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

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.

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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.

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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 microclimates 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 (NO_3-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, refertilization 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 activitiy (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 (Depuit 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 quantifing 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 bromegrass 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 teatment 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 choosen 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.) Schribn.), 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 Erasia (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 Belguim 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 Cn 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 Artic 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 m^3 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.

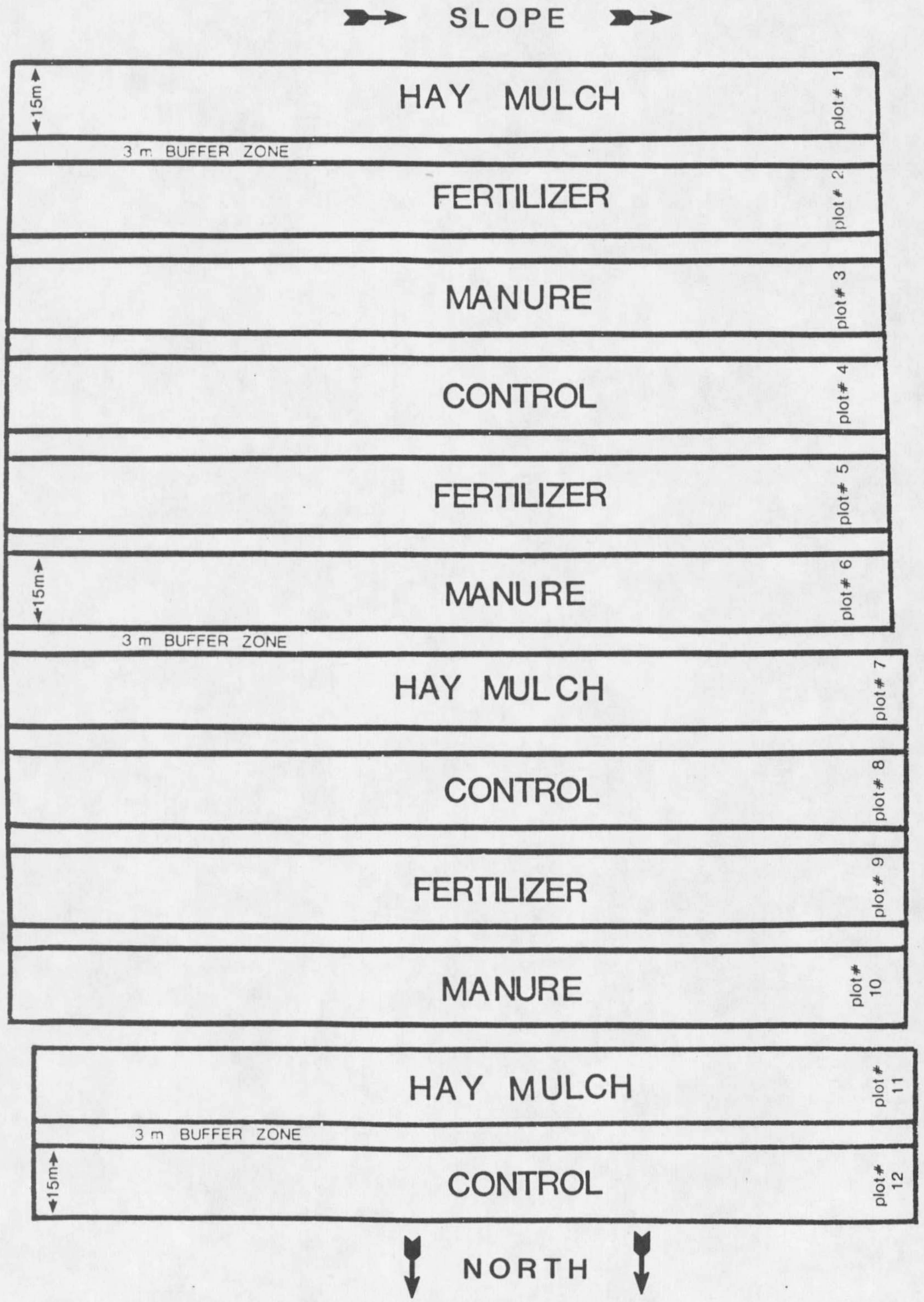

Figure 1. Plot design.

