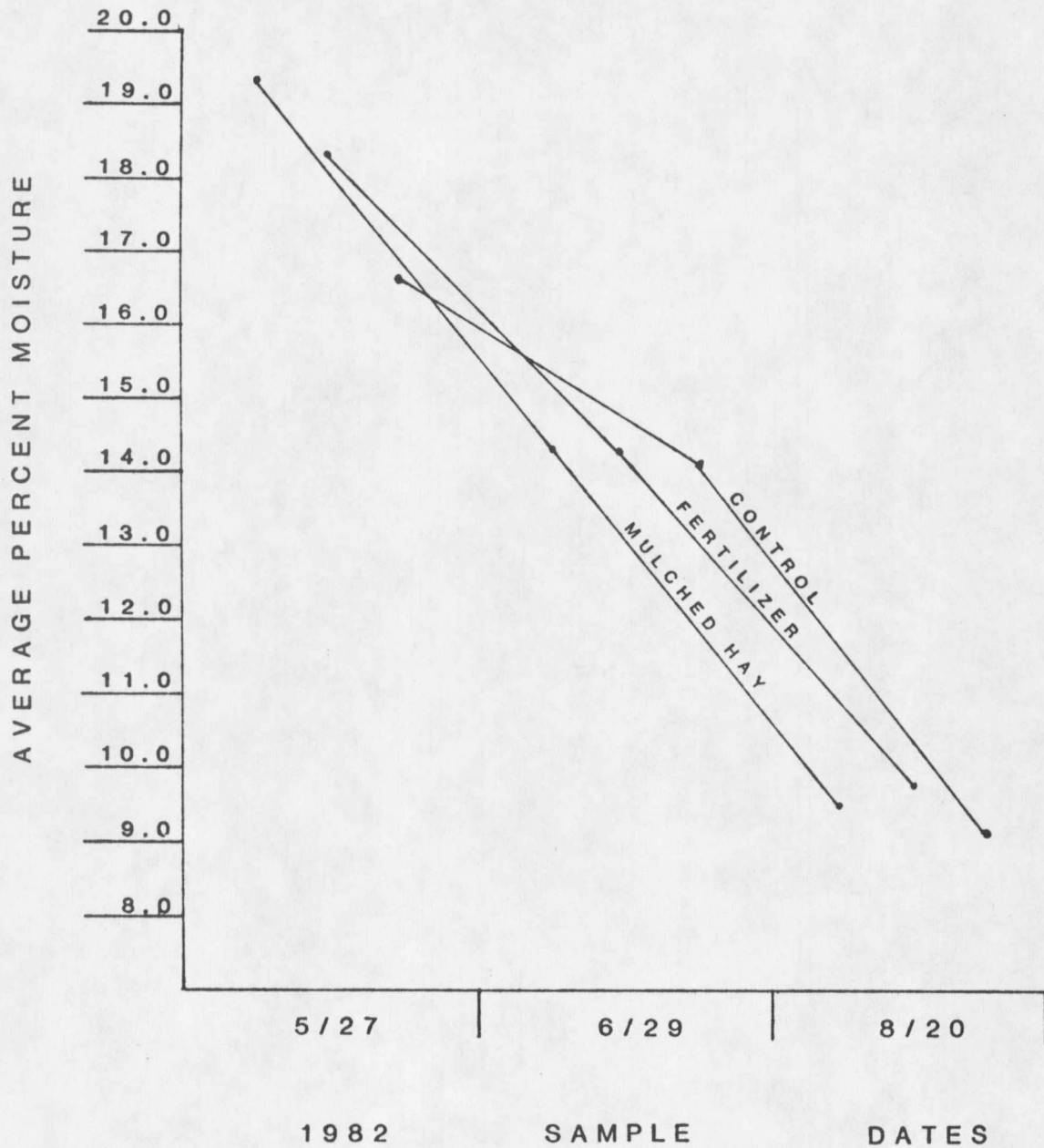


Figure 5. Changes in average percent soil moisture in nontreated alluvium and two surface amendments, during the 1982 growing season.

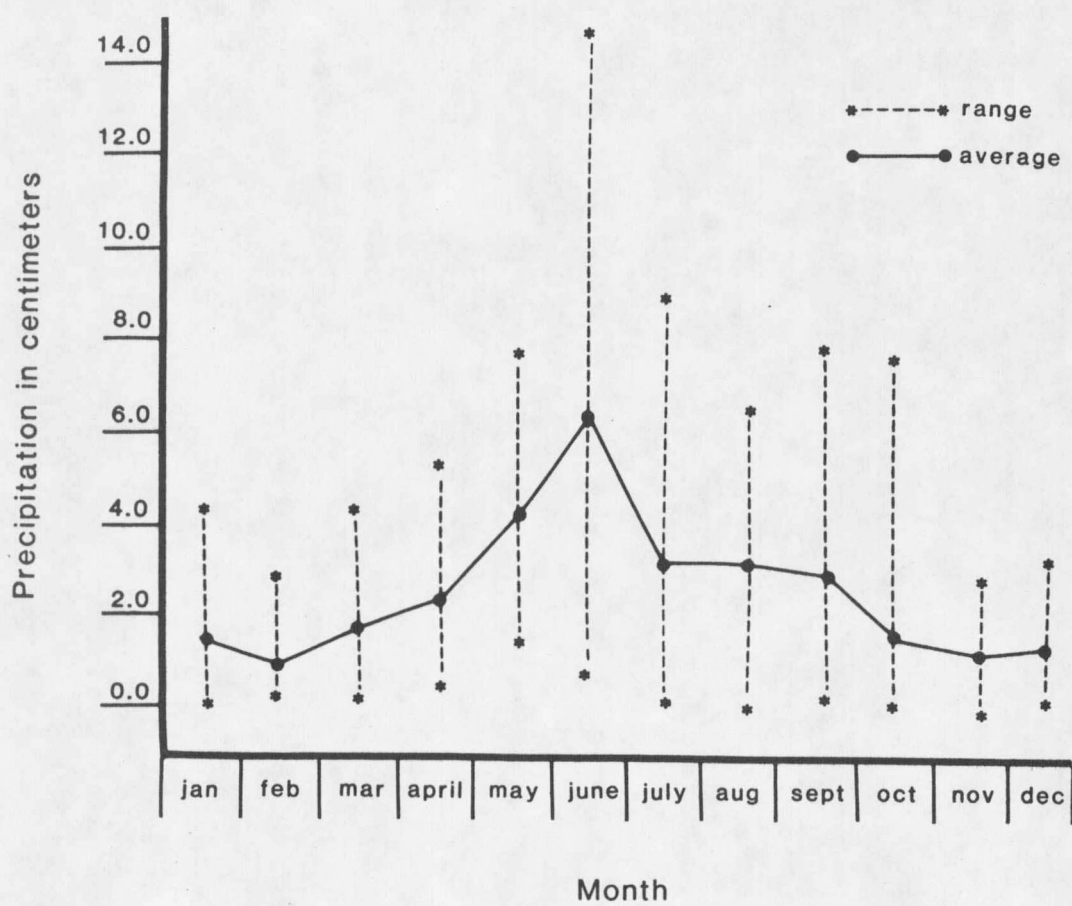


Figure 6. Monthly precipitation averages and ranges for the Butte area (1948-1977; data acquired from the Butte airport).

wheatgrasses. In general optimum germination temperatures for wheatgrasses are 15-25°C (AOSA 1978); however, these conditions were not reached until July. While the 1-16°C soil temperature range (April 27 through July 1) is drastically below optimum as reported by AOSA, germination continued to increase rapidly during June. To avoid mechanical impedance from soil crust, seedling germination in alluvium must be complete during the wettest months and therefore, seed must have the ability to germinate in less than optimum soil temperature regimes. These data indicate wheatgrass germination and emergence is possible early in the growing season and is therefore critical to revegetation success at the Berkeley complex.

Alluvium pH

The intent of the initial quick-lime application was to improve the microclimate for seedling emergence and establishment. Although the majority of grass species selected for this project were chosen according to previous reports (Watson et al. 1980) based on environmental tolerances (ie. low pH tolerant), it was felt that an average pH of 5.3 (range 4.28 - 6.18, n = 36) might inhibit the critical first year establishment success. Therefore, to assess the effects of a quick lime application (1545 kg/ha), soil pH was determined in all treatments four times over a 16 month period.

As graphically shown in Figure 7 and tabulated in Table 5, a significant difference ($p < 0.05$) existed between pre- and post-lime alluvium pH in all treated plots. Results indicate liming had a

neutralizing effect on all treatments during initial plant establishment. The significant pH difference reported in manure may relate to elevated levels of NH_3^+ and other soluble forms of cations associated with livestock manure (e.g. Ca^{2+} and Mg^{2+}).

Table 5. Mean¹ pH of three alluvium treatments and a control one year after liming (Summer 1982).

CONTROL	HAY	FERTILIZER	MANURE
5.1a*	7.1b	7.0b	7.7c

*Means followed by the same letter are not significantly different at the 0.05 probability level as determined by standard analysis of variance.

¹Means were calculated from 9 values.

Although a complete assessment of this treatment was not possible due to the time frame allowed for this research, results indicate that an application of quick lime at a rate of 1500 kg/ha can moderate alluvium pH through the initial year of plant establishment.

These preliminary results are in agreement with other research in which hydrated lime was applied to improve plant establishment (Vandevender and Sencindiver 1982; Harper and Spooner 1982; and Richardson 1980). They found that hydrated lime increased soil pH initially, but reacidification occurred over time. These results further exemplify the need for establishing proper lime requirements to meet revegetation goals.

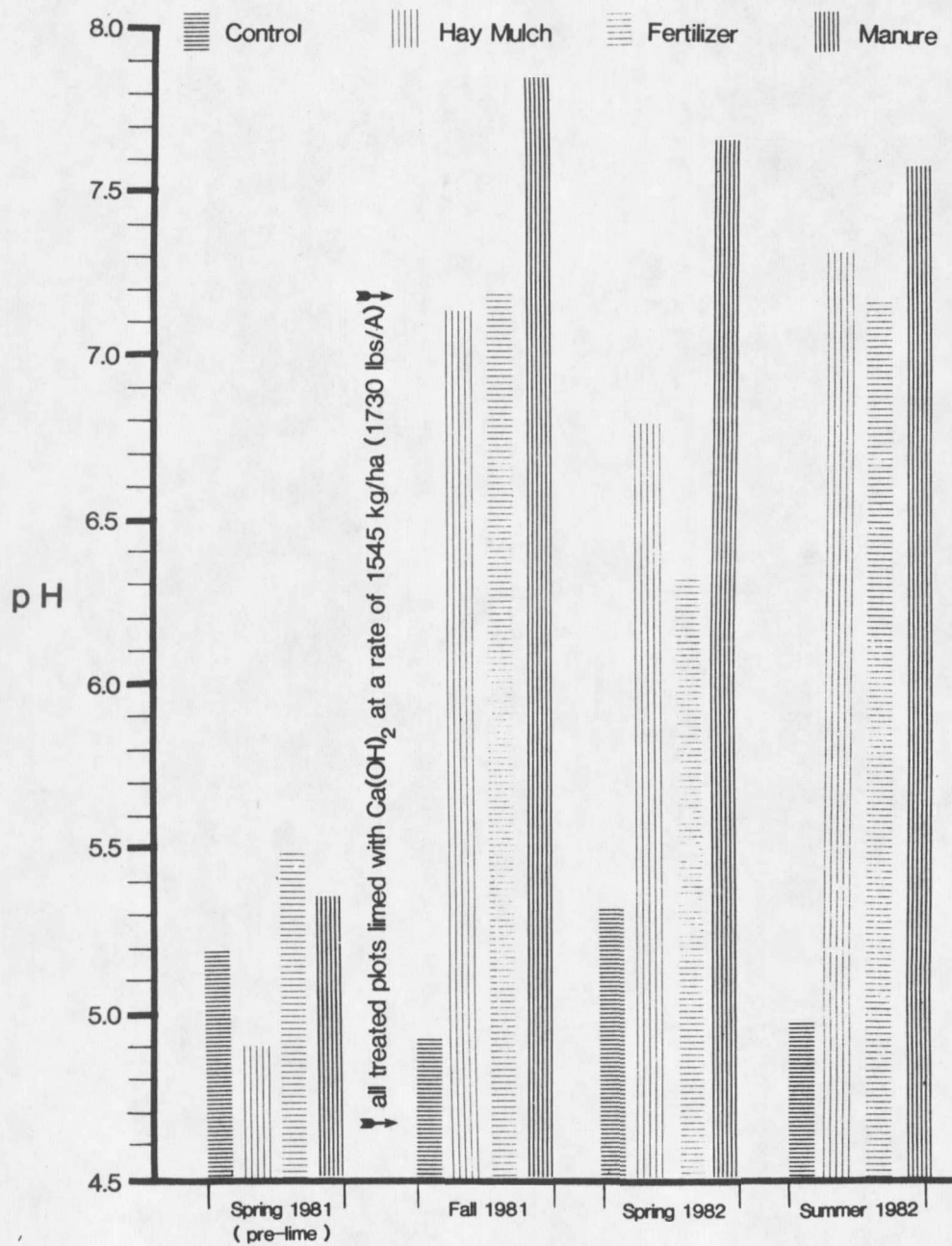


Figure 7. Affects of liming on three alluvium treatments over a 16 month period.

Time of Seeding

A comparison of spring 1981 to fall 1981 seedings (see Figure 3) revealed that by October 15, 1982, spring seeded plots supported only minimal vegetative growth (exceptions were microplot margins where seed was carried from up-slope by spring run off and weed species were present in the manure). No differences in plant cover and phytomass (of seeded species) were found between plots treated with methyl bromide and the combined spring 1981 and fall 1981 seeded areas. These results indicate that plant performance and numbers were not influenced by the early seeding. In addition, there was a noticeable decline in weed species numbers within the sterilized zone in the manure treatment. Results of these measurements and observations of plant performance indicate that methyl bromide (applied in concentrations reported here) is an effective soil sterilant. Vegetative production and cover reported here reflect a seeding rate of 870 PLS/m². Furthermore, fall seeding was more effective than spring seeding in maximizing first year vegetation performance.

Crust Strength and Soil Moisture

The most significant factor found to affect alluvium crust formation was soil moisture. Crust strength measurements made as the 1982 growing season progressed indicated an increase in crust strength as well as a decrease in alluvium percent moisture.

