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Edited by

Thomas A. Colbert and Robin L. Cuany

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PREFACE

With this Workshop the Committee on High Altitude Revegetation embarks on a second decade of activity. We have held a workshop every two years since 1974, and a field tour every summer, and none of this would have been possible without the continuing and faithful help of the members of the Committee. Members come and members go, but many people have served throughout the duration. We give thanks not only to the continuing and departing people, but also to the organizations which sponsor their participation and thus help us strive toward the goals of exchanging information on the latest topics of reclamation, and its scientific and economic basis.

These Proceedings are of course the product of the authors who prepared and presented the papers in the several sessions. Once again we express our gratitude to them, and our apologies for delays, due to unavoidable circumstances, in the publication process. Not so easy to reproduce, but a definite enhancement to the 1984 Workshop, was the activity of a group of exhibitors who displayed everything from seeds to fiber mulches to slides of projects in progress, from plant materials to reclamation.

The next workshop is already scheduled for the first half of March (probably 6 & 7) 1986. Our committee has been able to coordinate with the Billings reclamation conference so that the latter is lined up for 17-19 March, 1987 and will avoid the conflict of the two meetings held in March, 1984. We also appreciate the ideas and suggestions of our participants and readers so as to make the 7th Workshop even more successful and helpful to you. Let us know about topics you want to hear or present in our group.

Finally, be advised that our 1985 summer tour has just been arranged and scheduled for August 15 and 16 in the area of the Beartooth Plateau and Cooke City, Montana. At the invitation of Ray Brown, we can see the mine remains and revegetation experiments which Ray and his co-authors Robert Johnston and Jeanne Chambers have described at several previous workshops, and on pages 200 to 224 of the present volume. Detailed information on the itinerary will be sent early in 1985.

Tom Colbert
Robin Cuany

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Membership in late 1984

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Keynote Address
By
Robert Burford, Director
Bureau of Land Management
Washington, DC

Members of the High Altitude Revegetation Committee, Guests, Ladies, and Gentlemen.

I am honored by your invitation. This is a very select group and I understand that service on the Committee is entirely voluntary. It's one of the strengths of America that when there is a need there are always capable people who are willing to put their shoulder to the wheel. I congratulate those who have volunteered for this worthwhile effort.

I am told that previous keynote speakers have been ecologists, and that I have been selected because of my experience as the administrator of a land management agency.

Most of you know that the Bureau of Land Management is responsible for the management of more Federal land than any other agency. Currently we manage about 290 million surface acres. This land is located mainly in the west and Alaska. In addition the Bureau is responsible for the mineral resources on 300 million acres of land belonging to other Federal agencies and 65 million acres where the surface is in private ownership. Only a small percentage of BLM lands in the lower 48 states lie at high altitudes. Historically, those lands at the higher altitudes were incorporated into the National Forest.

The BLM organization is designed to give maximum responsibility to the local manager. We believe that those closest to the problem are best able to make those decisions that effect local conditions.

Presently we have state offices in each of 11 major public land states, including Alaska. Five state offices, including New Mexico, Colorado, Wyoming, Montana, and Oregon have responsibility for relavitely small amounts of land in adjoining states. Our Eastern States Office has responsibility for public lands and the Federal mineral estate in all states east of the Mississippi River and the first tier of states west of the River.

Each State Office is headed by a State Director who has the responsibility and the authority to carry out Bureau programs in their states.

In addition we have 55 District Offices and 153 Resource Areas. The District Office is headed by a District Manager, accountable to his State Director. Resource Areas are headed by an Area Manager, accountable to the District Manager.

Our District and Area offices are the cutting edge of the Bureau's programs. These are the people who get the job done on the ground and they are the people who will be working with you to carry out rehabilitation efforts.

BLM is only one of the Federal agencies that has responsibility for the reclamation of areas that have been mined. As you are aware, the Office of Surface Mining has much of the responsibility in this area. They work within the states and can exercise control over lands beyond the jurisdiction of the Bureau of Land Management.

There are also many state agencies and universities involved in the reclamation of mined lands in the west.

The Bureau's reclamation policy is fourfold:

1. Reclaimed lands will be capable of supporting an equal or higher mix of land uses at bond release time as they did prior to their disturbance;

2. The desired post-disturbance land use will be based on resource management and activity plans in effect at the time the lease permit is issued;

3. The Area manager will determine the need for rehabilitation potential before the lease or permit is issued,

4. Stipulations concerning rehabilitation will be aimed at producing a final result. Only in special instances will the stipulation deal with the specific technology of rehabilitation.

In a large sense the land manager is a problem solver. He takes the resources at hand and uses them to resolve the conflicts he must face daily. Many of the things the land manager does have widespread social significance. He produces food by providing for livestock grazing. He tries to alleviate our national energy crisis by making the public resources of coal, petroleum and gas available for development. He contributes to the need for housing by developing policies for the harvest of timber, and when technology demands minerals, he encourages prospecting and mining. I might remind you that all of these activities are a part of the total BLM program for public lands.

But one of the more unfortunate side effects of solving one problem is often to create another. As we make public land available to the livestock operator we may be faced with problems of overgrazing. One of our more persistent problems arises in connection with our efforts to develop mineral resources.

Back in Appalachia much of the coal is taken from deep mines. Not only must miners spend much of their lives under ground where they are subjected to the dangers of rock falls, cave ins and noxious gases, but if the individual survives long enough, he is also a prime candidate for black lung disease.

In light of these conditions we could well view the trend toward open pit or strip mining as a viable solution to a serious social problem.

But as I've indicated we solve one problem only to create another. Strip mining causes extensive soil disturbances, the destruction of plant and animal habitats and unsightly scars on the land. We can now restore strip mined areas to approximately their original contours, sow seed and hope for recovery. Fortunately this works most of the time. When it fails we have a problem.

Soil technicians speak of "fragile soils." But since the soil itself is not always the limiting factor, I prefer the term fragile environments. Fragile environments can be found at high altitudes and in high latitudes. Here growing seasons are short, high winds make plant survival uncertain and the soil itself is apt to be shallow and highly mineral. But the impacts of the fragile environment extend far beyond the mountain range or the far north.

We also find fragile environments in areas with limited rainfall such as the California Desert.

In Oregon we are deeply concerned about cutting timber on steep slopes. The danger lies in the probability of avalanches where the soil slips downhill from its bedrock once the binding effect of living tree roots is destroyed.

Our land managers are routinely asked to approve rights-of-way across rugged land to facilitate the development of resources. A manager will often approve such applications knowing that he will be required to take steps to establish vegetation on road cuts, and that he must expect erosion of gullies in the tracks of passing vehicles. We expect our managers to weigh risk against benefit before he makes such decisions. But once the risk has been determined we also expect him to take steps to minimize it as much as possible.

As I deal with the many public land concerns that come across my desk daily, I am forced to concede that for the most part, BLM land and fragile habitats are almost synomous.

Considering their history, this is not surprising.

As the line of settlement pushed into new frontiers, each man tried to find the best land available for his private use. These lands were then taken out of public ownership. Eventually we were left with what we have today. Our present public domain has been described as what was left over -- the land that was too poor -- too dry -- too steep -- or too rocky for private development. A former BLM director described the public domain as one dirt and two rocks. Somebody else called it the land where nobody could find a way to make a buck.

Now let me explain that while there may be a grain of truth in all of these statements, they are mostly exaggerations. Public lands have many values, and they are being appreciated more every day as a public resource.

They can also be highly productive, but the land manager must constantly bear in mind that he works with a fragile legacy.

Fortunately for man, life on earth is both aggressive and tenacious. There is almost no place on the globe where some living organism cannot survive. Lichens cling to storm lashed rock surfaces, and in the driest desert seeds lie dormant waiting for the occasional shower in order to blossom forth as flowers.

But the limitations of fragile soils and fragile environments are much more severe than in more favorable places.

This means that fewer plants can survive there, and that growth and development is much slower. On the public lands we see evidence of this in many places. The tracks left by covered wagons on the Oregon Trail can still be seen on public lands in Wyoming, Idaho and Oregon. On the north slope of Alaska, I am told that you can still find tracks from Army tanks that were used in training exercises there during World War I, and that tracks from General Patton's tanks are still visible in the California Desert. Some of you are familiar with the problems we have faced in our efforts to revegetate the Alaska Pipeline.

Some of our problems stem from the fragile nature of the soils and the environments that our managers have to work with, but others stem from the nature of soil disturbance.

When we build a road, approve a pipeline, or allow a strip mine to open, we often destroy plant communities that have been centuries in the making. Frequently the accomodations that been developed between one kind of plant and another are extremely delicate. Suddenly all this is torn away and we are left with bare soil. Under the very best of conditions we are left with a restoration problem that is going to be tedious and time consuming.

But there is more. In the upheaval, thin layers of top soil are sometimes buried under layers of mineral subsoil leaving the chemistry of the soil changed. Plants that formerly grew there may now find the new habitat hostile and will no longer be able to survive.

In the process of upheaval, soils are compacted, changing their texture. They become less permeable and the underlying water table may change.

The plant community consists of other plants and animals that bear directly on the individual plant's well being. Disturbance may also effect the biological nature of the community.

Taken all together, the new environment is often changed to the point where old plant species will no longer grow. Having created a new environment, we must now create a new plant community that may be radically different from the one we started with.

I can see nothing in the future that indicates any reduction in the amount of land we will have to disturb. Any significant changes are apt to be in the opposite direction.

Conversely I see nothing to indicate that rehabilitation requirements will be any less rigid. Again the change is more apt to be in the other direction.

This means that we will be more, not less, dependent on the research ecologists.

However, not all of our rehab problems are caused by human activity. Sometimes nature itself creates the problem. We recently had a most dramatic demonstration of this in the eruption of Mount St. Helens. In the years to come, it will be interesting to watch the changes in the plant community that evolve as the area recovers. Hopefully we will learn some valuable lessons.

The thing that demands much of our rehab efforts on BLM lands is wildfire. The majority of these fires are caused by lightning. Presently we are experiencing an average of over a million acres burned each year.

The number of acres burned in any given fire usually depends on how soon we can get a fire crew on the scene. Today we have extremely sophisticated electronic equipment that lets us know within seconds where there has been a lightning strike. We have computers that calculate the likelihood of any given strike starting a fire. We maintain well trained fire crews on standby and have access to aircraft and other vehicles that will get the crew to the scene of fire as quickly as possible. This means that barring some new and startling development, we can see no way of bringing about any further reduction in the number of acres burned in each given year.

The only area we can make significant improvements in our reduction of fire damage is to be more responsive to the need for rehabilitation of those areas that have been burned. As a rule the reseeding of these areas causes no special problems, but because of their very magnitude we expend considerable effort to provide timely rehabilitation. As we identify high risk fire areas, we plan ahead to have seed on hand and the men and machinery available to restore these burned over areas in the quickest possible time.

For example the Sharp Top fire in south central Oregon burned over 72,000 acres of rangelands last August. Before snow fell in November we had reseeded 66,000 acres of this range.

The logistics of this operation are impressive. For reseeding we brought in 35 rangeland drills and used 500 thousand pounds of seed. About one fourth of the area, consisting of the more rugged areas, was seeded by helicopter. To expedite the operation we brought in road maintenance equipment from western Oregon.

A camp was set up to accomodate machinery operators and mechanics. Crews worked 10 hour days and 6 day weeks. All told the project cost in excess of one million dollars, but the bottom line is that we were able to marshal the resources and talent of the Bureau to respond to a need for rehabilitation in a timely manner.

There is one resource that land managers always need more of and that is knowledge. Today managers are deluged with reports, information memoranda and the out put of computers, all demanding their attention and a place in their memory. So far we have found no way to train managers so they will know all that they will need to know.

This means that we must depend on people such as you who have specialized in a specific field of knowledge. I can assure you that as we move into the future, the one thing you can count on is that we will be calling on you. We rest assured in the knowledge that a committee such as this one already exists and that you will be able to help us solve some of our problems.

I thank you for your invitation and your attention.

GLOBAL CLIMATE CHANGE DUE TO HUMAN ACTIVITIES

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INTRODUCTION

We think of climate as average weather conditions, but we get different averages depending on the time period involved. Climate is and has been continually varying rather than constant. For example, over the last 150 thousand years, there have been the present and 125 thousand BP interglacials, the remaining time having ice ages of varying intensities with global temperatures up to 10°F colder than now. Over the last 100 years, variations in global temperatures of a magnitude of about 1°F have occurred on a year-to-year and longer-term basis. Larger variations are seen in local regions and for shorter, e.g., monthly, averages.

Even without the human race, climate would continue to vary. But there is now an additional consideration--human activities could make major changes in climate over the next 100 years. One measure of the potential human global environmental impact is world energy use, which has increased by a factor of about 100 since the time of the U.S. Civil War. Thus, we are now threatening our global environment in a number of ways, e.g., through acid rain over several continents, potential changes of global ozone, and other changes in atmospheric composition, such as increasing carbon dioxide, that are likely to affect our lives significantly in the future.

Carbon dioxide, in particular, is expected to double its concentrations within the next 100 years from what it was at the beginning of this century. Such a doubling would warm the globe by about 2 to 5°F. A change of this magnitude may not seem large compared to our day-to-day or day-to-night temperature changes, but because of its persistence it could have large impacts. For example, a 4°F increase in temperature with no change in rainfall would be expected to reduce by about 50% river runoff in the arid west, e.g., within the Colorado Basin. It takes many decades to construct large-scale water-resource systems, so it is desirable to be able to anticipate such changes for at least several decades in the future.

MODELS OF CLIMATE CHANGE

How do we make projections of the behavior of our climate system? We have not found nor do we expect to find any plausible

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[1]The National Center for Atmospheric Research is sponsored by the National Science Foundation.

laboratory analogues to our climate system, and we cannot perform field experiments involving global climate change. How, then, can we hope to make any predictions as to future climate? We get some clues by studying our climatic past. However, our major tools are mathematical models of the climate system. These models come in all shapes and sizes, but overall they are continually being refined by more detailed and more clever comparisons with the mechanics of the real climate system, through more powerful computing resources, greater numbers of scientists studying these questions and, I would hope, through increases in our intuition and understanding of the system.

The most detailed models are the three-dimensional general circulation models. These compute the motions of the atmosphere coupled with temperatures which, in turn, not only depend on the motions but also on latent heat of precipitation and heating by various solar and infrared radiation terms. In these models, as in reality, water is evaporated from the surface, carried by atmospheric winds, forms clouds, and is eventually returned to the surface by rain or snow. Components of these models describe surface processes over land and oceans.

Atmospheric radiation is especially important for understanding climate and climate-change questions. Solar radiation is absorbed by the atmosphere and surface; surface absorption, on the average, is about twice as large as that in the atmosphere. The mean reflectivity or albedo of the system is about 0.30. Anything that modifies albedo, such as change in cloudiness or land characteristics, affects the amount of solar radiation absorbed by the climate system. The other key radiative term is the trapping of outgoing thermal infrared radiation by atmospheric clouds and gases. This trapping warms the earth by 33°C over the temperature of an earth with the same albedo but no atmosphere. Since atmospheric temperature decreases by about 6°C per kilometer in altitude, the role of clouds and gases is roughly equivalent to that of a shell of greenhouse glass 6 km above the earth that absorbs the infrared radiation from the earth and reemits it at temperatures 33° colder.

Besides CO_2, other important infrared radiating gases are water vapor and tropospheric ozone, methane and nitrous oxide to a lesser extent, and recently the freons. All of these appear to be increasing somewhat because of human activities; atmospheric water vapor is increased with increasing temperatures; tropospheric ozone varies with modifications in atmospheric chemical processes. Methane and nitrous oxide are produced at the surface by biological processes. Why these gases are increasing is not now known. Changes of carbon dioxide have the largest impact on global radiation of the gases added by human activity, but increases of all other gases together may nearly double the effect expected from carbon dioxide alone.

Averaged over the globe and for a long time, the climate system is in radiative balance, that is, the net heating Q = 0. But Q can be modified, either because of some external change in radiative processes, such as a variation in the composition of the atmosphere, or because global temperature is perturbed. Thus, the global temperature perturbation is given by the external change in net heating divided by the negative of the variation of global energy balance with temperature variation. This latter term is referred to as the global feedback parameter and has a value of about 1 watt/m^2 per °F. That is, an addition of 4 watts/m^2 to the climate system warms it by about 4°F. This is the magnitude of the heating from a 2% increase of the solar constant or doubling of CO_2. These energy-balance arguments leave out the role of oceans as reservoirs of heat. Because of oceanic heat storage, the climate change is expected to lag modifications in the global heat balance by several decades.

Global temperature warming is, of course, the tip of the iceberg. Since natural climate has considerable variability, we would expect human-produced changes to also vary in time and space. How future climate modifications will be distributed geographically and with season is now an active research topic for three-dimensional modeling groups. We are at least as interested in changes in rainfall and surface radiative fluxes as air temperature, for these are also crucial in determining impacts on vegetation and water resource at the surface. The clearest modeling result so far is an increase of temperature with increasing latitude. There are also indications from models and historical analogues of increasing drought stress in continental interiors, but we cannot yet quantify or even be very confident of this conclusion.

MODELING EFFECTS OF VEGETATION ON CLIMATE

One of the by-products of our current interest in questions of climate change is an increasing awareness in the climate community of the importance of interactions between various land-surface processes and climate. The effects of vegetation on climate need to be included in climate models more realistically than they have been up to now. This is especially true in attempting to answer questions about the possible climate change due to changing vegetation cover. The largest-scale vegetation modifications presently occurring and projected are the rapid conversions of moist tropical forests into agriculture and grassland. This process is already at least half completed, but many large undisturbed tracts of forest still remain, especially in tropical South America.

Vegetation interacts with climate by absorption of solar radiation, by increasing the aerodynamic roughness of the surface, and by control of fluxes of sensible heat and water vapor to the atmosphere. Water vapor fluxes are modified by the interception and reevaporation of rainfall on foliage as well as by removal of soil water by transpiration.

Studies of the climate effects of tropical deforestation have so far given ambiguous results. However, they indicate important regional consequences but global impacts probably significantly less than those from CO_2.

In conclusion, most climate changes anticipated to occur over the next 50 to 100 years could have serious, but probably not catastrophic, consequences for human economies. By far the most catastrophic climate perturbation that has been imagined is that due to a full-scale nuclear war during Northern Hemisphere summer. Such an event might not only reduce solar radiation to levels far below those necessary for plant growth but also lower surface temperatures to values well below freezing over most continental areas of the Northern Hemisphere.

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Trends in Colorado Reclamation

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INTRODUCTION

In the fifteen years since the Colorado General Assembly passed the first legislation regarding reclamation of lands disturbed by mining, there has been considerable progress and change on many fronts. Those developments are discussed in this paper and the trends are projected into the future. The elements covered include: 1) Statutes and Regulations, 2) Administrative Structure and staff Development, 3) Fiscal, 4) Science of Reclamation, 5) Industry's Approach, 6) Public Involvement, 7) Regulator/Regulatee Relationship, 8) Intergovernmental Relations and 9) On-The-Ground Reclamation.

Mined land reclamation in Colorado, as with most other states in the country, is a relatively new concept and concern and has, therefore, been subject to major changes during the last fifteen years. Those changes have had a substantial impact on the industry, the government, the public and most importantly the environment.

STATUTES AND REGULATIONS

Prior to 1969 when the first reclamation statute was adopted by the Colorado legislature there were no formal requirements for reclamation. Some coal companies involved in open pit or strip mining did, however, enter into voluntary memorandums of understanding with the Executive Director of the Department of Natural Resources. At that time, with coal production limited to a very few mines and environmental consciousness relatively low, there was little interest or concern for coal mine reclamation in general. Similarly, mining for aggregate and precious metals was not conflicting with other land use or environmental values to a degree which warranted any legislative response.

As a result of growth pressures in Colorado and the accompanying increasing coal production to supply power plants, and conflicts between mining and other land uses, the legislature, in 1969, passed the first law dealing specifically with the reclamation of lands disturbed by mining. That act, HB 1388, entitled "The Colorado Open

Cut Land Reclamation Act of 1969", applied only to the surface mining of coal. It required that all operators obtain a permit from the Department of Natural Resources prior to engaging in any new surface mining. Permits issued under the 1969 law were for one year only, required a bond or security for reclamation (not to exceed $100 per acre), but otherwise were essentially a formalization of the memorandum of understanding agreements which had been voluntarily used prior to this legislation. Reclamation standards emphasized grading peaks and ridges to a width of at least 15 feet with the major objective being a "gently undulating skyline". Revegetation was contemplated, but no topsoil salvage was required. With the 1969 law the legislature, for the first time, set general performance standards for reclamation and involved the State in regulating the mining industry for reclamation concerns.

In 1972, the legislature amended the 1969 law by the passage of HB 1119. That law created a Land Reclamation Board replacing the Executive Director of Natural Resources and for the first time defined reclamation. A major change was the elimination of the $100 per acre limit for bonding. The act specified what information must be contained in an application, installed the Board as the decision-making body, and further refined the performance standards and enforcement procedures. The board was created as part of the Division of Mines, Department of Natural Resources. It consisted of five members including the Executive Director of the Department of Natural Resources, the Deputy Commissioner of Mines, Chief Inspector of Coal Mines, State Geologist and a member of the State Soil Conservation Board designated by such Board. The law still, however, only applied to open cut coal mining.

In 1973, the legislature adopted HB 1529, the Colorado Open Mining Land Reclamation Act of 1973. Part of this Bill was a major amendment to the 1969 law as amended by the 1972 Act. (Another part dealt with the preservation of "commercial mineral deposits" in the populous counties of the State). Major new elements included: 1) Expanding the mining to be regulated to include deposits of limestone used for construction purposes, sand, gravel and quarry aggregate in addition to coal. It applied only to the extraction of those by surface mining methods. 2) The Act defined the relationship between the Land Reclamation Board and local government indicating that reclamation permits were to be issued by the Board, not by local government and by implication that the land use decisions were to be made by local government. 3) The permit term was extended from one year to five years, otherwise the law was not substantially changed regarding performance standards or procedures.

The first comprehensive reclamation law which applied to all mining in the State of Colorado was passed by the legislature in 1976 and was entitled the "Colorado Mined Land Reclamation Act". Major changes from the 1973 law included: 1) The law applied to all mining of all minerals in Colorado. 2) The permit term was extended from 5 years to "life of the mine". 3) The Board's name was changed to the Mined Land Reclamation Board (MLRB). 4) The Mined Land Reclamation Board was redefined and placed in the Department of Natural Resources as part of the office of the Executive Director. The Board was defined as consisting of seven members including; the Executive Director of the Department of Natural Resources, a member of the State Soil Conservation Board and five persons appointed by the Governor with the consent of the Senate. Such appointed members were to consist of three individuals with substantial experience in agricultural or conservation, no more than two of whom were to have had experience in agricultural or conservation and two individuals with substantial experience in the mining industry. Thus, the Board became a multi-interested Board to represent mining conservation, agriculture and government. 5) Permitting requirements were differentiated between small and large mines. 6) Requirements for prospecting were included. 7) Administrative procedures were specified for enforcement to be exercised by the Board. 8) Bonding for small operations was limited whereas bonding for regular permits or large operations was to be the actual cost of reclamation with no limit. 9) The law clearly included all governmental agencies as operators. 10) Substantial additions to the definitions and performance standard sections were included. 11) Although regulations had been adopted in May of 1976 for the 1973 law, the first comprehensive regulations regarding reclamation were adopted in May of 1977 to accompany and implement the 1976 Act.

The regulations adopted by the MLRB to implement the 1976 law created considerable interest in the legislature. An Interim Committee on Mined Land was formed by the General Assembly to examine the regulations during the summer and fall of 1977. In Senate Joint Resolution 3 (S.J.R. No. 3), passed in 1978, the Legislature specifically "disapproved" many parts of the regulations which they felt went beyond the interest of the 1976 law. Although the Attorney General's and Governor's offices advised the Board that S.J.R. No. 3 as a resolution did not have the force of law, the Board did, upon reconsideration, complete rulemaking which removed most of the rules objected to in S.J.R. No. 3. That process was completed when the Legislature acting under a law passed in 1976 (SB 76) reviewed all the regulations for a second time and by law (HB 1151), removed the few remaining items contained in S.J.R. No. 3, but not removed by the MLRB.

The 1976 law and corresponding regulations constitute the current "Minerals" program of the MLRB and MLRD. Other statutory and regulatory amendments than those noted above have altered the program, but only in minor ways, except for HB 1223 as discussed below.

In 1979, the General Assembly of Colorado adopted HB 1223 entitled the "Colorado Surface Coal Mining Reclamation Act". This law was passed in response to the Federal Surface Mining Control and Reclamation Act (SMCRA), PL 95-87, and adopted by Congress in 1977. SMCRA established national standards for the operation and reclamation of coal mines in the United States. A major part of that federal legislation was the recognition of the high degree of variability of conditions between the coal mining states and that states should develop programs based on SMCRA to better administer the law than the federal government. Colorado passed HB 1223 in an effort to obtain this primacy and the authority to regulate the coal industry for reclamation and environmental concerns. This, however, was only the first step in obtaining primacy. As part of an acceptable program which could be approved by the Secretary of Interior, Colorado was required to develop regulations which were essentially equivalent to those promulgated by the Department of the Interior, Office of Surface Mining (OSM). In June of 1980, the MLRB adopted such regulations and Colorado's program was approved by the Secretary of the Interior in the Federal Register, December 15, 1980. The statute and regulations removed coal from the 1976 law and set up a far more rigorous and detailed program for permitting, inspection and enforcement, and general control of the coal mining industry.

Among the more important differences of the 1979 law from the 1976 law are: 1) The MLRD is officially recognized and given primary permitting, inspection, and enforcement responsibility. 2) The MLRB's primary roles are changed to rulemaking, appeals board for actions taken by MLRD, and actions on unsuitability petitions. 3) The permit term is reduced to five years (as under the 1973 law). 4) Cummulative hydrologic impacts must be evaluated. 5) The concept of lands "unsuitable" for coal mining is introduced. 6) Subsidence impacts from underground mining must be evaluated and minimized. 7) Very detailed baseline data and other permit application requirements are specified. 8) All coal mines must be inspected 12 times per year (no inspection frequency specified in the 1976 law). 9) A very complex and lengthy set of regulations were developed and promulgated to implement the law. Whereas the Minerals Regulations basically restate the language in the statute, the Coal Regulations deal in great detail with each element of the statute explaining how to comply.

In order for the State to apply this program to federal lands, one additional regulatory step had to occur. On October 6, 1982, the Secretary of the Interior approved a Cooperative Agreement between the State of Colorado and the federal government for primacy on federal lands. This agreement has yet to be fully implemented by OSM, and we continue to be concerned about what "primacy" really will means in the long-run. However, we are committed to the principles that support the Cooperative Agreement and will continue to push for its fill implementation. For Colorado, primacy means as much control as is allowed under the law so that we control the destiny of the environmental reclamation aspects of coal mining.

In addition to the regulatory program under HB 1223 and SMCRA, there is an Inactive Mine Reclamation or Abandoned Mined Land Program as referred to in SMCRA, which allowed the MLRB and MLRD to expend funds on hazards and serious environmental problems created in the past by the mining industry but are still with us today. The money for this program is derived from a reclamation fee paid to the Federal Treasury by the active coal mining industry at the rate of 35¢/ton for surface coal mine and 15¢/ton for underground coal mines.

This then briefly summarizes the statutory and regulatory history of reclamation in Colorado. There has been a progression from a program which was essentially voluntary, limited to certain types of mining, excluded governmental agencies as operators, included no performance standards, had unclear regulatory authority and did not provide for adequate bonding to the current programs where all of these issues have been reversed or clarified. The legislature and the MLRB, through their respective authorities, have combined to create a statutory and regulatory framework which regulates all mining in the State of Colorado through two major programs, the Minerals Program and the Coal Program, as well as the opportunity to abate some of the serious problems from inactive mines in the State.

ADMINISTRATIVE STRUCTURE

As the statutes were changing so was the administrative structure. From 1969 to 1972, the Executive Director for the Department of Natural Resources with no designated staff was the entire administration for the 1969 law. The 1972 amendment created the first Land Reclamation Board and placed it in the Division of Mines in the Department of Natural Resources. Thus, at this point, the Division of Mines became officially active in the administration of the law. In 1973, the Colorado Open Mining Reclamation Act of 1973 retained the same government Land Reclamation Board as the 1972 law, however, the permitting process became more substantive and the need for a staff in the Division of Mines became apparent and two reclamation specialists were hired with a third added in 1974.

In 1976, the new Mined Land Reclamation Board with varied interests and backgrounds and the Mined Land Reclamation Division (MLRD) were created. The Division was created administratively by the Executive Director of Natural Resources. The 1976 law does not recognize a MLRD or any staff to the Board. In law, the MLRD was first recognized in the appropriations of 1977 and more fully in the 1979 coal law. Whereas in 1975, 4 employees (in the Division of Mines) were authorized by the legislature, in 1976 this jumped to 7 (in MLRD), 1977- 13.5, 1978-15.5, 1979-25, 1980-32, 1981-32, 1982-33 and in 1983-32 (see Table 2). The sudden increase in the Division staff starting in 1979 was due to federal funding and the development of the Coal Program. The current authorized level of 32 employees does not include the 6 employees hired to implement the Inactive Mine Reclamation Program which is 100% federally funded.

One interesting situation is the differing roles of the MLRB and MLRD under the Minerals and Coal Programs. As mentioned earlier, the MLRB makes all decisions in the Minerals Program. The Board meets monthly for two days to consider 60-80 agenda items including permitting, enforcement, rulemaking, and advisory decisions. The Board is voluntary (other than direct expenses) and is unable to spend much additional time on MLRB business. Thus, the Board must rely heavily on the MLRD staff analyses and judgment in making decisions. Under the Coal Program, however, the MLRB must treat the MLRD as another party to the proceedings, no different than the permittee, operator, or other interested party. Very few Coal Program agenda items are before the Board each month, but those that are, generally are formal hearings resulting from an appeal, or are rulemaking. The Board is much less familiar with the coal hearings (because there are so few) and must largely alter its approach to the MLRD staff and its informal style. Similarly, the Division must change from staff to the Board, to a party to the proceedings.