* fertilizer = ammonium phosphate sulfate (16-20-0) incorporated at a rate of 269 kg/ha.

† lime = a quick or hydrated lime ($Ca(OH)_2$) 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	Width* 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 bromegrass (*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 $(NH_4\ H_2PO_4\ (NH_4)_s\ SO_4)$, which is a mixture of 16% nitrogen (all ammonium form), 20% $P_2\ O_5$ (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.

Applied Nutrient	%	kg/ha
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

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

*Fall 1981 seeding are double these rates.

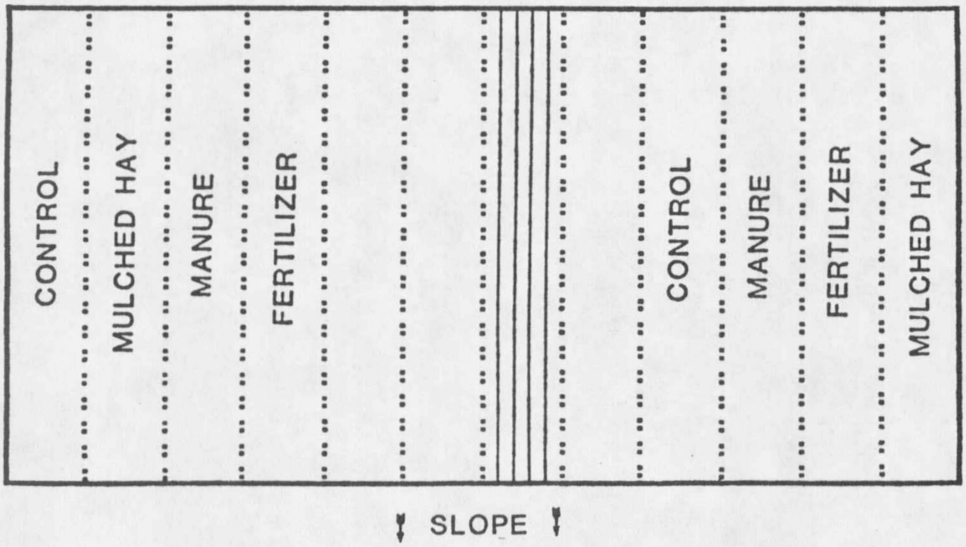

Figure 2. Treatment diagram. The area between the broken lines represent amendments. The solid lines in the middle of the figure denote microplots located within each amendment. All treatments were replicated three times.

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.