When considering only the first two sample dates (5/27/82 and 6/9/82, Figure 8), saturated alluvium (soil moisture > 16%) had no crust strength. However, by June 29, 1982, a surface crust had

formed on all amendments (Figure 8) and soil moisture was less than 14.5 percent (Figure 5). No statistical differences ($P < 0.1$) in soil moisture among treatments were found on the June and August sample dates by treatment. The mulched hay treatment had significantly higher ($P < 0.05$) soil moisture than the non-treated alluvium on the initial sample date (Figure 5).

Soil moisture measurements on August 20, 1982, were between 9 and 10 percent. Corresponding crust strengths were; $>65 \text{ kg/cm}^2$ in the control, 60 kg/cm^2 in the fertilizer and $\geq 55 \text{ kg/cm}^2$ in the mulched hay condition (Figure 8). Therefore, within a period of 52 days (June 29 to August 20, 1982) soil moisture decreased five percent while crust strength increased well over ten times in all but the manure treatment. Precipitation for this period was 3.0 cm.

Comparison of alluvium moisture content and corresponding crust strength was made for both phases of this study. Using the figure of 14.5 percent soil moisture, Parady (1981) (phase I) reported crust strength levels between 1.1 and 1.2 kg/cm^2 under controlled laboratory conditions. Crust strength averaged 4.5 kg/cm^2 ($n=48$) at 14.5 percent soil moisture in nontreated alluvium in this study. The difference (3.3 kg/cm^2) arises from use of different methods of determining moisture content (laboratory gravimetric soil moisture vs. field measurements with the Troxler model 3411 soil moisture/density gage) and differences in comparing a controlled laboratory situation with variable field conditions. Although discrepancies in specific results are found between both phases of this research,

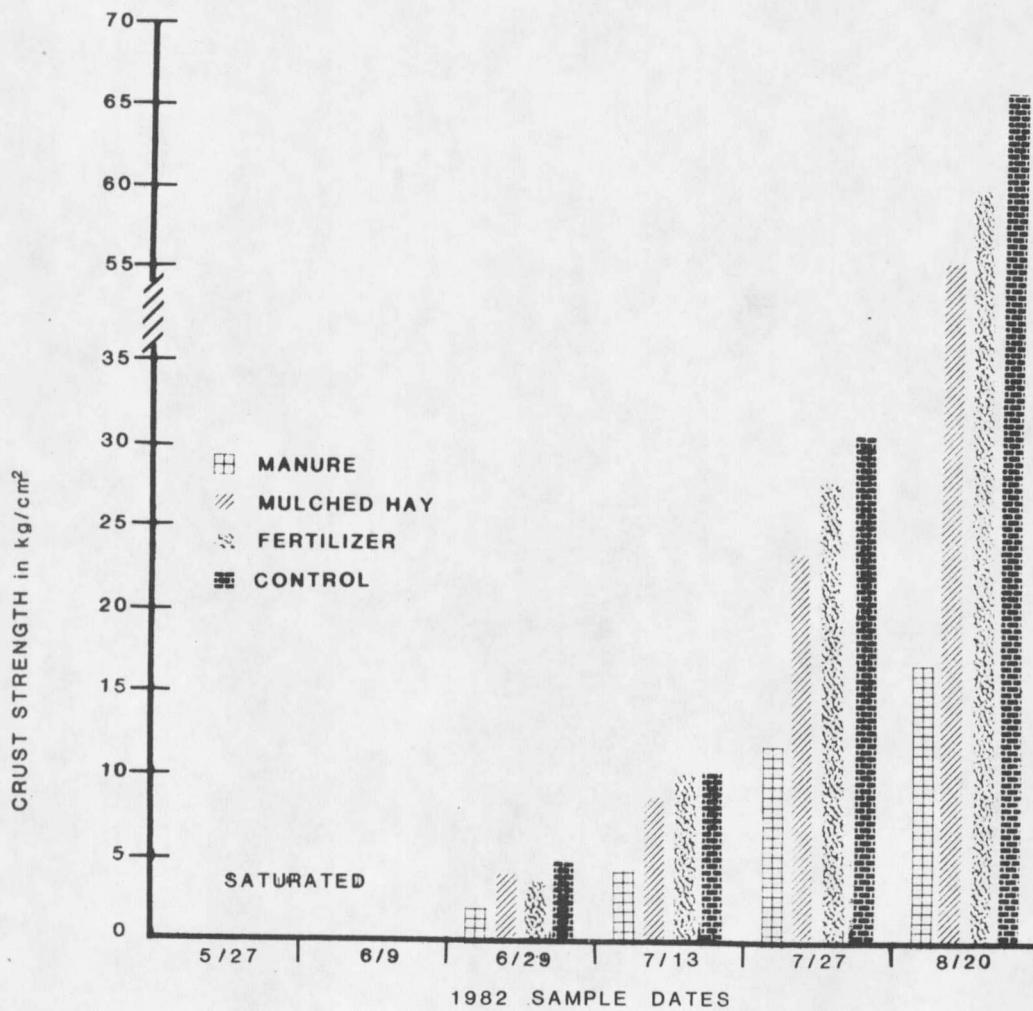


Figure 8. Crust strength measurements of three surface amendments and non-treated alluvium, during the 1982 growing season.

the basic inverse relationship between crust strength and alluvium moisture is parallel.

Parady (1981) reported the alluvium crusting mechanism as grain packing and clay adhesion within the sand fraction. Field observations during this study indicated that as soil moisture increased, clay adhesion within the sand fraction decreased. However, long periods of soil wetting seem to have contributed to greater clay particle orientation within sands, resulting in stronger and thicker crust formation.

Crust Strength and Incorporated Amendments

Crust strength was significantly ($P < 0.01$) and successively greater in all treatments when compared to the manure amended plots on the last four sample dates (Figure 8). There were no significant differences ($P < 0.01$) in crust strength among the mulched hay, fertilized or control plots on any date.

Both phases of this research found applications of livestock manure significantly decreased overall crust strength. Application of 190 MT of manure/ha resulted in a 75 percent reduction in crust strength on the last sample date (August 20, 1983). These results are in accordance with those reported by Mazurak et al. (1975) on heavily manured Nebraska soils and a lightly manured Indian soil (Das and Chandrhri 1981).

The major benefits observed from the addition of manure are found in decreased soil bulk densities and disruption of the sand

grain packing phenomenon reported by Parady (1981) as the mechanism of alluvium crust formation.

Crust Strength and Seedling Emergence

The first major increase in alluvium crust strength occurred during the two weeks between July 13 and 27, 1982 (Figure 8). Seedling emergence for the same period decreased slightly or remained the same (Figure 9). These data indicated that increases in crust strength after seedling emergence had little affect on seedling density.

Observations made during the summer of 1981 however, indicated crust strengths in excess of 25 kg/cm^2 inhibited seedling emergence and were correlated with volumetric soil moisture less than 14.5 percent. Measurements and observations made during the 1981 and 1982 growing seasons revealed that in the Butte environment germination and seedling emergence had to be completed prior to surface crust formation. During peak seedling emergence periods in 1982, soil temperatures ranged from 1-16 degrees Centigrade, soil moisture was above 14.5 percent and crust strengths did not exceed 5 kg/cm^2 .

Alluvium crust strength apparently inhibits seedling emergence only when soil moisture is less than 14.5 percent. Therefore, to minimize crusting soil moisture must be greater than 14.5 percent, which was the case in May and June of 1982. Although these are preliminary data, surface crusting of alluvium should not affect seedling emergence provided seedling emergence coincides with soil moistures > 14.5 percent. This was accomplished by implementing a dormant fall seeding.

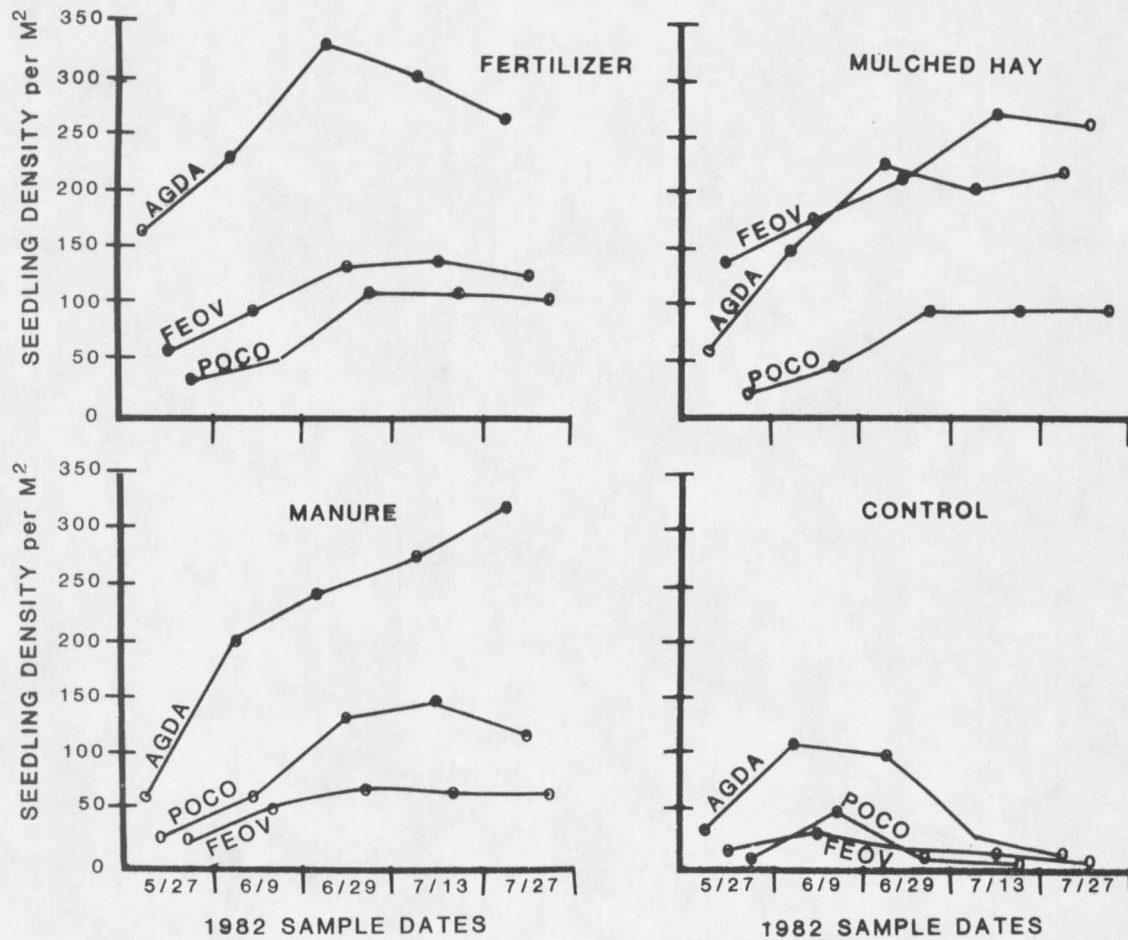


Figure 9. Seedling density of three native grass species over five dates, in three alluvial overburden (cover-soil) amendments and a control. The grass species considered were: *Agropyron dasystachyum* (Agda), *Poa compressa* (Poco), *Festuca ovina* (Feov).

Seedling Density

It became obvious that species specific density data were impractical to collect given time constraints. Therefore, all counts were made on the three grass monoculture microplots within each plot. In each of the monoculture blocks, however, all plant species were identified (Table 6).

Although 46 different plant species were identified over all research plots, only seven invading species were identified as problem species. Those seven appeared to influence seeded species performance. Invading grass species Bromus japonicus and B. tectorum were most prevalent in thickspike wheatgrass plots, indicating some contamination from the seed source. The five forbs identified as problem species originated from the manure application, as none was present in other treatments.

Maximum seedling density was recorded for all amendments and species, except thickspike wheatgrass in manure, by July 13, 1982 (Figure 9). Seedling density of thickspike wheatgrass in the manure amendment continued to increase on all sample dates. All species in the non-treated alluvium had decreased in density by June 29, 1982 (Figure 9). On July 29, 1982, all nontreated alluvium was completely devoid of vegetation. This appeared to be a result of the inherent lack of fertility in the alluvium.

In all but the mulched hay treatment thickspike wheatgrass showed higher seedling densities when compared to Canada bluegrass and sheep fescue. The higher sheep fescue density in the mulched hay treatment was thought to be a reflection of a competitive advantage

Table 6. Plant species identified on research plots during the 1982 growing season (plant names follow Beetle 1970).

Scientific Name	Common Name
<u>Grasses</u>	
* <u>Agropyron dasystachyum</u>	thickspike wheatgrass
* <u>Agropyron riparium</u>	streambank wheatgrass
* <u>Agropyron trachcaulum</u>	slender wheatgrass
<u>Agrostis alba</u>	redtop
<u>Bromus japonicus</u>	Japanese brome
<u>Bromus tectorum</u>	cheatgrass brome
* <u>Calamovilfa longifolia</u>	prairie sandreed
* <u>Elymus junceus</u>	Russian wildrye
* <u>Festuca ovina var. durisicula</u>	hard sheep fescue
* <u>Festuca ovina var. covar</u>	sheep fescue
<u>Hordeum jubatum</u>	foxtail barley
<u>Koeleria cristata</u>	prairie junegrass
* <u>Oryzopsis hymenoides</u>	Indian ricegrass
<u>Phleum pratense</u>	common timothy
<u>Poa compressa</u>	Canada bluegrass
<u>Poa pratensis</u>	Kentucky bluegrass
<u>Forbs</u>	
* <u>Achillea millefolium</u>	common yarrow
<u>Amaranthus retroflexus</u>	Redroot pigweed
<u>Ambrosia psilostachya</u>	Western ragweed
* <u>Astragalus cicer</u>	chick pea milkvetch, (cicer milkvetch)
<u>Capsella bursa-pastoris</u>	common shepherds purse
<u>Centaurea maculosa</u>	spotted centoureo, (spotted knapweed)
<u>Chenopodium album</u>	lambsquarter goosefoot
<u>Cirsium arvense</u>	Canada thistle
<u>Descurainia sophia</u>	flaxweed tansymustard
<u>Gypsophila paniculata</u>	common babysbreath
<u>Kochia scoparia</u>	fireweed summer cypress
<u>Lactuca seriola</u>	prickly lettuce
<u>Lepidium densiflorum</u>	prairie pepperweed
<u>Linaria dalmatica</u>	dalmation toadflax
<u>Linaria vulgaris</u>	butterandeggs
* <u>Linum lewisii</u>	Lewis flax
<u>Lychnis alba</u>	white cockle campion
<u>Aster canescens</u>	hoary tansy aster
<u>Malva neglecta</u>	common mallow
<u>Melilotus officinalis</u>	yellow sweetclover
* <u>Onobrychis viciifolia</u>	common sainfoin
<u>Phacelia leucophylla</u>	silverleaf phacelia
<u>Polygonum spp.</u>	knotweed
<u>Salsola kali</u>	common Russian thistle
<u>Solanum triflorum</u>	cutleaved nightshade
<u>Spharalcea coccinea</u>	scarlet globemallow
<u>Taraxacum officinale</u>	common dandelion
<u>Trifolium hybridum</u>	alsike clover
<u>Trifolium pratense</u>	red clover
<u>Verbascum thapsus</u>	flannel mullein

*Seeded species

.Problem species that influence first year seeded plant performance

offered sheep fescue by the mulch. The incorporation of manure also created a favorable seedling environment for thickspike wheatgrass. However, weed species originating in manure contributed to the depressed seedling density of sheep fescue, where thickspike wheatgrass showed less deleterious effects from weed competition. In all but the mulched hay treatment thickspike wheatgrass expressed the highest seedling density. Thickspike wheatgrass in the manure treatment had the highest overall seedling density when compared to all other species/amendment combinations by the last sample date. Statistical analyses for seedling densities by species and amendment were not reported due to the high degree of variability within species and amendments.