The administrative structure throughout the past has clearly been subject to substantial fluctuation and change through time. It was not until 1980 that there was some stability within the Division in terms of structure, growth and staff. In more recent years there has been very little staff turnover and thus, a significant maturing of the Division. Within the last three years, there has been a total turnover of Mined Land Reclamation Board members who are Governor appointees. The current Board contains none of the original members established in 1976. Additionally, there was substantial turnover in Division Directors during the period 1976 through mid 1980 when four different directors served the Division and Board. Since July of 1980, there has been only one Director of the Division. This staff stability has added greatly to a consistent development of policies and consistent application to the mining community and the public at large.

FISCAL

As one would expect, as the program has grown so has the financial commitment of the State, and with the Coal Program, the federal government. Under the 1969 law, no finances were directly committed to the implementation of the statute. All expenses related to it were absorbed by the Executive Director's office of the Department of Natural Resources and other divisions like the Geological Survey who assisted the Executive Director. As can be seen in Table 2, legislative funding for expenses began in 1973. Not until 1975 were any employees specifically authorized by the legislature to administer the reclamation law. The growth in funding and personnel from that point through 1980, is apparent from Table 2. From 1980 to the present, funding has remained stable for the Coal and Minerals Programs.

It is interesting to note that although the legislature does not control the federal grant process directly, where matching funds are required, such as under the Coal Program, by controlling the general fund amount and limiting the spending authority, the legislature does in fact control the amount of money we are able to receive from the federal government for the regulatory program. SMCRA specifies the federal government will pay 100% of the cost of implementation of the Coal Program at federal mines and 50% at state and private mines. In contrast to this, where we receive 100% federal dollars with no general fund match, our spending authority is not subject to limitation by the legislature. The Inactive Mine Reclamation Program uses 100% federal dollar and thus is not included in Table 2. Total funds received by that program from the federal government to date are approximately $14.1 million, the vast majority of which have been and are being used in construction projects to mitigate serious hazards and problems from past coal mining.

As the funding currently stands for the two regulatory programs, the Division is unable to carry out the mandate of the statutes in their entirety. The Minerals Program in particular suffers from a shortage of personnel and an extremely high workload. The very large number of mines (approximately 1600 permitted and 200 new applications each year), the continuing problems of illegal mining operations, violations at permitted operations, and the number of very large projects such as oil shale, molybdenum and precious metals result in the Division and Board not being able to fully implement parts of the statute and program. It is impossible to inspect each mining operation in the State once a year, fulfill our permitting obligations, carry out our enforcement obligations and fulfill our other obligations of public participation, assistance to small operators, etc., under current funding levels. Thus, priorities must be set to accomplish the most important tasks. Through this selective process, we have maintained as effective a program as possible given the time and resource restrictions.

SCIENCE OF RECLAMATION

Prior to 1969, the science of reclamation was poorly developed. Although some mining companies and highway departments were using reclamation techniques, the practice of reclaiming disturbed lands was not generally understood or accepted. Many of the concepts related to reclamation were being developed or had developed from other activities, but the science and practice of applying all of these concepts to the reclamation of lands disturbed by mining had not occurred to any great extent. The science of mined land reclamation is the science, technology and practice of applying engineering and scientific principals from other disciplines. These include surface hydrology, ground water hydrology, geochemistry, soils, plant ecology, geomorphology, engineering geology, civil engineering, wildlife and other specific disciplines.

Since 1969, there has been an extremely rapid expansion of our knowledge base of reclamation science. This is a result of several factors: 1) much practicable, hands-on experience gained as a result of legislation forcing reclamation; 2) very complex demands have been placed on the industry, particularly the coal industry with regard to the environmental control reclamation; 3) increased communication between scientists through conferences, studying applications and permits others have prepared; 4) reviewing scientific journals; 5) government and industry have supported substantial reclamation research; 6) minute scrutiny of many projects, particularly the mega projects such as oil shale; 7) college and graduate educational opportunities have expanded; 8) there is a public record of successes and failures to learn from; and 9) financial need to quantify reclamation success and failures for the purposes of financial warranties and bonds and to allow the industry to plan projects.

In Colorado, the advancement of the reclamation knowledge is a particularly great challenge because of the tremendous variability in conditions. This variability occurs in the natural environment as well as the types of mining and scale of mining. This variability demands creativity and individualized attention to each situation. The Minerals Program allows for this creativity because of the general nature of the performance standards. Under the Coal Program, it is much more difficult to apply this same creativity because of the specificity of the law and regulations.

The challenge of both the Minerals and Coal Programs is to define what environmental variables are most important in determining the environmental and reclamation success of a project. Once defined, we must project these variables into the future given specific mining scenarios. It is that predictive modeling which has made substantial advances, but must be the subject of continuing efforts.

INDUSTRY'S APPROACH

Industry's approach and attitude toward reclamation has changed markedly from the 1960's to the present; from one of "don't do it if you don't have to" to "it is in our best interest to do it". Why has this change occurred? 1) The regulations and laws have required it and created a significant down side to companies who have not changed their attitude. Failing to comply with the reclamation laws has serious consequences of enforcement. 2) Companies have found that there are substantial public relations gains to be made by successfully mitigating environmental impacts and causing good reclamation to occur. This is particularly true in Colorado because of the high environmental consciousness of the citizenry. 3) The industry has found that there are some substantial economic benefits to compliance with the law and increasing the value of the land by reclamation practices. This influence is strongest when mining occurs on lands near developed areas where the land may be used for some higher uses other than wildlife habitat upon completion. 4) Industry personnel have had a change in philosophy just as has the public at large. More frequently now, industry managers and responsible project personnel have the same environmental consciousness as do the regulators and the public.

The result of this industry approach and awareness has been an ever increasing integration of reclamation and environmental controls into the mine planning and economic assessment processes. This integration in turn has resulted in higher quality permit applications and higher quality on-the-ground reclamation.

PUBLIC INVOLVEMENT

Legislative and regulatory developments since 1969 have modified the opportunity for the public involvement in the reclamation process from little or no opportunity to extensive opportunity. Although the opportunity for public involvement under the 1976 and 1979 laws are substantial, the reality is that the opportunity is not exercised very frequently. In particular, under the Coal Program, where maximum opportunity exists, there seems to be less public participation than under the Minerals Program where slightly lessor opportunity exists.

Under the Coal Law, any interested party can become involved in the process from prior to permit application all the way through to final bond release. Mechanisms for involvement include: 1) petitions for rulemaking, 2) petitions for designation of lands as unsuitable for coal mining, 3) requests for on-site hearings, 4) citizen complaints, 5) review and comment on permit applications and revisions, 6) petitions for declaratory orders, 7) requests for MLRB hearings on permit decisions, 8) requests for party status and participation at MLRB hearings on bond release, and 9) direct access to court to compel compliance if MLRD or MLRB fail to take action on a nondiscretinary requirement of law or if any person is alleged to be in violation of the law. All meetings of the MLRB and MLRD and all materials on file, with few exceptions, are open to the public. Although these many opportunities are not enumerated under the Minerals Program, many similar opportunities exist with fewer formal requirements.

There are several reasons why these many opportunities for public participation are not fully utilized. The complexity of the scientific issues related to reclamation and environmental control of mining operations is probably a deterrent to involvement. This complexity also is present, particularly in the Coal Law, with regard to application requirements. The laws and regulations themselves, the requirements for intervention and, in all probability, the lack of resources available to any one individual to fight the system have thwarted the legislative effort to involve the public. By creating an overly complex situation, the coal law and regulations appear to have reduced the public's ability to participate.

In Colorado, the area where public participation seems to be most active and perhaps the most appropriate (most concerns about a mine center or the land use issues) is at the local government level. It is at this level where issues of land use compatibility, truck traffic, land values, noise and nuisance can be heard. Under the 1976 law, a permit cannot be issued by MLRB without the applicant being in full compliance with local requirements. Thus, many individuals have turned to this forum as their primary focus for opposition or support of a project.

RELATIONSHIP OF REGULATOR TO REGULATEE

The relationship of the Mined Land Reclamation Board and Division to the mining industry has gone through several phases. In the early 1970's there was an attempt by many in industry to ignore the regulatory process and those individuals involved in it. This resulted in little respect for the individuals and a very strained relationship. As the number of individuals involved increased at the government level, industry probably characterized the regulators as ignorant and considered them primarily as a source of harassment. The counties as operators of sand and gravel mines, and MLRB have had a particularly strained relationship during the late 1970's as counties were forced to comply with the 1976 law. The current relationship with all operators has improved substantially. There is now significant respect for each other because of increased competence of the regulators and regulatees. Thus, a constructive relationship with improved communication has developed and the ultimate quality of the permitting process has risen resulting in better on-the-ground reclamation.

INTERGOVERNMENTAL RELATIONS

As the reclamation program has grown in complexity and sophistication, so also has the need for and advancement of intergovernmental relations become necessary. The late 1960's and 1970's brought with them many environmental laws directly affecting the mining industry. At the federal level those laws included the National Environmental Policy Act of 1969, the Federal Water Pollution

Control Act of 1972, the Endangered Species Act of 1973, the Mineral Leasing Act of 1920 as amended by the Federal Coal Leasing Amendments Act of 1975, the Federal Land Policy and Management Act of 1976, the Resources and Conservation Recovery Act of 1976, the Toxic Substances Control Act of 1976, the Federal Mine Safety and Health Act of 1977, the Surface Mining Control and Reclamation Act of 1977, the Clean Air Act amendments of 1977, and the Archaeological Resources Protection Act of 1979, and the Energy Security Act of 1980. In addition to these federal actions, many state laws were passed to coincide and complement with these national mandates regarding air, water, solid and hazardous wastes, radioactive materials, mining and reclamation. An excellent summary of these statutes and there requirements can be found in the Colorado Permit Directory which is authored and distributed by the Colorado Department of Natural Resources.

Because of these many statutory and resulting regulatory changes, there was an obvious need to increase coordination and communication between state and federal agencies. Additionally, local government strengthened its position in Colorado as the agencies of government responsible for land use planning and land use decisions. The Minerals Program mandates coordination with other agencies to insure that the applicants to the Mined Land Reclamation Board are in process with applications to all necessary State and federal agencies. The law reserves a very special status for local government, however. Prior to the Board issuing a permit, the operation must be found to be in compliance with local requirements. Thus, in effect, local government holds the key to whether or not a mining operation will proceed in the State of Colorado. Under the Coal Program, local government, while having their normal zoning authority, does not have the same direct tie to the MLRD permitting process and thus the processes may proceed independently from each other.

The Coal Program sets up a special relationship with the federal government. SMCRA sets up national standards and requirements for the permitting, operation, and reclamation of coal mines. Any state desiring primacy must develop and maintain its program at certain minimum levels and ensure certain minimum federal standards are met. In addition, funding is received from the federal government for the Coal Program at a 100% level for coal mining activities on federal lands and a 50% level for those activities on state and private lands. The Inactive Mine Reclamation Program receives 100% of its funding from the federal government, although the monies originate from fees paid by Colorado coal operators. Thus, programmatically and fiscally the federal government has considerable control over the Coal Program. That control is exercised through an oversight process which reviews programmatic aspects on a yearly basis, a grant process, as well as a fiscal auditing process to control and review our fiscal management. Colorado is not allowed to change its program without receiving prior approval from the Office of Surface Mining in the Department of Interior. During the permitting process on federal lands, we must ensure that all of the federal agencies and laws which apply to the operation are adhered to or met. This requires considerable coordination with a large number of federal agencies, particularly in the Departments of Interior and Agriculture.

These relationships set up in the Coal Program have caused considerable problems. The federal government by its nature looks at each state program from a national perspective. The states each look at the specific application of the program to the unique conditions of the specific state. The states are struggling to actually make the program work from a management and environmental point of view while the federal government appears to be more concerned about process than substance. The stress created by these different view points has created several struggles. A central issue is how much individuality while adhering to the minimun standards is allowed under SMCRA. What does "primacy" mean if the states must behave identically to each other and cannot develop a program attentive to its own needs. What should the oversight program of OSM consist of? How can OSM set up measures of success of the program for on-the-ground performance? To this point, OSM has concentrated on a paper analysis of the program to indicate its overall effectiveness and compliance. We believe that this type of analysis does not adequately reflect the quality or effectiveness of the program.

The other reason for the rapid development of the need for intergovernmental relations is the nature of reclamation science itself. Since reclamation is the blend of many scientific disciplines, one must coordinate with agencies who have responsibilities relative to those disciplines. These include wildlife, water quality, water quantity, air quality, soils and others. Those of us who regulate reclamation must balance the interests and laws regarding each of these areas in coming up with the best plan for the reclamation of any particular site. In some cases, this balance causes friction with other regulatory agencies who feel we should be giving more emphasis to their particular regulatory or mandated concerns. A certain level of friction and stress between governmental agencies, environmentalists, and the industry is undoubtedly healthy. When that stress reaches a level where communication breaks down, however, it becomes an impediment to the success of our program and reclamation in Colorado. The challenge is to keep the communication lines open so as to avoid the long-term detriment to Colorado and to focus our efforts on issues of substance which result in better on-the-ground performance.

ON-THE-GROUND RECLAMATION

Successful and improving on-the-ground reclamation is the bottom line. On-the ground success is the best measure of the progress of the reclamation program in the State of Colorado. It is why we exist. Progress measured by reclamation success indicates, with few exceptions, that we have advanced markedly from pre 1969 practices (or lack thereof) to the present. Reclamation performed under the 1969 law and its loose performance standards was not as successful as reclamation performed under the 1979 Coal law. As one would expect, there has been incremental improvements in reclamation as the statutes and awareness have dictated such improvements. The few exceptions to our current successes are matters that are being handled successfully by our enforcement procedures.

No longer does the State allow the creation of short or long-term liabilities in the area of environmental control and reclamation at mine sites. Lands are being returned to beneficial use, streams are not being degraded as they once were, wildlife habitats are being restored. Where problems occur they are being mitigated by the operators voluntarily or through our enforcement process.

FUTURE TRENDS

Statutes and Regulations

Statutory changes of the reclamation programs will be minimal in the future. The programs have succeeded and there appears to be little interest in attempting any substantive changes. The Minerals Program may be the subject of some minor statutory changes as a result of problems which have become apparent during its eight years of existence. These changes, however, would not constitute any major shift in direction.

The regulations of both the Coal and Minerals Programs are the subject of continuing examination and improvement. Both programs have undergone regulation amendments and will continue to do so. The Coal Program regulations are currently undergoing a major examination by the Division, industry and environmentalists. The Mined Land Reclamation Board has already initiated rulemaking on a major proposal from the Colorado Mining Association Coal Committee. This proposal came out of a working group that met every two weeks for eight months. A second initiative should be forthcoming from this group within the next several months. All interested parties have had the opportunity to participate in this working group in an attempt to reach consensus on the issues. In actuality, only the Division and coal industry have been regular, active participants.

Administrative Structure

Unless the legislature provides substantially altered funding for the Division, the administrative structure should remain essentially constant. Since the Inactive Mine Program will be in existence at the national level and presumably at the state level until 1992, there should be no significant change in the staffing level until the conclusion of that program.

Fiscal

The Division hopes to obtain some additional funding for both the coal and Minerals Programs. That need for additional funding has been recognized by the federal government and in the Governor's budget submitted to the legislature. However, due to the difficult economic period of the last several years, we have not succeeded in our efforts to obtain the funding. It is hoped that within the next several years we will receive some limited additional funding.

Science of Reclamation

Undoubtedly there will be continued significant advances in the science of reclamation. One area in which this advancement should occur is in the identification of key variables which are critical to the success or failure of reclamation. As closer scrutiny is given to more ongoing reclamation through monitoring data and field observations, these variables should become more apparent and will aid in the design of reclamation plans and permitting. The parameters monitored and analyzed should become less numerous, but each one will have greater significance. Additionally, we are seeing new types of mining and processing which always leads to new frontiers in reclamation. Field experience and research in these areas will benefit reclamation in all areas.

Industry's Approach

The industry's approach will be to continue greater incorporation of reclamation as a major element of the mining process. This positive attitude can only improve the ultimate on-the-ground performance. The increased integration of the reclamation issues into mine planning and operations will ultimately make the job of regulators easier and the performance of the operators more successful.

Public Involvement

Public involvement appears to have been constant for the last several years and will probably remain so for the future. The most vulnerable area of mining and public interaction is in the areas that are being urbanized. These areas, by their nature, develop conflicts between various land uses. Because those conflicts center around land use compatibility, the public involvement will undoubtedly occur primarily at the local government level and should not have a great impact on the Mined Land Reclamation Board and Division.

Relationship of Regulator to Regulatee

The improvement in the relationship between the regulators and the mining industry is bound to continue to improve as it has in the past. The staff and the Mined Land Reclamation Board will continue to increase their competence and thus, the trust and communication will be increased between all interested parties in the regulatory process. Also, as industry performance improves, so will the quality of the relationship between the regulators and the regulatees.

Intergovernmental Relations

We look forward to improved relationships at the local, state and federal level. As the program matures, institutional relationships and expectations will stabilize. The intergovernmental relations will never be without a certain stress, but this stress is healthy as long as it does not increase to the point of being counterproductive. The greatest area of strain will continue to be between the state and federal government. As the State continues to improve its competence, the trust level should increase and relations between the federal government and State should improve.

On-the-ground Reclamation

Because of all of the above factors, we can only expect the on-the-ground performance of mining companies to improve. Areas most susceptible to improvement are: 1) rapidity of reclamation success, 2) decreasing hydrologic impacts, 3) greater efficiency in achieving successful reclamation, and 4) creation of landforms and ecosystems which function more like the natural undisturbed environment.

CONCLUSIONS

Why have the reclamation programs in Colorado succeeded? There has been a logical progression of the laws with no sudden radical changes to derail the efforts. There has been general support of the programs from the legislature, industry, public and government with no particular dissention to disrupt the efforts. The use of a multi-interested Mined Land Reclamation Board as the policy making body has lead to a very rational program and rational decisions on a case-by-case basis avoiding the polorization which can occur. The Division has developed a competent stable staff to implement the programs.

Due to the variability of environmental and mining conditions, Colorado has not developed a robot-like approach to reclamation.

Instead, Colorado has attempted to deal with the variability on a site-specific basis to develop the rational sensible solution while still meeting standards which are high.

I have been very proud to play a part in the development of Colorado's reclamation program. I believe that Colorado is a national leader and should be proud of its progress. Perhaps Colorado's greatest resource is its natural environment which attracts tourists, recreation, agriculture and industry. Mining will and must continue because the mine resources are essential to our State and nation. Mining interests and activities must co-exist with other interests, not to their exclusion. Competing land uses and interests must exist in harmony for the long-term health of the State of Colorado. A strong and successful reclamation program is central to that effort.

Table 1
List of Legislation Affecting Reclamation

Legislation Session Year	Bill Number
1969	HB 1383
1972	HB 1119
1973	HB 1529
1975	HB 1706
1976	HB 1065
1977	SB 498
1977	HB 1547
1977	HB 1377
1979	HB 1223
1979	HB 1182
1979	SB 149
1980	HB 1195
1980	HB 1151
1980	SB 101
1981	HB 1518
1981	SB 161
1981	SB 392
1981	HB 1097
1981	HB 1320
1981	HB 1276
1981	SB 370
1982	SB 121
1982	HB 1099
1983	HB 1449
1983	SB 414

Note: The above statutes can be found in the session laws of each legislative year. The current version of the law can be found in the Colorado Revised Statutes, 1983 Supplement. In addition to the above legislation, appropriations are included in the Long Bill yearly which can also be found in the session laws. HB and SB stand for House Bill and Senate Bill respectively.

Table 2

State Authorized Budget
(Long Bill)

Year	Minerals and Admin. General Fund	Coal Program Total	Coal Program Gen. Fund/Fed. Fund	Authorized FTE's Min./Coal
1973	$ 4,000	---	--- / ---	--/--
1974	4,000	---	--- / ---	--/--
1975	60,493	---	--- / ---	4/--
1976	132,078	---	--- / ---	7/--
1977	288,336	---	--- / ---	13.5/--
1978	254,941	$ 134,358	$ 12,693/$121,665	13.5/2
1979	180,000	283,000	80,000/ 203,000	13/12
1980	310,338	419,892	139,962/ 279,930	13/19
1981	343,087	457,716	91,543/ 366,173	13/19
1982	434,081	580,909	98,755/ 482,154	14/19
1983	419,457	645,454	109,727/ 535,727	13/19

ACIDIC DEPOSITION IN THE ROCKY MOUNTAIN REGION

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INTRODUCTION

Acid rain or more appropriately, acidic deposition is probably the single most important environmental concern facing us today. We have good reason to believe that in regions of the northeastern United States and southeastern Canada we are seeing impacts due to acidic deposition, specifically the acidification of lakes and streams with subsequent losses in fish populations. There is also a growing concern that declines in forest productivity in the eastern United States which have been occurring for the last 20 years may also be related to the deposition of strong acids. In addition acidic deposition has a corrosive effect on materials such as limestone, marble and various metallic surfaces. These concerns have prompted the investment of millions of dollars, both federal and private, in determining the extent of detrimental levels of acidic deposition and effects on the terrestrial and aquatic environment. Effects observed in Canada, particularly in acidification of lakes and streams, have prompted the Canadian government to demand that steps be taken both in Canada and the United States to reduce emissions of sulfur and nitrogen oxides, the primary contributors to the strong acid component of both wet and dry deposition. Since over 95% of sulfur emissions are contributed by the combustion of fossil fuels, the necessary reduction would force industry to obligate billions of dollars in emission reducing technologies. This would add substantially, for example, to the cost of electricity generated from coal-fired power plants. Because of this, little action has been taken to date to reduce emissions, but we are seeing increasing expenditures in research on the effects of acidic deposition, as well as questions related to source strengths and the atmospheric transport and deposition velocities of sulfur and nitrogen compounds. Since there appears to be little likelihood of legislation aimed at reducing emissions in the near future, and since any such legislation would most likely apply only east of the Mississippi River, questions have been raised concerning the extent of problems related to acidic deposition in the Rocky Mountain region, as well as other regions of the western United States.

The purpose of this paper is to address specifically the question in the Rocky Mountain region. While research in this area has not been as extensive as that in the eastern United States, there are several programs addressing the two main issues: deposition chemistry and resource sensitivity. The National Atmospheric Deposition Program is measuring the level of acidic decposition with 20 stations in the Rocky

Mountains, and federal and university researchers are examining regional "sensitivity" to acidic deposition. In this paper we will discuss acidic deposition and regional "sensitivity" and draw conclusions as to the potential threat to the aquatic and terrestrial environments in the Rocky Mountains.

BACKGROUND

In order to describe whether potential detrimental affects due to acidic deposition exist in an area one has to take into consideration two factors: (1) The levels of deposition being received and (2) the "sensitivity" of the area. One can evaluate the situation in the Rockies by comparing it to a region where lakes and streams have already been acidified and forests are on the decline, presumably due in some part to acidic deposition. We will thus compare both deposition composition and regional sensitivity to the northeastern United States and Canada.

In discussing deposition, we will confine ourselves to wet deposition only. This is not meant in any way to suggest that dry deposition in the form of gases and aerosols is not an important factor. In many areas dry deposition is believed to contribute amounts of acidic materials which are equal to or greater than those contributed through wet deposition. However, there is no good methodology available today to measure dry deposition on a network basis. Wet deposition can give us a measure of the relative deposition of these materials and can be used to make interregional comparisons.

Regions of the United States east of the Mississippi River are receiving precipitation with a pH less than 5.0 with many areas receiving precipitation with a pH of 4.1 or below. This is illustrated in Figure 1. When coupled with rainfall amounts, this results in a hydrogen ion deposition value of 60 mg/m^2 (0.6 kg/hectare) (Fig. 2). In addition, these areas are receiving sulfate deposition of over 40 kg/hectare and nitrate deposition of over 25 kg/hectare, as is seen in Figures 3 and 4.

The deposition of sulfate and nitrate are equally important in evaluating environmental impact not only because they are the carriers of incoming H^+ ion as sulfuric and nitric acid, but along with hydrogen ion they play a significant role in the acidification of lakes, streams and soils. A recent survey of data in Scandinavia by Wright (1983) suggests that acidification of lakes and streams in sensitive areas occurs when the pH of precipitation drops below 4.7. As illustrated in Figure 1, this encompasses a large area of the eastern United States. Expressed in terms of sulfate deposition the upper limit is thought to be 20-30 kg/ha.

The second factor important in evaluating potential environmental effects is "sensitivity", a measure of the lack of ability of soils, parent geologic materials and surface waters to buffer, or resist

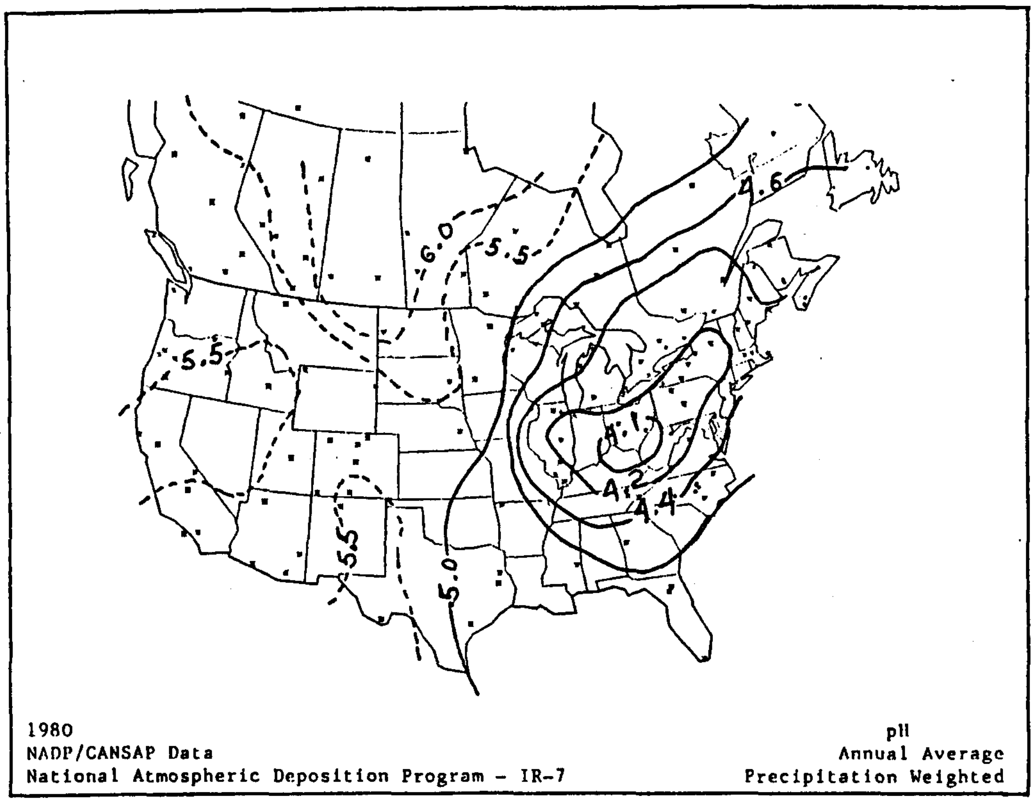

Figure 1. Average precipitation weighted pH values for the United States and Canada, 1980.

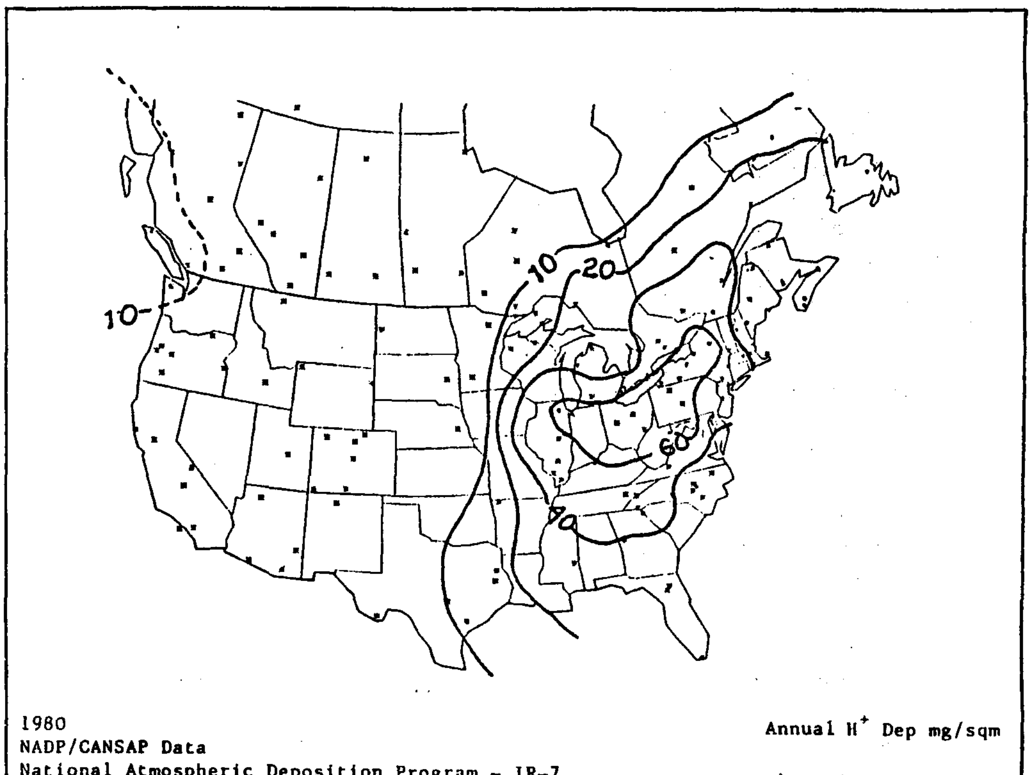

Figure 2. Annual H^+ deposition (mg/m^2) for the United States and Canada, 1980.

increases in acidity. Acidic deposition can result in increased acidity of surface waters as well as the leaching of nutrient cations and toxic metals from soils and rock surfaces. Alkalinity has been used as the measure of surface water sensitivity. Waters with alkalinity values less than 200 μeq/l are classified sensitive. Significant areas of the eastern United States can be characterized as sensitive by this definition. These are the regions underlain by granite or other low solubility materials. If we were to overlay the deposition of acidity, sulfate and nitrate, we would see that many of these sensitive areas, particularly in the northeastern United States and Ontario, Canada, fall into regions receiving the highest deposition. Perhaps not coincidentally, these are also areas where forests are in decline.

In conclusion, then, it can be stated that in areas which have little buffering capability and which are receiving precipitation of a pH less that 4.7 (sulfate deposition greater than 20-30 kg/ha) we may expect to find acidified surface waters with a concurrent loss of fish populations and possibly a decline in forest productivity. Based on these observations in the eastern United States and Canada, which are in keeping with those in the Scandinavian countries and parts of central Europe, we can now evaluate the situation in the Rocky Mountain region.