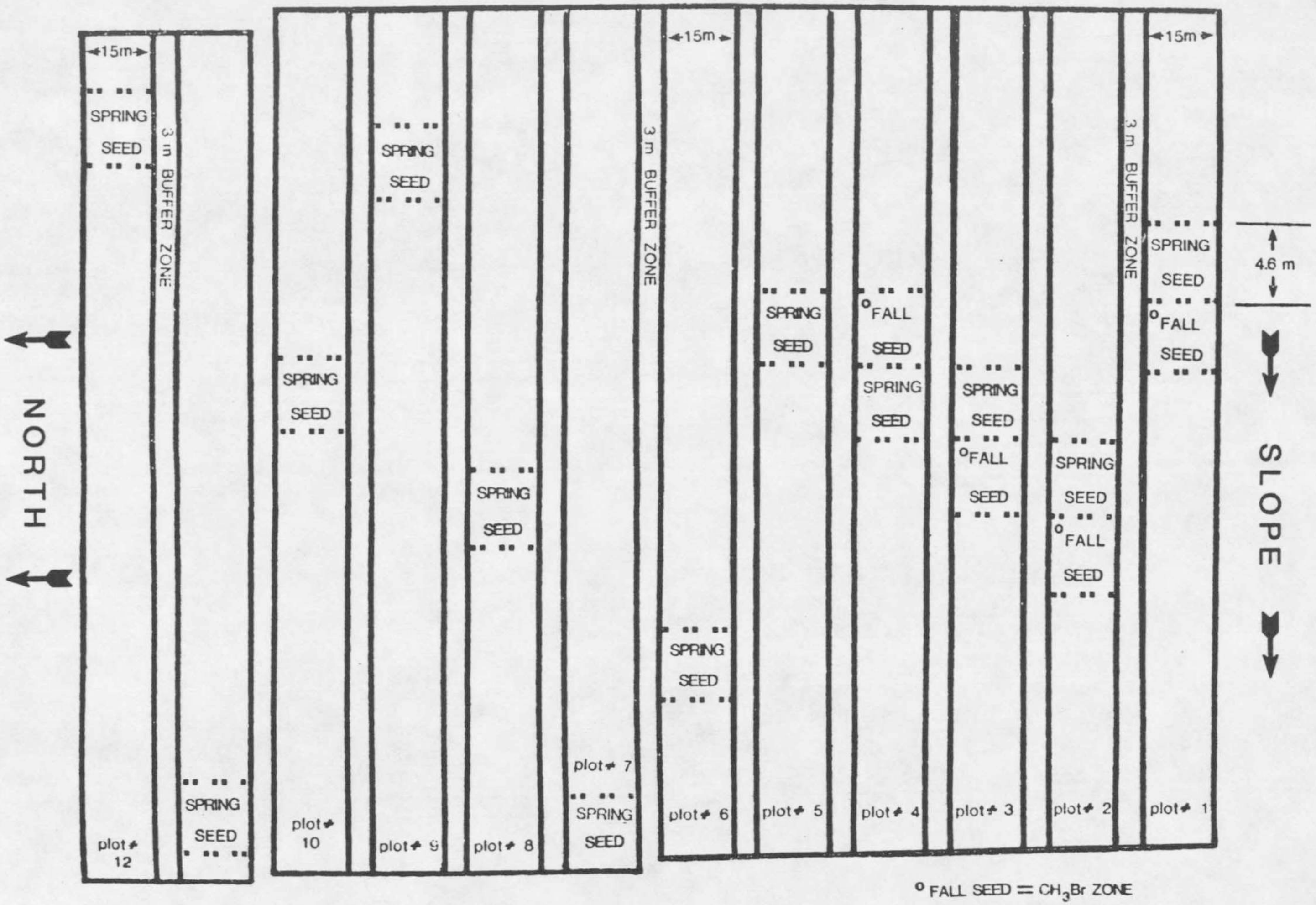

Figure 3. Research plot fall 1981 seeding diagram. Areas not within the broken lines are spring and fall seeded.