Plant Cover

Canopy cover data were recorded in accordance with Daubenmire (1959) after a fall green-up period on October 15, 1982. When analyzing single species performance, thickspike wheatgrass in the manure amendment produced significantly greater cover than all other species/amendment combinations (Table 7). Although thickspike wheatgrass decreased in cover in both the mulched hay and fertilized treatments, as compared to manure, this species had more cover than sheep fescue or Canada bluegrass in the mulched hay treatment and Canada bluegrass in fertilized alluvium.

In all but the manure treatment, Canada bluegrass produced significantly less cover than all other species. This seems to be due in part to the low growing habit of this plant.

Table 7. Mean² percent canopy cover in three amendments and non-treated alluvium on October 15, 1982 (all figures are in kg/ha).

Species	Treatment			
	Manure	Control	Mulched Hay	Fertilizer
*Agda	47.0 Aa ¹	0.0	25.5 Ab	16.2 Ac
*Feov	16.1 Ba	0.0	16.0 Ba	17.5 Aa
*Poco	9.8 Ba	0.0	7.9 Ca	6.8 Ba

¹Means in the same row followed by the same letter (vertically for capital and horizontally for lower case letters) are not significantly different at the 0.01 probability level as determined by standard analysis of variance techniques. Analysis of variance tables are located in Appendix B.

²Means were calculated from 15 replicates and averaged over three blocks to minimize slope effect. No plant growth was recorded in any control plot on October 15, 1982, therefore, control plots were uniformly omitted from analysis of variance.

*Agda = thickspike wheatgrass, Feov = sheep fescue, Poco = Canada bluegrass

Although sheep fescue exhibited no differences in canopy cover by treatment, it did produce slightly more cover than thickspike wheatgrass in the fertilized treatment. This phenomenon is not completely understood but appears to be due to soil condition preferences. Sheep fescue is better adapted to coarse textured, well drained soils and therefore may function more efficiently in the non-mulched condition than thickspike wheatgrass, which prefers heavier or less well drained soils (Watson 1980 et al. and Long 1981).

Production

Thickspike wheatgrass significantly produced the highest above-ground yield of all species (Table 8). Thickspike wheatgrass and Canada bluegrass increased in production in mulched hay plots, while

sheep fescue declined slightly. The greatest difference in total phytomass production appeared in the incorporated manure plots where thickspike wheatgrass significantly out-produced all other species. Furthermore, when considering above and belowground yield for total species production, A. dasystachyum and P. compressa expressed a 2:1 above to belowground phytomass ratio while F. ovina exhibited a 1:1 ratio. Because no species tested had a greater below to aboveground phytomass ratio, overall performance in this medium could be extrapolated from aboveground yield (Table 8).

Differences in plant performance (i.e. cover and phytomass) reported in this study are a function of plant habit and site condition preference. Sheep fescue is a small culmless bunchgrass (Watson et al. 1980); hence, variation in canopy cover would not be expected to be great over all treatments. In addition, this growth habit produces relatively low aboveground yield. Conversely, thickspike wheatgrass is a larger, culmed, rhizomatous species with a much more open growth habit and therefore, lower relative canopy cover. Furthermore, the vigorous growth habit of one plant of this species produces greater phytomass volume when compared to a single sheep fescue plant.

Production of Canada bluegrass was consistently less than thickspike wheatgrass and more than sheep fescue. When mature, Canada bluegrass is a medium growing species with vigorous sod forming capabilities and dense root systems (Watson et al. 1980). Typically this grass requires 2-3 years to establish and therefore did not reach maximum production during the initial year of growth.

Table 8. Mean above and belowground phytomass production in three ammendments and nontreated alluvium on October 15, 1982 (all figures are in kg/ha).

Species	Treatment			
	Manure	Control	Mulched Hay	Fertilizer
*Agda				
aboveground phytomass	833 Aa ¹	0	433 Aa	267 Aa
belowground phytomass	416	0	216	133
above : belowground phytomass ratio	2:1	-	2:1	2:1
*Feov				
aboveground phytomass	114 Ab	0	83 Bb	137 Ab
belowground phytomass	114	0	83	137
above : belowground phytomass ratio	1:1	-	1:1	1:1
*Poco				
aboveground phytomass	136 Ab	0	245 Cc	225 Aa
belowground phytomass	68	0	122	112
above : belowground phytomass ratio	2:1	-	2:1	2:1

¹Means in the same row followed by the same letter (vertically for capital and horizontally for lower case letters) are not significantly different at the 0.01 probability level as determined by standard analysis of variance techniques. Analysis of variance tables are located in Appendix B.

²Means were calculated from 15 replicates and averaged over 3 blocks (no plant growth was recorded in any control plot on October 15, 1982; therefore control plots were uniformly omitted from analysis of variance).

*Agda = thickspike wheatgrass, Feov = sheep fescue, Poco = Canada bluegrass

SUMMARY AND CONCLUSIONS

Hard rock mining disturbances present a unique set of reclamation problems at the Berkeley complex in Butte, Montana. Establishment of permanent vegetative cover must be rapid to insure slope integrity and minimize cover-soil, seed and fertilizer loss through erosion during revegetation of mine dumps. When alluvium overburden material is utilized as a cover-soil medium, selection of specific surface amendments and seed mixtures will dictate revegetation success or failure. Chemical and physical characteristics of the alluvium require surface amendments to bolster fertility, decrease erosion, acidity and crust formation in order to initiate plant growth.

To test the suitability of this material as a plant growth medium three surface amendments were incorporated into the alluvium (fertilizer, manure and mulched hay). Plant performance in each treatment was investigated through the use of three grass species (thickspike wheatgrass, sheep fescue and Canada bluegrass). In addition, crust strength and soil moisture were compared in each treatment to nontreated alluvium.

In 1981, crust strengths of 25 kg/cm^2 were found to inhibit grass seedling emergence. Crust strengths exceeded 65 kg/cm^2 on August 20, 1982, in untreated alluvium. Average crust strengths ranged from $\geq 55 \text{ kg/cm}^2$ to $<70 \text{ kg/cm}^2$ and average volumetric soil moisture was <10 percent on August 20, 1982, in all treatments but manure.

Soil moisture greater than 16 percent prevented crust formation. No differences in crust strength were found among treatments on any date except in the manure amendment, which had significantly less crust strength than all others on all sample dates.

Volumetric soil moisture decreased steadily throughout the 1982 growing season on the control, fertilized and hay mulch plots. The Troxler moisture density gauge produced unrealistic soil moisture values in the manure amendment and were not included in the statistical analysis. Soil moisture was significantly higher in the mulched hay plot on the initial sample date (May 27, 1982) when compared to the control condition. Successive measurements (June 29 and August 20, 1982) found no differences among treatments. Incorporation of hay to 30 cm failed to produce a mulch effect and the resulting soil moisture was not different than the control or fertilized condition which had no mulch treatments.

Alluvium pH was significantly elevated over a 16 month test period after an application of $\text{Ca}(\text{OH})_2$ at a rate of 1545 kg/ha. Small differences in pH were noted over all treated plots and significant differences were noted among manure and all other plots. Manure appeared to be more basic due to the presence of cations.

Examination of grass seedling densities revealed that overall thickspike wheatgrass seedlings were the most vigorous. By July 27, 1982, thickspike wheatgrass seedlings in the manure treatment had the highest seedling density. Seedling numbers increased rapidly during May and June, 1982 in all but the control treatment. Seedling density in the control decreased between June 9 and 29, 1982. Control plots

were devoid of vegetation by July 27, 1982. This result appears to be due to lack of macronutrients in alluvium as all other treatments maintained seedling densities ≥ 50 plants/m² to July 27, 1982. Statistical analyses were not reported due to a high degree of variability within species and amendments.

Canopy cover and phytomass were measured after fall green-up. Thickspike wheatgrass in manure produced more cover and phytomass when compared to all other species in any amendment. Sheep fescue and Canada bluegrass varied only slightly in canopy cover over each treatment; however, sheep fescue did produce slightly more cover in fertilized alluvium. Both thickspike wheatgrass and Canada bluegrass had 2:1 above to belowground phytomass ratio, while sheep fescue expressed a 1:1 ratio. In each case thickspike wheatgrass produced more phytomass than either Canada bluegrass or sheep fescue while sheep fescue produced the least phytomass over all treatments. Sheep fescue yield was consistent over all treatments.

A comparison of each treatment for plant performance and soil suitability indicated that alluvium amended with 190 MT of manure/ha produced the most plant cover and phytomass, the highest overall seedling density and reduced surface crusts more than all other treatments. When comparing limed and fertilized alluvium with alluvium that was limed, fertilized and incorporated with 1800 hg of hay mulch/ha, few differences in plant performance and no differences in crust strength were found.

APPENDICES

APPENDIX A

SOIL PROFILE HYDROLOGY

Soil Profile Hydrology

Background Information

Successful reclamation at the Berkeley Complex must address the chemical and physical suitability of cover-soil to support plant life. Knowledge of the physical movement (rates and patterns) of soil water is fundamental to long term reclamation success. Water movement through cover-soil and spoil material is critical to plant life, slope stability and may affect ground water systems through deep leaching. Therefore, a short term investigation of groundwater flow was performed concurrent to investigations of the suitability of alluvium to support plant life.

Experimental Approach

Determinations of percent volumetric water content were made in alluvium and underlying spoil material on the previously described research plots, over a 17 month period, utilizing the neutron scattering technique (McHenry 1963). Instruments employed were a Troxler 2601 scaler and 1255 depth moisture probe. Nine aluminum neutron access tubes (50.8 mm O.D.) were installed to an average depth of 390 cm. The tubes were installed in holes (79.4 mm in diameter) drilled by an Ardvark rotary drill mounted on an agricultural type D-5 Caterpillar tractor. Drill cuttings were blown from the hole by an air compressor attached to the Ardvark system. Cuttings were collected on 30 cm increments and placed in plastic soil bags to

retain moisture. The mass of each bag and soil was determined upon collection.

Due to the difference in the hole diameter and outside tube diameter (79.4 vs. 50.8), an air gap was created between the tube and the drill hole wall. Initial moisture readings were collected without correcting the gap. However, the gap area was filled with sifted alluvium (≤ 6.35 mm in diameter) to limit further error prior in subsequent measurements (Richardson and Burroughs 1972).

The retained drill cuttings were oven dried at 100°C for 24 hours and reweighed to determine gravimetric moisture. The initial soil moisture measurements, made through the neutron method were compared to the gravimetric method of soil moisture analysis and a regression line between volumetric soil moisture (gravimetric $\times$ bulk density) and count ratio (neutron counts $\div$ background counts) was formed for each neutron access tube location. On-site calibration procedures were intended to maximize the accuracy of neutron probe method for measuring soil water. For purpose of calibration a constant bulk density of overburden (1.8 g/cm^3) was estimated based on results of phase I.

Outcome of Field Calibration

Attempts to field calibrate gravimetric moisture and neutron probe soil moisture counts produced unacceptable results. A linear regression equation that related field count ratios to field water content (gravimetric) resulted in very low correlation coefficients (r). A correlation coefficient (r) of 0.8 was used as a cut off for

correlating gravimetric moisture and field neutron counts. Therefore, a factory calibration was employed to convert field neutron counts to percent volumetric moisture.

Speculation as to the unacceptability of field calibrations stems from the narrow moisture range of soil samples and the soil sampling technique used. Soil samples were air lifted from the drill hole through an air compression system. The introduction of air into the samples had a drying effect on the soil. The average percent gravimetric moisture over all collected drill samples was 9.5 percent ($n=105$, range = 3.2-14.4, $S_D = 9.8$). Using the factory calibration for determining percent volumetric moisture, the neutron probe produced an average percent moisture directly after drilling of 30.8 percent or an increase of 180 percent over the gravimetric method. Therefore, it was felt that differences between actual gravimetric and calculated volumetric moisture were too great to utilize the field calibration scheme.