DEPOSITION PATTERNS

The pH of precipitation in the western United States is generally 5 or above as illustrated in Figure 1 (the dotted lines represent the fact that there were insufficient western stations reporting during this period to generate concentration patterns with the same confidence as those represented for the eastern United States). We also see in Figure 2 that H^+ deposition in this area is less than 10 g/m^2 (0.1 kg/hectare) which is a result of both the lower acidity of rainfall as well as lesser rainfall amounts. One can see similar reduction in sulfate and nitrate deposition as compared to the eastern United States (Figs. 3 and 4). This paper will focus on Colorado data which is presented as average annual ion concentrations for 1980 and 1981 and deposition for 1981 (Tables 1-3) for each of the state's monitoring stations (Fig. 5). In Table 1 data is presented not only for hydrogen ion, sulfate and nitrate concentrations but also for calcium, magnesium and ammonium which represent alkaline materials responsible for reducing potential acidity. Included in this Table are two sites which demonstrate the extreme values found in the United States. These are Olympic National Park in Washington and Parsons, West Virginia. The values for Olympic National Park (not corrected for marine salts) are relatively similar to those found in the southern hemisphere in areas where values are considered to be at or near natural background levels. Table 2 presents similar data for 1981, and Table 3 presents deposition values for hydrogen ion, sulfate and nitrate. Several conclusions can be reached when reviewing the Colorado data:

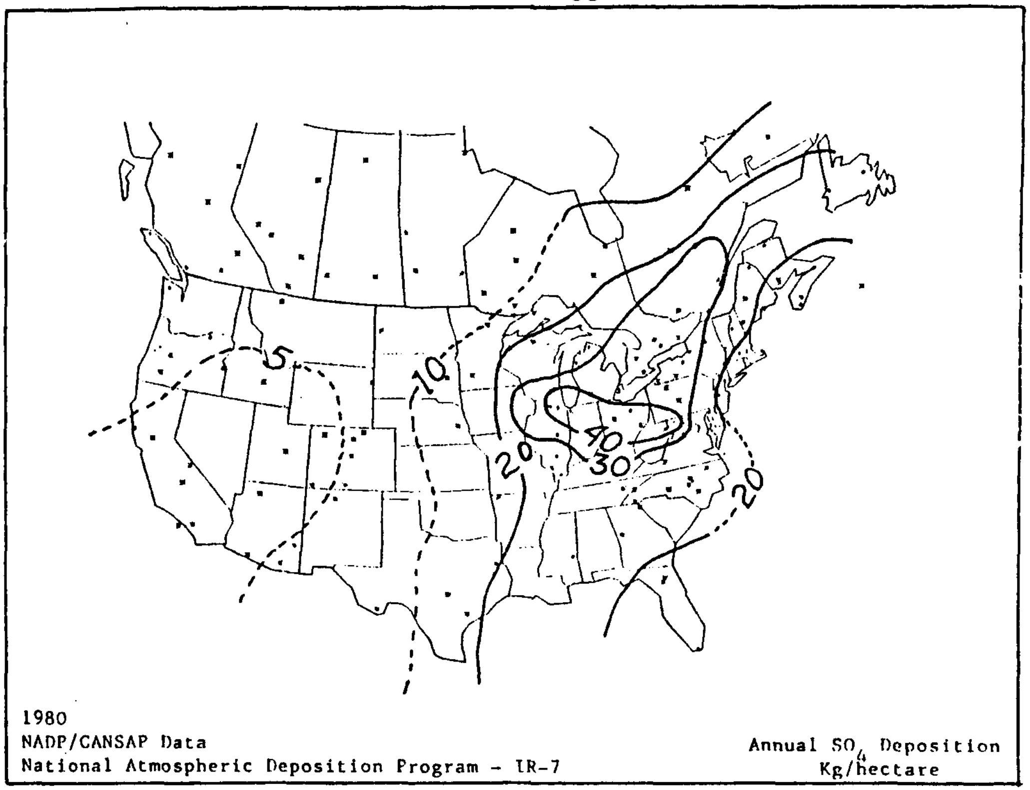

Figure 3. Annual $SO_4^{=}$ deposition (kg/ha) for the United States and Canada, 1980.

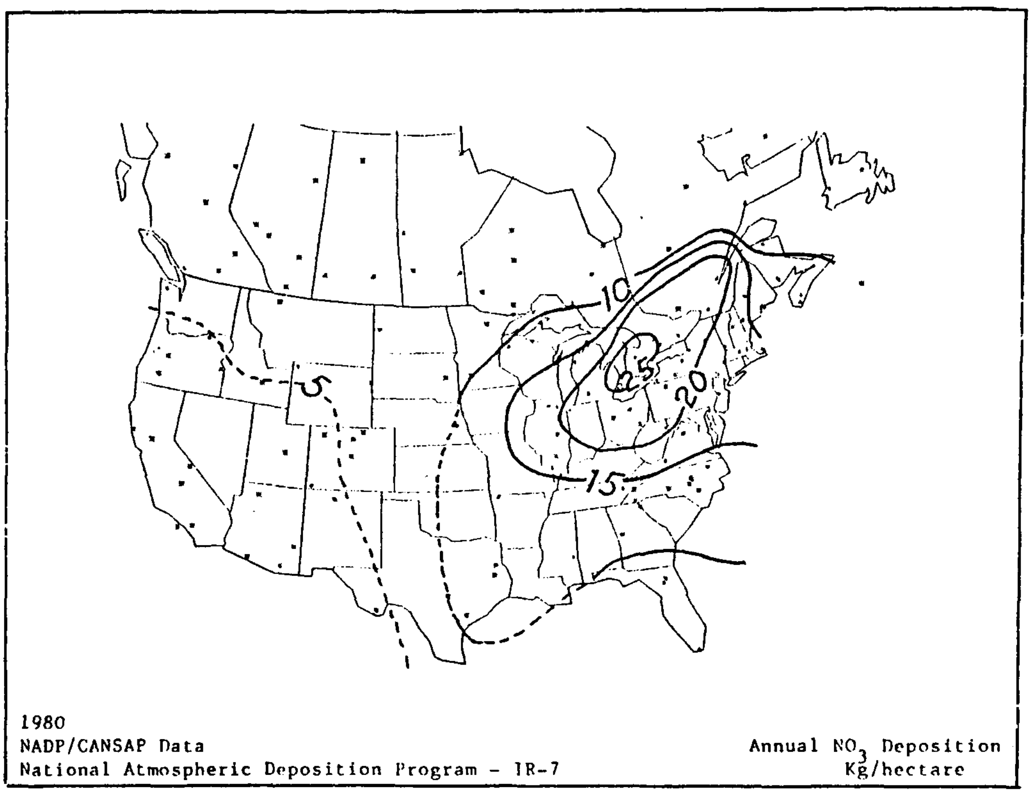

Figure 4. Annual NO_3^- (kg/ha) deposition for the United States and Canada, 1980.

Table 1. Average annual concentration, 1980.

Site	pH	SO_4	NO_3	NH_4	Ca & Mg
	μeq/l - precipitation weighted				
Alamosa, CO	5.6	27.0	15.0	20.0	18.5
Sand Springs, CO	4.8	22.0	14.0	8.4	16.0
Rocky Mountain National Park, CO	5.0	25.0	22.0	20.0	17.0
Manitou, CO	4.9	45.0	33.0	21.0	33.0
Pawnee, CO	5.5	31.0	28.0	38.0	22.0
Olympic National Park, WA	5.4	7.0	1.5	1.0	5.0
Parson, WV	4.2	74.0	33.0	13.0	17.0

Table 2. Average annual concentration, 1981.

Site	pH	SO_4	NO_3	NH_4	Ca & Mg
	μeq/l - precipitation weighted				
Alamosa, CO	5.2	38.0	17.0	23.0	28.0
Sand Springs, CO	5.0	33.0	16.0	10.0	31.0
Rocky Mountain National Park, CO	5.0	33.0	23.0	19.0	26.0
Manitou, CO	4.8	34.0	24.0	13.0	24.0
Pawnee, CO	5.1	45.0	28.0	39.0	29.0
Olympic National Park, WA	5.4	8.0	1.5	1.0	10.0
Parson, WV	4.2	74.0	30.0	16.0	18.0

Table 3. Annual deposition, 1981.

Site	H^+	SO_4	NO_3	ppt (cm)
	kg/ha			
Alamosa, CO	0.01	5.4	2.7	22.0
Sand Springs, CO	0.04	7.3	4.4	40.0
Rocky Mountain National Park, CO	0.03	4.9	4.5	32.0
Manitou, CO	0.07	6.7	6.2	40.0
Pawnee, CO	0.03	7.2	5.7	30.0
Olympic National Park, WA	0.10	18.0	4.4	366.0
Parson, WV	0.90	46.0	24.0	130.0

COLORADO NADP SITES

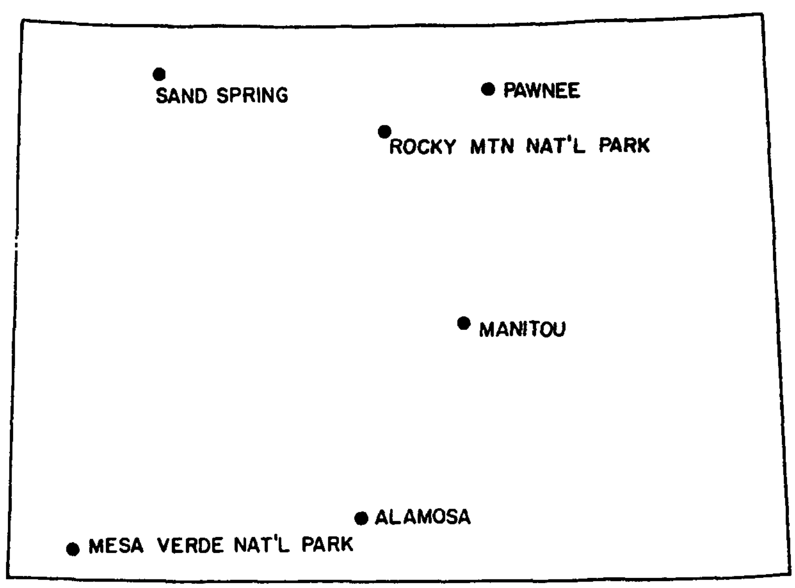

Figure 5. Location of Colorado NADP monitoring stations. Pawnee, Rocky Mountain National Park, and Manitou are located east of the Continental Divide; Mesa Verde, Sand Springs and Alamosa are on the western slope.

1. Precipitation pH ranges from approximately 4.8 to 5.6.

2. Calcium and ammonium concentrations represent significant levels of alkalizing materials which are responsible for lower acidities than would be expected from the concentrations of sulfate and nitrate (if these are considered to originate as sulfuric and nitric acid).

3. Concentrations of sulfate in Colorado are 4 to 5 times that in Olympic National Park and approximately 1/2 to 1/3 those in West Virginia.

4. While there are small variations, sulfate concentrations are reasonably consistent across the State indicating limited influence of local sources.

5. Concentrations of nitrate are 10 to 20 times those in Olympic National Park with "east slope" levels approximately equal to those in Parsons, West Virginia.

6. Nitrate concentrations are approximately 50% of sulfate levels on the west slope but 70% of those on the east slope most likely due to mobile sources in urban areas.

7. Because of lower concentrations and low precipitation at Colorado sites (20 to 40 cm/yr), sulfate deposition values are less than 20% of those in Parsons, West Virginia and nitrate less than 25%.

As stated earlier, one of the major factors in determining potential for acidification of aquatic and terrestrial ecosystems is the level of deposition. It has been stated that acidic deposition represented by a rainfall pH of 4.6 or greater (sulfate deposition less than 20-30 kg/hectare) is not believed to be significant in terms of acidification even in sensitive areas. Rainfall pH on the average is not below 4.8 and it should be kept in mind that the pH of 4.7 value was determined in areas of the world where rainfall amounts are considerably higher than in the Rocky Mountain region in Colorado. Sulfate deposition averages 5-7 kg/hectare and the deposition of nitrates and sulfates is less than 20% of that in the eastern U.S. Therefore, deposition is currently below that which would be considered significant in terms of lake or stream acidification.

RESOURCE SENSITIVITY

Much of Colorado in the mountains is underlain by granite and other precambrian metamorphosed bedrock, which as discussed earlier does not provide significant buffering of acidic deposition. The mountainous areas, and the mesas in the west composed of basalt, another slow weathering rock type, have thousands of lakes and streams and are some of Colorado's most beautiful recreational resources. Without even sampling these waters it would be relatively easy to guess their sensitivity to acidic deposition. Fortunately, there have been several studies of lake sensitivity in the state, which we will summarize and discuss.

Surface waters serve as integrators of processes that occur in the watersheds above them. If there is little interaction with the soils or parent geologic material above a body of water, its composition will reflect that of precipitation. A beaker on top of a mountain in Colorado will collect water whose chemical makeup will be similar to the rainfall. In the same way the chemical content of high elevation lakes and streams will be essentially that of the precipitation. However, the greater the amount of time precipitation is in contact with bedrock, or vegetation, or soils, the more its composition will reflect that influence. This translates into an elevational gradient such that higher lakes and streams have less buffering capacity than those at increasingly lower elevations. This gradient has been observed by John Turk in Colorado's Flattops Wilderness area and on Grand Mesa. Similar results were found in a survey of Rocky Mountain National Park sponsored by the Fish and Wildlife Service. The most sensitive lakes are those highest in their drainages. Waters gain buffering capacity as they move to lower elevations, where the crystalline rocks are overlain by sedimentary strata or below the basalt caps with sediments having a tremendous buffering capacity. Surface waters at these lower elevations are not sensitive. Figure 6 shows sensitive areas of the state based upon bedrock material.

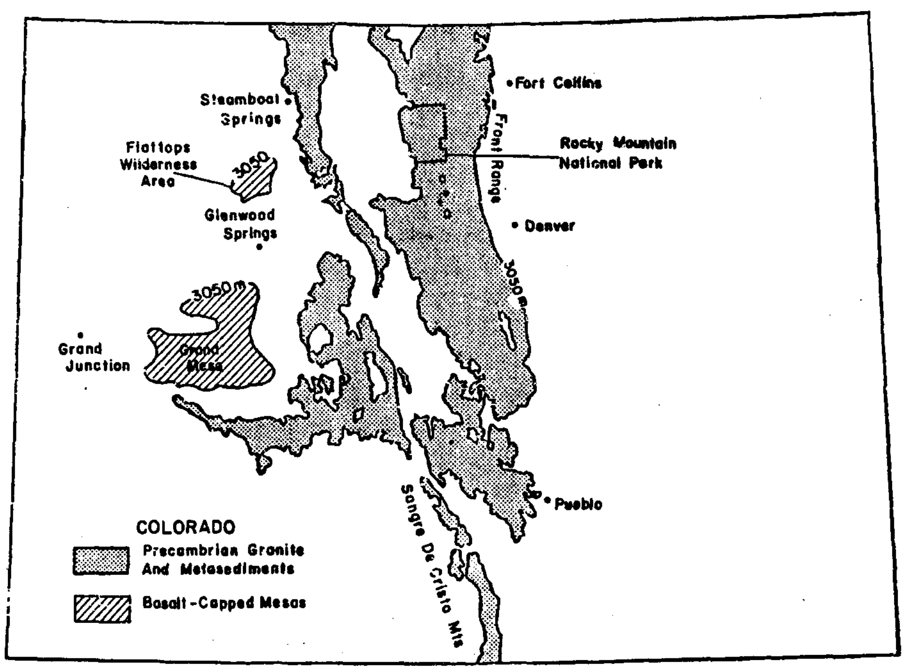

Figure 6. Areas of Colorado which are sensitive to acidification due to acidic deposition.

Throughout the sensitive areas, individual basin characteristics can influence surface water alkalinity and this has been seen in Rocky Mountain National Park. Most waters within the survey which were located on granitic substrates had alkalinity values between 10 and 150 μeq/l, well below the 200 μeq/l sensitivity cutoff. Where there were tertiary volcanic intrusions, waters were not sensitive. While high elevation waters throughout the state are generally as sensitive as any in the world, individual pockets of more weatherable substrates make some less sensitive than others.

We have already mentioned how bedrock composition, at least in the sensitive areas of Colorado, changes to provide more buffering with decreasing elevation. Another influence on surface water buffering capacity that changes with elevation is soil. High elevation soils play a dual role in that they may both buffer and acidify nearby surface waters. We have looked extensively at soils in Rocky Mountain National Park. This was carried out intensively in the Loch Vale basin, and in a general survey of park soils. We see soils above 10,000 feet that are acidic to extremely acidic. While eastern United States soils contribute base cations, in this region they contribute base cations plus a fair amount of hydrogen ion and soluble aluminum (Table 4).

Tundra soils were examined by Scott Burns in his work on Niwot Ridge. He found them to be moderately acidic (pH 4.4-5.9) and have sizeable amounts of base cations to contribute to soil water. Most high Colorado lakes are located in the glacial valleys however and the soils surrounding them are their immediate contributors. These soils are extremely acidic (pH 3.5-4.9). This is due to a large amount of organic material whose breakdown products are organic acids.

During periods of the year when there is little dilution from the less acidic precipitation, these soils exert an acidifying influence. We see a slight soil influence throughout the year (Figure 7) in the waters of one of our study lakes. The Loch is almost entirely surrounded by acidic soils and pH values in its waters are significantly lower than those of Sky Pond and Glass Lake, which are tarns surrounded by bedrock and talus material. Should the acidity of deposition increase, the soils will provide minimal buffering and instead may contribute soluble toxic metals to the lakes and streams.

The situation changes as one descends below 10,000 feet (3,050 m) where mineral content of the soils increases relative to organic matter. The pH of the soil rises and the percentage of base cations increases as H^+ and Al^{+++} cations decreases. Lakes at lower elevations benefit from these soils by having much higher alkalinities.

There has been much discussion in the United States and Europe about the effect of acidic deposition on soils and there are about as many theories as there are scientists studying the problem. Some researchers claim that additional inputs of sulfuric acid and nitric acid will cause significant leaching of nutrient cations, resulting in a loss of soil fertility. Many researchers believe acidic deposition is

Table 4. Characteristics of some high elevation soils on granitic and metasedimentary substrate in Colorado.

Soil Type (elev. m)	Depth (cm)	pH (1:1 water)	CEC (meq/100 g) Σ cations	Base Saturation (%)	Organic Matter (%)	Exchangeable Acidity (meq/100g)	Source of Data
Cryochrept (> 3300 m)	0-5	5.6	24.8	48.0	14.0	-	Burns 1980
	5-50	5.9	6.6	58.0	1.3	-	
TUNDRA	50-107+	5.5	5.3	67.0	0.6	-	
Cryochrept (> 3300 m)	0-14	5.5	29.8	53.0	16.7	-	Burns 1980
	14-24	5.0	19.7	26.0	3.9	-	
	24-46	5.1	16.4	12.0	2.1	-	
TUNDRA	46-110	5.2	9.2	11.0	0.9	-	
Cryoboralf (> 3050 m)	9-0	4.8	95.5	62.6	---*	35.7	Baron & Walthall 1983
	0-19	3.8	20.0	38.7	2.7	12.3	
	19-32	3.7	28.9	21.0	3.1	22.8	
SUBALPINE	32-56+	3.7	16.5	13.7	1.6	14.3	
Cryohemist (> 3050 m)	0-4	3.8	49.4	22.1	---	38.5	Baron & Walthall 1983
	4-15	4.0	41.8	8.8	---	38.1	
	15-25	4.1	39.8	12.3	---	34.9	
	25-33	4.3	41.3	14.9	---	35.1	
SUBALPINE	33-43+	4.4	25.4	25.2	7.0	19.1	
(2798 m)	4-0	4.9	52.1	34.6	65.4	34.1	Gibson et al. 1984
	0-4	4.9	27.6	21.0	6.1	21.8	
	4-10	5.1	7.7	19.9	0.9	6.2	
UPPER MONTANE	10-46+	-	-	-	-	-	
(2615 m)	20-0	5.1	34.9	32.8	17.1	23.5	Gibson et al. 1984
	0-22	5.3	35.3	48.5	12.4	18.2	
UPPER MONTANE	22-37+	5.5	20.3	69.2	1.2	6.2	

*Organic matter not determined for organic horizons

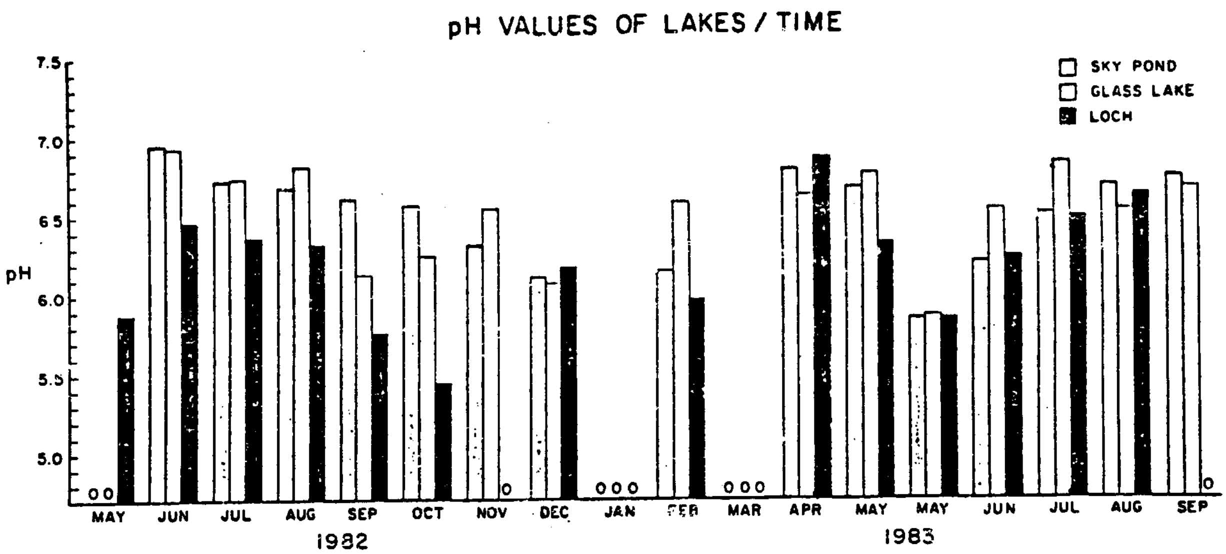

Figure 7. pH values of Loch Vale Lakes over time. The difference between pH of the Loch and average pH of Sky Pond and Glass Lake is significant, $\alpha = .01$.

lowering soil pH values to the point where the solid phases of aluminum will enter the soil water in a toxic soluble state, with detrimental effects on tree roots, soil microbes and aquatic biota. Another view receiving attention states that since soil formation itself is an acidifying process, producing on the order of 1000 keq/ha exchange acidity in eastern soils, the input from atmospheric deposition, equal to about one kiloequivalent/ha at pH 4, will have negligible effect (Krug and Frink 1983). That extra acidity may pass through the soil with little change, or it might be swallowed up in the immense pool of soil acidity. What is clear about the nature of soil acidification is that there is a great deal of work to yet be conducted before these contradicting theories can be sorted out and understood. Our work characterizing Rocky Mountain soils reveals that (1) soils are extremely acidic above 10,000 ft (3,050 m) elevation and (2) become less so at lower elevations.

The link between forest decline and acidic deposition throughout the world is nebulous at best and any discussion of Colorado vegetation would be speculation. There is always the potential that some plant species will be very sensitive to lowered pH, but nothing is known about Colorado flora. Northern European and eastern North American forests have been in noticeable decline since 1965, but the cause for this loss of vigor eludes scientists. Currently some researchers (Johnson and Siccama, 1983) believe a variety of disturbances might be responsible, but the only one they can point to specifically is drought. Acidic deposition might well be compounding the effect of other environmental disturbances and this is a field ripe for study. However, it will likely be many years before we understand these processes.

SUMMARY

While the deposition of hydrogen ion, sulfate and nitrate are currently below those which are believed to cause the acidification of sensitive aquatic and terrestrial systems, the higher elevations of Colorado and the Rocky Mountain region represent areas of extreme sensitivity. Soils may be extremely acidic and lakes and streams have very low bicarbonate concentrations. Little is currently known about the mechanism of soil acidification and leaching processes and subsequent impacts on surface and ground water alkalinities. Based on observations in Scandinavia, Canada and the United States it can be stated that such areas are subject to acidification if the deposition of acidic materials exceeds certain limits (pH < 4.7 or sulfate > 20-30 kg/hectare). It seems safe to assume that if acidic deposition reached these levels in the Rocky Mountain region that a large number of lakes and streams would become acidified with the likelihood of increasing aluminum levels. Fish populations would suffer. On the other hand, there is no evidence that such a process is currently taking place. As was seen, deposition levels are well below the critical limits. Deposition would have to increase four or five times to reach values found in the Eastern United States. As long as we manage emissions of SO_2 and NO_x such that they do not exceed current levels, our high mountain lakes, streams and forests should not be affected.

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REVEGETATION CONSIDERATIONS FOR MOUNTAIN SUBDIVISIONS

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INTRODUCTION

A relatively new industry is making steady progress in mountainous areas of the western United States, particularly in Colorado. The growth of recreation oriented mountain developments is creating environmental impacts of considerable magnitude. Disturbances resulting from the construction (or expansion) of ski areas, golf courses, commercial outlets, and residential developments pose significant challenges to environmental improvement professionals.

Two important consequences of these disturbances are unique to the mountain environment. First, there is a very high potential for erosion. Steep topography contributes most to the threat of rapid erosion. In addition to a high erosion potential and the related ecological implications, developments can noticeably interrupt the visual integrity of mountain landscapes. For developers and property owners, as well as local governments, visual impact is becoming an increasingly vital issue.

Revegetation is essential to the protection and enhancement of disturbed mountain terrain. This paper addresses three basic revegetation considerations which are integral parts of any successful environmental restoration approach, and are especially applicable to mountain residential developments.

TOPSOIL REPLACEMENT

Disturbances resulting from road construction are typically the most difficult revegetation sites in residential developments. Road cut and fill slopes present numerous problems: south facing exposure, steep slope angles, abrupt transitions to undisturbed slopes, and poor soil (often subsoil or parent rock material). If slopes are properly designed, topsoil can be replaced and will enhance revegetation success more than any other single treatment. Unfortunately, topsoil replacement is sometimes viewed as an unnecessary construction cost, a valid concern particularly for steep slopes. However, if topsoil replacement occurs concurrently with road construction, and not after pavement and other structures are in place, the expense can be minimized.

In the long term, replaced topsoil can be very economical. Topsoil contains native plant material whose growth, as in the case of shrubs, is often stimulated. This is, perhaps, the most effective way of reestablishing the native, adapted plant communities. Additionally, replaced topsoil may eliminate the need for fertilizer amendments. When subsoil material is revegetated, treatments generally are more intensive and, therefore, more costly. Even with intensive treatments, revegetated subsoil material is often less productive than topsoiled areas.

When replaced on slopes, the topsoil surface should be as rough as possible. Roughness provides microenvironments which promote germination, water retention, and erosion control. Contour furrowing, ripping, and imprinting with dozer tracks are all suitable means of creating a rough soil surface. These methods should be employed as the topsoil is being replaced. Attempting to prepare soil after road construction is complete is usually very expensive, if not impossible.

PLANT MATERIAL SELECTION

Shrubs

The most widely used plant material for revegetation purposes are grasses. They are economical, establish quickly, and provide substantial erosion control. However, one of the more important categories of plant material which needs to be included more in mountain revegetation treatments is shrubs. Mountain developments often favor the drier, south facing slopes. In this environment shrubs can be a dominant component of the plant community.

Unfortunately, the establishment of shrubs is a very difficult task, regardless of the nature of shrub material used - seed, bare root, containerized, or transplants. Until this situation can be significantly improved, efforts to restore the native plant communities and to visually "blend" the disturbed and undisturbed environments will continue to be incomplete.

There are two factors which seem to be related to successful shrub establishment in mountain environments. One, already mentioned, is the use of replaced topsoil. Particularly effective is "live" topsoil (topsoil which has not been stockpiled, but used immediately after it has been removed) which contains live shrub propagating material such as seed and rootstocks. Vigorous shrub growth can be achieved in only a few growing seasons with this method.

Perhaps the most important factor to consider when establishing shrubs from seed or grown stock, and even with the replaced topsoil approach, is competition from grasses. Shrubs will establish poorly, if at all, when competing with the aggressive grasses used for erosion control. Therefore, shrubs should be seeded or planted in areas where erosion control is less critical and competition from grasses is minimal or nonexistent. Since shrubs have a relatively slow growth rate, grasses will inevitably invade shrub sites.

Wildflowers

The use of wildflowers in mountain residential developments is an excellent means to enhance the visual appeal of disturbed ground. However, an unrealistic expectation of many people, including revegetation specialists, is the establishment of a permanent "alpine meadow" effect, where flowers are abundantly and visibly dispersed through a stand of luxuriant grass. Similar to the problems of shrub establishment, wildflowers compete poorly, in the long term, with the grasses commonly used for erosion control on mountain slopes. Initial showy wildflower/grass displays are not uncommon, due primarily to the rapid growth of annual wildflower species. But, after two or three growing seasons annual species may be absent altogether while perennial wildflower species, if established, are represented by relatively small populations, which are not visually significant.

Because of their beauty and public appeal, the establishment of wildflowers should be encouraged. Effective utilization of wildflowers, which are relatively expensive, can be best realized in areas of high visual impact such as entryways, signs, corners, and green belt areas. Combinations of grasses and wildflowers should be discouraged, especially in areas where erosion control is critical. Even a healthy stand of wildflowers will eventually be invaded by grasses in mountain environments.

MAINTENANCE

Rarely do revegetation plans specify long term maintenance of treated areas. More commonly, guarantees may be required of the revegetation contractor to establish a specified density of plants in a fairly short period of time. Guarantees usually involve the application of supplemental water to insure the proper environmental conditions for germination and establishment. Application of supplemental water, especially to steep and varied terrain, is expensive.