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

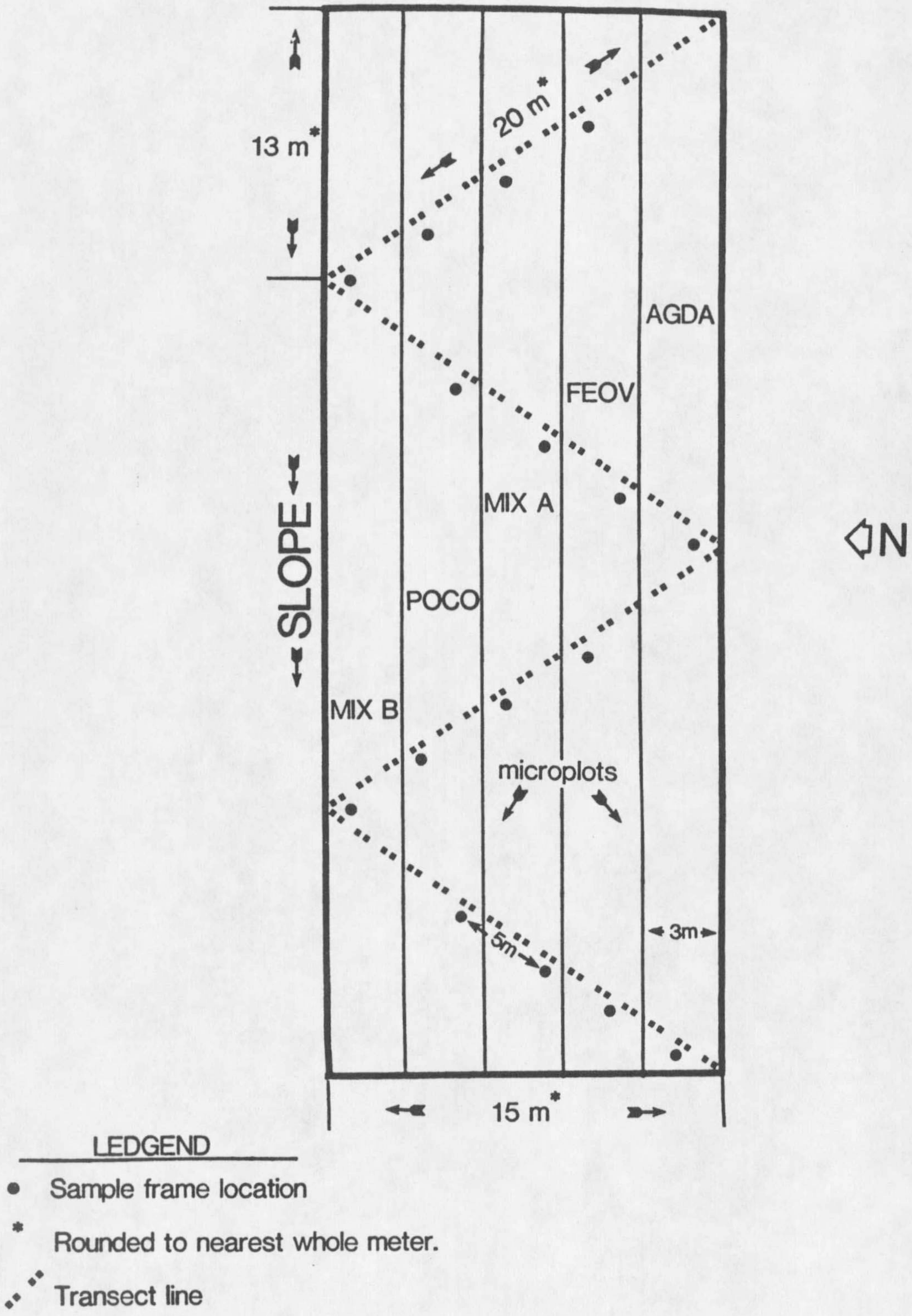

Figure 4. Example of plot lay out and sampling scheme.

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. Mean[1] research plot soil temperature for the 1982 growing season.

Date	Control	Mulched Hay	Fertilizer	Manure
	Temperature in °C			
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