Soil Profile Moisture Patterns

A specific hydrologic concern in utilizing alluvium in reclamation deals with soil water movement at the interface between alluvium and underlying spoil material. Analysis of monthly fluctuations in soil water over nine different sample locations revealed that neither alluvium nor the spoil material presented a barrier to water flow. Figure 10 reveals the extremes in soil moisture patterns for a typical sample point measured over a 17 month period. The shaded zone represents the alluvium/spoil interface. Changes in soil water were

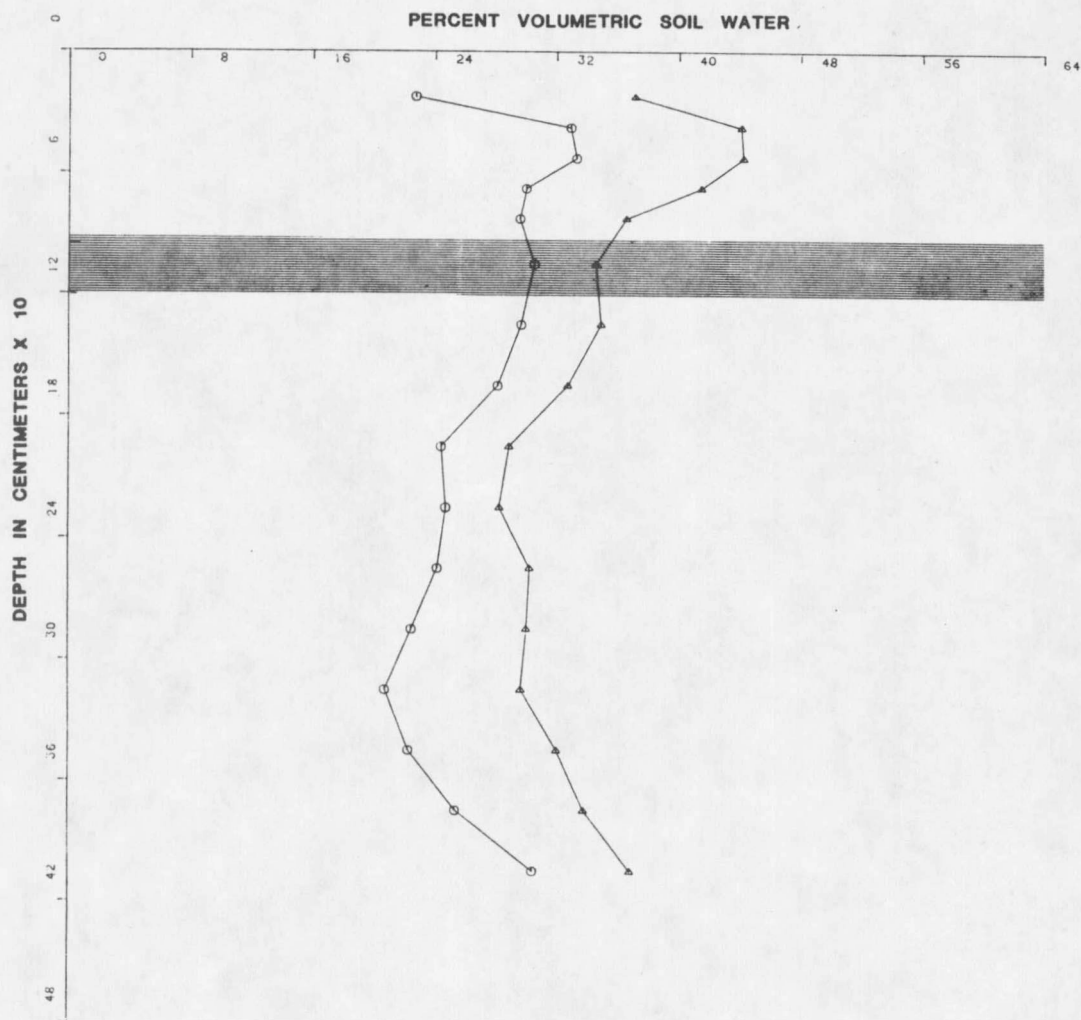


Figure 10. Soil profile hydrology for a typical sample location on the driest July 1981 $\odot$ and wettest April 1982 $\triangle$ sample dates. The shaded area represents the alluvium/spoil interface zone.

noticed above, through and below the interface, however, these differences are not of the magnitude expected in a perched or impenetrable soil zone. If the alluvium/spoil interface had been a barrier to water flow a near saturated zone would have been perched directly above the interface. Such a perched wet zone was never measured during this study and it can be assumed the interface presents no meaningful barrier to downward movement of water through the profile. Furthermore, averages in volumetric soil water content were calculated for all sample locations on two dates (driest and wettest) for the 30.5 cm zones above, through and below the alluvium/spoil interface. Table 9 reflects the average (n=9) change in percent soil water content at three locations critical to assessing possible water perching at the alluvium/spoil interface.

Table 9. Mean¹ values for percent volumetric soil water as measured by the neutron method and averaged over nine sample locations, 30 cm above, 30 cm below and at the alluvium/spoil interface for the driest (July 1981) and wettest (April 1982) sample dates.

	Percent volumetric soil water	
	July 1981	April 1982
30.5 cm zone above interface	31.5	36.5
30.5 cm interface zone	30.6	37.6
30.5 cm zone below interface	29.3	36.0

¹Each figure represents a mean of nine sample locations. Means were drawn from each location from the soil zone critical to investigating the possibility of water perching at the cover-soil/spoil interface.

Over the ten month period of moisture accumulation the critical interface zone increased in soil moisture. During this period volumetric soil water increased an average of 14 percent in the

zone 30.5 cm above the interface, 19 percent within the actual interface zone and 19 percent in the zone 30.5 cm below the alluvium/spoil interface. These figures indicate that the wetting front flows freely through the interface area during the wettest soil conditions measured. Although these data suggest a slight difference between the 30.5 cm zone above and below the interface on the driest date (July 1981) measured, the differences appear to correspond to seasonal advances in the wetting front. An additional hydrologic concern in reclamation at the Berkeley Pit is penetration of soil water into deeper alluvium or spoil zones. A review of all nine sample locations indicates that precipitation will permeate to at least a depth of 405 cm. Although 405 cm was the maximum depth recorded for soil moisture utilizing the neutron method, soil water is expected to flow slightly beyond this level. However, deep leaching of surface water to the spoil base is not anticipated as the average thickness of spoil material in this region of the Berkeley Complex exceeds 40 m.

The following graphs represent the alluvium/spoil hydrology as determined by the neutron technique of soil moisture determination. Alluvium access tubes were installed in three transects located north of plot number 12, in between plots 6 and 7 and south of plot number 1 (refer to Table 1 for dimensions and Figure 1 for research plot design). Each sample point was numbered and given a name corresponding to the location on the research plot slope. The three transects were broken down into top, middle or bottom locations. Top access tubes were placed on the crest of the slope, middle tubes were

located midway between top and bottom tubes and bottom access tubes were placed at the lowest elevation on each transect. Therefore, tube names corresponding to location appear as North Top, North Middle, North Bottom etc. The shaded zone on each graph represents the alluvium/spoil interface. Each graph depicts the relationship between percent volumetric moisture and cover-soil/spoil depth on the driest (July 1981) and wettest sample dates. Tube number 281 (South Middle) was destroyed during the fall 1981 seedbed preparation and therefore, represents only four months of data (July-October 1981).

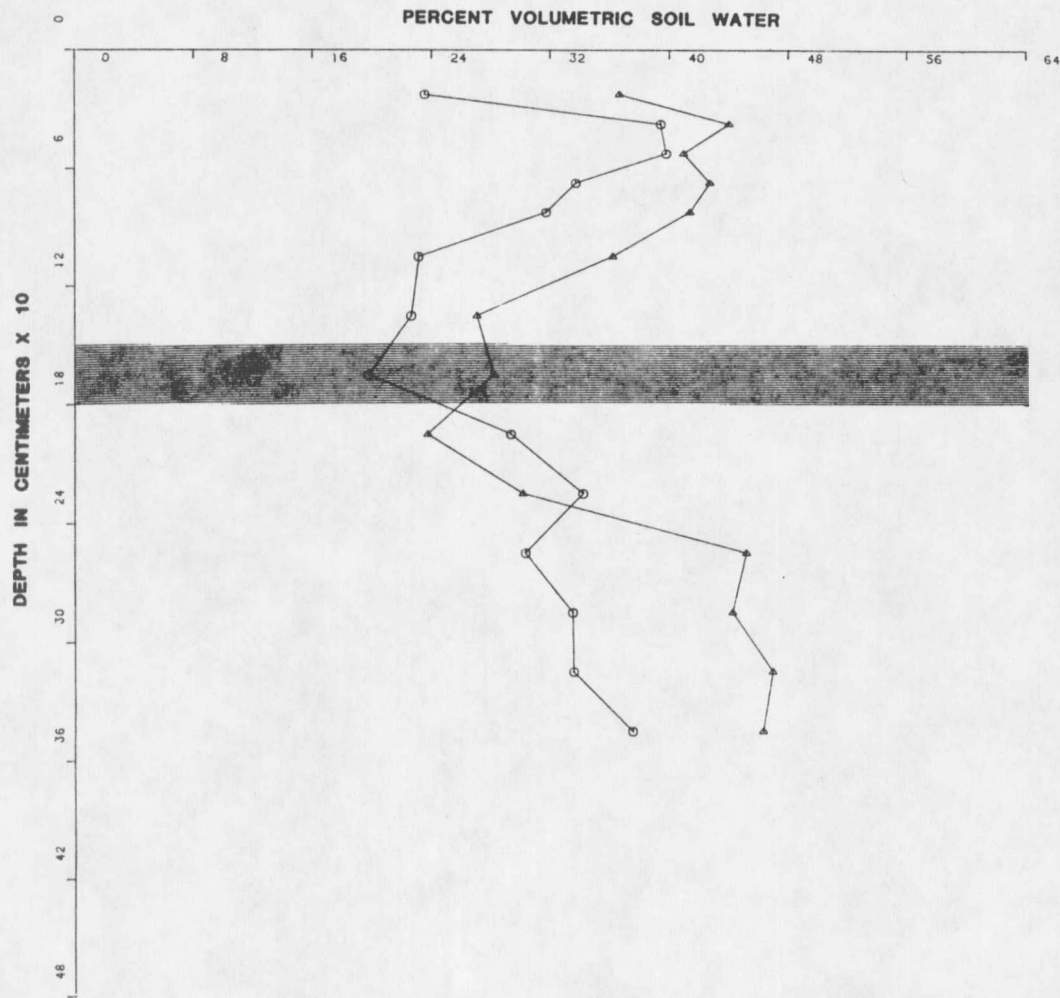


Figure 11. Soil profile hydrology during July 1981 $\circ$ and April 1982 Δ for site number 278, North Top. The shaded area represents the cover-soil/spoil interface.

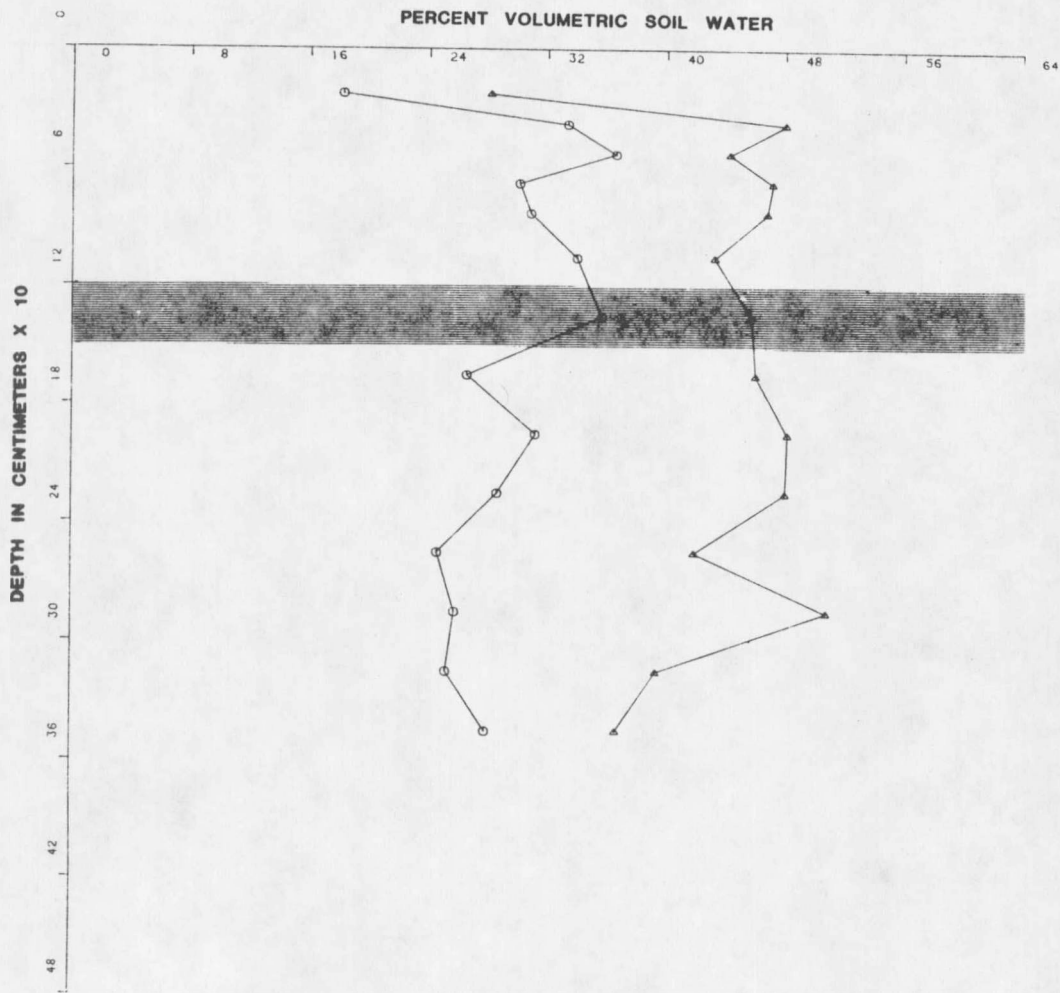


Figure 12. Soil profile hydrology during July 1981 $\odot$ and April 1982 $\triangle$ for site number 283, North Middle. The shaded area represents the cover-soil/spoil interface.