A more reasonable approach to "insure" establishment is to allow nature to take its course while providing regular maintenance activities such as touch-up reseeding, fertilizing, and weed control. There are several advantages to this approach. First, the unnecessary expense of supplemental water can be avoided. More often than not, there will be adequate precipitation in mountain environments to establish vegetation, provided the correct revegetation treatments are specified for the site conditions and the time needed for establishment is kept in proper perspective. It generally takes a minimum of two to three growing seasons for revegetated areas to attain maximum performance. Secondly, a scheduled maintenance program can facilitate the treatment of problem areas that may not initially be apparent. Finally, success of the revegetation treatments can be easily evaluated. This information can then be applied to the design of future work.

CONCLUSION

The development of mountain areas for recreation oriented purposes will continue to demand effective revegetation methodology. In addition to the obvious concern for soil stabilization, a better educated and more demanding consumer is expecting faster, more natural appearing restorative efforts.

In the severe environment of the mountains, providing effective erosion control and quick visual impact amelioration while maintaining economy is, indeed, a formidable challenge. It is a challenge that can and will be met. Although many disciplines are involved in the realization of any development, revegetation is a vital component.

The revegetation effort must work with the environmental conditions of the site. The replacement of displaced topsoil, the selection of plant material whose function is matched to the site conditions, and the institution of maintenance programs are basic methods which work with the environment to achieve effective revegetation. Once these methods can be consistently implemented, revegetation practices in mountain residential communities can become routinely successful.

ELEMENTS OF COST EFFECTIVE COMPLIANCE

J. A. Sturgess
P. B. Johnson

Presented at the 6th High Altitude Revegetation Workshop on March 5 or 6th at Fort Collins, Colorado

When asked to consider giving a presentation on the Thompson Creek Mine Reclamation program, my response was "sure", but I wanted to know what specific subject would fit the agenda for the conference. The response was "something interesting and controversial, and humorous". Sure, humor, controversy, and interesting! So we picked the bellringer title "Elements of Cost Effective Compliance". That takes care of the humor.

Now for controversy. We at Thompson Creek are utilizing the philosophy that percent germination, stem counts, root-shoot ratios, biomass, and percent density, are useless parameters and shouldn't even be measured the first two years after planting disturbed sites. That takes care of the controversy.

Traditional revegetation parameters such as those just mentioned - stem counts and root shoot ratios, are not being used in our reclamation program because they are not necessary for our short term reclamation objectives, and cost money that is best spent on other programs.

Having clear objectives is the first requirement for cost-effective compliance. The primary reclamation objective at Thompson Creek is not to grow 86 stems per square foot, the objective is to stabilize as many surface acres as possible in order to maximize water quality. We are not as concerned with minor cut-slope soil movement as we are with where that soil might go, and how can we keep it from reaching surface water. This objective is in compliance with section 208 of the Clean Water Act, which governs non-point-sources of runoff.

Our second objective is obtaining release of our reclamation bonds, for the lowest possible cost. If these bonds could be released for less cost by paving all of the disturbed sites than by planting a heterogenous mixture of site-specific grasses and forbs with excellent wildlife value, then paving would have to be considered. This may sound cold- blooded, but it demonstrates the point, cost-effectiveness.

At present, reclamation bonds of 5.2 million dollars are in place with three agencies of the federal and state government. (Table 1) Another half- million dollar bond is being negotiated with a fourth agency. Total reclamation bonding may exceed 10 million dollars later in the life of the mine. Annual carrying costs for a 10 million dollar bond may range from around forty thousand to

BOND AMOUNTS TO COVER CYPRUS THOMPSON CREEK THROUGH DECEMBER 31, 1988

BOND I D	AGENCY HOLDING BOND	DISTURBANCE TYPE	AREA	BASE RATE	PORTION COVERED BY OTHER BONDS				ADJ. RATE	TOTAL ($)
			ACRES	COST/ACRE	LANDS	WATER RESOUCES	USFS	BLM	COST/ACRE	
	Idaho Dept. Lands	All	1809.5	$750	---	--	--	--	750	1,357,125
	Idaho Dept. Water Resources	Tailing Deposition	191.5	5,512,472 28,800	750				28,050	5,371,575
	United States Forest Service	Mine	37.5	250	750				(500)	--
		Dumps	343	2,000	750				1,250	428,750
		Tailing-Deposition	176.5	28,800	750	28,050			--	--
		Tailing-Non-Deposition	64	1,500	750				750	48,000
		Borrow	--	250	750				(500)	--
		Roads & Utilities	11.5	1,000	750				250	2,875
		Laydown & Shops	--	1,500	750				750	--
		Subtotal								$479,625
	United States Bureau of Land Management	Mine	173	250	750				(500)	--
		Dumps	316.5	2,000	750				1,250	395,625
		Tailing-Deposition	15	28,800	750	28,050			--	--
		Tailing-Non-Deposition	35	1,500	750				750	26,250
		Borrow	17	250	750				(500)	--
		Roads & Utilities	200	1,000	750				250	50,000
		Laydown & Shops	175.5	1,500	750				750	131,625
		Subtotal								603,500
		Total								$7,811,825

two or three hundred thousand dollars per year, depending on a company's credit rating. Those carrying costs are clear incentive for bond release as an important reclamation objective.

Our third objective is less pragmatic. All things being equal, or nearly so, we will choose species that have wildlife values, aesthetic appeal, and that blend with the surrounding natural landscape. We are, after all, human, and have a company policy which directs us to conduct our activities consistent with these types of considerations. There are limits however, to how much effort can be expended for esoteric success. The rocky, steep, sparsely vegetated lands in the area fetch land prices of only a couple of hundred dollars per acre. Is twice this market value too much to pay for reclamation? Is four times?, or six?....

This is where clearly defined reclamation objectives are essential. Four times the market value may be a lot to pay to meet an aesthetic or wildlife objective-better to pave the disturbed site and improve an acre where it is more cost effective. On the other hand, four times market value can be cheap indeed when stabilizing an over-steepened roadcut in erosive soils directly above a water course. With several thousands of acres to reclaim, the choices between reclamation objectives and methods become critical.

First let me assure you, we are not in the paving business. Amoco Mineral's Cyprus Thompson Creek Mine recently completed construction activities and is in the first year of Molybdenum production. Located in Central Idaho, the mine is surrounded by the Salmon River as it flows from the Sawtooth Wilderness area, east, north and then to the west through the River of No Return Wilderness area.

Popular with recreationists, and the tourism industry, this great river establishes our first reclamation objective: Maintenance of Water Quality.

The mine is located on Public Lands administered by both the BLM and the USFS. These administrative boundary lines go right through the middle of the pit and the tailing pond. The pit itself is on private patented lands.

Idaho state agencies that regulate mining on federal, state, and private lands include the Water Resources and State Land Departments.

Between these four agencies, bonds are in place to cover the estimated reclamation costs (in 1983 dollars) for all disturbed sites on the property. It is the release of these bonds that dictates our second compliance objective.

If these two objectives have defined the need for reclaiming an area, then a treatment prescription is determined by the project reclamation specialist - forester Bryan Johnson.

Treatments range from hand broadcast seeding to topsoiling, contouring, hydromulching, and jute netting.

These treatment costs vary from a mere $100/acre for handseeding to over $7,000/acre for more elaborate treatments where earthmoving equipment or labor-intensive jute netting is required. With these orders-of-magnitude cost differences deciding which treatment to use on a particular area is where budgets are made or broken. (Table 2)

At Thompson Creek we did not have the luxury of extensive greenhouse or field plots that had been laid out in years past. We also face the challenges of elevations from 5600 to 8300 feet above sea level, with aspects ranging from north to south, and slopes from flat to upside down.

With annual precipitation varying from less than 10 inches to over 30 inches, test plots have only limited value. They can tell us only what did happen at one site, for that planting year, at that elevation.

Rather than expending 10 or 20,000 dollars per year evaluating test plots, counting stems, and doing statistics we have instead expended those energies on spreading seed.

Tapping the available services of the Forest Service, Soil Conservation Service, Bureau of Mines, Department of Lands and the Bureau of Land Management, yielded the advice and suggestions of many proven seed mixes and treatments. Use of these services are cost effective in that they don't come out of my budget as a reclamation line item. Instead they come out as a corporate tax line item.

Where we have established shrub plots, they are simple indeed. Sixty bare root shrubs of 12 different species took 10 hours to plant at each of two sites. We count the survivors each fall. You can see why first year records don't really mean anything. Table 3)

Total planting in 1983 covered 134 acres. Because of slope, 165 surface acres were actually seeded.

TABLE 2 - THOMPSON CREEK RECLAMATION (1983)

METHODS		MATERIALS											RESULTS
SITES	RECLAMATION METHOD	PLAN ACRES	COSTS ($)								TOTAL COST PER SITE $	COST PER ACRE $	RECLAMATION SUCCESS- % OF GOALS- 1983
			EQUIP. OP. & MAINT.	LABOR	SEED	FERTILIZER	BONDING	WOOD FIBER MULCH	STRAW MULCH	JUTE			
≥ 45° SOUTH FACING CUT SLOPE	LAY JUTE NETTING, HYDROSEED AND FERTILIZE, THEN HYDROMULCH	0.17 (7200 FT^2)	7	723	13	3	1	42		452	1241	7300	80
UPPER ABANDONED ROAD	RIP EARTH, SOWERSEED AND FERTILIZE, SPREAD STRAW MULCH	6.0	3645	2388	462	98	23		534		7150	1192	80
LOWER ABANDONED ROAD	RIP EARTH, SOWERSEED, HYDROMULCH AND FERTILIZE	6.5	4088	1344	551	106	24	836			6949	1069	80
INTER-SECTION ABANDONED ROAD	RIP EARTH, SOWERSEED AND FERTILIZE	5.5	3313	504	424	90	21				4352	791	70
≥ 45° SOUTH FACING CUT SLOPES	HYDROSEED AND FERTILIZE, HYDROMULCH	9.0	461	2700	693	147	34	2205			6240	693	50
TOPSOIL STOCKPILE	SOWERSEED AND FERTILIZE FOR 3 CONSECUTIVE YRS. SPREAD STRAW MULCH 3RD YR.	12	40	1536	1759	249	68		534		4186	349	70

Table 3 PERCENT SURVIVAL OF SHRUB SPECIES PLANTED AT THE MAINTENANCE PAD AND PAT HUGHES CREEK AREA (N=30)

	1982 % Survival			1983 % Survival		
Common Name	Main-tenance Pad	Pat Hughes Creek	Total	Main-tenance Pad	Pat Hughes Creek	Total
Western Serviceberry	100	100	100	80	100	90
Buckbrush	93	80	87	60	73	66
Squaw Carpet	67	53	60	13	33	23
Stickey-laurel	47	80	64	0	67	34
Mountain Mahogany	100	100	100	93	73	83
Rabbitbrush	80	67	74	40	60	50
Grey Rabbitbrush	73	67	70	53	67	60
Stansbury Cliffrose	87	87	87	7	13	10
esert Bitterbrush	87	93	90	7	40	24
ntelope Bitterbrush	100	100	100	60	67	64
ood's Rose	100	100	100	93	100	97
lderberry	53	67	60	0	60	30

The most expensive treatments were along the access road where some slopes had been left oversteepened. Treatments used in these areas ranged from backsloping and contouring using heavy machinery, with and without jute mesh netting, and hydromulching. Return on effort, or success weighted against cost, was quite variable.

For wildlife or aesthetic values, these areas only marginally met objectives for the first year. For water quality maintenance objectives, the jute netting was quite successful in preventing gully erosion.

These slopes and gullies enter road drainage ditches, which lead to a nearby creek.

Whether we obtain release of reclamation bonds for this area won't be known for several years. We don't want to pursue bond release until an area is known to be physically stabilized, not just cosmetically covered with heavily fertilized first year wonder plants.

The least expensive treatments we have used are broadcast seeding of abandoned roads and backwoods buried pipelines. Costs here are less than $150/acre. Immediate guaranteed success? Hardly. Wildlife value?....the ground squirrels and birds which follow the seeder do pretty well.

But a week or two of moist ground and some minor frost heaving that loosens surface soil and buries the seed often gives quite acceptable results. If the weather gods don't cooperate, and it doesn't rain, the seedlings suffer heavy mortality after germination. But for cost-effectiveness we can go in and redo an area two or three times, and carry bonds for extra time, for less than the cost of one hydromulching coverage. And in our seasonally arid area, even an extensive three-pass jute net, hydroseed, and hydromulch application can be devastated by two weeks of drought following germination. The money at risk to the weather, with handseeding, is less than $150/acre, instead of some $1,000 - $1,500/acre for hydromulching.

Reseeding a failed hydromulched area has other drawbacks besides cost. Once the wood fibers have baked in the sun and set up, reseeding over the top perches the new seed an extra ¼ inch away from the soil surface. This may further reduce success. Hydromulching over a failed broadcast seeded area has no such added difficulty.

Then why do we use hydromulching at Thompson Creek? Because in many areas the 50% or 75% better chance of success makes the extra cost worth it. The first objective of water quality maintenance on critical slopes can be aided by hydromulch even if plant survival is low. The paper-mache'-like cover acts like a large insulating sponge in holding soil and moisture on steep slopes, although it can slough and peel after a winter of freeze/thaw conditions.

Another advantage of hydromulching in critical areas is visibility. How else except sodding can a half-mile of fresh roadcut be turned green in one day by two people?

Several of our mine operators asked how come we kept planting that green grass when it just died and turned brown in two days?

While the costs involved for seeding methods vary by as much as tenfold, the decision on whether to contour, backslope, rip, or topsoil an area can be even more important. Simple ripping or contour smoothing may cost $600/acre. Costs for scraping, stockpiling, and respreading top soil can be astronomical.

At Thompson Creek we go back to our objectives to decide whether or not to call in the heavy equipment. If runoff water quality is not critical in an area, for example upstream of the tailing pond, then we let nature do a little free resloping and revegetation.

While freshly slumped roadcuts or spoil piles may not be aesthetically pleasing, they are stable. Waiting a season or so before planting in low erosion-risk areas can save considerable frustration and replanting costs.

When outside of our critical water quality areas, and in corridor-type disturbances such as pipe or power lines, natural revegetation is certainly cost-effective. On flatter slopes where soil loss, runoff quality, and protection of plant equipment are not concerns, the ruderals, dormant native seeds, and native fall seed may provide adequate revegetation.

Reclamation bonds, while significant costs for the project as a whole, may be more economical than even the cheaper seeding methods. If the bonds won't be released for several years anyway, and if there is good chance for natural revegetation, and if not excluded by specific permit requirements, then in some areas we intend to let nature take it's course.

Many areas, obviously, do require sloping, ripping, and contouring, and there is no avoiding the high costs involved. These areas also have the most potential for rewarding success.

In closing, so that no misconceptions are left, we acknowledge that research certainly is important and has an irreplaceable spot in mine reclamation. We will start this year on 20-year plots of tailing treatments and soil amendments. Also on waste dump tops next year. In these two disturbance types, research will be cost effective, because homogenous planting conditions, elevations, and flat topography will cover in excess of 3 square miles. Shaving even a few dollars per acre off of costs will more than pay for the research effort expended. Except for these two applied research areas, our efforts will continue to focus on our primary objectives - water quality, bond release, and aesthetics.

Thank you.

Reclamation Challenges and Accomplishments at Snowmass Coal, Carbondale, Colorado

by
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Why this project?

It's too bad it's not possible to show our color slides in a paper like this. Any reader who saw our presentation at the Workshop will remember we showed quite a number of informative as well as beautiful slides of the project which is the subject of this paper. That project is the coal loadout facility of the Snowmass Coal Company, located on the west side of Colorado State Highway 82 about ten miles south of Glenwood Springs. As an industrial facility, the loadout is not particularly noteworthy. There is little about it which would someday make it a tourist attraction or historical landmark; it is not the biggest, nor the tallest, nor the first, nor the last, nor the greatest of its kind, nor is it otherwise unique in any similar regard. But as a case study in local politics, environmental regulation, and reclamation, this project has much to offer. And so although we can't show you in this paper what the loadout looks like, we will focus our discussion on certain issues--a combination of environmental and political--encountered during the design and construction of the facility, and how reclamation technology ultimately played a key role in how many of these issues were resolved.

The facility.

The purpose of the loadout is to load coal into railroad cars for shipment. Coal is brought to the loadout by truck from the North Thompson Creek mines about nine miles away. The trucks dump their coal into a hopper at the end of a long conveyor system. This conveyor is the most visible feature of the facility--it is enclosed in a long green metal tube which runs 2,100 feet from the truck dump site on the edge of a mesa to the west of the Roaring Fork River, down the slope toward the east, across the river, and terminating at the loading tower just west of Highway 82. In addition to these components, the loadout also includes about one mile of private haul road, a crescent of railroad track connecting the loading tower to the Denver and Rio Grande Western track, and a shed at the far end of the rail crescent which houses a locomotive. Total surface disturbance is about twenty acres. Construction of the loadout was completed in 1981.

First problem--coal storage and visibility.

The loadout was designed by an engineering firm out of Pittsburgh. The original design, which was submitted to the Garfield County planning department, included plans for a 120-foot tall coal storage silo near the rail crescent. The company did everything in its power to convince county government to grant the project a variance from the county's 55-foot height restriction, to no avail. The loadout would be redesigned. Not only that, the county would still not approve the project unless the design incorporated an approved plan to minimize "visual impacts." Additional environmental concessions demanded by the county included assurances of dust control, noise abatement, and restrictions on operating hours and night-time lighting. Snowmass Coal discovered it was difficult being a relatively small coal company dealing with a county government which was much more accustomed to dealing with large oil shale developers.

But a consultant was subsequently hired, co-author Jeff Pecka, who was then with the landscape architecture firm of Philip E. Flores & Associates. The visual impact mitigation plan, which was produced in a great hurry, by the way, involved several elements. First, the loadout's structures would be painted a particular green color similar tothe surrounding pinyon and juniper vegetation. Second, any unnecessary disturbance to surrounding vegetation would be avoided during construction. Next, landscape plantings off-site, near certain neighboring homes, would be installed. And finally, extensive berming and landscaping around the facility itself would be required. To give an idea of the extent of all the landscaping work, it was estimated that the nursery stock along would cost about $250,000. But the important thing was that the county approved the plan and work on the project could go on.

Now that the county was happy, what did the state want?

Along about this time work was beginning on the permit application to be submitted to the Colorado Division of Mined Land Reclamation. From the standpoint of this agency's regulations--about 350 pages--this facility had just about every hurdle to cross, in spite of the fact that this would hardly be a major disturbance, in the usual sense of a mining project, anyway. There were hydrology concerns, and the rail crescent and loading tower would be situated on a designated "alluvial valley floor"--something which could have dire regulatory consequences. There were wildlife officials who were concerned about disturbances to an old ponderosa pine snag growing near the river which had been noted as a raptor perch tree. Others were worried about effects to the river itself--would the structure disrupt kayaking or fly fishing? And finally, although this list is not intended to be comprehensive, the baseline soils investigation revealed that a portion of the haul road leading to the truck dump site crossed an area of prime farmland. (This became, we believe, the first permitted disturbance of prime farmland by a coal operation in Colorado.)

Snowmass Coal had a team of environmental specialists compiling technical information into various exhibits which would be required for the permit application. In addition to compiling some environmental baseline information, senior author Tom Colbert was assigned the task of preparing the reclamation plan for the loadout. Completion of this reclamation plan entailed several challenges. The first would be to accommodate any special requirements imposed due to the existence of prime farmland and the alluvial valley floor. Then, the Mined Land Reclamation Division's general requirements had to be addressed. And most significant, the requirements of the visual impact mitigation plan would have to be accommodated. This last point was a bit worrisome at first since the state's regulations for reclamation were not written with this kind of elaborate landscaping in mind. We were afraid there might be lurking one or more "Catch-22's between what the county and what the state would be asking the company to do.

Putting the pieces together.

Would the state go along with landscape species not indigenous to the site? Would the county approve native dryland seed mixtures encouraged by the state? Would the state object to the proposed trickle irrigation system? The county wanted assurance that the trees would be maintained, but the state wouldn't approve a maintenance plan unless it was spelled out in minute detail. The county had approved plans for extensive berming using stockpiled topsoil and subsoil materials, but would these plans meet approval of the state, which has its own extensive and specific requirements for protecting these resources?

The ultimate solutions to these problems involved a great deal of creative effort, cooperation, patience, and compromise by all involved. The permit application was submitted, and after some months of negotiateed give-and-take it was approved, and the loadout was finally built. At the end of the construction period a landscape contractor, Randall and Blake, came in and made the "interim reclamation plan," as the visual landscaping plan was called, a reality.

We have visited this project every summer since. The seeding and landscaping work gives the area a unique and perhaps even a spectacular appearance, at least as loadout facilities go. Tree and shrub survival has been good and the seeded areas are well established. There have been minor problems with the trickle irrigation system, winter kill, livestock damage, and thistle, but overall we have been impressed with the company's diligent maintenance. In this regard we should acknowledge the efforts of Bill Tate, Scott Jones and Craig Sherwood of Snowmass Coal, and thank each of them additionally for their assistance in the preparation of this paper.

PERSISTENCE AND PERFORMANCE OF GRASS AND LEGUME STRAINS AT SUBALPINE TEST PLOTS IN COLORADO

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Disturbances of high altitude areas have necessitated a thorough review of current reclamation and revegetation techniques. Subalpine and alpine areas are important watersheds and provide critical wildlife habitat, minerals, and recreational opportunities. Careful evaluations must be made of available plant materials which might be appropriate for seeding in alpine areas and in the more hospitable subalpine. The purpose of this study was to examine the performance of selected grass and legume strains in subalpine test plots.

The most appropriate species for revegetating high altitude disturbance areas would be adapted natives (Berg, 1974). Of these, slender wheatgrass [Agropyron trachycaulum (Link) Malte] may be the only commercially available species, although a few others are in various stages of study and production. Tufted hairgrass [Deschampsia caespitosa (L.) P. Beauv.] is in production at the Forestry Science Laboratory of the USDA at Utah State University, Logan, Utah. Tufted hairgrass, Thurber fescue (Festuca thurberi Vasey) and varileaf cinquefoil (Potentilla diversifolia Lehm.) are being evaluated at the Environmental Plant Center, Meeker, Colorado. An obvious need exists to develop and make available adapted cultivars (Cuany, 1974). Cultivars of introduced species from similar climates may prove to be adapted to the conditions of disturbed areas and may do a better job of soil stabilization than native species in early years of revegetation.

A number of studies have examined the performance of introduced species at high elevations and were varied in their design and emphasis depending upon the land use. Considerable attention has been focused upon mining reclamation (Brown, 1976; Brown et al., 1976; Brown and Johnston, 1978; Jackson, 1982), range restoration (Gates, 1962; Plummer et al., 1968; Brown and Johnston, 1979) and ski slope revegetation (Walker, 1982; Behan, 1983). Other studies have evaluated species performance in test plots (Gomm, 1962; Hull, 1964; Kenny and Cuany, 1978).

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Although several of these studies had included native species, introduced species predominated because of their availability. Grasses have been the major plant group seeded but various introduced legumes have also been evaluated because of their forage quality and ability to fix nitrogen (Townsend, 1974). The use of legumes results in an increase in plant-available nitrogen which is often limited at high elevations (Faust and Nimlos, 1968).

Five subalpine sites were selected to test 22 grass species and 10 legume species which were represented by a total of 107 varieties. These sites included two ski areas, two mining areas and one site on the edge of a gravel quarry. Fall and spring plantings were conducted to test the hypothesis that over-wintering may promote higher germination and better early establishment in some species. Time of seeding may be critical for species that have dormancy mechanisms such as those associated with many legumes (Townsend, 1974). Several authors recommended fall plantings on high altitude ranges, because plants that emerge in early spring can take better advantage of moisture and the short growing season (Cook et al., 1974; Brown and Johnston, 1979).

Test plots were observed over a period of five years in order to evaluate both early establishment and long-run persistence. In order to select appropriate species for a seeding mix, consideration must be given to those species which will fulfill both the need for soil stabilization by providing a quickly established cover and also the need for long term survival.

MATERIALS AND METHODS

Test plots were successfully established at five sites in the central Colorado mountains (Table 1). Two plantings were made, one in the fall of 1978 and the other in the late spring of 1979. Fall plantings consisted of 88 varieties of grasses and legumes and spring plantings included up to 100 varieties. Most of the varieties were the same for both the spring and fall plantings (see the detailed listing in the Appendix).

Although we have used the terms cultivar, strain, and variety interchangeably in the text, the stricter meaning of 'cultivar' would be a released, documented, cultivated variety. We tested some of those as well as collections and experimental strains. A number of introduced grasses, and over twenty strains of grasses native to Colorado or Alaska (Mitchell, 1978), as well as ten introduced species of legumes, were included in the tests. Legume seed lots were scarified in the laboratory a few days before planting.

Plots were prepared by incorporating 112 kg/ha P_2O_5 as superphosphate. A top-dressing of 56 kg/ha of N as ammonium nitrate was applied during the first season of growth. Seeds were hand-planted in parallel hoe-drawn rows approximately 30 cm apart and 3.0 - 4.6 m long (according to limitations of terrain) at a depth of 1.3 - 2.5 cm, and a rate of 83 seeds per meter (25 seeds per linear foot).

Table 1. Site description of the five Colorado test plots for high altitude revegetation study.

Site	Location	Elevation Meters	Elevation Feet	Approx. Slope/Aspect
Breckenridge	Ski slope	3895	10,700	20%/NE
Climax	Clearing NW of Fremont Pass	4004	11,000	5%/N
Eisenhower Tunnel	Bench cut above gravel quarry	4004	11,000	5%/SE
Urad	Disturbed subalpine clearing	3858	10,600	5%/E
Winter Park	Ski slope	3858	10,600	15%/N

Table 2. Significance of cultivar and location effects for subalpine cultivar test plots.

PLANT GROUP	FALL Cultivar	FALL Location	FALL Cult.x Loc.	SPRING Cultivar	SPRING Location	SPRING Cult.x Loc.
SMALL FORBS						
ES[1]	*	NS	*	*	NS	***
EV	*	NS	NS	*	NS	*
FS	NS	NS	NS	*	NS	***
FV	NS	NS	NS	*	NS	***
LARGE FORBS						
ES	***	*	NS	***	**	NS
EV	NS	**	NS	***	**	NS
FS	*	***	**	NS	**	**
FV	NS	***	**	NS	**	*
SMALL GRASSES						
ES	***	*	NS	***	*	***
EV	***	NS	NS	***	NS	*
FS	***	NS	NS	***	NS	NS
FV	***	*	NS	***	NS	NS
MEDIUM GRASSES						
ES	***	**	*	***	NS	NS
EV	***	**	NS	***	NS	NS
FS	***	*	**	NS	*	***
FV	***	NS	**	*	***	***
LARGE GRASSES						
ES	***	NS	NS	***	*	NS
EV	***	NS	NS	***	*	NS
FS	***	NS	NS	***	**	*
FV	***	*	NS	***	**	*

1/ ES = Early Stand   FS = Final Stand
EV = Early Vigor   FV = Final Vigor

2/ * Significant at p = .05
** Significant at p = .01
*** Significant at p = .001
NS Non-significant

Plots were observed near the end of the growing season for the first few years after planting and finally in 1983. This allowed for an evaluation of both establishment and persistence of each cultivar. Ratings were made for stand and vigor, each on a scale of 0 to 5 (0 = not present, 5 = excellent). Plants were rated relative to the capacity for growth of the species (rather than in comparison to other species). For example a red fescue rated 3 for vigor would be smaller than a smooth brome rated 2 for vigor because it has achieved better growth within its own potential.

Cultivars were assigned to the following five plant groups for the purpose of statistical comparisons: small and large forbs, and small, medium, and large grasses. Analyses of variance were done to determine performance differences among sites and cultivars for each of the five plant groups and two seasons of planting. T-tests were conducted to compare planting seasons for each of the five plant groups.

RESULTS AND DISCUSSION

Table 2 shows how significantly the four performance measures (early stand and vigor, and final stand and vigor) varied among cultivars, locations, and the cultivar-by-location interaction, for each of the five plant groups and from the two planting seasons. The frequent occurrence of significant differences among locations and the cultivar by location interactions indicate, as could be predicted, that our subalpine sites were not identical, and that cultivars responded differently to them.

Locations

Winter Park was a particularly poor site for the forbs, and grasses performed best at the Eisenhower Tunnel and Breckenridge plots. The following results are therefore not applicable indiscriminately to all subalpine sites in Colorado. Revegetation experts should examine cultivar performance at each of the study sites to help select the appropriate species for their own areas.

Cultivars

The cultivars will be discussed in five separate groups consisting of small and large forbs and small, medium and large grasses. Seasonal differences will be taken up before cultivar comparisons. Detailed results for cultivars at the individual locations and for the separate seasons are presented in Appendix Tables 5-8 (forbs) and 9-12 (grasses). Salient features of those results are discussed in the following sections, and the best candidate species will be summarized at the end.

SMALL FORBS

Season of planting

The small forbs established best in the spring plantings (Table 3) with the exception of alsike clover. Early stand was poor for fall plantings. Although Hull (1964) found no consistent difference between fall and spring plantings of legumes and grasses on mountain rangelands, our results were unexpected since fall plantings are usually recommended for legumes (Townsend, 1974; Brown and Johnston, 1979). Since our seeds were scarified before planting, we can discount the dormancy-breaking effects of overwintering. Another explanation is that since the first thorough evaluation of plots for establishment was not conducted until the fall of 1980 and the fall plantings were made in 1978 and spring plantings in 1979, a true comparison of early establishment is difficult. A 1979 evaluation near the end of the growing season might have given different results. There was however, no significant difference between the two seasons for the persistence ratings so the early seasonal differences were apparently moderated over time.

Cultivar evaluations

For the fall plantings, establishment ratings were highest for alsike and medium red clovers, and birdsfoot trefoil performed well at several locations (Appendix Table 5).

For the spring plantings, medium red clover and birdsfoot trefoil had the highest ratings for both establishment and persistence (particularly 'Viking' and 'Empire'). White clover grew well initially but did not persist as well as the other species. Dwarf English trefoil had good growth at Climax and Urad.

These results were in partial agreement with a study conducted in Hayden, Gunnison, and Fairplay, Colorado in the late 1950's: red clover persisted for 2-5 years (Townsend, 1963) but performance of alsike clover was poor (Townsend, 1962).

LARGE FORBS

Season of planting

Stand establishment was significantly better ($p = .01$) for the spring planting of large forbs than for the fall planting, with the exception of the cicer milkvetch cultivars which all established better when planted in the fall. As with the small forbs, this better overall establishment by the spring planting for most large forbs was unexpected.