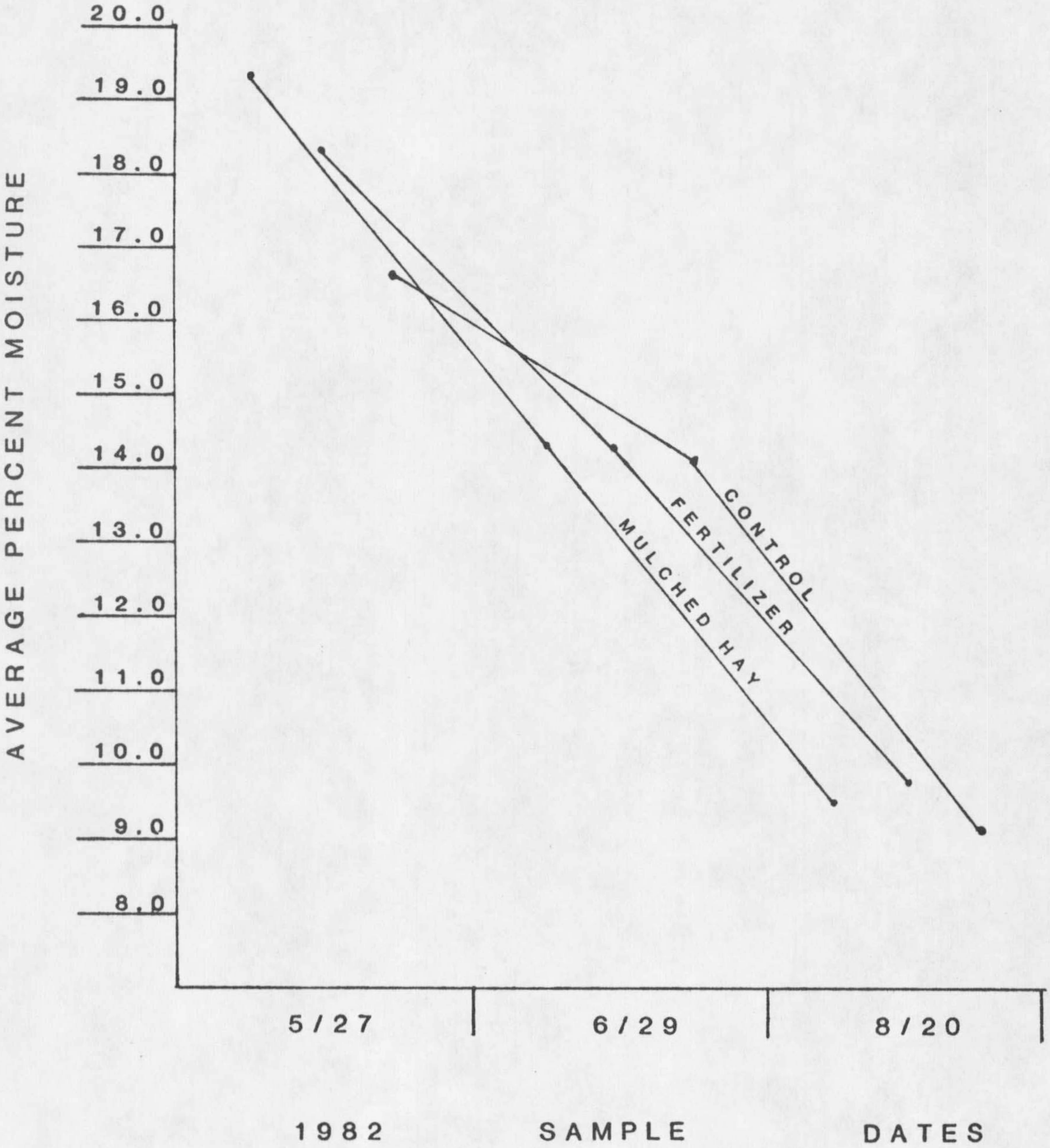

Figure 5. Changes in average percent soil moisture in nontreated alluvium and two surface amendments, during the 1982 growing season.