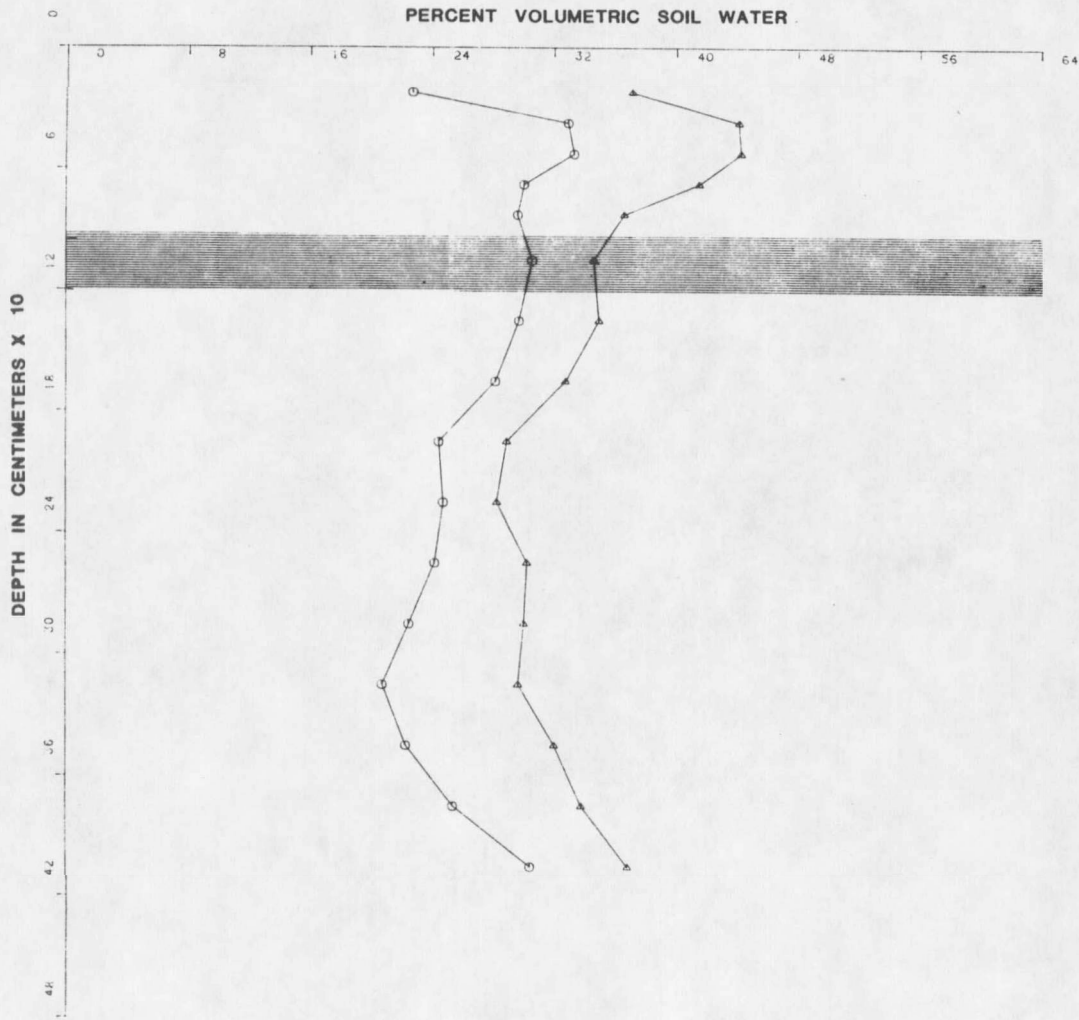


Figure 13. Soil profile hydrology during July 1981 $\odot$ and April 1982 $\triangle$ for site number 275, North Bottom. The shaded area represents the cover-soil/spoil interface.

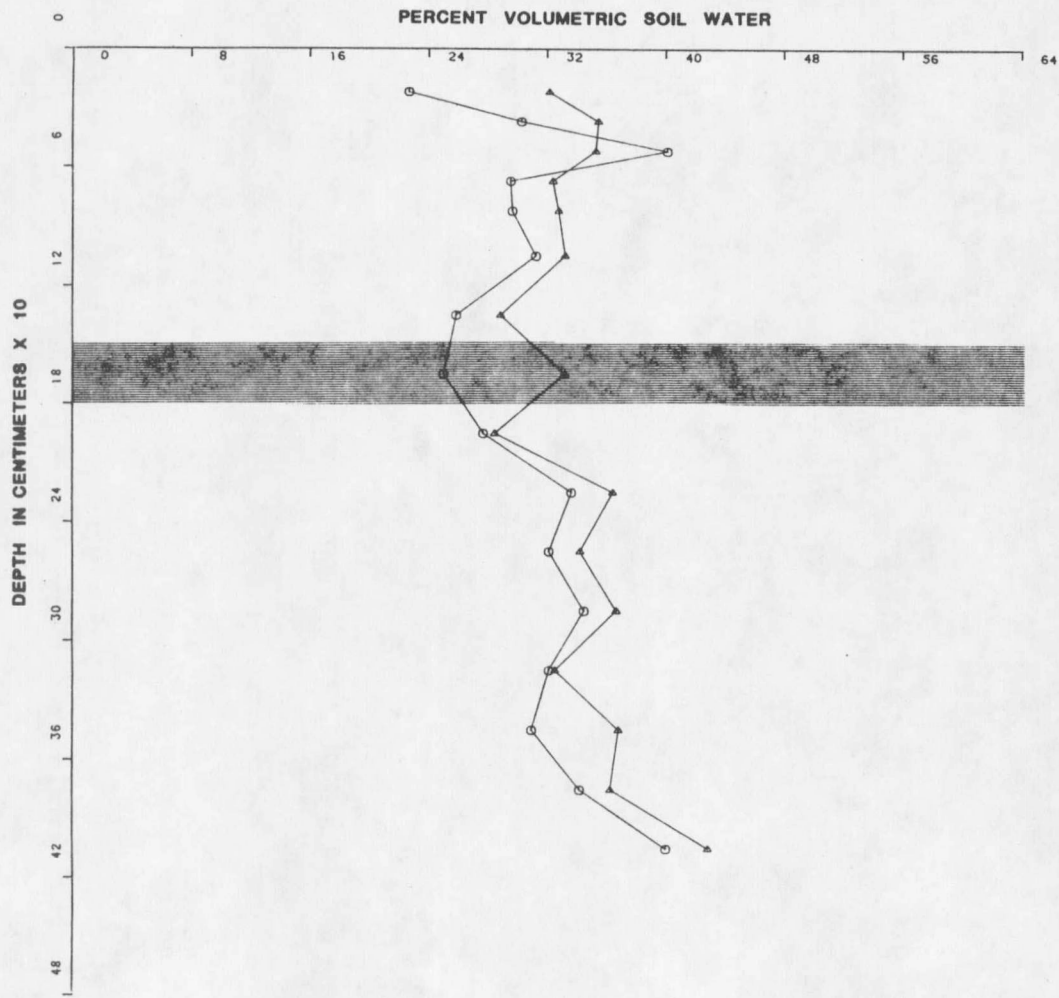


Figure 14. Soil profile hydrology during July 1981 $\odot$ and April 1982 $\triangle$ for site number 279, Middle Top. The shaded area represents the cover-soil/spoil interface.

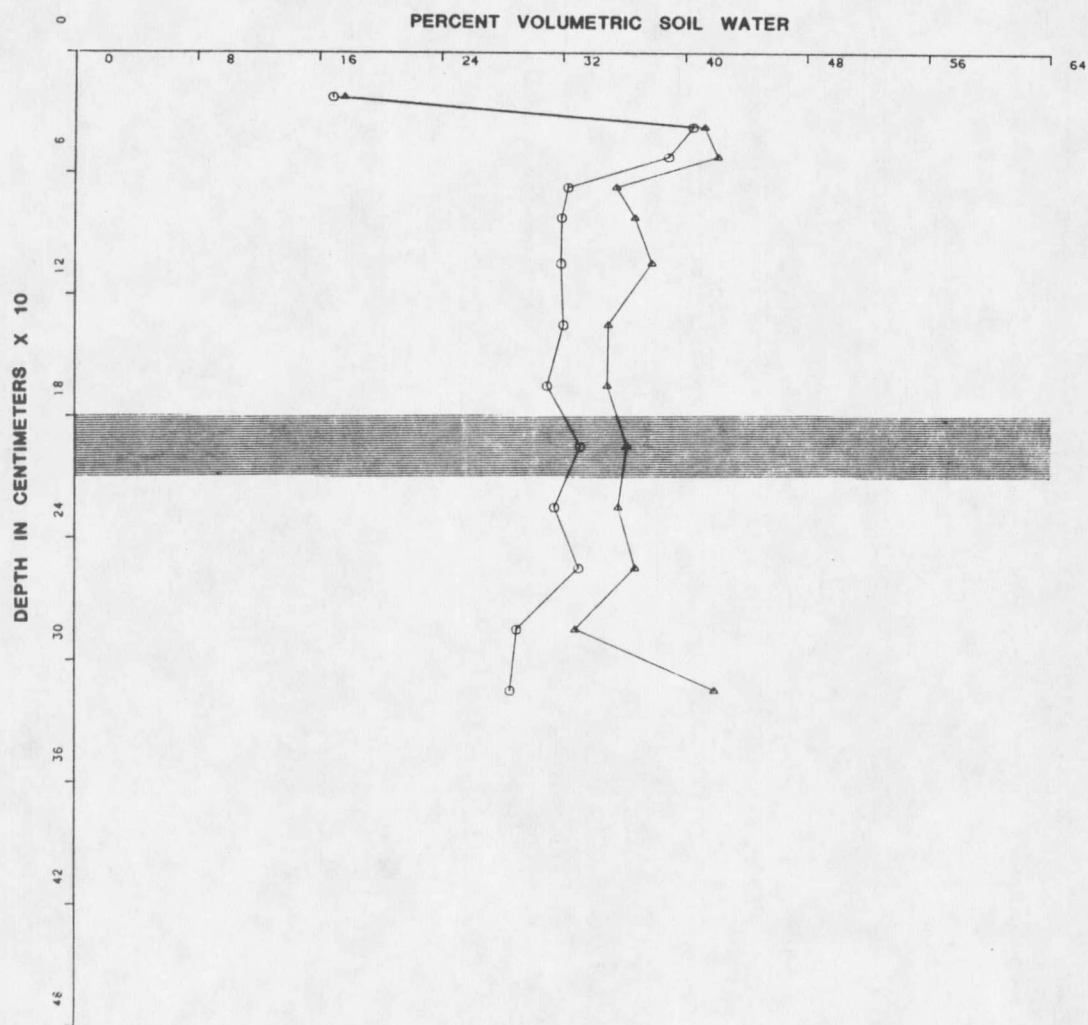


Figure 15. Soil profile hydrology during July 1981 $\ominus$ and April 1982 $\triangle$ for site number 282, Middle Middle. The shaded area represents the cover-soil/spoil interface.

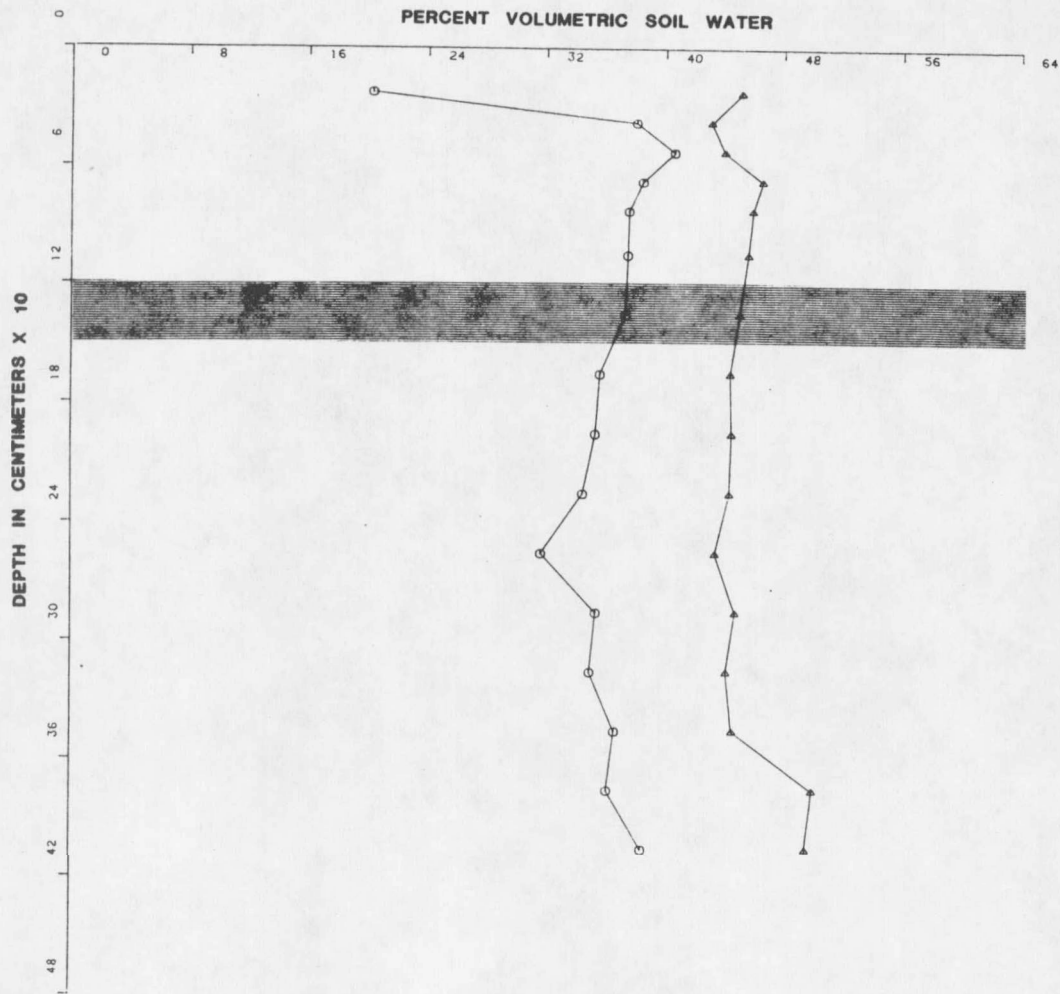


Figure 16. Soil profile hydrology during July 1981 $\odot$ and April 1982 $\triangle$ for site number 276, Middle Bottom. The shaded area represents the cover-soil/spoil interface.