Cultivar evaluations

There was a significant difference among cultivars in the fall planting for both early and final stand evaluations. Cicer milkvetch

Table 3.. Best season to plant (Fall or Spring).

	ESTABLISHMENT		PERSISTENCE	
	Stand	Vigor	Stand	Vigor
Small Forbs	*[1/] Spring	NS	NS	NS
Large Forbs	*** Spring	NS	NS	NS
Small Grasses	*** Fall	* Fall	NS	NS
Medium Grasses	NS	NS	NS	NS
Large Grasses	NS	NS	NS	NS

[1/]* Significant at p = .05
** Significant at p = .01
*** Significant at p = .001
NS Non-significant

received high ratings for both establishment and persistence and it appeared to be the best species tested. Of seven cultivars tested, only cicer milkvetch '20-15' performed noticeably poorer than the mean for the group of seven.

Spring plantings showed very different results. There was a significant difference among cultivars for the establishment stand and vigor ratings, with sainfoin and alfalfa being outstanding entries. There were no significant differences among cultivars for persistence ratings. This may have been because time evened out the effects, or because of a significant cultivar by location interaction (Table 2). Breckenridge and Winter Park were poor sites for the large forbs. Alfalfa, flatpea and crownvetch (especially 'Chemung' and 'Emerald') however, did persist at the other sites (Appendix Table 8). Although sainfoin also persisted, stand and vigor ratings declined over the years.

Townsend (1962) and Siemer and Willhite (1972) also found excellent persistence by alfalfa in Colorado mountain meadow test plots.

S M A L L G R A S S E S

Season of planting

Stand and vigor scores for small grasses at the establishment rating were significantly higher for the fall plantings. This plant group contains two species native to Colorado (tufted hairgrass and spike trisetum), one native to Alaska (Bering hairgrass) and five entries of red fescue, native to North American and Eurasian subarctic areas. These species would be expected to benefit from a period of over-wintering, a natural condition for them. There was no significant difference between seasons for the persistence ratings, indicating that after a few years any early advantage is lost.

Cultivar evaluations

Real differences among cultivars existed for the fall plantings. Outstanding entries included red fescue (all cultivars with the exception of 'Tolerant'), creeping red fescue, chewings fescue and hard fescue. These established and persisted exceptionally well and are attractive in growth pattern and color. Tufted hairgrass and spike trisetum persisted well although their establishment was slow.

Spring plantings produced similar results and the same fescues successful in the fall plantings were also excellent in the spring. In addition, sheep fescue showed good persistence.

Several similar studies support these findings. Walker (1982) found red fescue (Festuca rubra rubra) to be successful after three years and Behan (1983) showed good persistence by red and sheep fescue. Both of these studies were conducted on ski slopes in the northern Rocky Mountains. Kenny and Cuany (1978) included chewing's, red, and hard fescue among their best performing small grasses in subalpine test plots, from the 1974 and 1976 test plantings. In contrast, Hull (1964) found poor persistence by red and hard fescue four years after seeding at one test site in Utah.

MEDIUM GRASSES

Season of planting

There was no significant difference between fall and spring plantings of the medium grasses for either the establishment or persistence ratings.

Cultivar evaluations

Of the cultivars tested in the fall plantings, slender wheatgrass (particularly 'Revenue') and Kentucky bluegrass ('Park' and 'CSU 45') showed very good establishment and persistence. Although the perennial ryegrasses performed well initially, they did not persist. In contrast, alpine timothy improved over time.

Spring plantings yielded similar results. Slender wheatgrass (particularly 'Revenue' and 'Primar') established and persisted well. The perennial ryegrass showed fair and excellent persistence only at Climax and Eisenhower Tunnel, respectively. Kentucky bluegrass, however, performed poorly at both of these sites but showed good persistence at the Urad and Breckenridge plots.

The literature shows varied results. Gates (1962) found good establishment by Kentucky bluegrass on revegetated slopes in Idaho (persistence was not examined) and Behan (1983) found good persistence. Our results are in partial agreement with Berg (1974) who concluded that Kentucky bluegrass does persist in subalpine areas, but he said slender wheatgrass and perennial ryegrass do not. Walker (1982) and Behan (1983) found good persistence by slender wheatgrass, but Eaman (1974) found it to be poor in its ability to persist.

LARGE GRASSES

Season of planting

No significant differences were found for establishment or persistence between the spring and fall plantings in the large grasses group.

Cultivar evaluations

Fall and spring plantings produced similar results. Highly significant differences among cultivars occurred in both plantings. The best species for establishment and persistence included meadow and smooth brome, orchardgrass, intermediate wheatgrass and timothy. Tall fescue also performed well, but was better in the spring than in the fall plantings. 'Manchar', 'CSU-3', and 'Carlton' were particularly good varieties of smooth brome, while 'Tegmar' was the poorest of the intermediate wheatgrass entries. Meadow brome 'Regar' was outstanding in both planting seasons.

Most of these results were consistent with other studies. Persistence by smooth brome was found by Gomm (1962), Hull (1964), Berg (1974), and Behan (1983). Orchardgrass persisted in studies conducted by Gomm (1962), Behan (1983), and Kenny and Cuany (1978), but not in studies by Hull (1964) and Berg (1974). Hull (1964) also found excellent persistence by intermediate wheatgrass. Timothy persisted in the study by Behan (1983) but not in studies by others (Hull, 1964; Berg, 1974).

CONCLUSIONS AND SUMMARY

These adaptation trials consisted of five subalpine test plots which were established in the central Rocky Mountains of Colorado during the fall of 1978 and the late spring of 1979. A total of 107 strains of grasses and legumes, mostly introduced cultivars but a few natives, belonging to 32 species, were rated by visual inspection almost every year from 1979 to 1983 for stand and vigor (0 = not present, 5 = excellent). This allowed for separate evaluations of establishment success and long-term persistence, both essential to revegetation of high altitude disturbed lands for various end-uses.

Statistical comparison was facilitated by dividing the 107 strains into five groups consisting of 17 small forbs, 17 large forbs, 24 small grasses, 24 medium grasses, and 25 large grasses. The outstanding species within each group, noted separately by planting season, are presented in Table 4, and have been commented on in the previous section. Most cultivars or experimental strains within a species were not significantly different in performance, although exceptionally good or poor strains were noted. There was some evidence of cultivar by location interaction, shown in Table 2, and therefore detailed results for the strains tested at the five locations would need to be consulted in Appendix Tables 5 through 12. The species named in Table 4 are recommended because they showed overall good performance in establishment or persistence or both.

A t-test was performed for each plant group to determine differences between fall and spring plantings. Small and large forbs established better in spring plantings, which was rather unexpected. The moisture and temperature conditions are probably better for seed that can germinate early in the season, after overwintering in the soil, than for seed planted later in the spring when drier and hotter conditions prevail. Small grasses established better in fall plantings, while medium and large grasses showed no significant difference in establishment due to planting season. Large grasses in general have large seeds and considerable seedling vigor. The persistence evaluations showed no significant difference between planting seasons for any of the plant groups, suggesting a moderating influence of time.

Although most of the species tested are not native to this region they appear adapted to subalpine conditions and can be successfully used in revegetation projects. This may not be true at higher elevations

Table 4. Best species tested for revegetation of subalpine sites in Colorado.

SMALL FORBS

Fall	E,P[1]	Spring	E,P
medium red clover	E	medium red clover	E,P
birdsfoot trefoil	E	birdsfoot trefoil	E,P
alsike clover	E		

LARGE FORBS

Fall	E,P	Spring	E,P
cicer milkvetch	E,P		
		alfalfa	E,P
		crownvetch	P
		flatpea	P
		sainfoin	E,P

SMALL GRASSES

Fall	E,P	Spring	E,P
chewing's fescue	E,P	chewing's fescue	E,P
hard fescue	E,P	hard fescue	E,P
red fescue	E,P	red fescue	E,P
creeping red fescue	E,P	creeping red fescue	E,P
tufted hairgrass	E,P		
spike trisetum	P		
		sheep fescue	P

MEDIUM GRASSES

Fall	E,P	Spring	E,P
Kentucky bluegrass	E,P	Kentucky bluegrass	E
perennial ryegrass	E	perennial ryegrass	E
slender wheatgrass	E,P	slender wheatgrass	E,P
alpine timothy	P		

LARGE GRASSES

Fall	E,P	Spring	E,P
meadow brome	E,P	meadow brome	E,P
smooth brome	E,P	smooth brome	E,P
orchardgrass	E,P	orchardgrass	E,P
interm. wheatgrass	E,P	interm. wheatgrass	E,P
timothy	E,P	timothy	E,P
tall fescue	E,P	tall fescue	E,P

1/ E = Establishment
P = Persistence

where native species may be most appropriate for revegetation. Etra (1983) and Guillaume (1984) have addressed this topic more thoroughly, from the viewpoints of seed supplies of suitable species and the reclamation techniques needed in the alpine zone.

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APPENDIX TABLE 5. FALL PLANTINGS: ESTABLISHMENT

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		$\bar{X}$	
			S	V	S	V	S	V	S	V	S	V	S	V
	SMALL FORBS													
alsike clover	7-20052	Trifolium hybridum	2.5	1.5	1.0	3.2	1.0	2.0	2.5	1.0	1.0	1.0	1.6	1.7
*	coated													
*	uncoated													
ladino clover	Merit	Trifolium repens	1.0	1.5	0.5	0.7	1.0	0.7	0	0	0.5	0.5	0.6	0.7
medium red clover	Bemidji	Trifolium pratense	1.5	2.0	0.5	1.5	1.0	2.0	1.0	2.5	1.0	1.0	1.0	1.8
*	MSS78 (Jack)													
*	Montrose													
	Mi/Mo (NK)		1.5	1.5	0.5	2.0	2.0	1.7	1.0	1.5	1.0	1.0	1.2	1.5
white clover	Idaho	Trifolium repens	1.5	1.5	2.0	2.2	1.0	0.7	0	0	1.0	1.0	0.8	0.8
	New Zealand		2.5	2.0	0.5	0.7	1.0	1.2	0.5	1.0	0	0	1.8	1.0
*	N.Z. coated													
*	N.Z. uncoated													
big trefoil	Marshfield	Lotus pedunculatus	0.5	0.5	1.0	1.5	0	0	0	0	0	0	0.3	0.4
birdsfoot trefoil	Cascade	Lotus corniculatus	1.5	2.0	2.0	2.7	2.0	2.7	0	0	0	0	1.1	1.5
	Empire		1.0	1.5	2.5	3.0	1.5	3.2	0.5	0.5	0	0	0.9	1.6
	Viking		1.5	2.5	1.0	1.2	2.0	2.5	0	0	0	0	0.9	1.2
dwarf English trefoil	Kalo	Lotus corniculatus arvensis	2.0	2.0	2.5	2.0	1.5	2.5	0.5	0.5	0.5	0.5	1.4	1.5
	LARGE FORBS													
alfalfa	Ladak	Medicago sativa	1.5	1.0	1.0	1.7	1.0	2.7	1.5	1.5	0	0	1.0	1.4
*	Ladak coated													
*	Ladak uncoated													
crownvetch	Chemung	Coronilla varia	1.0	1.0	1.0	1.0	1.5	2.5	0.5	1.0	0	0	0.8	1.3
	Emerald		1.5	1.5	0.5	1.0	2.0	3.2	0	0	0	0	0.8	1.1
	Penngift		1.0	1.0	2.0	1.7	2.5	3.5	0.5	1.0	0	0	1.2	1.4
flatpea	Lathco	Lathyrus sylvestris	2.0	1.5	2.0	1.7	2.0	2.5	1.0	1.0	0	0	1.4	1.3
cicer milkvetch	C-4	Astragalus cicer	1.5	1.5	1.5	3.0	2.5	2.5	2.0	2.0	0	0	1.0	1.8
	Dotzenko		2.0	2.0	2.5	2.5	2.5	3.0	2.0	2.0	0	0	1.8	1.9
	Lutana		2.0	1.0	1.5	2.7	1.5	2.5	1.5	1.5	0	0	1.3	1.5
	Strohman		2.0	2.0	2.5	3.2	2.5	2.7	1.5	1.5	0	0	1.7	1.9
	Sugarbeet #2		2.5	2.5	2.5	3.5	3.0	2.5	1.5	2.0	0	0	1.9	2.1
	Wellington		2.5	1.0	2.0	2.7	2.5	2.5	2.0	2.5	0	0	1.8	1.7
	20-15		2.0	1.5	1.0	2.5	2.5	2.7	1.5	2.0	0	0	1.4	1.7
sainfoin	Eski	Onobrychis viciaefolia	2.0	3.0	1.0	1.0	0.5	0.2	0	0	0	0	0.7	0.8
	Melrose		1.5	2.0	1.0	1.5	1.0	1.2	2.0	2.0	0	0	1.1	1.3
	Remont		1.5	2.0	1.0	1.0	0.5	1.2	1.5	2.5	0	0	0.9	0.9

*Not planted

APPENDIX TABLE 6. FALL PLANTINGS: PERSISTENCE

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		$\bar{X}$	
			S	V	S	V	S	V	S	V	S	V	S	V
	SMALL FORBS													
alsike clover	7-20052	Trifolium hybridum	2.5	4.0	3.0	3.0	1.0	2.0	0.5	1.5	0.5	0.5	1.5	2.2
*	coated													
*	uncoated													
ladino clover	Merit	Trifolium repens	2.5	4.0	0.5	1.0	1.5	2.0	1.0	3.0	0	0	1.1	2.0
medium red clover	Bemidji	Trifolium pratense	2.5	4.0	1.5	2.5	1.0	2.0	1.0	3.0	0.5	0.5	1.3	2.4
*	MSS78 (Jack)													
*	Montrose													
	Mi/Mo (NK)		2.5	4.0	0.5	1.5	1.5	2.0	0.5	1.0	0	0	1.0	1.7
white clover	Idaho	Trifolium repens	2.5	4.0	2.0	2.5	1.0	1.5	0	0	0	0	1.1	1.6
	New Zealand		2.5	4.0	2.0	2.5	1.5	1.5	0	0	0	0	1.2	1.6
*	N. Z. coated													
*	N. Z. uncoated													
big trefoil	Marshfield	Lotus pedunculatus	0	0	1.5	1.0	0	0	0	0	0	0	0.3	0.2
birdsfoot trefoil	Cascade	Lotus corniculatus	1.5	2.0	2.5	2.5	3.5	4.5	0.5	0.5	0	0	1.6	1.9
	Empire		1.5	2.0	1.5	3.0	3.0	4.0	2.0	3.5	0	0	1.6	2.5
	Viking		1.5	2.0	1.5	1.5	3.0	3.5	0.5	0.5	0	0	1.3	1.5
dwarf English trefoil	Kalo	Lotus corniculatus arvensis	0	0	2.5	3.0	3.0	4.0	1.5	2.0	0	0	1.4	1.8
	LARGE FORBS													
alfalfa	Ladak	Medicago sativa	0	0	0.5	1.0	2.5	3.5	2.0	3.0	0	0	1.0	1.3
*	Ladak coated													
*	Ladak uncoated													
crownvetch	Chemung	Coronilla varia	0	0	0	0	4.0	5.0	0	0	0	0	0.8	1.0
	Emerald		0	0	1.0	1.0	4.0	5.0	0	0	0	0	1.0	1.2
	Penngift		0	0	2.0	2.0	4.0	5.0	0.5	1.0	0	0	1.3	1.6
flatpea	Lathco	Lathyrus sylvestris	0	0	0	0	1.5	2.0	1.0	1.5	0	0	0.5	0.7
cicer milkvetch	C-4	Astragalus cicer	2.0	2.5	1.5	3.0	3.5	4.0	1.5	2.5	0	0	1.7	2.4
	Dotzenko		2.0	2.5	2.0	2.5	3.5	4.0	1.5	2.0	0	0	1.8	2.2
	Lutana		2.0	2.5	2.0	2.5	3.5	4.0	1.5	1.5	0	0	1.8	2.1
	Strohman		2.0	2.5	2.5	3.5	3.5	4.0	2.0	2.0	0	0	2.0	2.4
	Sugarbeet #2		2.0	2.5	1.0	1.5	3.5	4.0	2.0	2.5	0	0	1.8	2.0
	Wellington		2.0	2.5	2.0	2.0	3.5	4.0	3.0	2.5	0	0	2.1	2.2
	20-15		2.0	2.5	0.5	0.5	3.5	4.0	1.5	2.5	0	0	0.7	1.9
sainfoin	Eski	Onobrychis viciaefolia	1.0	1.5	1.5	2.0	0	0	1.0	1.5	0	0	0.7	1.0
	Melrose		1.0	1.5	2.0	2.5	1.0	1.5	1.5	1.5	0	0	1.1	1.4
	Remont		1.0	1.5	1.5	1.0	1.0	1.0	2.0	3.0	0	0	1.1	1.3

*Not planted

APPENDIX TABLE 7. SPRING PLANTINGS: ESTABLISHMENT

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		X̄	
			S	V	S	V	S	V	S	V	S	V	S	V
SMALL FORBS														
alsike clover	7-20052	*Trifolium hybridum*	2.5	3.5	1.0	1.2	1.5	1.5	2.0	2.0	0	0	1.4	1.6
	coated				0.5	1.7					0	0	0.2	0.9
	uncoated				1.0	1.7					0	0	0.5	0.9
ladino clover	merit	*Trifolium repens*	3.0	2.5	1.0	0.5	1.5	1.5	1.5	1.0	0.5	0.5	1.5	1.2
medium red clover	Bemidji	*Trifolium pratense*	1.5	2.5	0.2	1.5	2.0	2.5	3.0	3.5	0	0	1.3	2.0
	MSS78 (Jack)		1.5	2.5	1.5	2.7	2.0	2.2	2.0	3.0	0	0	1.4	2.1
	Montrose		2.5	2.0	1.5	3.0	2.5	2.5	3.0	3.0	0	0	1.9	2.1
	Mi/Mo (NK)		1.5	2.0	1.0	2.2	2.0	2.0	2.5	3.0	0.5	0.5	1.5	1.9
white clover	Idaho	*Trifolium repens*	2.0	3.5	0.5	1.7	1.5	1.7	2.0	2.0	0.5	0.5	1.3	1.9
	New Zealand		2.0	2.5	0.5	1.2	0.5	0.7	1.5	2.0	0	0	0.9	1.3
	N. Z. coated		2.5	2.0			2.0	2.0	1.5	1.0			2.0	1.6
	N. Z. uncoated		2.5	2.5			2.5	2.5	1.0	1.5			2.0	2.2
big trefoil	Marshfield	*Lotus pedunculatus*	0	0	0	0	0	0	0	0	1.0	1.0	0.2	0.2
birdsfoot trefoil	Cascade	*Lotus corniculatus*	1.5	2.0	1.5	2.2	1.5	1.7	1.5	2.0	0.5	0.5	1.3	1.7
	Empire		3.0	2.0	1.0	2.5	1.5	2.0	2.5	2.0	0.5	0.5	1.7	1.8
	Viking		1.5	2.0	2.5	2.6	1.5	1.5	2.0	2.5	0.5	0.5	1.6	1.8
dwarf English trefoil	Kalo	*Lotus corniculatus arvensis*	2.0	1.5	1.5	1.7	2.5	2.2	2.5	2.5	0.5	0.5	1.8	1.7
LARGE FORBS														
alfalfa	Ladak	*Medicago sativa*	1.5	1.5	1.5	1.5	3.0	3.0	3.5	2.0	0	0	1.9	1.6
	Ladak coated		2.0	2.0	1.0	3.0	3.0	2.7	3.0	2.5	0	0	1.8	2.0
	Ladak uncoated		2.0	2.0	0.5	1.5	3.5	3.0	2.5	2.5	0	0	1.7	1.4
crownvetch	Chemung	*Coronilla varia*	1.0	1.0	1.0	1.7	2.5	2.2	0.5	0.5	0	0	1.0	1.1
	Emerald		1.0	1.5	2.0	1.7	2.5	2.5	1.0	1.5	0	0	1.3	1.4
	Penngift		1.0	1.0	0.5	0.2	2.5	2.2	0.5	1.0	0	0	0.9	0.9
flatpea	Lathco	*Lathyrus sylvestris*	2.5	1.5	2.5	2.2	3.5	2.7	1.5	2.0	1.5	1.0	2.3	1.9
cicer milkvetch	C-4	*Astragalus cicer*	0.5	0.5	1.0	2.0	3.0	2.7	2.0	2.0	0	0	1.3	1.4
	Dotzenko		1.0	1.0	0.5	2.0	3.5	3.2	2.0	2.5	0	0	1.4	1.7
	Lutana		1.0	0.5	1.5	1.0	1.0	1.5	2.0	2.0	0	0	1.1	1.0
	Strohman		1.0	1.5	1.0	0.7	3.5	3.2	1.5	1.5	0	0	1.4	1.4
	Sugarbeet #2		1.0	1.0	0.5	1.2	3.5	3.2	3.0	2.5	0	0	1.6	1.6
	Wellington		1.0	1.0	1.5	1.0	3.0	3.0	2.0	1.5	0	0	1.5	1.3
	20-15		1.0	1.0	1.0	1.2	4.0	3.5	2.5	2.0	0	0	1.7	1.5
sainfoin	Eski	*Onobrychis viciaefolia*	2.5	3.0	3.5	3.2	3.0	3.0	3.5	2.5	1.0	0.5	2.7	2.4
	Melrose		2.5	2.5	3.0	3.0	3.5	3.5	4.0	2.5	1.5	1.0	3.1	2.5
	Remont		2.0	2.0	3.0	3.5	2.5	2.7	3.5	2.5	1.5	1.0	2.5	2.3

*Not planted

APPENDIX TABLE 8. SPRING PLANTINGS: PERSISTENCE

Common Name	Variety	Specific Name	Breck.		Climax		Eisen Tun		Urad		W Park		X̄	
			S	V	S	V	S	V	S	V	S	V	S	V
SMALL FORBS														
alsike clover	7-20052	*Trifolium hybridum*	2.0	3.5	1.0	1.5	2.5	3.0	2.0	3.0	0	0	1.5	2.2
	coated				2.0	2.5					0	0	1.0	1.2
	uncoated				1.5	1.5					0	0	0.7	0.7
ladino clover	Merit	*Trifolium repens*	2.0	3.5	0	0	2.0	2.5	0	0	0.5	1.0	0.9	1.4
medium red clover	Bemidji	*Trifolium pratense*	2.0	3.5	1.5	1.5	3.0	3.0	2.5	3.0	0	0	1.8	1.7
	MSS78 (Jack)		2.0	3.5	1.5	1.5	2.5	3.0	1.0	2.5	0	0	1.4	2.1
	Montrose		2.0	3.5	1.5	1.5	2.5	3.0	3.0	3.0	0	0	1.4	1.5
	Mi/Mo (NK)		2.0	3.5	2.0	2.0	3.0	3.0	2.5	3.0	0	0	1.9	2.3
white clover	Idaho	*Trifolium repens*	2.0	3.5	1.0	1.5	1.5	2.0	0	0	0	0	0.9	1.4
	New Zealand		2.0	3.5	1.0	1.5	1.5	1.5	0	0	0	0	0.9	1.3
	N.Z. coated		3.0	3.5			1.0	1.5	2.0	2.5			2.0	2.5
	N. Z. uncoated		3.0	2.5			1.5	1.5	0.5	0.5			1.7	1.8
big trefoil	Marshfield	*Lotus pedunculatus*	0	0	0	0	0	0	0	0	0.5	0.5	0.1	0.1
birdsfoot trefoil	Cascade	*Lotus corniculatus*	1.0	2.0	2.5	2.5	2.5	3.5	1.0	2.5	0	0	1.4	2.1
	Empire		1.0	1.5	2.5	3.5	2.5	3.5	3.0	3.5	0	0	1.8	2.4
	Viking		2.0	3.0	4.0	4.0	3.0	3.5	3.0	4.0	0	0	2.4	3.6
dwarf English trefoil	Kalo	*Lotus corniculatus arvensis*	1.0	1.5	2.5	3.5	3.5	3.0	1.5	3.5	0	0	1.7	2.3
LARGE FORBS														
alfalfa	Ladak	*Medicago sativa*	0	0	2.5	2.0	3.5	3.0	3.5	3.0	0	0	1.8	1.6
	Ladak coated		1.0	0.5	2.0	2.5	2.0	2.5	3.5	3.0	0	0	1.7	1.7
	Ladak uncoated		0	0	2.0	2.5	3.5	3.0	2.5	3.0	0	0	1.6	1.7
crownvetch	Chemung	*Coronilla varia*	0	0	1.5	3.0	3.5	4.5	1.0	1.5	0	0	1.2	1.8
	Emerald		0	0	2.5	2.5	3.5	4.5	1.5	2.0	0	0	1.5	1.8
	Pennigift		0	0	1.5	1.5	3.5	4.5	0.5	1.0	0	0	1.1	1.4
flatpea	Lathco	*Lathyrus sylvestris*	0	0	3.0	3.5	4.5	4.5	2.0	2.5	0	0	1.9	2.1
cicer milkvetch	C-4	*Astragalus cicer*	0	0	1.0	2.0	3.5	3.5	1.0	1.0	0	0	1.1	1.3
	Dotzenko		0	0	1.0	2.0	3.5	3.5	1.5	1.0	0	0	1.2	1.3
	Lutana		0	0	1.0	2.0	3.5	3.5	1.0	1.5	0	0	1.1	1.4
	Strohman		0	0	1.0	2.0	3.5	3.5	1.0	1.0	0	0	1.1	1.3
	Sugarbeet #2		0	0	1.0	2.0	3.5	3.5	1.0	1.0	0	0	1.2	1.3
	Wellington		0	0	1.0	2.0	3.5	3.5	1.5	1.0	0	0	1.2	1.3
	20-15		0	0	1.0	2.0	3.5	3.5	0.5	0.5	0	0	1.0	1.2
sainfoin	Eski	*Onobrychis viciaefolia*	0	0	2.0	2.0	3.5	3.0	2.5	2.5	0	0	1.6	1.5
	Melrose		0	0	3.0	3.0	3.5	4.0	3.0	2.0	0	0	1.9	1.8
	Remont		0	0	1.5	1.0	2.5	2.5	2.5	1.5	0	0	1.3	1.0