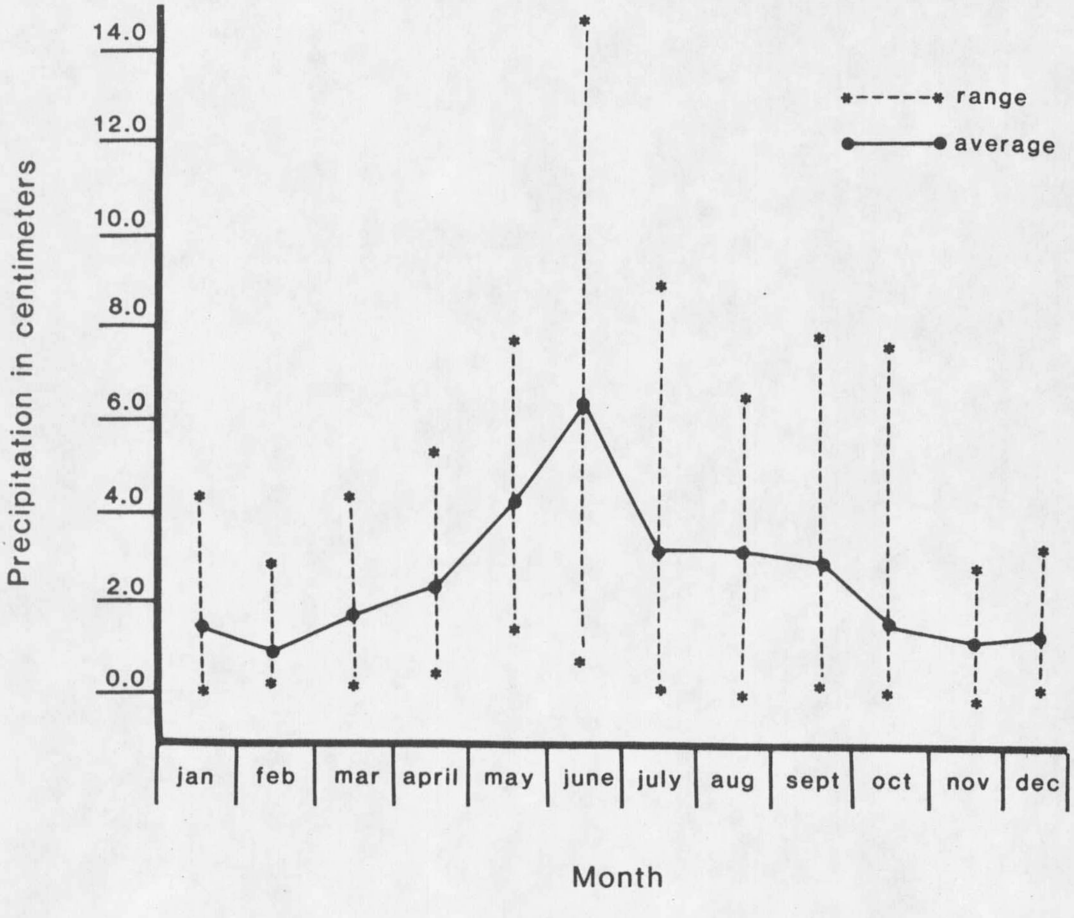

Figure 6. Monthly precipitation averages and ranges for the Butte area (1948-1977; data acquired from the Butte airport).

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. Mean[1] 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.

[1] Means 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.