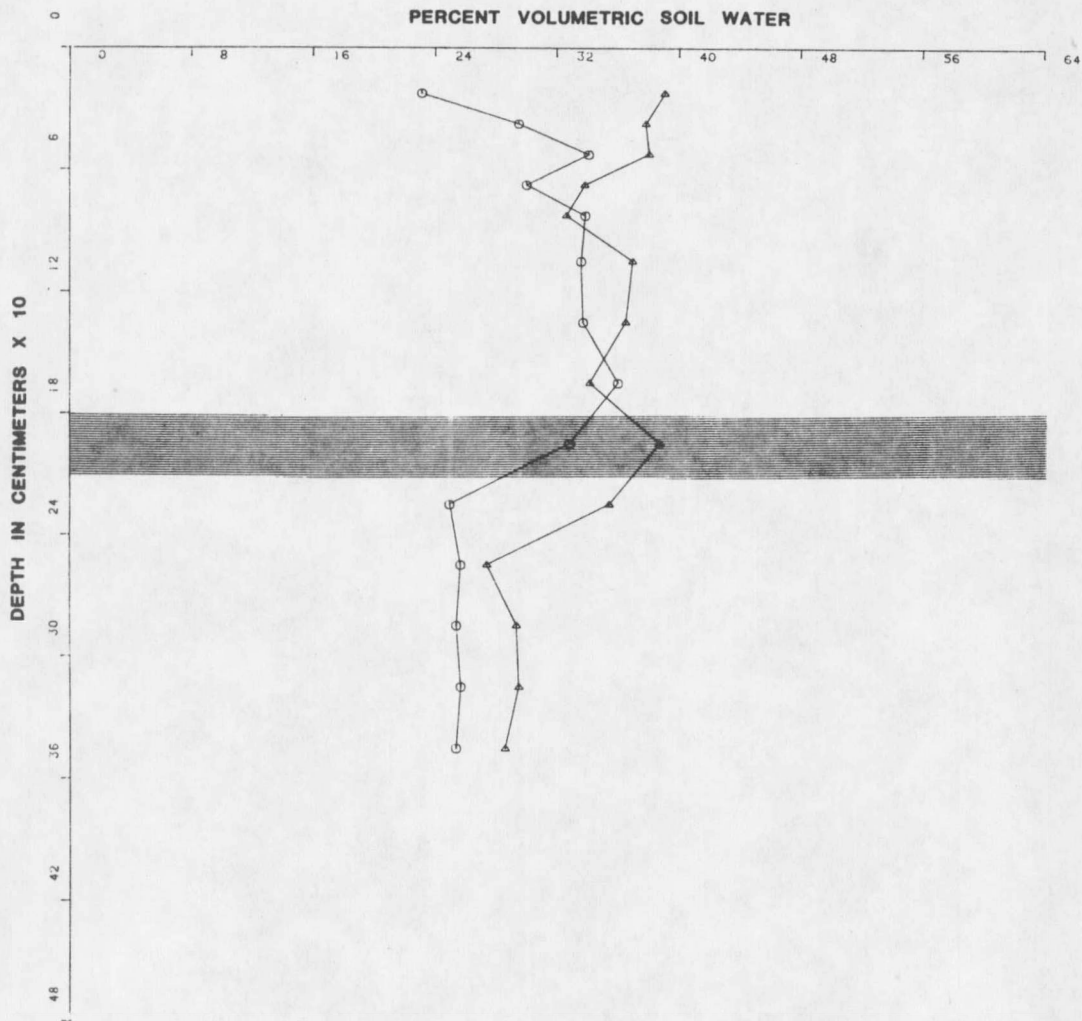


Figure 17. Soil profile hydrology during July 1981 $\odot$ and April 1982 $\triangle$ for site number 280, South Top. The shaded area represents the cover-soil/spoil interface.

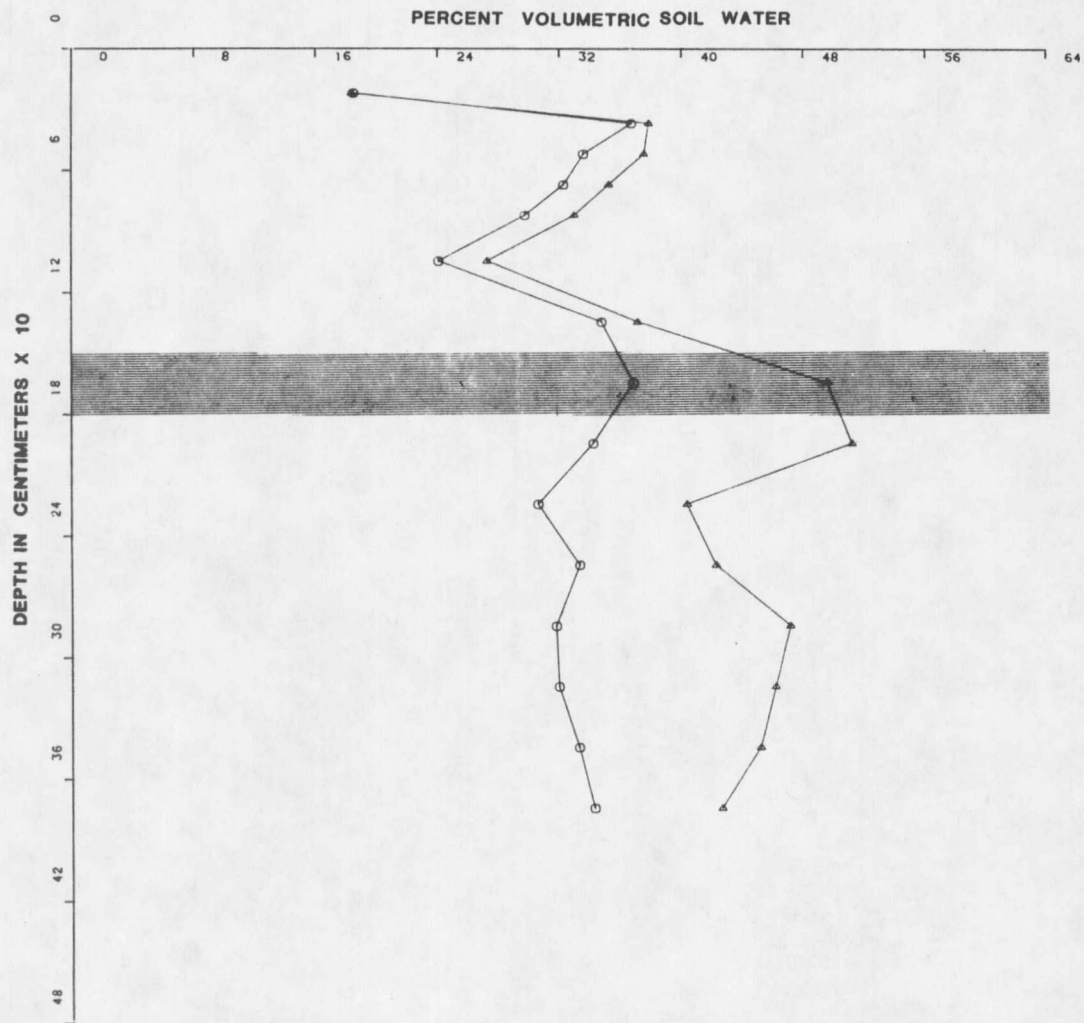


Figure 18. Soil profile hydrology during July 1981 $\odot$ and October 1982 $\triangle$ for site number 281, South Middle. The shaded area represents the cover-soil/spoil interface.

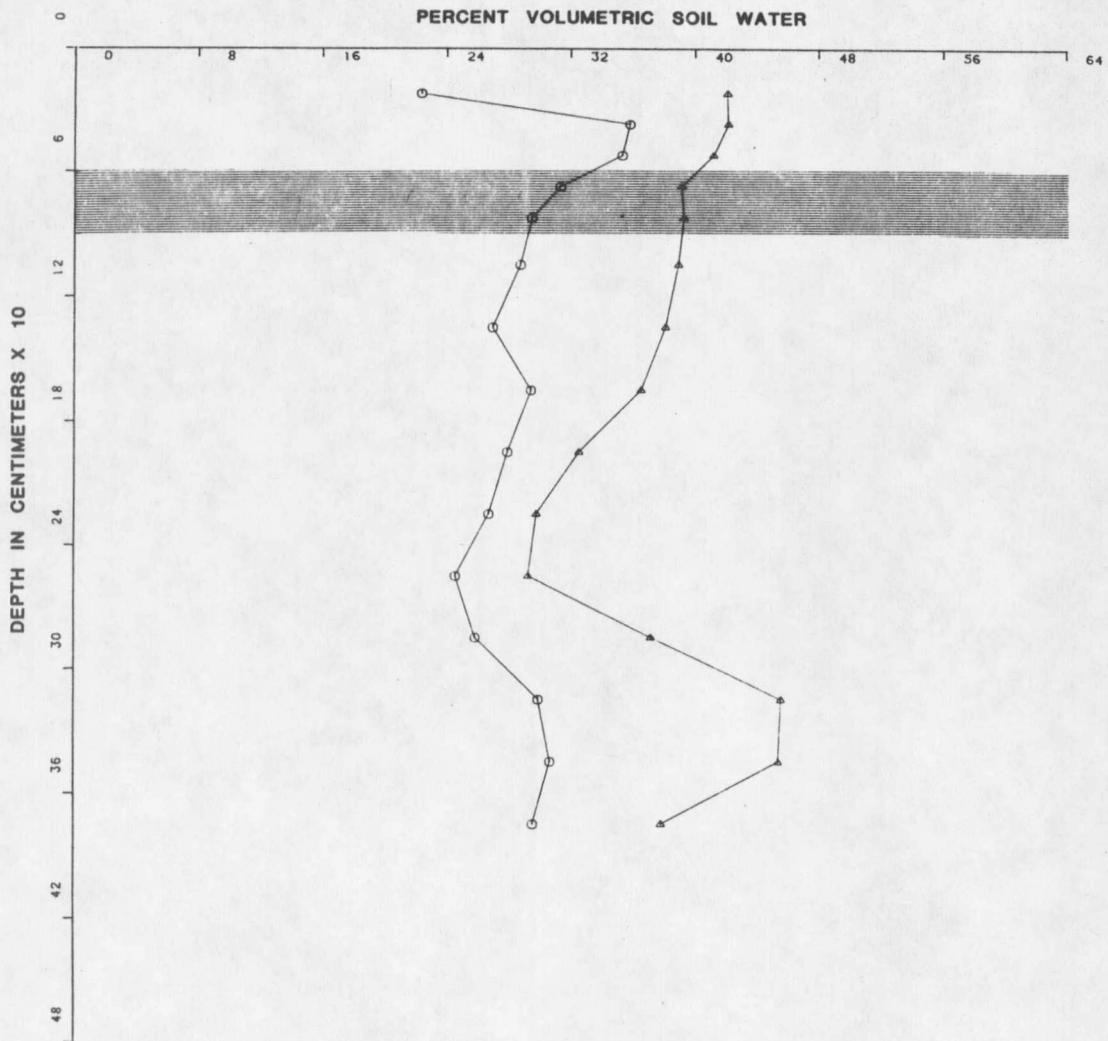


Figure 19. Soil profile hydrology during July 1981 $\circ$ and April 1982 Δ for site number 277, South Bottom. The shaded area represents the cover-soil/spoil interface.

APPENDIX B

ANALYSIS OF VARIANCE TABLES

Table 10. Analysis of variance of percent canopy cover of three species of grasses in manure treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	43.51		
Grasses	2	2381.00	1191.00	$9.80 \times 10^{-4*}$
Error	4	33.98		
Total	8	2458.49		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Poco vs. Poco	9.8 A	--
Poco vs. Feov	16.1 A	5.60×10^{-2}
Poco vs. Adga	47.0 B	0.00*
Feov vs. Adga	47.0	0.00*

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Adga=thickspike wheatgrass

Table 11. Analysis of variance of percent canopy cover of three species of grasses in hay mulch treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	00.31		
Grasses	2	463.80	231.90	$5.30 \times 10^{-4*}$
Error	4	2.98	00.75	
Total	8	467.09		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Poco vs. Poco	7.9 A	--
Poco vs. Feov	16.0 B	0.00*
Poco vs. Adga	25.5 C	0.00*
Feov vs. Adga	25.5	0.00*

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Adga=thickspike wheatgrass

Table 12. Analysis of variance of percent canopy cover of three species of grasses in fertilizer treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	1.04		
Grasses	2	205.30	102.70	$6.20 \times 10^{-4*}$
Error	4	1.67	00.42	
Total	8	208.01		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Poco vs. Poco	6.8 A	--
Poco vs. Feov	17.5 B	0.00*
Poco vs. Adga	16.2 B	0.00
Feov vs. Adga	16.2	6.5×10^{-2}

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Adga=thickspike wheatgrass

Table 13. Analysis of variance of percent canopy cover of Feov[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8)

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	13.9		
Treatments	2	4.0	2.01	8.40×10^{-1}
Error	4	44.4	11.11	
Total	8	62.34		

DISPLAY OF ALL DIFFERENCES

Identification	Mean Cover Value	P-Value
hay mulch vs. hay mulch	16.0 A	--
hay mulch vs. manure	16.1 A	9.70×10^{-1}
hay mulch vs. fertilizer	17.5 A	6.20×10^{-1}
manure vs. fertilizer	17.5	6.40×10^{-1}

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Adga=thickspike wheatgrass

Table 14. Analysis of variance of percent canopy cover of Poco[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	4.21		
Treatments	2	14.05	7.02	1.40×10^{-1}
Error	4	8.49	2.12	
Total	8	26.75		

DISPLAY OF ALL DIFFERENCES

Identification	Mean Cover Value	P-Value
fertilizer vs. fertilizer	6.77 A	--
fertilizer vs. hay mulch	7.93 A	3.80×10^{-1}
fertilizer vs. manure	9.80 A	6.30×10^{-2}
hay mulch vs. manure	9.80	1.90×10^{-1}

*indicates significant difference at P=0.01. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 15. Analysis of variance of percent canopy cover of Agda[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 8).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	4.82		
Treatments	2	1504.00	751.80	0.00*
Error	4	7.67	1.92	
Total	8	1516.49		

DISPLAY OF ALL DIFFERENCES

Identification	Mean Cover Value	P-Value
fertilizer vs. fertilizer	16.2 A	--
fertilizer vs. hay mulch	25.5 B	$1.20 \times 10^{-4*}$
fertilizer vs. manure	47.0 C	0.00*
hay mulch vs. manure	47.0	0.00*

*indicates significant difference at P=0.01. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 16. Analysis of variance of aboveground phytomass of three species of grasses in manure treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	6.23×10^3		
Grasses	2	1.00×10^6	5.02×10^6	8.39×10^{-3}
Error	4	1.19×10^4		
Total	8	1.09×10^6		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Feov vs. Feov	113.7 A	--
Feov vs. Poco	135.6 A	6.49×10^{-1}
Feov vs. Agda		0.00*
Poco vs. Agda		0.00*

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 17. Analysis of variance of aboveground phytomass of three species of grasses in hay mulch treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	2.37×10^3		
Grasses	2	1.84×10^5	9.18×10^4	$8.12 \times 10^{-3*}$
Error	4	2.09×10^3	5.23×10^2	
Total	8	1.88×10^5		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Feov vs. Feov	83.4 A	--
Feov vs. Poco	244.8 B	0.00*
Feov vs. Agda	432.8 C	0.00*
Poco vs. Agda	432.9	0.00*

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 18. Analysis of variance of aboveground phytomass of three species of grasses in fertilizer treatment as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	7.22x10 ⁴		
Grasses	2	2.64x10 ⁴	1.32x10 ⁴	1.80x10 ⁻¹
Error	4	1.94x10 ⁴	4.84x10 ³	
Total	8	1.18x10 ⁵		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
Feov vs. Feov	136.8 A	--
Feov vs. Poco	224.9 A	1.96x10 ⁻¹
Feov vs. Agda	266.7 A	8.40x10 ⁻²
Poco vs. Agda	266.7	5.02x10 ⁻¹

*indicates significant difference at P=0.01. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 19. Analysis of variance of aboveground phytomass of Feov[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

ANOVA				
Source	DF	SS	MS	P-Value
Blocks	2	1.49x10 ⁴		
Treatments	2	4.30x10 ²	2157.00	3.20x10 ⁻¹
Error	4	5.60x10 ²	1400.00	
Total	8	2.48x10 ⁴		

DISPLAY OF ALL DIFFERENCES

†Identification	Mean Cover Value	P-Value
hay mulch vs. hay mulch	83.3 A	--
hay mulch vs. manure	113.7 A	3.78x10 ⁻¹
hay mulch vs. fertilizer	136.8 A	1.55x10 ⁻¹
manure vs. fertilizer	136.8	4.91x10 ⁻¹

*indicates significant difference at P=0.01. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 20. Analysis of variance of aboveground phytomass of Poco[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

Source	DF	ANOVA		
		SS	MS	P-Value
Blocks	2	2.35×10^4		
Treatments	2	2.03×10^4	1.01×10^4	1.82×10^{-1}
Error	4	1.51×10^4	3.76×10^3	
Total	8	5.89×10^4		

DISPLAY OF ALL DIFFERENCES

Identification	Mean Cover Value	P-Value
hay mulch vs. hay mulch	244.9 A	--
hay mulch vs. manure	135.6 A	9.48×10^{-2}
hay mulch vs. fertilizer	224.9 A	1.49×10^{-1}
manure vs. fertilizer	224.9	7.11×10^{-1}

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

Table 21. Analysis of variance of aboveground phytomass of Agda[†] in three surface treatments as measured on October 15, 1982 on the Berkeley Complex research plots (expanded from Table 9).