*Not planted

APPENDIX TABLE 9. FALL PLANTINGS: ESTABLISHMENT

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		$\bar{X}$	
			S	V	S	V	S	V	S	V	S	V	S	V
	SMALL GRASSES													
arcticgrass	IAS 405	Arctagrostis latifolia	0	0	0	0	0.5	0.2			1.5	0.5	0.5	0.2
Canada bluegrass	Reubens	Poa compressa	4.0	3.5	1.5	2.2	3.0	2.7	1.5	2.0	0.5	0.5	2.1	2.2
Chewing's fescue	Banner	Festuca rubra commutata	0.5	3.5	1.5	1.2	3.0	3.0	3.0	3.0	3.0	2.5	2.2	2.6
	Koket		4.5	4.0	2.0	2.0	3.0	3.0	2.5	2.5	2.5	2.5	2.9	2.8
creeping red fescue	Corona	Festuca rubra trichophylla	4.5	3.0	0.5	1.2	3.0	3.7	2.5	2.5	2.5	2.5	2.6	2.6
	Fortress		4.5	3.5	1.0	1.2	4.0	3.5	2.5	3.0	2.5	3.0	2.9	2.8
hard fescue	Balmoral	Festuca ovina duriuscula	3.5	2.5	0.5	1.0	2.5	2.5	2.0	2.0	3.0	2.5	2.3	2.1
	Biljart		4.0	3.0	1.0	1.5	3.0	2.2	2.5	2.5	3.0	3.5	2.7	2.5
	Durar		3.0	2.0	1.0	1.2	2.5	3.0	2.0	2.0	2.5	3.0	2.2	2.2
red fescue	Arctared	Festuca rubra	3.5	2.5	1.0	1.5	2.5	2.5	2.0	2.5	2.0	3.0	2.2	2.4
	Jamestown		4.5	3.5	2.5	2.2	3.0	3.2	3.0	2.5	2.5	2.5	3.1	2.8
	Pennlawn		4.5	3.0	2.0	2.2	2.5	2.7	2.5	2.5	2.5	3.0	2.8	2.7
	Tolerant		0.5	0.5	0.5	0.7	1.0	1.2	0	0	0	0	0.4	0.5
	IAS 294		3.0	2.0	0.5	0.5	2.5	2.5	2.5	2.0	2.0	2.0	2.1	1.8
	IAS 83		4.5	3.5	1.0	1.2	4.0	4.0	2.5	2.5	2.5	2.5	2.9	2.7
sheep fescue	IAS 293	Festuca ovina	3.0	3.0	0.5	0.7	2.0	2.2	0.5	0.5	1.5	1.5	1.5	1.6
	IAS 299		1.5	2.0	0	0	1.0	1.5	0.5	1.0	0.5	0.5	0.7	1.0
	77-156		3.5	3.0	0.5	1.2	1.5	2.2	2.0	2.5	1.5	2.0	1.8	2.2
Bering hairgrass	IAS 19	Deschampsia beringensis	3.5	3.0	2.0	2.2	1.0	1.5	0.5	1.0	1.5	1.5	1.7	1.8
	IAS 74		2.0	2.0	1.0	1.5	1.0	1.0	1.0	1.5	1.5	1.0	1.3	1.4
tufted hairgrass	Eisenhower	Deschampsia caespitosa	1.5	2.0	2.0	2.2	2.0	2.2	1.0	1.5	3.0	3.0	1.9	2.2
	IAS 319		2.0	2.0	2.0	1.5	1.5	2.2	0	0	2.5	3.0	1.6	1.7
spike trisetum	Climax	Trisetum spicatum	1.5	1.5	1.5	1.7	2.0	2.2	1.5	2.0	1.0	1.0	1.5	1.7
	Leadville		1.0	1.0	0	0	1.5	2.0	0.5	0.5	0	0	0.6	0.7
	MEDIUM GRASSES													
Kentucky bluegrass	Baron	Poa pratensis	2.5	3.0	1.0	0.5	1.5	2.0	1.0	1.5	0.5	0.5	1.3	1.5
	CSU 45KB		2.0	1.5	1.0	1.5	2.5	2.5	0.5	1.5	0.5	0.5	1.3	1.3
	CSU 58KB		1.0	2.0	0.5	0.7	2.0	2.0	1.0	1.0	0.5	0.5	1.0	1.2
	CSU 85KB		1.5	2.5	0	0	1.0	2.0	0.5	0.5	0.5	0.5	0.7	1.1
	Parade		3.0	2.5	1.0	1.5	1.5	2.0	1.0	1.0	0.5	0.5	1.4	1.5
	Park		2.5	3.5	0.5	1.0	2.5	2.5	2.0	3.0	0.5	0.5	1.6	2.1
*	Park coated													
*	Park uncoated													
	Rugby		1.5	2.0	0.5	0.7	1.5	2.5	1.0	0.5	0.5	0.5	1.0	1.2
bluejoint reedgrass	Sourdough	Calamagrostis canadensis	0	0	0	0	0	0	0	0	0	0	0	0
perennial ryegrass	Citation	Lolium perenne	2.0	2.5	1.0	1.7	3.0	2.2	2.5	2.0	2.5	1.5	2.2	2.0
	Linn		4.0	4.0	2.0	2.2	3.0	2.5	2.5	2.0	0	0	2.3	2.1
	Manhattan		3.5	3.0	0.5	1.5	4.0	3.2	3.0	2.5	1.0	1.0	2.4	2.2
	Pennfine		3.5	3.0	2.0	2.0	3.0	2.5	2.5	2.0	1.0	1.0	2.4	2.1
alpine timothy	Climax	Phleum commutatum	3.0	3.0	1.0	2.2	1.5	1.5	0	0	1.0	1.0	1.3	1.5
	Eisenhower		3.0	3.0	1.0	1.7	1.0	1.5	0.5	1.0	0.5	0.5	1.2	1.5
bearded wheatgrass	IAS 72 (AK)	Agropyron subsecundum	0	0	0.5	0.2	0	0	1.0	1.0	0.5	0.5	0.4	0.3
silky wheatgrass	619 D11	Agropyron macrourum	0.5	0.5	0	0	0.5	0.5	0	0	0.5	0.5	0.3	0.3
slender wheatgrass	Primar	Agropyron trachycaulum	1.5	1.0	0	0	1.0	1.5	1.5	1.0	0.5	1.0	0.9	0.9
	Revenue		4.5	2.5	1.0	1.0	3.0	4.0	3.0	3.0	1.0	1.0	2.5	2.3
	IAS 70		1.5	0.5	0	0	1.0	0.7	0.5	1.0	0.5	0.5	0.7	0.5
	731 B5		1.0	1.0	0.5	0.5	0.5	0.7	0	0	0	0	0.4	0.3
	M60 141		0.5	1.0	0.5	0.7	0	0	0	0	0	0	0.2	0.3
western wheatgrass	Tincup	Agropyron smithii	2.0	1.5	0.5	1.0	2.0	3.0	3.0	2.5	0.5	0.5	1.6	1.7
	LARGE GRASSES													
arctic brome	71807	Bromus pumpellianus dicksonii	1.5	1.0	0	0	0.5	0.2	0.5	1.0	0	0	0.5	0.4
meadow brome	Regar	Bromus bierbersteinii	4.0	2.5	2.0	3.2	3.0	3.0	2.5	3.0	1.0	1.0	2.5	2.5
smooth brome	Carlton	Bromus inermis	3.0	2.5	2.0	2.5	3.5	2.7	2.5	3.0	1.5	1.5	2.5	2.4
	CSU-3		2.5	1.5	2.5	2.2	2.0	3.0	2.0	3.0	1.5	1.5	2.1	2.2
*	Lincoln coated													
*	Lincoln uncoated													
*	Magna													
	Manchar		2.5	1.5	3.0	2.2	3.0	3.0	3.0	3.0	1.5	1.5	2.6	2.2
tall fescue	CSU-R	Festuca arundinacea	2.0	1.5	1.5	2.2	3.5	2.7	1.0	1.0	0	0	1.6	1.5
	Fawn		2.0	2.5	1.5	2.0	3.5	2.7	1.0	1.0	0	0	1.6	1.6
*	Fawn coated													
*	Fawn uncoated													
	Kentucky-31		2.0	2.0	2.0	2.5	3.5	3.2	1.5	1.5	0.5	1.0	1.9	2.0
	T-5		3.0	2.5	1.5	1.7	3.0	2.2	3.0	3.0	1.0	1.0	2.3	2.1
*orchardgrass	Chinook	Dactylis glomerata												
	Potomac		3.0	2.5	2.5	3.0	3.0	3.0	1.0	1.0	1.0	1.0	2.1	2.1
	Sterling		3.5	3.0	2.0	2.0	3.5	3.0	2.5	3.0	2.0	2.5	2.7	2.7
timothy	Bottnia II	Phleum pratense	4.0	4.0	1.0	2.0	2.5	2.2	2.0	3.0	1.0	1.5	2.1	2.5
	Climax		4.0	3.5	3.0	2.7	2.0	2.0	2.0	3.0	1.5	1.5	2.5	2.5
	Itasca		3.5	3.5	2.0	1.7	3.0	2.5	1.0	1.5	1.5	1.5	2.2	2.1
intermed. wheatgrass	Amur	Agropyron intermedium	3.5	3.0	2.5	3.0	3.0	4.0	3.5	2.0	1.0	0.5	2.7	2.5
*	Chief													
*	Slate													
	Tegmar		3.5	2.0	1.5	2.5	3.0	3.7	1.5	1.0	0	0	2.4	2.3
*altai wildrye	Prairieland	Elymus angustus												

*Not planted

APPENDIX TABLE 10. SPRING PLANTINGS: ESTABLISHMENT

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		X̄	
			S	V	S	V	S	V	S	V	S	V	S	V
	SMALL GRASSES													
*arcticgrass	IAS405	Arctagrostis latifolia												
Canada bluegrass	Reubens	Poa compressa	2.5	2.5	0.5	0.5	2.0	2.0	1.5	1.5	0	0	1.3	1.3
Chewing's fescue	Banner	Festuca rubra commutata	3.0	3.5	2.0	2.0	3.0	3.0	2.0	3.0	3.5	3.0	2.7	2.9
	Koket		4.0	3.5	0.5	1.7	3.0	3.2	3.0	2.5	4.0	3.0	2.9	2.8
creeping red fescue	Corona	Festuca rubra tricophila	2.0	2.0	1.0	1.2	3.0	2.7	2.0	2.5	3.5	2.5	2.3	2.2
	Fortress		3.5	3.0	2.0	1.5	2.5	3.2	2.5	2.5	3.0	3.0	2.7	2.6
hard fescue	Balmoral	Festuca ovina duriuscula	2.5	2.5	0.2	0.5	2.5	2.2	3.0	3.0	1.0	1.0	1.8	1.8
	Biljart		2.5	2.5	0.2	0.5	2.5	3.0	2.0	3.0	2.0	2.5	1.8	2.3
	Durar		2.0	3.0	0.5	0.7	1.5	2.2	2.0	3.0	1.0	1.5	1.4	2.1
red fescue	Arctared	Festuca rubra	1.5	1.5	2.0	1.7	1.5	2.5	2.0	2.0	2.5	2.0	1.9	1.9
	Jamestown		3.0	3.0	1.0	2.0	3.0	2.7	3.0	2.5	3.0	3.0	2.6	2.6
	Pennlawn		1.5	2.5	0.5	1.2	2.0	2.2	2.0	2.5	2.5	2.0	1.7	2.1
	Tolerant		0.5	1.0	0.5	1.0	0.5	0.7	0	0	0	0	0.3	0.5
	IAS 294		1.5	1.5	1.5	1.2	2.5	1.5	2.5	2.0	1.0	1.5	1.8	1.5
	IAS 83		3.0	3.0	2.5	2.5	2.5	2.7	2.5	2.5	3.0	2.5	2.7	2.6
sheep fescue	IAS 298	Festuca ovina	1.5	2.0	1.0	1.0	2.0	2.5	2.0	1.5	0.5	0.5	1.4	1.5
	IAS 299		0.5	0.5	0.2	0.2	1.0	1.7	1.0	1.5	1.5	1.5	0.8	1.1
	77-156		1.5	2.0	0.2	0.2	3.0	2.7	2.5	2.0	2.0	3.0	1.8	2.0
Bering hairgrass	IAS 19	Deschampsia beringensis	2.0	1.5	1.0	0.5	1.5	1.7	0.5	1.0	2.0	2.0	1.4	1.3
	IAS 74		0.5	1.0	0.5	0.5	2.0	1.7	1.0	1.0	1.5	1.5	1.1	1.1
tufted hairgrass	Eisenhower	Deschampsia caespitosa	0.5	1.0	0.2	0.7	1.0	1.2	0.5	1.0	1.5	1.5	0.7	1.1
	IAS 319		1.0	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.1	1.2
spike trisetum	Climax	Trisetum spicatum	0	0	0.2	0.5	1.0	1.0	2.0	1.5	0.5	1.0	0.7	0.8
	Leadville		0	0	0.2	0.2	0	0	0	0	0	0	0.1	0.1
	MEDIUM GRASSES													
Kentucky bluegrass	Baron	Poa pratensis	0	0	1.0	0.7	1.0	1.0	0.5	0.5	0	0	1.3	1.3
	CSU 45KB		2.0	1.5	0	0	1.0	1.0	2.0	2.0	0	0	1.0	0.9
	CSU 58KB		1.0	1.0	0.5	0.5	1.0	1.0	1.0	1.0	0	0	0.7	0.7
	CSU 85KB		0.5	0.5	1.0	0.7	1.0	1.0	0.5	1.0	0	0	0.6	0.6
	Parade		2.0	2.5	0	0	1.0	1.0	1.0	3.0	0	0	0.8	1.3
	Park		1.0	2.0	0.5	1.0	1.0	1.2	1.5	1.5	0	0	1.0	1.2
	Park coated		1.0	1.0	0.5	0.2	0	0	2.0	2.0	0	0	0.7	0.6
	Park uncoated		1.5	1.0	0.5	0.5	0.5	0.7	1.5	2.0	0	0	0.8	0.8
	Rugby		0.5	0.5	0	0	1.0	1.2	1.0	1.5	0	0	0.5	0.6
bluejoint reedgrass	Sourdough	Calamagrostis canadensis	0.5	0.5	0	0	0.5	0.2	0	0	0	0	0.2	0.1
perennial ryegrass	Citation	Lolium perenne	3.0	2.0	1.5	1.5	3.0	2.7	2.0	2.0	2.0	2.0	2.3	2.0
	Linn		4.0	3.5	2.0	1.7	2.5	3.0	3.0	2.5	3.0	3.0	2.9	2.7
	Manhattan		2.0	2.0	2.0	2.0	2.5	3.7	3.5	3.0	3.5	3.0	2.7	2.7
	Pennfine		3.0	3.0	1.5	1.5	2.5	3.0	2.5	3.0	3.0	2.5	2.5	2.6
alpine timothy	Climax	Phleum commutatum	0.5	1.0	0.2	0.5	1.0	1.2	1.0	2.0	0	0	0.5	0.9
	Eisenhower		0.5	1.0	0.5	0.7	0.5	0.7	1.0	1.5	0.5	1.0	1.7	1.0
*bearded wheatgrass	IAS 72(AK)	Agropyron subsecundum												
*silky wheatgrass	619 D11	Agropyron macrourum												
slender wheatgrass	Primar	Agropyron trachycaulum	0.5	1.0	0.5	0.5	2.0	2.7	1.0	2.0	0	0	0.8	1.2
	Revenue		2.0	2.5	3.0	2.5	3.5	4.2	2.0	2.5	1.5	1.5	2.4	2.6
	IAS 70		0.5	0.5	1.0	1.0	0.5	1.2	0	0	0	0	0.4	0.5
*	731 B5													
*	H60 141													
western wheatgrass	Tincup	Agropyron smithii	1.5	2.5	0.2	0.5	2.0	2.5	1.0	1.5	0	0	1.0	1.4
	LARGE GRASSES													
*Arctic brome	718C7	Bromus pumpellianus dicksonii												
meadow brome	Regar	Bromus bierbersteinii	2.5	3.0	3.0	3.0	4.0	4.0	2.5	3.5	2.0	3.0	2.8	3.3
smooth brome	Carlton	Bromus inermis	2.5	2.5	1.0	1.3	3.0	2.7	2.0	2.5	2.0	2.0	2.1	2.2
	CSU-3		2.5	3.5	2.0	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.3	2.7
	Lincoln coated		2.5	2.5	2.0	2.7	3.0	3.5	2.5	2.5	1.5	1.0	2.3	2.4
	Lincoln uncoated		2.0	3.0	2.0	2.5	3.5	3.2	2.0	2.5	1.5	1.0	2.2	2.4
	Magna		1.5	2.0	1.0	1.5	3.0	3.5	2.5	2.5	1.5	2.0	1.9	2.3
	Manchar		2.5	3.0	2.0	1.5	3.0	3.2	3.5	3.0	2.5	2.0	2.7	2.5
tall fescue	CSU-R	Festuca arundinacea	1.5	1.0	0.5	1.2	3.0	3.0	1.0	1.5	1.5	1.0	1.5	1.5
	Fawn		2.0	3.0	1.5	2.2	3.0	4.0	2.0	2.0	1.0	1.0	1.9	2.4
	Fawn coated		3.0	3.5	2.0	2.2	3.0	2.7	2.0	2.5	0	0	2.0	2.2
	Fawn uncoated		3.0	3.5	2.0	2.5	3.0	3.2	3.0	2.0	0	0	2.2	2.2
	Kentucky-31		1.5	2.0	1.0	1.3	3.0	3.0	2.0	1.5	1.0	1.0	1.7	1.7
	T-6		1.0	2.0	2.0	2.0	2.5	3.2	2.0	2.0	1.0	1.0	1.7	2.0
orchardgrass	Chinook	Dactylis glomerata	3.0	3.0	2.5	2.5	3.0	3.2	1.5	2.5	2.0	2.0	2.4	2.6
	Potomac		3.0	4.0	2.0	3.0	2.5	3.5	0.5	1.0	1.0	1.0	1.8	2.5
	Sterling		3.0	4.0	1.5	2.2	3.5	3.2	1.0	1.5	2.0	3.0	2.2	2.8
Timothy	Bottnia II	Phleum pratense	1.5	2.5	1.5	2.5	2.5	2.7	2.5	2.0	0.5	1.0	1.7	2.1
	Climax		2.0	3.0	1.5	2.2	2.0	3.0	2.5	3.0	0.5	1.0	1.9	2.3
	Itasca		2.0	2.5	1.0	2.0	2.5	3.2	2.5	2.5	1.5	1.5	1.9	2.3
intermediate wheatgrass	Amur	Agropyron intermedium	3.0	3.0	2.5	2.7	4.0	4.2	3.0	3.0	2.5	3.0	3.0	3.2
	Chief		4.5	3.5	3.0	3.2	3.5	3.0	3.5	3.0	3.0	3.0	3.5	3.7
	Slate		4.0	3.5	2.5	2.0	3.5	4.2	3.0	3.0	2.5	3.0	3.1	3.1
	Tegmar		2.0	2.5	3.0	2.2	3.5	4.0	2.5	3.0	1.0	1.5	2.4	2.6
altai wildrye	Prairieland	Elymus angustus	1.0	2.0	1.5	1.5	3.0	2.7	3.0	2.5	0	0	1.7	1.7

* Not planted

APPENDIX TABLE 11. FALL PLANTINGS: PERSISTENCE

Common Name	Variety	Specific Name	Breck S	Breck V	Climax S	Climax V	Eisen Tun S	Eisen Tun V	Urad S	Urad V	W Park S	W Park V	$\bar{X}$ S	$\bar{X}$ V
SMALL GRASSES														
arcticgrass	IAS 405	Arctagrostis latifolia	0	0	0	0	0	0	0	0	1.5	1.5	0.3	0.3
Canada bluegrass	Reubens	Poa compressa	3.5	3.5	2.0	1.5	4.5	4.0	2.0	3.0	2.0	2.5	2.8	2.9
Chewing's fescue	Banner	Festuca rubra commutata	4.0	4.0	2.5	3.0	3.5	4.0	3.0	2.5	3.0	3.5	3.2	3.4
	Koket		3.5	3.0	2.5	3.0	3.5	3.5	3.0	3.0	2.5	3.0	3.0	3.1
creeping red fescue	Corona	Festuca rubra tricophila	3.5	3.0	2.0	3.0	4.0	4.0	3.0	3.0	3.0	3.5	3.1	3.1
	Fortress		3.0	3.0	2.0	3.0	4.0	4.0	4.0	3.0	2.5	2.5	3.1	3.1
hard fescue	Balmoral	Festuca ovina duriuscula	3.5	3.5	2.0	2.0	3.0	3.5	3.0	2.5	3.0	3.0	2.9	2.9
	Biljart		3.5	3.5	1.0	1.0	3.0	3.5	3.0	3.0	4.0	3.0	2.9	2.8
	Durar		3.0	3.0	1.5	2.0	3.0	3.0	3.0	2.5	2.5	2.0	2.6	2.5
red fescue	Arctared	Festuca rubra	4.0	3.5	2.0	2.0	3.0	3.5	2.5	2.5	3.0	2.5	2.9	2.8
	Jamestown		4.5	4.5	3.0	3.0	3.0	3.5	2.5	2.5	2.5	3.0	3.3	3.3
	Pennlawn		4.0	4.0	2.5	3.0	3.0	3.0	2.5	2.5	3.0	3.0	3.0	3.1
	Tolerant		2.0	2.5	1.0	1.0	1.0	1.0	2.0	2.5	2.5	3.0	1.7	2.0
	IAS 294		2.5	3.0	1.0	0.5	3.0	3.0	3.5	3.0	2.5	2.5	2.5	2.4
	IAS 83		4.5	4.0	2.0	2.5	4.0	4.0	3.5	3.0	2.5	2.5	3.3	3.2
sheep fescue	IAS 298	Festuca ovina	4.0	3.5	1.0	1.0	3.5	4.0	1.0	1.0	1.5	1.0	2.2	2.1
	IAS 299		3.0	3.0	1.0	1.0	2.0	3.0	2.0	2.0	1.0	1.0	1.8	2.0
	77-156		3.0	4.0	1.5	2.0	3.0	4.0	2.0	2.5	1.5	1.5	2.2	2.8
Bering hairgrass	IAS 19	Deschampsia beringensis	2.5	3.5	2.5	2.0	2.0	2.0	0.5	1.0	2.0	2.0	2.1	2.1
	IAS 74		3.0	3.0	2.5	2.0	1.5	1.5	0.5	1.0	2.0	1.5	1.9	1.8
tufted hairgrass	Eisenhower	Deschampsia caespitosa	3.5	3.5	3.0	3.0	3.5	2.5	1.0	1.0	3.5	4.0	2.9	2.8
	IAS 319		3.0	3.0	2.0	2.0	3.5	2.5	1.5	2.5	3.5	3.0	2.7	2.6
spike trisetum	Climax	Trisetum spicatum	3.0	3.0	2.5	2.5	3.0	3.5	2.0	2.0	2.0	2.5	2.5	2.7
	Leadville		3.0	4.0	2.5	2.5	3.5	4.5	1.5	3.0	2.0	3.5	2.5	3.5
MEDIUM GRASSES														
Kentucky bluegrass	Baron	Poa pratensis	3.0	3.5	1.0	1.0	2.5	3.0	2.0	2.0	1.0	1.0	1.9	2.1
	CSU 45KB		3.0	3.5	3.0	2.5	4.0	3.5	1.5	1.5	1.0	1.5	2.5	2.5
	CSU 58KB		3.0	3.5	2.0	2.0	3.0	3.0	1.5	1.5	1.0	1.0	2.1	2.2
	CSU 85KB		3.0	3.5	1.0	1.0	2.5	3.5	1.0	1.0	2.0	2.0	1.9	2.2
	Parade		3.0	3.5	1.0	1.0	1.5	1.5	1.5	1.5	2.0	1.5	1.8	1.8
	Park		3.0	3.5	1.5	1.5	4.0	4.0	2.5	2.5	1.5	2.0	2.5	2.7
*	Park coated													
*	Park uncoated													
	Rugby		3.0	3.5	1.0	1.0	3.0	3.0	1.0	1.0	1.5	1.5	1.9	2.0
bluejoint reedgrass	Sourdough	Calamagrostis canadensis	0	0	0	0	0	0	0	0	0	0	0	0
perennial ryegrass	Citation	Lolium perenne	0	0	2.0	2.0	3.0	3.0	1.0	1.0	0	0	1.2	1.2
	Linn		0	0	2.0	2.5	3.0	3.5	1.0	1.0	0	0	1.2	1.4
	Manhattan		0	0	1.5	1.5	4.0	3.5	0	0	0	0	1.1	1.0
	Pennfine		0	0	1.5	1.5	3.0	3.0	0.5	0.5	0	0	1.0	1.0
alpine timothy	Climax	Phleum commutatum	3.5	3.5	2.5	3.0	3.0	3.5	1.5	1.5	1.5	1.5	2.4	2.6
	Eisenhower		3.0	3.5	2.0	2.5	2.5	3.5	1.0	2.0	1.5	2.0	2.0	2.7
bearded wheatgrass	IAS 72 (AK)	Agropyron subsecundum	0	0	0	0	1.0	1.0	0	0	1.0	1.0	0.4	0.4
silky wheatgrass	619 D11	Agropyron macrourum	0	0	0	0	1.0	1.5	0	0	1.0	1.0	0.4	0.5
slender wheatgrass	Primar	Agropyron trachycaulum	1.0	1.5	0	0	1.5	1.5	1.5	2.5	0	0	0.8	1.1
	Revenue		3.0	3.0	2.0	2.5	4.0	4.0	4.0	3.5	1.0	1.0	2.8	2.8
	IAS 70		0	0	1.0	1.0	1.0	1.0	0	0	1.0	1.0	0.6	0.6
	731 B5		1.0	1.5	0	0	1.0	1.5	0	0	0	0	0.4	0.6
	H60 141		0	0	2.0	2.5	1.0	1.5	0	0	0	0	0.6	0.8
western wheatgrass	Tincup	Agropyron smithii	1.5	1.5	1.0	1.0	2.5	3.0	2.0	2.0	1.0	1.0	1.6	1.7
LARGE GRASSES														
arctic brome	718C7	Bromus pumpellianus dicksonii	0	0	0	0	0	0	0	0	0	0	0	0
meadow brome	Regar	Bromus bierbersteinii	3.0	2.5	2.5	3.5	4.0	4.0	3.0	2.5	1.5	1.0	2.8	2.7
smooth brome	Carlton	Bromus inermis	3.0	2.0	2.5	2.5	3.5	3.0	3.0	2.5	2.0	1.5	2.8	2.3
	CSU-3		3.0	2.5	2.5	2.5	3.0	3.0	3.0	2.5	1.5	1.5	2.6	2.4
*	Lincoln coated													
*	Lincoln uncoated													
*	Magna													
	Manchar		3.0	2.5	2.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.6	2.6
tall fescue	CSU-R	Festuca arundinacea	1.5	1.0	2.0	3.0	3.0	4.0	2.0	2.0	0	0	1.7	2.0
	Fawn		1.5	1.0	2.5	3.0	3.0	4.0	2.0	2.0	0	0	1.8	2.0
*	Fawn coated													
*	Fawn uncoated													
	Kentucky-31		1.5	1.0	2.5	3.0	3.0	4.0	2.5	2.5	0	0	1.9	2.1
	T-6		1.5	1.0	3.0	3.0	3.0	3.0	1.5	1.5	0	0	1.8	1.7
*orchardgrass	Chinook	Dactylis glomerata												
	Potomac		3.0	2.5	2.5	3.5	3.5	4.0	3.0	2.5	2.0	2.0	2.8	2.9
	Sterling		3.0	2.5	2.0	3.0	3.5	3.5	2.5	2.0	2.0	2.0	2.6	2.6
timothy	Bottnia II	Phleum pratense	3.0	3.0	3.0	3.0	3.0	2.5	2.0	2.5	2.0	2.0	2.6	2.6
	Climax		3.0	3.5	2.5	3.0	3.0	3.0	1.5	2.0	2.0	2.0	2.4	2.7
	Itasca		2.5	3.5	2.5	2.5	3.0	3.0	1.5	2.5	1.5	2.0	2.2	2.7
intermediate wheatgrass	Amur	Agropyron intermedium	2.0	2.0	3.0	3.0	3.5	4.5	3.0	3.0	1.0	1.0	2.5	2.7
*	Chief													
*	Slate													
	Tegmar		2.0	2.0	2.5	2.0	2.5	3.5	2.5	2.5			2.4	2.5
altai wildrye	Prairieland	Elymus angustus												

*Not planted

APPENDIX TABLE 12. SPRING PLANTINGS: PERSISTENCE

Common Name	Variety	Specific Name	Breck		Climax		Eisen Tun		Urad		W Park		X̄	
			S	V	S	V	S	V	S	V	S	V	S	V
SMALL GRASSES														
*arcticgrass	IAS 405	Arctagrostis latifolia												
Canada bluegrass	Reubens	Poa compressa	4.0	3.5	0	0	1.0	1.0	1.0	1.5	1.0	1.0	1.6	1.7
Chewing's fescue	Banner	Festuca rubra commutata	2.5	3.5	3.0	3.5	2.5	3.5	3.0	3.5	3.5	4.0	2.9	3.6
	Koket		2.5	3.0	3.0	4.0	3.5	3.5	4.0	3.0	3.5	4.0	3.3	3.5
creeping red fescue	Corona	Festuca rubra tricophila	3.5	2.5	2.0	2.5	3.5	3.0	3.0	2.0	3.0	3.0	3.0	2.6
	Fortress		4.0	3.0	3.0	3.0	4.0	3.5	3.0	2.0	3.0	3.0	3.4	2.9
hard fescue	Balmoral	Festuca ovina duriuscula	2.0	2.0	1.5	1.5	3.0	3.0	4.0	3.0	3.0	3.0	2.7	2.5
	Biljart		4.0	4.0	1.5	1.5	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
	Durar		3.0	4.0	1.5	1.5	3.0	2.5	3.5	3.0	1.5	1.0	2.5	2.4
red fescue	Arctared	Festuca rubra	3.5	3.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0
	Jamestown		3.5	3.0	2.5	2.5	3.0	3.5	4.0	3.0	3.5	4.0	3.3	3.2
	Pennlawn		3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.5	3.0	3.0	3.1	3.2
	Tolerant		3.0	2.5	2.0	2.5	2.5	2.5	1.0	1.5	2.5	3.0	2.2	2.4
	IAS 294		3.5	3.0	3.0	2.0	3.5	2.5	3.5	3.0	3.0	3.0	3.3	2.7
	IAS 83		3.5	3.0	3.0	3.0	3.0	3.0	2.5	2.5	2.5	3.0	2.9	2.9
sheep fescue	IAS 298	Festuca ovina	2.5	3.0	1.5	2.5	2.5	2.5	3.0	3.0	1.0	1.0	2.1	2.4
	IAS 299		1.5	1.5	2.0	2.5	2.5	3.0	2.5	2.5	1.0	1.0	1.9	2.1
	77-156		2.5	3.5	1.0	1.5	3.0	3.5	3.5	3.5	2.5	2.0	2.5	2.8
Bering hairgrass	IAS 19	Deschampsia beringensis	2.5	3.5	0	0	2.5	3.0	2.0	2.0	2.0	2.0	1.8	2.1
	IAS 74		2.0	2.5	0	0	2.5	3.0	2.5	2.5	1.5	1.5	1.7	1.9
tufted hairgrass	Eisenhower	Deschampsia caespitosa	2.0	3.0	1.0	1.0	2.0	2.5	2.0	2.5	1.5	1.5	1.7	2.1
	IAS 319		2.5	3.5	0	0	2.0	2.5	2.0	2.5	1.5	1.5	1.6	2.0
spike trisetum	Climax	Trisetum spicatum	2.0	2.0	1.5	2.5	2.5	3.0	3.0	2.5	2.5	3.0	2.3	2.6
	Leadville		2.0	2.0	1.0	1.0	1.5	1.5	3.0	3.0	1.0	1.0	1.7	1.7
MEDIUM GRASSES														
Kentucky bluegrass	Baron	Poa pratensis	3.5	3.5	1.0	1.0	1.0	1.0	2.5	2.5	0	0	1.6	1.6
	CSU 45KB		3.5	3.5	1.0	1.0	1.0	1.0	3.0	2.5	0	0	1.7	1.6
	CSU 58KB		3.5	3.5	1.0	1.0	0	0	3.0	2.5	0	0	1.5	1.4
	CSU 85KB		3.5	3.5	1.0	1.0	0	0	2.5	2.5	0	0	1.4	1.4
	Parade		3.5	3.5	1.0	1.0	0	0	2.5	2.5	1.0	1.0	1.6	1.6
	Park		3.5	3.5	1.0	1.0	2.5	2.5	3.0	2.5	0	0	2.0	1.9
	Park coated		2.0	2.0	1.0	1.5	1.0	1.0	3.0	3.0	0	0	1.4	1.5
	Park uncoated		2.0	2.0	1.0	1.5	1.0	1.0	3.0	3.0	0	0	1.4	1.5
	Rugby		3.5	3.5	1.0	1.0	0.5	1.0	2.5	2.5	0	0	1.5	1.6
bluejoint reedgrass	Sourdough	Calamagrostis canadensis	0	0	0	0	0	0	0	0	0	0	0	0
perennial ryegrass	Citation	Lolium perenne	0	0	2.0	2.5	3.0	3.0	0	0	0	0	1.0	1.1
	Linn		0	0	2.0	2.5	3.0	3.5	1.5	1.5	0	0	1.3	1.5
	Manhattan		0	0	2.0	2.5	3.5	3.5	0.5	1.0	0	0	1.2	1.4
	Pennfine		0	0	2.0	2.5	2.5	3.0	0.5	1.0	0	0	1.2	1.3
alpine timothy	Climax	Phleum commutatum	2.5	3.0	1.0	1.0	1.0	1.0	2.0	3.5	1.5	3.0	1.6	2.3
	Eisenhower		2.5	3.0	1.5	1.5	2.0	2.0	1.5	2.5	1.5	2.0	1.8	1.6
*bearded wheatgrass	IAS 72 (NK)	Agropyron subsecundum												
*silky wheatgrass	619 D11	Agropyron macrourum												
slender wheatgrass	Primar	Agropyron trachycaulum	2.0	3.0	2.0	3.0	3.0	3.5	3.0	3.0	1.0	1.0	2.2	2.7
	Revenue		2.5	2.5	3.0	2.5	4.0	4.0	3.5	3.5	1.5	1.5	2.9	2.8
	IAS 70		2.0	1.5	1.0	1.0	0.5	2.0	2.5	3.0	1.5	2.0	1.5	1.9
*	731 B5													
*	H60 141													
western wheatgrass	Tincup	Agropyron smithii	2.0	2.5	1.0	1.0	3.0	3.5	1.0	1.5	0	0	1.4	1.7
LARGE GRASSES														
*arctic brome	718C7	Bromus pumpellianus dicksonsii												
meadow brome	Regar	Bromus biebersteinii	4.5	4.0	3.0	3.0	4.0	4.0	4.0	3.0	2.0	2.0	3.5	3.2
smooth brome	Carlton	Bromus inermis	3.5	3.5	2.0	2.0	4.0	3.0	3.0	2.5	2.0	2.0	2.9	2.6
	CSU-3		3.5	3.5	2.0	3.0	3.5	2.5	3.0	2.5	1.0	1.0	2.6	2.5
	Lincoln coated		2.5	2.0	3.0	2.5	3.5	3.0	2.5	2.5	1.0	1.0	2.5	2.2
	Lincoln uncoated		2.0	2.0	2.5	3.0	3.5	3.0	2.5	2.0	1.0	1.0	2.3	2.2
	Magna		3.5	3.5	2.0	2.5	3.0	3.5	3.5	2.5	2.0	2.0	2.8	2.7
	Manchar		3.5	3.5	2.0	2.0	3.0	3.0	3.5	3.0	2.5	2.0	2.9	2.7
tall fescue	CSU-R	Festuca arundinacea	1.0	1.5	2.0	3.0	3.5	4.0	2.0	3.5	0	0	1.7	2.4
	Fawn		1.0	1.5	3.0	3.0	4.0	3.5	2.5	2.5	0	0	2.1	2.1
	Fawn coated		1.5	1.5	2.5	3.0	3.0	3.5	2.0	2.0	0	0	1.8	2.0
	Fawn uncoated		1.5	1.5	2.5	3.0	3.0	4.0	2.5	2.0	0	0	1.9	2.1
	Kentucky-31		1.0	1.5	2.5	3.5	3.0	4.0	2.5	3.5	0	0	1.8	2.5
	T-6		1.0	1.5	2.5	3.0	4.0	3.0	2.5	3.0	0	0	2.0	2.1
orchardgrass	Chinook	Dactylis glomerata	3.0	3.0	3.0	3.5	3.5	3.5	3.0	3.0	2.0	2.0	2.9	3.0
	Potomac		3.0	3.0	3.0	3.5	3.5	3.5	2.0	2.5	2.0	2.0	2.7	2.9
	Sterling		3.0	3.0	3.0	4.0	3.5	3.0	1.5	2.0	1.0	1.0	2.4	2.6
Timothy	Bottnia II	Phleum pratense	3.0	3.5	2.5	3.0	3.0	3.0	3.0	3.0	1.0	1.0	2.5	2.7
	Climax		3.5	3.5	2.5	3.5	2.5	3.5	2.0	4.0	0.5	1.0	2.2	3.1
	Itasca		2.5	3.0	1.5	3.5	3.0	4.0	3.5	3.5	1.0	1.0	2.3	3.0
intermediate wheatgrass	Amur	Agropyron intermedium	2.5	3.0	2.5	2.5	3.5	3.5	3.0	3.5	0	0	2.3	2.5
	Chief		3.0	3.0	4.0	3.5	3.5	4.0	3.0	3.0	1.0	1.0	2.9	2.9
	Slate		3.0	3.0	2.5	2.5	4.0	4.0	3.0	3.0	1.0	1.0	2.7	2.7
	Tegmar		3.0	3.0	2.5	2.5	3.5	3.5	2.5	2.5	0	0	2.3	2.3
altai wildrye	Prairieland	Elymus angustus	0	0	0	0	2.5	3.0	1.5	1.5	0	0	0.8	0.9

* Not planted

SOIL CHARACTERISTICS WHICH INFLUENCE ALPINE REVEGETATION DURING ROAD RECONSTRUCTION IN SOUTHEASTERN WYOMING

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The Department of Transportation, Federal Highway Administration (Denver Office), the U.S. Forest Service (Medicine Bow National Forest), and the Wyoming State Highway Department in cooperation with the University of Wyoming have organized a Landscape, Erosion Control Advisory Team (LECAT) to aid in the planning of, and monitor construction related activities associated with, the Snowy Range Road Project in Southeastern Wyoming. An outgrowth of this organization has been research funded by the DOT and carried out by the University. Much of this work is related to establishment of plants in disturbed soils at high elevations (alpine and subalpine environments); however, initial phases of work were directed at chemical, physical and biological analyses of soils existant along the Snowy Range Road. This is a report on these initial phases.