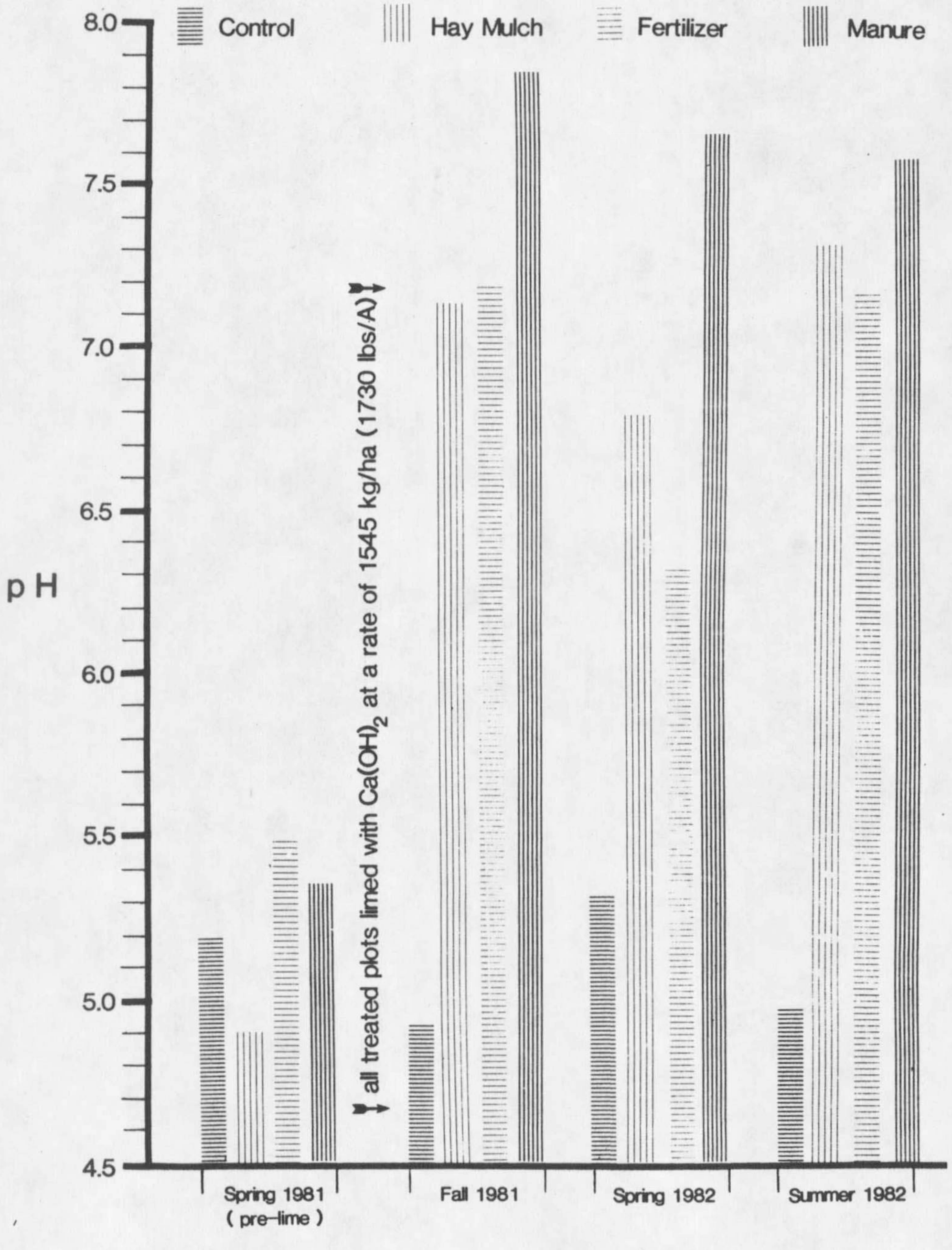

Figure 7. Affects of liming on three alluvium treatments over a 16 month period.

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/m^2. 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 kg/cm^2 in the control, 60 km/cm^2 in the fertilizer and ≧55 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,

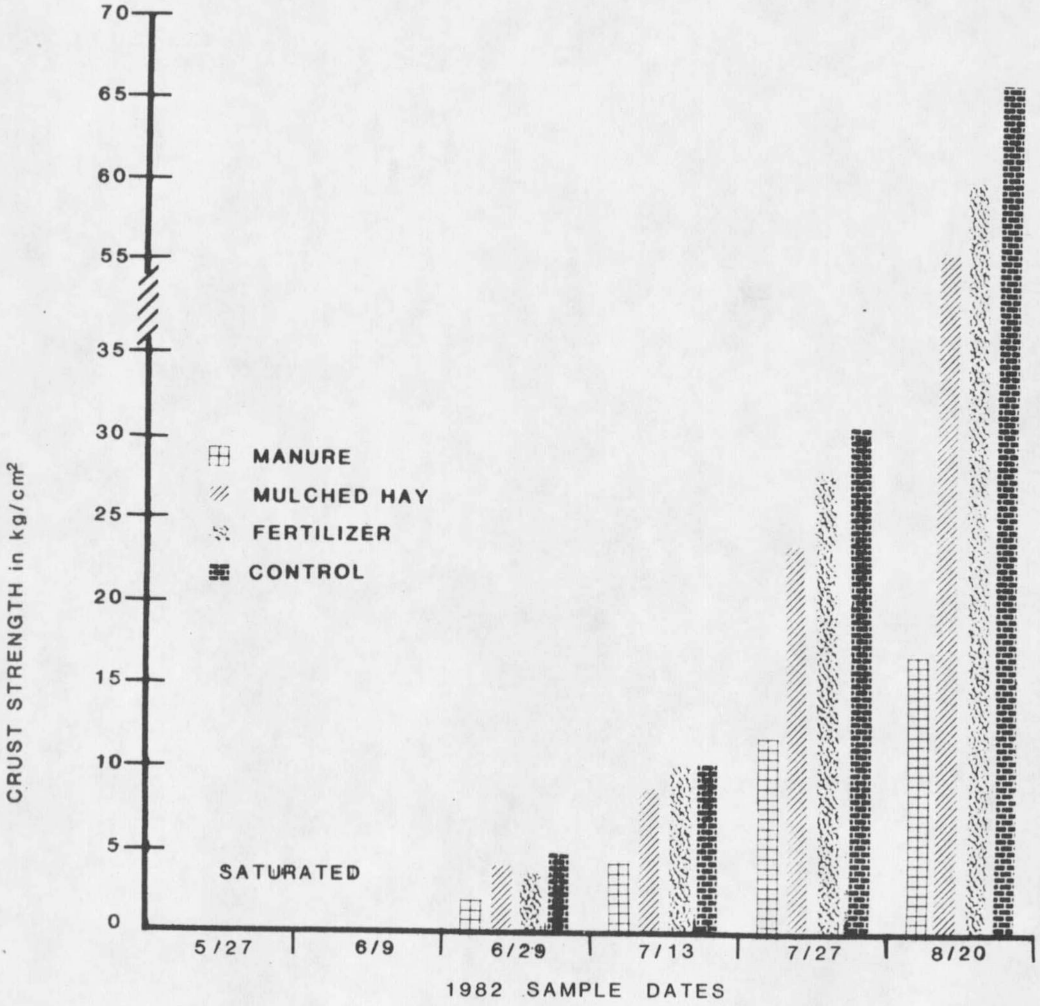

Figure 8. Crust strength measurements of three surface amendments and non-treated alluvium, during the 1982 growing season.