Source	DF	ANOVA		
		SS	MS	P-Value
Blocks	2	3.05×10^5		
Treatments	2	5.08×10^4	2.54×10^5	$3.69 \times 10^{-3*}$
Error	4	2.46×10^4	6.15×10^3	
Total	8	5.63×10^5		

DISPLAY OF ALL DIFFERENCES

Identification	Mean Cover Value	P-Value
hay mulch vs. hay mulch	432.9 A	--
hay mulch vs. manure	832.7 A	3.35×10^{-2}
hay mulch vs. fertilizer	266.7 B	6.04×10^{-2}
manure vs. fertilizer	266.7	0.00*

*indicates significant difference at $P=0.01$. Same letter next to mean cover value indicates no significant difference between means.

†indicates grass species: Poco=Canada bluegrass, Feov=sheep fescue and Agda=thickspike wheatgrass

LITERATURE CITED

LITERATURE CITED

- Ahmad, N. and A.J. Roblin. 1971. Crusting of River Estate soil, Trinidad, and its effect on gaseous diffusion, percolation, and seedling emergency. *J. Soil Sci.* 22:23-31.
- Allison, L.E., and D.C. Moore. 1956. Effect of VAMA and HPAN soil conditioners on aggregation, surface crusting and moisture retention in alkali soils. *Soil Sci. Soc. Amer. Proc.* 20:143-146.
- Alloway, B.J. and B.E. Davies. 1971. Heavy metal content of plants growing on soils contaminated by lead mining. *J. Agr. Sci.* 76(2):321-323.
- Arndt, W. 1965. The nature of the mechanical impedance to seedlings by soil surface seals. *Aust. J. Soil Res.* 3:45-54.
- Association of Official Seed Analysts. 1978. Rules for testing seeds. *J. Seed Tech.* 3(3):3b.
- Barth, R. C., and B. K. Martin. 1982. Soil-depth requirements to reclaim surface-mined areas in the Northern Great Plains. Colorado School of Mines Research Institute Envir. Tech. Div., Golden, 182 p.
- Bauer, A., P. Nyren, G. Reichman, G. Gee, and J. Gilley. 1978. Fertilization of wheat, corn, and grass-legume mixture grown on reclaimed spoilbanks. North Dakota Agr. Exp. Sta. Res. Rep. No. 67. North Dakota State Univ., Fargo. 15p.
- Beetle, A.A., and M. May. 1971. Grasses of Wyoming. Wyoming Agr. Exp. Sta. Res. J. No. 39 Univ. of Wyoming, Laramie. 153p.
- Bennett, O.L., D.A. Ashley, and B.D. Doss. 1963. Methods of reducing soil crusting to increase cotton seedling emergency. *Agron. J.* 56:162-165.
- Berg, W.A. 1974. Grasses and legumes for revegetation of disturbed subalpine areas. In: W.A. Berg, J.A. Brown, and R.L. Cuany (eds.) *Proc. Revegetation of High-Altitude Disturbed Lands.* Colorado State Univ., Fort Collins. p. 31-35.
- Berg, W.A. 1975. Use of soil laboratory analysis in revegetation of mined lands. *Mining Cong. J.* 61(4):32-35.

- Berg, W.A., and E.M. Barrau. 1978. Management approaches to nitrogen deficiency in revegetation of subalpine disturbances. *In*: S.T. Kenny (ed.) High Altitude Revegetation Workshop. No. 3 Colo. State Univ., Fort Collins p. 174-181.
- Bergman, E.L. and G.W. McKee. 1976. Dried poultry manure revegetates spoil banks. *Sci. in Agr.* 23(2)8-9.
- Bliss, L.C., and R.W. Wein. 1972. Plant community responses to disturbances in the western Canadian Arctic. *Canadian J. Bot.* 50(5):1097-1109.
- Bloomfield, J.R.G., and I.B. Ruxton. 1977. The effect of farm yard manure on weed introduction and crop establishment during land reclamation in arid land agriculture. *Jt. Agr. Res. Dev. Proj.* 87:19.
- Bonsu, M. 1980. Assessment of erosion under different cultural practices on a savanna soil in the Northern Region of Ghana. *J. Indian Soc. Soil Sci.* 29(4):247-253.
- Bradshaw, A.D., R.N. Humphries, M.S. Johnson, and R.D. Roberts. 1978. The restoration of vegetation of derelict land produced by industrial activity. *In*: M.W. Holdgate and M.J. Woodman (eds.). The Breakdown and restoration of ecosystems. Plenum Press. New York. p. 249-274.
- Brown, R.W., and R.S. Johnston. 1978. Rehabilitation of a high elevation mine disturbance. *In*: S.T. Kenny (ed.) High Altitude Revegetation Workshop. No. 3 Colorado State Univ., Fort Collins. p. 116-130
- Brown, R.W., B.Z. Richardson, and E.E. Farmer. 1976. Rehabilitation of alpine disturbances: Beartooth Plateau, Montana. p. 58-73. *In*: R.L. Zuck, and L.F. Brown (eds.) High Altitude Revegetation Workshop No. 2. Colorado State Univ., Fort Collins. p. 58-73.
- Butterfield, R.I. and P.T. Tueller. 1980. Revegetation potential of acid mine wastes in northeastern California. *Recl. Rev.* 3:21-31.
- Byrnes, W.R., W.W. McFee, and J.G. Stocton. 1980. Properites of plant growth potential of mineland overburden. U.S. Environ. Prot. Agency Rep. No. 600/780-054 68p.
- Carnes, A. 1934. Soil crusts. Methods of study, their strength and a method of overcoming their injury to cotton stands. *Agr. Eng.* 15:167-171.
- Chaudhri, K.G., K.W. Brown, and C.B. Holder. 1976. Reduction of crust impedance to simulated seedling emergence by the addition of manure. *Soil Sci.* 122:216-222.

- Coenenberg, J. 1982. Methods for establishment of diverse native plant communities at the Rosebud Mine. In: Mining and Reclamation of Coal Mined Lands in the Northern Great Plains. Montana Agr. Exp. Sta. Res. Rep. No. 194. pp. B-6-1 - B-6-20.
- Cook, C.W., R.M. Hyde, and P.L. Sims. 1974. Revegetation guidelines for surface mined areas. Range Science Dept. Colorado State Univ. Fort Collins. 73p.
- Czapowskyj, M.M., and E.A. Sowa. 1976. Lime helps establish crown-vetch on coal-breaker refuse. U.S. Dept. of Agr. For. Ser. Res. paper NE-348. 7p.
- Darling, A.P. 1983. The effects of native hay mulch on stabilization and revegetation of strip mined lands in southeastern Montana. M.S. Thesis Montana State Univ. 102p.
- Das, D.K., and K.G. Chaudhri. 1981. Infiltration and redistribution of soil water as influenced by crust formation, cultivation and farmyard manure application. J. Indian Soc. Soil Sci. 29(4):543-546.
- Daubenmire, R. 1959. A canopy method of vegetation analysis. Northwest Sci. 33:43-64.
- Daubenmire, R. 1968. Plant Communities. Harper and Row, New York. 300p.
- Day, A.D., G.F. Mitchell, T.C. Tucker, and J.L. Thames. 1979. Emergence and growth of plant species in coal mine soil. J. Environ. Qual. 8(1):110-114.
- Deput, E.J., and J.G. Coenenberg. 1979. Response of revegetated coal strip mine spoils to variable fertilization rates, longevity of fertilization program and season of seeding. Montana Agr. Exp. Sta. Res. Rep. No. 150. Montana State Univ., Bozeman. 81p.
- Dollhopf, D.J. 1971. The effects of gypsum rates and irrigation regimes on soil physical and chemical properties of saline-alkali soil. M.S. Thesis. Montana State Univ., 133 p.
- Dubbs, A.L., R.T. Horada, and J.R. Stroh. 1974. Evaluations of thickspike wheatgrass for dryland pasture and range. Montana Agr. Exp. Sta., Bull. No. 677., Montana State Univ., Bozeman. 13p.
- Eaman, T.K. 1974. Plant species potentials for high-altitude revegetation. In: W.A. Berg, J.A. Brown, and R.L. Cuany (eds.). Proc. Revegetation of High-Altitude Disturbed Lands. Colorado State Univ. Info. Ser. No. 10 p. 39-43.

- Elliot, C.R., and J.L. Bolton. 1970. Licensed varieties of cultivated grasses and legumes. Canada Dept. of Agr., Pub. No. 1405. In: Watson, L.E., R.W. Parker, and D.F. Polster. 1980. Manual of species suitability for reclamation in Alberta. Alberta Land Conservation and Reclamation Council Rep. No. RRTAC 80-5. 2 vols. 541p.
- Free, G.R. 1949. Efficient use of farm manure for erosion control. J. Soil Water Cons. 4:117-118.
- Frelich, J.R., E.H. Jensen, and R.O. Gifford. 1973. Effect of crust rigidity on emergency of six grass species. Agron. J. 65:26-29.
- Gerard, C.J., H.C. Mehta, and E. Hinojosa. 1972. Root growth in clay soil. Soil Sci. 114:37-49.
- Gould, W.L., S. Miyamoto, and D. Rai. 1976. Reclamation potential of overburden materials in the Fruitland Formation in the San Juan Basin. New Mexico Agr. Exp. Sta. Bull. 657. New Mexico State Univ., Las Cruces. 30p.
- Greb, B.W. 1967. Percent cover by six vegetative mulches. Agron. J. 59:610-611.
- Guttay, J.R., R.L. Cook, and A.E. Erickson. 1956. The effect of green manure and stable manure on the yield of crops and on the physical condition of a Tappan-Parkhill loam soil. Soil Sci. Soc. Am. Proc. 20:526-528.
- Hadas, A., and E. Stibbe. 1977. Soil crusting and emergence of wheat seedlings. Agron. J. 69:547-550.
- Hafenrichter, A.L., J.L. Schwendiman, H.L. Harris, R.S. MacLauchlan, and H.W. Miller. 1968. Grasses and legumes for soil conservation in the Pacific Northwest and Great Basin states. U.S. Dept. of Agr. Soil Cons. Ser., Agr. Handbook No. 339.
- Hanks, R.J. 1960. Soil crusting and seedling emergence. In: 7th Cong. Soil. Sci. 1:340-346.
- Harper, J., and A.E. Spooner. 1982. Effect of lime on pH of acid bauxite minesoils. In: Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Univ. of Kentucky., Lexington. p. 391-395.
- Hegarty, T.W., and S.M. Royle. 1978. Combined effects of moisture content prior to compaction, compactive effort and rainfall quantity on soil crust strength. J. Soil Sci. 29:167-173.

- Hertzog, P.J. 1983. Response of native species to variable rates of nitrogen, phosphorus and potassium fertilization on mine soils. M.S. Thesis. Montana State Univ. 122p.
- Holder, C.B., and K.W. Brown. 1974. Evaluation of simulated seedling emergence through rainfall induced soil crusts. Soil Sci. Soc. Amer. Proc. 38:705-710.
- Holecheck, J.L. 1982. Fertilizer effects on above- and below-ground biomass of four species. J. of Range Mgmt. 35(1) 39-42.
- Imhoff, E.A., T.O. Friz, and J.R. LaFevers. 1976. A guide to state programs for the reclamation of surface mined areas. U.S. Geol. Sur. Circ. No. 731 33p.
- Jacklin Seed Co. 1975. Rubens Canada bluegrass. Jacklin Seed Co. Pub., Post Falls, Idaho.
- Jeffrey, D.W., and C.D. Pigott. 1973. The response of grasslands on sugar-limestone in Teesdale to application of phosphorus and nitrogen. J. of Ecology 61(1):85-92.
- Jensen, E.H., J.R. Frelich and R.O. Gifford. 1972. Emergence force of forage seedlings. Agron. J. 64:635-639.
- Johnston, A., A.D. Smith, L.E. Latwich, and S. Smoliak. 1968. Fertilizer response of native and seeded ranges. Can. J. Plant Sci. 48:467-472.
- Johnson, R.C., and J.B. Law. 1967. Controlling soil crusting in sugar beet fields by applying concentrated sulfuric acid. J. Amer. Soc. Sugar Beet Technol. 14:615-618.
- Kay, B.L. 1978. Mulch and chemical stabilizers for land reclamation in dry regions. In: F.W. Schaller and P. Sutton (ed.). Reclamation of Drastically Disturbed Lands. Amer. Soc. of Agron. Madison, Wisconsin. 742p.
- Keane, P. and B. Craze. 1978. Captains Flat mined area field vegetation trials. J. Soil Cons. Ser. of New South Wales 34(1):37-42.
- Kelley, N.E. 1979. Vegetation stabilization of uranium spoil areas, Grants, New Mexico. M.S. Thesis Univ. of New Mexico, Albuquerque. 96p.
- Kohlman, H. 1978. Badbearbeitungstechnik im hopfenbau. Berichte uber Landwirtschaft. 56(2-3)511-514.