INTRODUCTION

Knowledge of revegetation of alpine tundra is quite limited; although there is little doubt as to the high susceptibility of alpine vegetation to disturbance. Alpine vegetations occur in what are among the most rigorous terrestrial environments, and without man they seem capable of almost indefinite persistance (Billings, 1973). However, alpine vegetation returns very slowly after disturbance. Greller (1974) examined alpine tundra which had been denuded in Rocky Mountain National Park during construction of the Trail Ridge Road. He found that 40 to 50 years after construction of the road, plant coverage on denuded sites was approximately half of that on undisturbed tundra. Greller also noted that one disturbed site which had adequate soil moisture and had been humus enriched from an upslope community of alpine willow had develcped coverage which did approximate coverage on undisturbed tundra. Human measured damage to tundra ecosystems has been documented by several researchers. A study of regional interest was conducted by Willard and Marr (1970). They indicate that wet alpine sites are easily damaged by human activities. Willard and Marr list additional references which address the fragile nature of alpine ecosystems.

Revegetation of alpine sites is a particularly difficult problem because of the shortness of the growing season, the frequent seasonal dry period of the soil, low soil fertility, and the absence of mechanized methods for seeding steep alpine areas (Cook, Hyde and Sims, 1974). Another feature of alpine sites which contributes to complexity of revegetation is what Billings (1973) calls mesotopographic gradients, or gradients from ridge tops to wet meadows or bogs. This gradient includes: (1) windward slope which tend to be quite dry; (2) ridge crests which are somewhat more mesic than the windward slopes; and (3) sites of deep snow accumulation on the leeward slope of ridges which will certainly have plenty of available moisture but have a very short effective growing season. Also considered part of this gradient are (4) meltwater meadows below the snow drift, which are probably the best sites for plant development, and (5) depressions occupied by bogs, often a product of long periods of organic matter accumulation.

Several authors address techniques and plants which have potential for use in revegetation at high altitudes. One of the earliest studies was performed in Rocky Mountain National Park by Harrington (1946). In this study native plants were seeded and establishment was evaluated after 5 and 6 years. His report suggests that for sites above 10,400 feet in elevation Deschampsia caespitosa, Penstemon shippleanus, Phacelia sericea and perhaps Trisetum spicatum and Thermopsis divaricarpa had high potential for revegegation. Other plants which have been reported to have high revegetation potential for alpine areas are indicated in Table 1. Unfortunately only a few of those recommended are native plants. Kenny and Cuany (1978) indicate that native plants should receive more emphasis in revegetation of alpine sites. They indicate that Lupinus argenteus has received some attention, and in Colorado, seed collections have been made at elevations up to 11,000 feet. Berg and Barrau (1978) suggest that native shrub establishment should receive more emphasis in alpine revegetation and further suggest that actinomycete nodulated shrubs (nitrogen fixing shrubs) should have a distinct advantage in alpine areas.

It is well documented that nitrogen fixing plants do have distinct survival advantage over plants which do not fix nitrogen (Bond, 1974 and Vincent, 1974). It should be noted that stockpiling of topsoil for longer than 3 years has been shown to decrease the number of bacteria which effect nodulation (Singleton and Williams, 1980). Other microbial associations which have an influence on survival of plants include mycorrhizal fungi. These fungi form symbiotic association with roots of almost all plants (Gerdemann, 1968) and their presence is crucial in water and mineral uptake by higher plants (Williams, 1979).

Several recommendations have been made concerning general techniques which should be followed in revegetation of alpine zones. Alpine soils tend to be quite deficient in plant available nitrogen. Brown and Johnson (1980) recommend that soil analysis be done on target soils prior to revegetation efforts. They recommend that soils found to be nitrogen deficient be fertilized with nitrogen. Berg and Barrau (1978) indicate that for best results nitrogen should be applied at a

Table 1. Plants which have been demonstrated to have potential for revegetation on alpine tundra.

Family	Species	Common Name	Reference(s)
Poaceae	Agrophyron trachycaulum	Slender wheatgrass	Kenny and Cuany (1978)
	Alopecuris pratensis	Garrison meadow foxtail	Kenny and Cuany (1978) Brown and Johnson (1980)
	Bromis inermis	Smooth bromegrass	Kenny and Cuany (1978)
	Deschampsia caespitosa 1/	Tufted hairgrass	Kenny and Cuany (1978) Brown and Johnson (1980)
	Festuca arizonica	Arizona fescue	Kenny and Cuany (1978)
	Phleum pratense	Timothy	Kenny and Cuany (1978)
Fabaceae	Astragalus cicer	Cicer milkvetch	Berg and Barrau (1978) Kenny and Cuany (1978)
	Trifolium hybridum	Alsike clover	Kenny and Cuany (1978)
	Trifolium repens	White clover	Kenny and Cuany (1978)

rate of 60 pounds per acre per year for at least 4 consecutive years. Soils found to have a pH of less than 5.5 should receive an application of limestone to bring the pH to near 6.0 (Brown and Johnson, 1980). Straw as a surface mulch tacked down with netting has been shown to enhance seedling survival (Brown and Johnson, 1980).

OBJECTIVES

This research is oriented towards revegetation of alpine and subalpine soils disturbed during reconstruction of the Snowy Range Road. The majority of the area under consideration is above 10,400 feet (3,170 m) in elevation. Soils disturbed during this project are being salvaged and replaced during the revegetation effort.

The objectives of this paper are to describe physical, chemical and biological characteristics of these soils and to describe mycorrhizal associations on roots of shrubs targeted for use in revegetation of this area.

MATERIALS AND METHODS

Soil Physical, Chemical and Taxonomical Characterization

Soil samples were taken at 16 locations adjacent to the Snowy Range Road which represent all the major soil types disturbed during the initial phase of reconstruction (Figure 1). These soils were analyzed for nitrogen (ammonium and nitrate) via Bremner distillation (Bremner, 1965), available phosphorus (Watanabe and Olsen, 1965 and Olsen and Dean, 1965), available potassium (Pratt, 1965), soluble magnesium (Bower and Wilcox, 1965), zinc and iron (Lindsey and Norvell, 1969), organic matter (Allison, 1965), pH (Peech, 1965), and particle size analysis (Day, 1965).

Soils in this area were mapped by the U.S. Forest Service (Medicine Bow National Forest, Laramie, WY 82070) according to Soil Taxonomy (Soil Survey Staff, 1975).

Biological Characteristics of Soils

This study was designed to assay soil for nitrogen fixing symbiotic bacteria (*Rhizobium trifolii*) and V.A. mycorrhizal fungi on plant root systems. The study was also designed to allow for harvest of plant root and shoot material and determine biomass production differences from soil to soil.

Each soil evaluated in this project (see Figure 1 for soil locations) was collected in bulk, sieved to pass a 5 mm sieve, and used to fill 10 clay pots having average inside diameter of 13.25 cm, height of 15 cm and total volume of 2,068 cm^3. Each pot was filled with 2.5 kg of soil. Five pots of each soil were planted to *Phleum alpinum* (Alpine timothy, supplied by the Bridger Plant Materials Center, #M-1346) and five to *Trifolium pratense* (Red clover). Pots were planted January 27, 1981 at rates of 35 timothy seeds per pot or 15 clover seed per pot. Pots were harvested in June 1981. Root and top materials were separated at harvest. Top material was cut at the soil surface, dried at 60°C in a forced air oven and top biomass determined gravimetrically. Roots were removed from the soil by soaking the root mass from each pot in tap water for 1 to 2 hours. Most soil material was removed by repeated vertical agitation of the mass in a volume of tap water. Final removal of adhering soil particles was done by placing the root mass on a sieve having 2 mm openings and washing with a stream of water. Broken roots were retained by the sieve.

Nodule quantity was determined by macroscopic as well as, when necessary, steroscopic counting.

Each mass of roots was assayed for vesicular arbuscular mycorrhizal infection according to the general methodology described by Williams (1979). Root infection percentage was estimated according to the methodology of Nicolson (1960). All root material was ultimately dried at 60°C and biomass determined gravimetrically.

Shrubs targeted for use in revegetation of the Snowy Range Road reconstruction are willow (*Salix*, spp.), Shrubby cinquefoil (*Potentilla fructicosa*) and currant (*Ribes* spp.). Generation of shrub materials for transplanting to the Snowy Range is being done using rooted cuttings of these shrubs. The rooted cuttings are transferred to snap-together plastic cells (containers) containing approximately 200 cc of rooting substrate. Containerized shrubs will ultimately be inoculated with mycorrhizal fungi and compared with control plants.

This comparison will be made by examining survival and growth of plants in greenhouse and field environments.

No attempt was made in the bioassay to identify mycorrhizal fungi. Therefore, root systems of shrubs being used in this study were collected from sites along the Snowy Range Road and examined in the laboratory for the presence of mycorrhizal fungi. Ectomycorrhizal fungi were isolated according to the methodology of Molina and Palmer (1982). Vesicular-arbuscular mycorrhizal spores were extracted from the soil by a sucrose flotation method (Allen et al., 1979) and identified according to Hall (1984).

RESULTS

Soil Physical, Chemical and Taxonomical Characterization

Sampling sites for soils for analysis were chosen to cover the range of soils in the study area. All soils examined fall into the broad classification of Alpine meadow soils.

Surface areas of soils available for use in revegetation and adjacent to the Snowy Range Road show that Typic Cryumbrepts are the two most common soils (Table 2).

Table 2. Soils adjacent to the high altitude portion of the Snowy Range Road Project.

Soil Name*	Length of Road to Which Soil is Adjacent
Typic Cryumbrept (7-12% slope)	1.50 miles (2.40 km)
Typic Cryumbrept (12-25% slope)	1.25 miles (2.00 km)
Lithic Cryumbrept	0.25 miles (0.40 km)
Cumulic Cryaquoll	0.25 miles (0.40 km)

*Soil Survey Staff, 1975.

The majority of soils adjacent to the high altitude portion of the Snowy Range Road are Cryumbrepts. These are cold, acid, freely drained inceptisols. Lithic Cryumbrepts have a minimal depth with a lithic contact within 50 cm of the soil surface.

Along water courses and in boggy areas are found Cumulic Cryaquolls. These are solid, naturally wet mollisols with an overly thickened mollic epipedon (50 cm or greater).

Of the soil characteristics examined (Table 3), Zn, P and N are probably deficient and plant would probably respond to addition of

Table 3. Soil analysis by taxonomical units affected in the high altitude section of the Snowy Range Road reconstruction project (see Figure 1 for location of sampling sites).

pH	% O.M.	Soil N, ppm		P, ppm	K, ppm	Mg, ppm	Zn, ppm	Fe, ppm	Mechanical analysis, %			Textural Class
		N as NO_3	N as NH_4						Sand	Silt	Clay	
Typic Cryumbrepts, 7-12% slope (sample sites 0, 4, 5, 8 and 13)												
5.4[1]	5.0	1.6	4.8	5.8	152.1	162.5	4.4	118.0	41.4	42.8	15.8	SL
±0.4[2]	± 0.6	±1.8	±4.9	±1.1	±19.5	±54.0	± 2.0	± 27.7	± 9.4	± 7.2	±2.3	
Typic Cryumbrepts, 12-25% slope (sample sites 2, 3, 7, 11, 12 and 14)												
5.2	5.7	0.5	2.3	5.7	191.1	112.2	4.5	158.3	37.0	45.2	17.8	SL
±0.3	± 2.5	±1.2	±2.3	±2.1	±36.7	±13.2	± 2.6	± 77.0	± 6.0	± 4.1	±2.6	
Lithic Cryumbrepts (sample sites 6 and 15)												
5.4	6.6	0.5	0.5	6.1	154.1	183.0	4.1	38.5	35.0	46.0	19.0	SL
±0.8	± 5.4	±0.7	±0.7	±3.3	±46.9	± 34.8	± 4.1	± 99.9	±14.1	± 5.7	±8.5	
Cumulic Cryaquoll (sample sites 1, 9 and 10)												
5.9	32.2	4.7	5.0	9.2	158.6	981.6	20.8	283.5	26.3	64.3	9.3	SL
±1.0	±20.7	±5.0	±5.0	14.5	±45.2	±931.2	±19.8	±190.3	±7.0	±13.7	±8.5	

[1]Each numerical entry is the mean of the analyses made at the sampling sites located on a particular soil subgroup.

[2]Standard deviation of mean.

these elements. For soils with extractable Zn of less than 5 ppm, an addition of 5 kg/Ha (5 lbs/Acres) would be appropriate. All sites are nitrogen deficient and should be fertilized at a rate of 150 kg/Ha (150 lbs/Acre). Most of the soils tested are low in available P. Soils less than 5.5 ppm P should be fertilized at 50 kg/Ha (50 lbs/Acre) P. Soils less than 9.5 ppm P should be fertilized at 15 kg/Ha (15 lbs/Acre) P. (see Table 3).

In addition to these chemical properties of soils which may limit plant growth, pH of many soils were found to be quite low. Liming of these soils to pH of between 6 and 7 would probably aid in nutrient availability.

Biological Characteristics of Soils

Root systems of all plants examined were found to be inhabited by mycorrhizal fungi (Table 4). Both Potentilla and Ribes as well as all the herbaceous plants were associated with VA fungi while willow was ectomycorrhizal. Roots of both VA mycorrhizal shrubs were only moderately infected but the large majority of willow root tips examined were colonized. Seven species of VA fungi and one species of ectomycorrhizal fungus were isolated from the field collections (Table 4.)

Table 4. Mycorrhizal activity in soils along the Snowy Range Road.

Plant	Type of mycorrhizae	% of examined root segments infected	Mycorrhizal fungi present
Salix spp.	ecto	77	Cenococcum spp.
Ribes spp.	VA	41	Acaulospora laevis
Potentilla fructicosa	VA	35	Acaulospora laevis Acaulospora scrobiculata
Geum rossii	VA	77	Glomus clarum Glomus fasciculatum
Festuca spp.	VA	64	Glomus microcarpum Glomus tenue

Results for bioassay of symbiotic microbial associations with T. pratense (red clover) show considerable variation in number of plant nodules produced from sampling site to sampling site (Table 5). Significant (0.05) differences exist between soils as to their capacity to nodulate this plant. Differences exist between soils as to their capacity to form VA mycorrhizae with red clover, however, these are not significant.

Table 5. Plant biomass, VAM infection and nodulation of test plants grown on potted soil from the high altitude portion of the Snowy Range Road project.

	Alpine timothy (Phleum alpinum)				Red clover (Trifloium pratense)				Number of Nodules per Plant
	Plant Biomass, mg/plant			% VAM	Plant Biomass, mg/plant			% VAM	
	Tops	Roots	Total	Infection	Tops	Roots	Total	Infection	
Typic Cryumbrepts, 7-12% slope	31[1]	93	124	20.4	73	156	240	42.6	33.8
(sampling sites 0, 4, 5, 8 and 13)	±12[2]	±46	± 54	± 7.4	±23	± 44	± 35	±16.6	±20.2
Typic Cryumbrepts, 12-25% slope	31	121	152	15.0	53	1.27	180	44.7	34.7
(sampling sites 2, 3, 7, 11, 12 and 14)	±28	±78	±101	±13.2	±27	± .85	± 98	±18.3	±31.9
Lithic Cryumbrepts	17	123	140	10.5	67	172	239	32.0	80.6
(sampling sites 6 and 15)	± 8	±59	± 67	± 3.5	±30	±120	±150	± 8.5	±15.0
Cumulic Cryaquolls	21	110	131	16.7	34	142	176	41.0	60.9
(sampling sites 1, 9 and 10)	± 3	±18	± 18	±16.1	± 4	± 52	± 52	±23.0	±15.6

[1]Each numerical entry is the mean of the bioassays made at the sampling sites located on a particular soil subgroup.

[2]Standard deviation of mean.

Simple correlation of plant dry weight parameters to the soil factors of pH, organic matter content, extractable P, extractable Fe, extractable Zn, extractable K, extractable Mg, and nodule number, show that top dry weight is highly significantly (0.01 level) correlated to nodule number, and significantly (0.05 level) correlated to both soil pH and extractable Mg. Top dry weight correlations with parameters were not significant. Root dry weights are highly significantly (0.01 level) correlated to nodule number, and strongly correlated (but not significantly) to soil pH and soil P. Total biomass is highly significantly (0.01 level) correlated to nodule number.

Simple correlation of plant dry weight parameters to the soil factors of pH, organic matter content, extractable P, extractable Fe, extractable Zn, extractable K, and extractable Mg show no significance. Alpine timothy growth seems relatively independent of soil characteristics. This may reflect an intrinsic properly of the plant to survive equally well on varying soils, although the red clover was consistently larger.

DISCUSSION

The chemical, physical and taxonomic characteristics of these soils are characteristic of high mountain soils at the interface of alpine and subalpine vegetation types. The magnesium content of these soils is high, but many of the soils in this area are derived from dolomite and would, therefore, be expected to have high magnesium.

That plants would respond to additions of nitrogen to these soils is supported by the fact that dry weights of the red clover have positive correlations with nodule number. This support for nitrogen fertilization, but also support for use of legumes on high altitude disturbed land.

Mycorrhizal fungi are common inhabitants of these soils. This is suggested not only by the bioassay work, but also by the field examinations. Certainly many of the coniferous areas adjacent to this area are dominated by ectomycorrhizal fungi, and one of the plants, *Salix* spp., important in revegetation of this area is ectomycorrhizal. However, the VA mycorrhizae are abundant in the area and very likely are important in revegetation. VA mycorrhizal fungi play an important role in recovery of disturbed land. Nicolson (1967) suggested that plant growth in industrial wastes could be improved by incorporating VA mycorrhizal fungi. Daft and Nicolson (1974), Daft, Hacskaylo and Nicolson (1975), and Daft and Hacskaylo (1976) observed extensive infection of most plants colonizing coal wastes in Pennsylvania and Scotland, and hypothesized that infection was essential for successful colonization by most (but not all) plants. Plants established during revegetation of surface mines in arid and semi-arid regions of western North America are frequently mycorrhizal (Christensen and Williams, 1977; Stahl et al., 1979; Allen and Allen, 1980; Call and McKell, 1981).

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A Definition of Reclamation and the Economics of Topsoiling

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INTRODUCTION

Individuals and organizations involved in broad-based programs such as mined-land reclamation should often pause to reevaluate the course selected to achieve the desired goals and objectives of the program. The definition of reclamation is a continuously moving target. Miners and regulators alike need to zero in on a fundamental definition of reclamation. The lack of agreement on a fundamental definition of reclamation is the source of many problems between industry, environmentalist and regulator. Lacking agreement on basic concepts, the definition changes with each new law, each new rule and regulation, each new interpretation of a law or a rule, and with each precedent. Precedents are established by ever-evolving legal interpretations or by innovative, voluntary reclamation achievements in the field. The objectives of this discussion are 1) to set forth a fundamental definition of mined-land reclamation which can be used as a base on which to build, and 2) to relate the implementation of that definition to the economics of using topsoil to accelerate reclamation in various sets of specific circumstances.

DEFINITION OF RECLAMATION

The meaning of the word reclamation has changed drastically from its traditional context in relation to the old U.S. Bureau of Reclamation. (In this context, the word generally meant the provision of water and other resources necessary to increase the agricultural productivity of land.) Confusion also results when the words "restoration" and "rehabilitation" are used in association with "reclamation".

Restoration

Webster's New World Dictionary defines RESTORATION as "a putting or bringing back into a former, normal, or unimpaired state or condition." Mining unalterably changes the preexisting conditions. Mined-land restoration is clearly impossible. A three-hundred-year-old tree cannot be restored. The precise replacement of topsoil horizons does not provide restoration of the soil structure. A filled valley or a removed ridge cannot be restored because the valley or the ridge no longer exist. The word restoration should not be used in the context of reclamation.

Rehabilitate

The same dictionary defines REHABILITATE as a process "to put back in good condition; reestablish on a firm, sound basis." This is very close to the generally accepted definition of reclamation. In fact, because of the widely differing definitions of reclamation, legislatures would have simplified things by passing "rehabilitation" laws rather than "reclamation" laws. The meaning of rehabilitation is more easily understood and relevant than is the meaning of reclamation.

Reclamation

However, reclamation is the word with which we are stuck. The dictionary definition of RECLAMATION is "the recovery of wasteland, desert, etc. by ditching, filling, or irrigating." Today, this process would itself be considered an act of disturbance. Reclamation is the act of repairing disturbances, not creating disturbances.

Legal Definitions of Reclamation

As you would expect, most of the legal definitions only serve to further confuse the issue. It's interesting to note that the Federal Surface Mining Control and Reclamation Act of 1977 and its hundreds of pages of rules makes no attempt to define the word. The Colorado Surface Coal Mining Reclamation Act of 1979 and the Regulations of the Colorado Mined Land Reclamation Board for Coal Mining define reclamation as "any activity or procedure required to achieve compliance with a reclamation plan approved under [Section] 2.05 including any necessary work required for compliance with the Act and these Rules." That definition might aid enforcement by the regulatory agencies, but it does not provide a clue to the meaning of the word.

The Colorado Mined Land Reclamation Act of 1976 (covering all mining other than coal) and its companion Rules and Regulations define Reclamation as "the employment during and after a mining operation of procedures reasonably designed to minimize as much as practicable the disruption from the mining operation and to provide for the rehabilitation of affected land through the rehabilitation of plant cover, soil stability, water resources, or other measures appropriate to the subsequent beneficial use of such mined and reclaimed lands." This definition provides both direction and goals. The direction is to minimize disruption as much as practicable and the goals are to rehabilitate to the subsequent beneficial use.

Reclamation is, however, a process. Reclamation is not an end product. Reclamation to a desired goal such as a pasture or forest is the process by which the pasture or forest is established.

Physical and Biological Aspects of Reclamation

Natural processes work toward stability, a state of high internal order. If a stable parcel of land is disturbed, it is changed from a condition of low entropy (low disorder) to a condition of higher entropy (higher disorder) after which it will tend to return to a stable state. By stability, I mean stability within the limitations of dynamic natural processes. The Grand Canyon is in a state of dynamic stability. A parcel of land which has stabilized both physically and biologically has recovered. A disturbed parcel of land will, if left alone and if given enough time, fully recover from the disturbance. Recovery is essentially unaided reclamation. Full recovery is not synonymous with restoration. Full recovery is the attainment of a stable ecosystem which may or may not be identical to the ecosystem which existed prior to disturbance. Full recovery differs from restoration in that restoration is the process of putting the land back to its exact former unimpaired state.

All disturbed parcels of land will fully recover with or without the process of reclamation. The length of time required for full recovery will vary depending on the environment. Some disturbances may fully recover in a few years; other disturbances may require hundreds of years to fully recover. Reclamation is simply the process of accelerating the recovery of a disturbed area. With this, the element of time becomes fundamental to the definition of the process of reclamation. Reclaimed disturbances will fully recover more rapidly.

Fundamental Definition of Reclamation

My definition of MINED-LAND RECLAMATION is: "The process of artificially initiating and accelerating the natural continuous trend toward recovery (stabilization) of a disturbed area." The two major aspects of reclamation are regrading and revegetation, which, in sequence, initiate and accelerate recovery of the physical and biological components respectively. This is the process which the industry reclamation engineer perpetrates when reclaiming a particular site.

Disturbance and reclamation are graphically illustrated in Figure 1. Construction disturbance of a relatively virgin (undeveloped) parcel of land rapidly degrades the condition of the land. If the parcel is abandoned at this point, wind and water erosion will continue to degrade the condition of the land until it reaches equilibrium, reverses the trend, and begins the slow process of natural recovery. Again, given enough time, the parcel will fully recover.

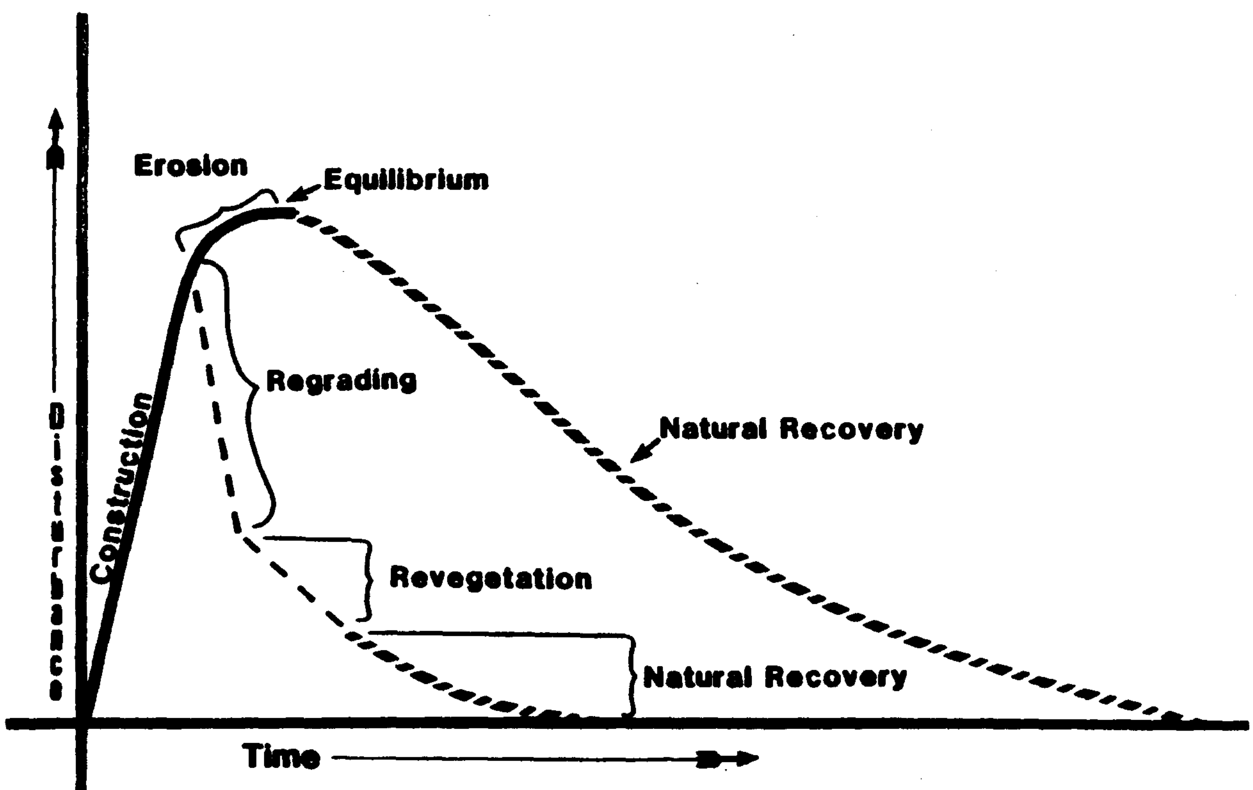

Figure 1: Reclamation accelerates the recovery of disturbed land.