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.

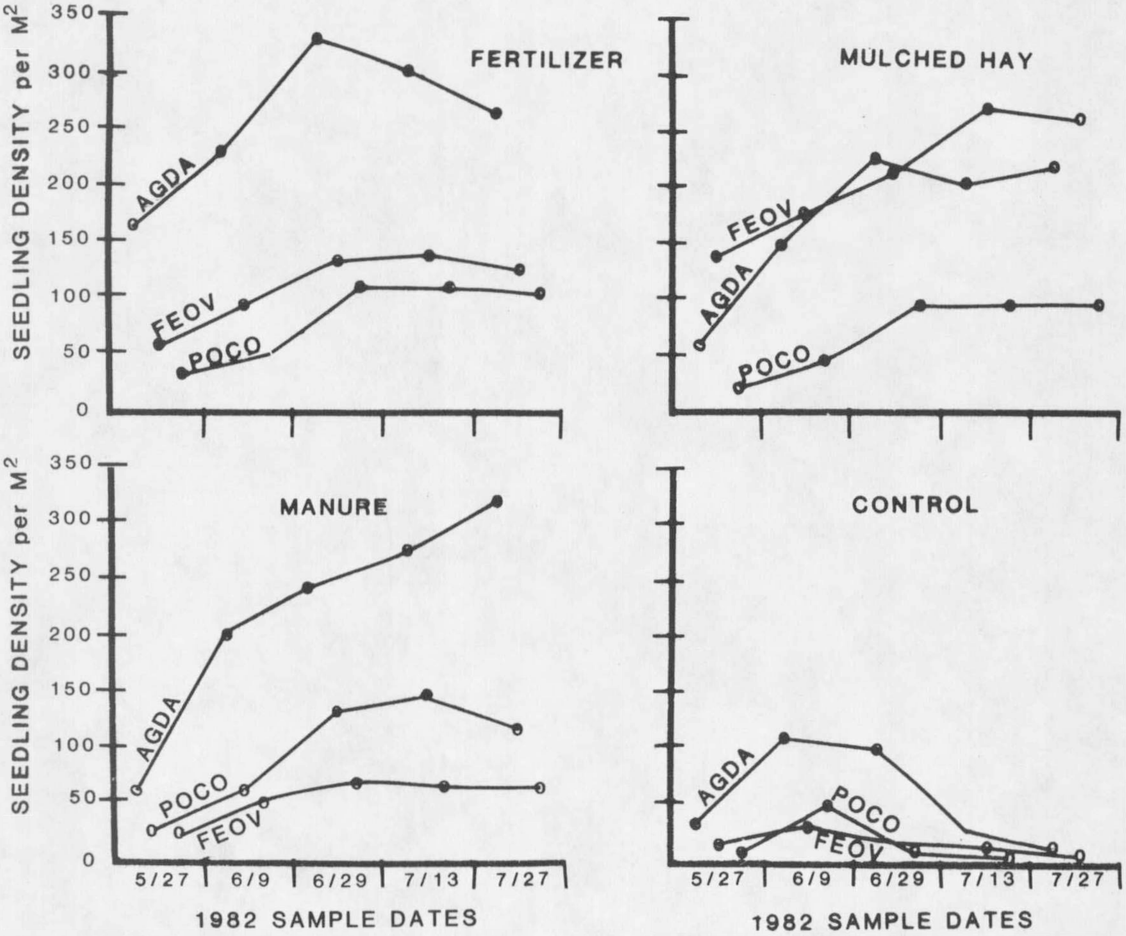

Figure 9. Seedling density of three native grass species over five dates, in three alluvial overburden (cover-soil) amendments and a control. The grass species considered were: Agropyron dasystachyum (Agda), Poa compressa (Poco), Festuca ovina (Feov).

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