- Kozel, J. 1978. Biological reduction of dust nuisance on power station waste dumps. *Sci. Agr. Bohemoslovaca*. 10(1):1-13.
- Langham, J.M. 1971. Nitrogen in relation to plant succession on intra-dune cobble flats with emphasis on germination and growth. *Dissertation Abstracts Internat'l*. 32(5):2655.
- Larson, T.A. 1977. *Wyoming A History*. W.W. Norton & Co., Inc. 198p. P. 168-170 mining in Wyoming and environmental.
- Lemos, P., and J.F. Lutz. 1957. Soil crusting and some factors affecting it. *Soil Sci. Soc. Amer. Proc.* 21:485-491.
- Lewis, O. 1963. Treasures of the American West. In: *The Book of the American West*. J. Monaghan (ed.) Simon and Schuster, New York. pp. 137-192.
- Leyer, C. 1981. Development of green cover on soilless slopes of motorway cuttings. III. Relationship with site factors. *Zeitschrift fur Vegetationstechnik im Landschafts-und Sportstattenbau*. 4(2):47-56.
- LICA. 1978. Land and water. *Offic. Pub. of Land Improv. Contract. Amer.*, April 1978. 3p.
- Lilley, L.P., and J. Benson. 1979. New understory cultivars for Pacific Northwest. *Rangelands* 1(3):103-104.
- Loiseau, P. 1975. Establishment of turf on soils denuded by tourist use in the Plomb du Cantal Massif. *Comptes Rendus des Seances de l'Acad. d'Agric. de France*. 61(15):982-991.
- Long, F.L., Z.F. Lund and R.E. Hermanson. 1975. Effect of soil-incorporated dairy cattle manure on runoff water quality and soil properties. *J. Environ. Qual.*, 4(2):163-166.
- Long, S.G. 1981. Characteristics of plants used in western reclamation. (2nd ed.) *Environmental Research and Technology, Inc.*, Fort Collins, Colorado. 138p.
- Lorenz, R.J. and G.A. Rogler. 1973. Growth rate of mixed prairie in response to nitrogen and phosphorus fertilization. *J. Range Manage.* 26:365-368.
- Lund, Z.F., and B.D. Doss. 1980. Residual effects of dairy cattle manure on plant growth and soil properties. *Agron. J.* 72:123-130.
- Magdoff, F.R. 1978. Influence of manure application rates and continuous corn on soil-N. *Agron. J.* 70:629-632.

- Magdoff, F.R., and J.F. Amadon. 1980. Yield trends and soil chemical changes resulting from N and manure application to continuous corn. *Agron. J.* 72:161-164.
- Martusewicz, J. 1974. Analysis of the variation of ecotypes and other forms of Poa pratensis L., P. palustris L. and P. compressa L. *Biuletyn Instytutu Hodowli i Aklimatyzacji Roslin* 5(6):37-43.
- Mason, M.L., D.L. Evans, G.E. Schuman, and G.M. Passini. 1980. The use of standing stubble, crimped straw and feedlot compost for establishing grass on mined land. In: *Adequate Reclamation of Mined Lands? A symposium. Western Agr. Exp. Sta. Coord. Committee on Mine Waste Reclamation. WRCC No. 21 pp. 21-1-21-13.*
- Mazurak, A.P., L. Chesnin, and A.E. Tiarks. 1975. Detachment of soil aggregates by simulated rainfall from heavily manured soils in eastern Nebraska. *Soil Sci. Soc. Amer. Proc.* 39:732-736.
- McHenry, J.R. 1963. Theory and application of neutron scattering in the measurement of soil moisture. *Soil Sci.* 95:294-307.
- McIntyre, D.S. 1958a. Permeability measurement of soil crusts formed by raindrop impact. *Soil Sci.* 85:185-189.
- McIntyre, D.S. 1958b. Soil splash and the formation of surface crusts by raindrop impact. *Soil Sci.* 85:261-266.
- Meyer L.D., W.H. Wischmeier and G.R. Foster. 1970. Mulch rates for erosion control on steep slopes. *Soil Sci. Soc. Amer. Proc.* 34:928-931.
- Michaud, L.H. 1981. A manual of Reclamation Practice. Internat'l. Academic Ser. Lim. Kingston, Ontario. 345p.
- Moe, R.A., G.A. Nielson, and R.T. Choriki. 1971. Soil crust studies. Montana Agr. Exp. Sta. Res. Rep. No. 6. Montana State Univ., Bozeman. 21p.
- National Oceanic and Atmospheric Administration. 1977. Climatography of the United States No. 20. Climate of Butte Montana. Addendum No. 3a. U.S. Dept. of Commerce, Environ. Data Ser., Asheville, North Carolina. 3p.
- Neilsen, G.A., and E.V. Miller. 1980. Crop yields on native soils and strip mine soils: A comparison. *J. Soil and Water Cons.* 35:44-47.
- Nielson, R.F., and H.B. Peterson. 1972. Treatment of mine tailings to promote vegetative stabilization. *Utah Agr. Exp. Sta. Bull.* No. 485. Utah State Univ., Logan.

- Nishimura, J.V. Soils and soil problems at high altitudes. 1974.
In: W.A. Berg, J.A. Brown, and R.L. Cauny (eds.) Revegetation
 of High-Altitude Disturbed Lands. Colo. State Univ., Info.
 Series No. 10. pp. 5-9.
- Olsen, R.J., R.F. Hensler, and O.J. Attoe. 1970. Effect of manure
 application aeration and soil pH on soil nitrogen transformations
 and on certain soil test values. Soil Sci. Soc. Am. Proc.
 38:826-830.
- Omodt, H.W., F.W. Schroer, and D.D. Patterson. 1975. The properties
 of important agricultural soils as a criteria for mined land
 reclamation. North Dakota Agr. Exp. Sta. Bul. No. 492. North
 Dakota State Univ., Fargo. 52p.
- Palazzo, A.J., and J.M. Graham. 1981. Cold Regions Res. and Eng.
 Lab. Spec. Rep. No. 81-4. 12p.
- Parady, F.E. 1981. Investigation of selected Berkeley Pit overburden
 as a medium for plant growth. M.S. Thesis, Montana State Univ.,
 Bozeman. 85p.
- Peech, M. 1965. Hydrogen-ion activity. In: Black, C. A. Methods
 of Soil Analysis, Part 2, Chemical and Microbiological Properties.
 Amer. Soc. Agron., Madison, Wisconsin. pp. 922-923.
- Powell, J.L., M.L. Ellis, R.I. Barnhisel, and J.R. Armstrong. 1982.
 Suitability of various cool-season grass species for reclamation
 of acid surface-mined coal spoils of Western Kentucky. In:
 Symposium on surface mining hydrology, sedimentology and reclama-
 tion. Univ. of Kentucky, Lexington. pp. 503-526.
- Rauzi, F., and R.L. Trester. 1978. A preliminary report on herbage
 yields, stand evaluation, soils and chemical content of selected
 grasses and a legume grown on topsoil, White River and Wind
 River geologic material. Wyoming Agr. Exp. Sta. Rex. J. No.
 124., Univ. of Wyoming, Laramie. 21p.
- Redmann, R.E. 1974. Photosynthesis, respiration and water relations
 of *Agropyron dasystachyum* measured in the laboratory. Univ. of
 Saskatchewan Tech. Rep. No. 47. 22p.
- Richardson, B.Z. 1980. Reclamation of acid-producing spoils on a
 western surface mine. In: C.L. Jackson and M.A. Schuster
 (eds.) High-Altitude Revegetation Workshop No. 4. Colo. State
 Univ., Fort Collins. pp. 101-112.
- Richardson, B.Z. and E.R. Burroughs, Jr. 1972. Effects of air gaps
 and saturated voids on accuracy of neutron moisture measurements.
 USDA For. Ser. Res. Pap. INT-120. 20p.

- Richardson B.Z. and E.E. Farmer. 1981. Test of methods for amending and seeding spoils at the Blackbird mine. U.S. Dept. of Agr. For. Ser. Res. paper INT-265. 6p.
- Ries, R.E., L. Hofmann, and W.C. Whitman. 1980. Potential control and value of seeds in prairie hay for revegetation. Recl. Rev. 3:149-160.
- Ries, R.E., F.M. Sandoval, J.F. Power, and W.O. Willis. 1976. Perennial forage species response to sodium and magnesium in mine spoil. In: Fourth Symposium on Surface Mining and Reclamation. Univ. of Kentucky, Lexington. pp. 173-183.
- Reynolds, J.F., M.J. Cwik, and N.E. Kelley. 1978. Reclamation at Anaconda's open pit uranium mine, New Mexico. Recl. Rev. 1:9-17.
- Safaya, N.M., and M.K. Wali. 1979. Growth and nutrient relations of a grass-legume mixture on sodic coal-mine spoil as affected by some amendments. Soil Sci. Soc. of Am. J. 43(4):747-753.
- Salisbury, F.B. and C.W. Ross. 1978. Plant Physiology. (2nd ed.) Wadsworth Pub. Co. Inc., Belmont California. 422p.
- Sandoval, F.M., J.J. Bond, J.F. Power, and W.O. Willis. 1973. Lignite spoils in Northern Great Plains - characteristics and potential for reclamation. Symp. on Research and Applied Tech. of Mined-Land Reclamation, Pittsburg, PA. pp. 117-133.
- Schafer, W.M. 1979. Guides for estimating cover-soil quality and mine soil capability for use in coal strip mine reclamation in the Western United States. Recl. Rev. 2:67-74.
- Schuman, G.E. and E.M. Taylor. 1978. Use of mine spoil to improve the topsoil Univ. of Wyoming Agr. Exp. Sta. Res. J. No. 130, Laramie. 10p.
- Schwendiman, J.L. 1974. "Durar" hard fescue: "grass of all trades." Soil Cons. 40(2):8.
- Simon, E. 1977. Cadmium tolerance in populations of Agrashs tenuis and Festuca ovina. Nature 265:328-330.
- Sindelar, B.W. and P.L. Plantenberg. 1979. Establishment, succession, and stability of vegetation on surface mined lands in eastern Montana. Mont. State Univ. Dep. of Energy Annu. Prog. Rep., Bozeman. 55p.
- Singer, M.J. and J. Blackard. 1977. Evaluation of wild oat straw as a soil erosion retardant using simulated rainfall. Agron. J. 69:811-814.

- Smith, R.I. 1953. History of early reduction plants of Butte, Montana. *De Re Metallica* 18:1-19.
- Smoliak, S., C.R. Elliott, and J. Willman. 1975. Hay and pasture crops for Alberta. *Alberta Arg.*, Agdex 120:20-1.
- Stroh, J.R., A.A. Thornburg and D.E. Ryerson. 1972. Registration of Critana thickspike wheatgrass. *Crop Sci.* 12(3):394.
- Taylor, H.M. 1962. Seedling emergence of wheat, grain sorghum and guar as affected by rigidity and thickness of surface crusts. *Soil Sci. Amer. Proc.* 26:431-433.
- Thornwaite, C.W. 1941. Atlas of climatic types in the United States; 1900-1939. U.S. Govt. Printing Office. Washington, D.C.
- Tisdale, S.L., and W.L. Nelsen. 1975. Soil Fertility and Fertilizers. Macmillan Publishing Co., New York. 694p.
- Troeh, F.R., J.A. Hobbs, and R.L. Donahue. 1980. Soil and Water Conservation for Productivity and Environmental Protection. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 718p.
- Troxler Electronic Laboratories, Inc. 1980. 3411 Series Surface Moisture-Density Gauges (Manual). Research Triangle Park, North Carolina.
- Tueller, P.T., and R. Butterfield. 1981. Soil and vegetation characteristics of the Levianthan mine, California, in relation to requirements of F. (Preliminary results from Buckskin Nat'l. Mine). Nevada Agr. Exp. Sta. Proj. No. NEV00652.
- Turkington, R.A., P.B. Cavers, and L.W. Aarssen. 1977. Neighbour relationships in grass-legume communities. 1. Interspecific contacts in four grassland communities near London, Ontario. *Canadian J. Bot.* 55(21):2701-2711.
- USDA. 1979. User guide to vegetation mining and reclamation in the West. USDA For. Ser. Gen. Tech. Rep. INT-64 85p.
- Valentine, J.F. 1980. Range development and improvements. Brigham Young Univ. Press., Provo, Utah. 545p.
- Vandevender, J.C., and J.C. Sencindiver. 1982. The effects of three forms of nitrogen fertilizer, phosphorus, and hydrated lime on abandoned mine land reclamation. In: Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Univ. of Kentucky, Lexington. pp. 497-502.

- Vories, K.C., and P.L. Sims. 1977. The plant information network vol. III: Reclamation and PIN in the Powder River Basin of Montana and Wyoming. U.S. Dept. Int., Fish and Wildlife Ser., Rep. No. FWS/OBS(70)40.
- Walsh, L.M., and R.F. Hensler. 1971. "Manage manure for its value" Wisconsin Ext. Circ. 550.
- Wambolt, C. 1981. Montana range plants. Montana Coop. Exten. Ser. Bull. No. 355. 27p.
- Watson, L.E., R.W. Parker, and D.F. Polster. 1980. Manual of species suitability for reclamation in Alberta. Alberta Land Conservation and Reclamation Council Report #RRTAC 80-5. 2 vols. 541p.
- Wenger, L.E. 1941. Re-establishing native grasses by the hay method. Kansas Agr. Exp. Sta., Ft. Hays Cir. 208. Kansas College of Agr. and Applied Sci., Manhattan. 6 p.
- Wild, A.E.R. 1979. Stabilization of a difficult landform - Brown Mountain. J. Soil Cons. Ser. of New South Wales 35(1)13-18.
- Williams, W.A. 1956. Evaluation of the emergence force exerted by seedlings of small seeded legumes using probit analysis. Agron. J. 48:273-274.
- Yaeger, R.R., W.C. Leininger, and D.E. Ryerson. 1976. Guide to common Montana range plants. Montana State Univ. Range Manage. Club Pub., Bozeman. 111p.
- Ziennicki, S., and D. Fijalkowski. 1975. Introduced and natural vegetation on the slopes of a dump at Piaseczyna. Zeszyty Problemowe Postepow Nauk Rolniczych No. 170. pp. 129-150.

NOV 22 2003

MONTANA STATE UNIVERSITY LIBRARIES



3 1762 10014473 0

NOV 22 2003

1985

NOV

MA

MAR 07 1991

1982

APR 24 RECD

NOV 21

NOV 1 1 RECD

AL 16 0 5 RECD

INTERLIBRARY LOAN

FEB 1 RECD

NOV 20

NOV 20 1890

NOV 20 2003

MAIN LIB.

N378

L445

cop.2