Regrading temporarily stabilizes the physical aspects of the disturbed parcel. If initiated immediately following the construction disturbance, regrading eliminates the interim period of erosional degradation and results in an immediate improvement in the condition of the land. The establishment of permanent self-sustaining vegetation at that point completes the process of initiating and accelerating natural recovery. Reclamation is complete when revegetation is complete even though full recovery has not been achieved. Reclamation merely reduces the time required for disturbed land to recover fully.

THE FUNCTION OF TOPSOIL

It is a commonly accepted premise that topsoil is prerequisite to successful revegetation; that revegetation is impossible without topsoil. This belief is quite inaccurate. Reclamation can be successful without the aid of topsoil. No one argues that topsoil is not extremely valuable for reclamation. The intent of this paper is to put that value in perspective.

Adequate revegetation requires a suitable growth medium, but the growth medium need not be topsoil. Differing environments dictate the quality of the growth medium required to establish permanent self-sustaining vegetation within a reasonable time frame. Under most circumstances, topsoil is simply an amendment which accelerates the process of reclamation. <u>Reclamation accelerates recovery; topsoil accelerates reclamation.</u> Other amendments may be required to properly perform the process of reclamation, whether or not topsoil is used. The single greatest asset of topsoil is its texture (particle size distribution) which is important to the soil/plant water relationships. A growth medium must be nontoxic and must possess the texture to provide adequate water for plant growth. If a growth medium satisfies these requirements, the nutrient and organic constituents can be easily and economically provided by amendment with organics and organic or inorganic fertilizer.

Topsoiling is expensive. At what point is topsoiling no longer cost effective? The following examples depict a spectrum of reclamation situations, including costs, ranging from using no topsoil to stockpiling soil for long periods of time prior to use. Costs will vary on a site by site basis. The costs presented herein are representative costs incurred at AMAX's molybdenum mines in Colorado. The type of site discussed is a typical mining disturbed site such as a road bed (or cut or fill), a facility site after structure removal, a gravel pit or borrow pit, a pipeline or power line with attendant road, reservoir shores or dam face, the pit of an open pit mine or a waste rock overburden dump. (Reclamation of tailing deposition areas incorporates different variables and is not considered in this discussion.)

Example #1 - No Topsoiling

Regrading for adequate drainage to minimize erosion, seedbed preparation and reseeding (including trees and shrubs) of this typical site will cost about $1,500/acre with or without the aid of topsoil (Table 1). Vegetation established on a subsoil or waste rock growth medium will require more maintenance fertilization than vegetation established on topsoil. Again, conditions will vary on a site by site basis, but a typical subsoil site might require fertilization the second, third, fourth and sixth years. The cost of purchasing and applying maintenance fertilizer is about $50/acre/year bringing the total cost of establishing permanent, self-sustaining, good quality vegetation to about $1,700/acre. The time required to attain good quality vegetation on a nontoxic subsoil or waste exhibiting adequate texture will range from six to eight years.

Example #2

The process of open pit mining requires removal of topsoil (if any) as a part of the overburden to access the orebody. In some circumstances, it may even be possible to immediately redistribute that soil on a nearby area currently being reclaimed. Soil which must be removed as a part of the overburden, and can be immediately respread, is essentially cost free. In other words, the cost is almost exclusively a mining cost. The additional environmental cost for using topsoil in this instance is probably about $500/acre for selective scraping and redistribution of topsoil to a depth of one foot. The use of one foot of topsoil reduces the maintenance fertilization requirement from perhaps four applications to perhaps one application bringing the total reclamation cost to $2,050/acre (Table 1). This approach to reclamation will provide good quality vegetation within 2 or 3 years. Much of the soil used in strip mining falls into this category. The use of topsoil under these circumstances is definately cost effective.

Table 1. Representative reclamation costs per acre under progressively increased topsoil handling requirements covering a variety of situations. (The calculations use $1.75/yd^3 for sufficient soil to cover to a depth of one foot, i.e., 1,613 yd^3/acre).

	Representative Cost of Basic Regrading and Reseeding	Maintenance Cost	Respreading Without Stockpiling	Cost of one move and Distribution	Cost of 2nd move and Distribution	Cost of 7.5% loss of revenue/year on $2800 for 40 years	Total/acre	Quality/Time
Example #1 No Topsoiling	$1,500	$200					$ 1,700	Initially fair, improves yearly to good with maintenance within 6 to 8 years
Example #2 Topsoil removal necessary for access to orebody, can be redistributed without stockpiling	$1,500	$ 50	$ 500				$ 2,050	Good within 2 to 3 years
Example #3 Topsoil removal necessary for access to orebody, cannot be redistributed immediately, (must be stockpiled)	$1,500	$ 50		$2,800			$ 4,350	Good within 2 to 3 years
Example #4 Topsoil removal not necessary for access to orebody, can be redistributed immediately, (no need to stockpile)	$1,500	$ 50		$2,800			$ 4,350	Good within 2 to 3 years
Example #5 Topsoil removal not necessary for access to orebody, cannot be redistributed immediately (must be stockpiled)	$1,500	$ 50		$2,800	$2,800		$ 7,150	Good within 2 to 3 years
Example #6 Topsoil removal not necessary for access to orebody, cannot be redistributed immediately and must be stockpiled for long period of time	$1,500	$ 50		$2,800	$2,800	$47,700	$54,850	Good within 2 to 3 years

Example #3

In most instances, (with the exception of strip mining noted above), topsoil removed as a portion of the overburden cannot be put to immediate use. If the soil cannot be immediately redistributed on a nearby area undergoing reclamation, the soil must be stockpiled. Stockpiled soil must be rehandled when it is redistributed and the cost of rehandling can be significant. The cost effectiveness of rehandling stockpiled topsoil requires close scrutiny on a case by case basis. The cost of contracting for scraping soil, moving it a distance of one mile, and stockpiling it, will range from \$1.50 to \$2.00/yd^3. Using \$1.75/yd^3, the cost of stockpiling soil to cover a disturbed area to a depth of one foot is approximately \$2,800/acre. This \$2,800/acre is strictly an environmental cost and must be added to the \$1,500/acre basic cost of regrading and reseeding. The total reclamation cost under these circumstances is \$4,350/acre (Table 1). (Additional environmental and monetary costs not considered in these examples are the additional disturbance created by the topsoil stockpile, the costs of temporary stabilization of the stockpile, and the cost of ultimate reclamation of the disturbance created by the stockpile.)

The use of topsoil under this set of circumstances may or may not be cost effective and should be carefully evaluated on a case by case basis. An alternative which should be taken into consideration is that of using less than a foot of topsoil. As little as two to three inches of soil will reduce the time required to attain good quality vegetation from the six to eight years (using no topsoil) to perhaps four to six years.

Example #4

Similar costs and benefits are incurred if topsoil removal is not required as a part of the mining plan to gain access to the orebody, but where specially salvaged soil can be redistributed immediately on an area currently being reclaimed.

Example #5

Segregation of topsoil is not required (beneficial to) for most mining excavations, i.e., facility site preparation, road construction, etc. If topsoil is salvaged specifically to aid revegetation, and if it cannot be immediately redistributed, the cost of both moves must be charged to the reclamation budget. The cost of reclamation under this set of circumstances totals $7,150/acre (Table 1). This is more than four times the base cost of $1,700/acre. The major benefit received from the additional cost is simply a reduction of the time required to achieve a good quality vegetation. Under this scenario, topsoiling has gone beyond the point of cost effectiveness.

Example #6

There is a set of circumstances under which it is yet less cost effective to utilize topsoil to accelerate the process of reclamation. If the stockpiled topsoil must be stored for an excessive period of time, interest income, over and above the inflation rate, is lost throughout the time period. This cost is normally referred to by economists as "real interest." Real interest is the difference between the prime interest rate and the inflation rate. To show a real profit on a long term investment, an investor must realize a rate of return on an investment which exceeds the sum of the inflation rate and the real interest rate. The difference between the prime rate and the inflation rate has generally ranged from five to ten percent. For purposes of illustration, I have selected 7.5%. If the inflation rate is 4%, as it was during 1982 and 1983, the rate of return expected by my hypothetical investor must exceed 11.5% to show a real profit. Seven and one-half percent loss of revenue/year compounded for 40 years on an investment of $2,800 is about $47,700. This cost is real, excludes inflation, and must be included as a reclamation cost. The total cost of reclamation under these circumstances is $54,850/acre, more than 32 times greater than the "base cost" of $1,700/acre. (Forty years may appear to some people to be an excessive length of time to store topsoil, however, Colorado has 120 years of history on which to reflect, and the life of many mines in Colorado has been in excess of 40 years.)

Again, I must reiterate that actual haulage and reclamation costs will vary on a site by site basis. These cost estimates are not maximum or minimum estimates; they are realistic approximations. Accuracy of the costs is not nearly as important as the relative costs of the various sets of circumstances.

CONCLUSION

The overall reclamation objectives of the mine operator and the reclamation regulatory authority are (or should be) identical; i.e., to artificially initiate and accelerate the natural continuous trend toward recovery. Many state mineral reclamation laws do not dictate the circumstances under which topsoil should or should not be salvaged for the various types of mining. This flexibility, although desirable, can result in unreasonable demands on industry. Whether provided explicit legislative direction or not, many regulations fail to recognize economics as a factor that must be taken into account. It is hoped that the concepts presented herein are taken into consideration by the operator when developing a mine plan and by the regulator when processing a permit application.

In conclusion, topsoil should be used where it is cost effective within reasonable limits. However, the expenditure of perhaps 4 or 10 or 30 times more of what is ultimately the consumer's money to achieve the same goal in a somewhat shorter time period with the aid of topsoil, should be carefully considered before being either mandated or implemented.

AN ECOPHYSIOLOGICAL EXAMINATION OF RECLAMATION PRACTICES ON A HIGH-ELEVATION MINED SITE (URAD MINE, COLORADO)

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ABSTRACT

This study reports on the influence of reclamation practices on plant water status and subsequent growth of containerized lodgepole pine (*Pinus contorta* Dougl.) seedlings planted in 1977 (five-year-old) and 1981 (one-year-old) on a high-elevation mine site. Seedlings were grown in two fertilization treatments, sewage sludge and wood chips (SSWC) each at 46,000 kg/ha, and a combination (N & P) of ammonium nitrate (68 kg N/ha) and superphosphate (90 kg P/ha). The one-year-old seedlings in the SSWC treatment exhibited the greatest level of seedling moisture stress. During conditions of high evaporative demand, one-year-old seedlings in N & P and SSWC fertilization treatments showed greater plant water stress in comparision to five-year-old seedlings in both fertilization treatments. The application of water conservation treatments (antitranspirant or a silicone latex emulsion to the soil) reduced seedling moisture stress of one-year-old seedlings, but did not reduce seedling moisture stress enough to enhance seedling growth.

Root system development of one- and five-year-old seedlings was dramatically reduced by SSWC fertilization treatment in comparison to the N & P fertilization treatment. Root extension out into amended rock waste material was poorest for one-year-old seedlings in SSWC, moderate for one-year-old seedlings in N & P, and good for five-year-old seedlings in both fertilization treatments. The ability of seedlings to survive the initial establishment phase in the field depended upon the adequate development of a root system out of the container plug to obtain soil moisture and reduce seedling water stress under demanding environmental conditions.

INTRODUCTION

The use of containerized seedlings in the reclamation of sites disturbed by mining has increased rapidly in the past decade. Generally, seedlings with more extensive root development have a better chance of growth survival on these sites than seedlings with poorly developed root systems. New root growth during the first field season following planting has been shown to be extremely important to the survival of conifer seedlings (Stone 1955, Lopushinsky and Beebe 1976).

Few studies have examined the physiological response of newly planted seedlings to the environmental conditions of the field site and their subsequent growth. The importance of new root growth on reducing water stress of newly planted seedlings was demonstrated by Baldwin and Barney (1976) who showed that ponderosa pine (*Pinus ponderosa* Laws.) seedlings required two growing seasons following planting before new root growth was effective in raising low leaf water potentials to the level of naturally established seedlings. Recent work by Grossnickle and Reid (1984) showed newly planted containerized Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) seedlings had reduced needle conductance and transpiration in comparison to established seedlings.

Previous attempts to establish containerized conifer seedlings on the study site indicated that the reclamation practice of incorporating sewage sludge and wood chips (SSWC) into the rock waste material reduced the survival of lodgepole pine (*Pinus contorta* Dougl.) seedlings during the first year in the field in comparison to other fertilization treatments (Reid and Grossnickle 1978). This influence of the SSWC fertilization treatment on seedling survival only appeared important during the first growing season, and subsequent height and diameter growth through four growing seasons was greater in SSWC in comparison to other fertilization treatments (Grossnickle and Reid 1982). It was hypothesized that seedling survival in the SSWC treatment was influenced by inadequate soil-root contact, and this alteration of the seedling microsite resulted in seedling dessication (Grossnickle and Reid 1982). Due to the beneficial long term effects of the SSWC treatment, a study was conducted to determine the reason for increased mortality in this treatment during the first field season and to examine possible ways to mitigate the problem.

Success of seedling establishment can be determined through interpretation of seedling water status in relation to existing environmental conditions and their subsequent shoot growth and root development patterns. This study examined the influence of reclamation practices on plant water status of both newly planted and previously established lodgepole pine (*Pinus contorta* Dougl.) seedlings and subsequent shoot and root growth.

SITE DESCRIPTION

The field location, 14 km west of Empire, Colorado, was a molybdenum tailing pond set in the subalpine forest, at an elevation of 3200 m. To prevent excessive wind erosion and provide a more favorable medium for vegetation establishment, the surface of the molybdenum tailing pond was covered to a depth of 1 m with deep mine rock waste. Chemical and particle size characteristics of this covering material are described in Grossnickle and Reid (1982).

MATERIALS AND METHODS

Experimental Design.

Field data were collected during the summer of 1981 from containerized lodgepole pine (Pinus contorta Dougl.) seedlings which had been field planted in 1977 (five-year-old) and 1981 (one-year-old). Specifics of field design, seedling growth and establishment data for five-year-old seedlings are presented in Grossnickle and Reid (1982). Specifics of field design for one-year-old seedlings and further growth data are presented in Grossnickle and Reid (1983).

Experiments were conducted with one- and five-year-old lodgepole pine seedlings planted in the following fertilization treatments:
1) 68 kg N/ha as ammonium nitrate and 90 kg P/ha as superphosphate (N & P), and 2) sewage sludge and wood chips each at 46,000 kg (dry weight)/ha (SSWC). Chemical characteristics of rock waste material amended with SSWC have been described (Grossnickle and Reid 1982).

After planting in 1981, water conservation treatments (WCT) were then applied to, or around the seedlings. The WCT were: 1) no water conservation, 2) antitranspirant as Folicote[R] applied as an aqueous spray, and 3) water harvesting technique as an aqueous spray containing a polymer latex (Dow[R] latex 233) and a water repellent (silicone fluid emulsion XEF 43543, Dow Corning[R]) (3:1 v/v). The latter was sprayed on the soil surface in a circular fashion in a 32.5 cm radius out from the seedlings. Precautions were taken to ensure a circle of 10 cm diameter around the immediate base of each seedling was not sprayed with the aqueous solution. The intended benefit of this treatment was increased soil moisture availability for seedling growth and survival. No WCT were applied to the seedlings planted in 1977.

At the beginning of the 1981 field season, 72 nine-month-old lodgepole pine seedlings were randomly selected, placed in cylindrical (25 cm diameter x 30 cm length) nylon mesh containers and planted in the field. This allowed for removal of the whole seedling at the end of the water relations experiment to examine root system development. These 72 nine-month-old seedlings were planted in (3) WCT x (2) fertilization treatments x (12) replications. At the end of the water relations experiment 12 lodgepole pine seedlings in their fifth growing season in the field were randomly selected from each of the N & P and SSWC treatments, and were excavated and analyzed for root system development. Root excavation procedures and field experimental design are described in further detail in Grossnickle and Reid (1983). In conducting the plant water status measurements seedlings were randomly selected at the beginning of each sampling period from each fertilization treatment for the 1977 field planting, and each fertilization treatment x WCT combination for the 1981 field planting.

Measurements of environmental conditions.

Environmental data were recorded on the site during the study period from June 15 to September 1, 1981. Air temperature and humidity were continuously recorded on a hygrothermograph (Belfort Instr. Co., No.5-594) mounted in a standard ventilated weather station shelter located 1.5 m aboveground. Air temperature and relative humidity were also measured at the start of each sampling period with an aspirated wet-dry bulb thermometer, located 10 cm above the soil surface and shaded from direct solar radiation. Air temperatures were recorded with shaded copper-constantan thermocouples placed at heights of 25, 10, and 5 cm above the soil surface in each fertilization treatment. Soil temperatures were determined using copper-constantan thermocouples placed at the surface and at 2, 10, and 25 cm soil depth in each fertilization treatment. Needle temperature in each fertilization treatment was measured with a copper-constantan thermocouple carefully placed under a single needle with its long axis oriented perpendicular to incoming solar radiation. The thermocouple leads for aboveground, surface, and needle temperatures were shaded from direct radiation to prevent heating of the wires near the junction. Soil surface and needle temperatures were compared periodically with measurements by an infared field thermometer (Barnes Eng. Co., model PRT-10).

Irradiance was continuously recorded with a pyrheliograph (Belfort Instr. Co., No. 5-3850) and windspeed was measured with a cup anemometer (C. F. Casella & Co. Ltd., No. W1200/1) at a height of 30 cm above the soil surface. Summer precipitation was recorded continuously on the site with a universal recording rain gauge (Belfort Instr. Co., No. 5-780).

Soil water tension curves were developed on bulk samples from each fertilization treatment using a pressure-plate apparatus for determining water retention values as described by Richards (1949). Water retention values were measured on the bulk samples at 0.03, 0.5, 1.0, and 1.5 MPa of tensions. Estimates of soil water potential (Ψ_{soil}) were then determined gravimetrically from a mean of three samples taken at each of the soil depths 2, 10, 25, and 35 cm for each fertilization treatment on each sampling date (Gardner 1965). The identical sampling procedures was used for the silicone and latex WCT in each fertilization treatment on each sampling date (Gardner 1965). Soil samples utilized in determination of soil water tension curves and gravimetric procedure were handled in a similar fashion to ensure consistency in soil structure characteristics. Only estimates of Ψ_{soil} at 10 cm are reported in this paper. The Ψ_{soil} data at 2, 25, and 35 cm has been extensively interpreted in a previous publication and will not be reported here (Grossnickle and Reid 1983).

Measurement of plant water status.

Xylem pressure potential (Ψ_x) measurements were taken on individual fascicles using a pressure chamber and dissecting microscope. Precautions were observed following the recommendations of Ritchie and Hinckley (1975). At any given sampling period two fascicles were measured from each sample seedling, and the average recorded. Between fascicle variability was rarely greater than 0.05 MPa. If greater variability occurred, samples were remeasured on the seedling.

Sampling procedure.

At two-week intervals during June, July and August, data were collected to characterize plant water status. A study day began with predawn measurements of xylem pressure potential ($B\Psi_x$) taken at 0430 h. Sampling was repeated at 2- and 3-h intervals until direct sunlight had left the site. Five sample sets were collected per day. Each sample set consisted of xylem pressure potential measurements on twenty-four sample seedlings (three five-year-old seedlings in each fertilization treatment and three one-year-old seedlings in each fertilization treatment x WCT combination), and recording of solar radiation, humidity, wind-speed, and air temperatures at 25, 10, and 5 cm. Temperatures were recorded for both fertilization treatments during each sampling set.

Data evaluation and analysis.

Evaporative demand as absolute humidity difference between needle and air (ABSHD, $\mu g\ H_2O \cdot cm^{-3}$) was determined for each fertilization treatment, based on air temperature and relative humidity at 10 cm above the soil surface, and needle temperature.

Data on seedling growth parameters for each age classification were analyzed by analysis of variance and Tukey's honestly significant difference (HSD) mean separation test. This same analysis was used in examining predawn and midday Ψ_x readings for all sampling dates and for area under the curve for selected diurnal patterns separated by fertilization treatment and WCT (Snedecor and Cochran 1967).

RESULTS

Diurnal patterns of environmental conditions and plant water stress.

Three days were selected (June 16, July 14 and August 12) to represent the range of environmental conditions which occurred on the mine site during the growing season. Data recorded on all other sampling days during the growing season were within these environmental parameters.

Data taken on June 16 were recorded two days after the seedlings were planted and WCT had been applied (Fig.1). The environmental conditions reflected a clear sunny day with peak irradiance of 984 $W \cdot m^{-2}$ (Fig.1A). Recorded temperatures showed predawn conditions to be just above freezing with needle temperatures reaching 20°C in the afternoon for both fertilization treatments (Fig.1B & C). Soil temperatures at -10 cm never exceeded

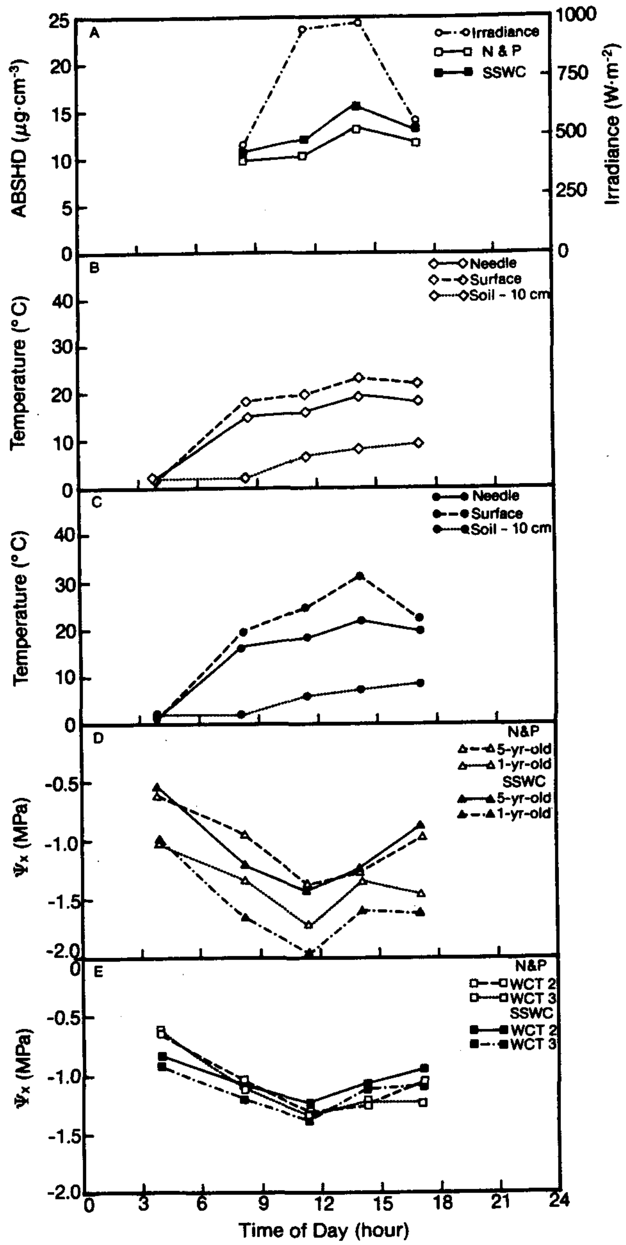

Figure 1. Diurnal patterns for June 16, 1981 of: (A) irradiance and absolute humidity difference between needle and air (ABSHD) for 68 kg N/ha and 90 kg P/ha (N & P) treatment, and sewage sludge and wood chips (SSWC) treatment; (B) needle, soil surface, and soil (-10cm) temperatures for N & P; (C) needle, soil surface and soil (-10cm) temperatures for SSWC; (D) xylem pressure potential (Ψ_x) for one- and five-year-old lodgepole pine seedlings in N & P and SSWC fertilization treatments; and (E) xylem pressure potential (Ψ_x) for one-year-old seedlings in N & P and SSWC separated by water conservation treatments. WCT 2 = antitranspirant, WCT 3 = silicone and latex.

8°C in both fertilization treatments. The diurnal ABSHD pattern for SSWC treatment was greater than for N & P treatment and can be attributed to greater temperatures in the aboveground temperature profile (Fig.1A, B & C).

The diurnal Ψ_x patterns for five-year-old seedlings and one-year-old control seedlings are shown in Figure 1D. Five-year-old seedlings in both fertilization treatments had significantly ($p = 0.05$) less negative Ψ_x readings in comparison to one-year-old control N & P seedlings, which in turn had significantly less Ψ_x readings in comparison to one-year-old control SSWC seedlings. One-year-old seedlings in both fertilization treatments with antitranspirant and silicone and latex showed similar diurnal Ψ_x patterns as the five-year-old seedlings (Fig.1D & E).

On July 14, environmental conditions were the warmest recorded during the growing season. Diurnal temperature patterns reflected a clear sunny day with a peak irradiance of 1082 $W \cdot m^{-2}$ being recorded at the 1130 h sampling period (Fig.2A). The soil surface temperatures at this time for the two fertilizations treatments were 35.4°C for N & P and 43.0°C for SSWC (Fig.2B & C). Soil temperatures at 10 cm ranged from 7.4 to 17.4°C for N & P and 7.2 to 15.7°C for SSWC (Fig.2B & C). Under these high irradiance and high temperature conditions, ABSHD reached 20.43$\mu g \cdot cm^{-3}$ for N & P and 23.2$\mu g \cdot cm^{-3}$ for SSWC fertilization treatments (Fig.2A).

On July 14, one-year-old seedlings in both fertilization treatments combined with the control and silicone and latex WCTs had Ψ_x readings which were more negative than -2.0 MPa during the midpart of the day (Fig.2D & C). These seedlings had a more negative Ψ_x diurnal pattern in comparison to antitranspirant treated one-year-old seedlings and five-year-old seedlings in both fertilization treatments.

On August 12, the skies were overcast with intermittent rain showers, and a peak irradiance of 444 $W \cdot m^{-2}$ at the 1130 h sampling period (Fig.3A). The constant cloud cover throughout the day resulted in negligible differences between temperature profiles for the fertilization treatments (Fig.3B & C). Soil surface temperatures reached their highest reading at the 1130 h sampling period and were 17.2°C for N & P and 21.8°C for SSWC. Due to little difference in temperature profiles between fertilization treatments, there was little difference in ABSHD levels (Fig.3A).

Diurnal patterns of Ψ_x on August 12 for five-year-old seedlings in both fertilization treatments showed no water stress and reflected the lack of harsh microclimatic conditions (Fig.3D). The diurnal Ψ_x patterns for five-year-old seedlings in both fertilization treatments were significantly less negative than the control one-year-old seedlings in the N & P treatment which, in turn, were significantly less negative than one-year-old control seedlings in SSWC. The control one-year-old seedlings in SSWC reached negative Ψ_x values of -1.5 MPa during the afternoon. The addition of antitranspirants and silicone and latex to one-year-old seedlings in SSWC reduced the level of water stress, but only the antitranspirants resulted in significant reduction in water stress (Fig.3D & E). One-year-old seedlings in N & P had similar diurnal Ψ_x patterns in all WCT (Fig.3D & E).

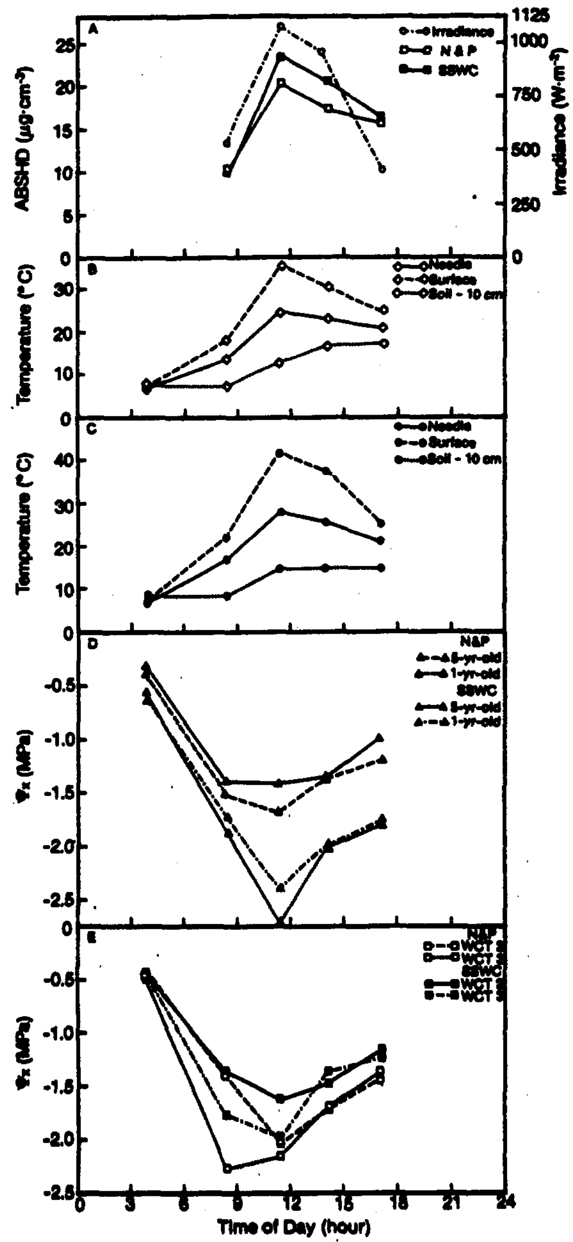

Figure 2. Diurnal patterns for July 14, 1981 of: (A) irradiance and absolute humidity difference between needle and air (ABSHD) for 68 kg N/ha and 90 kg P/ha (N & P) treatment, and sewage sludge and wood chips (SSWC) treatment; (B) needle, soil surface, and soil (-10cm) temperatures for N & P; (C) needle, soil surface and soil (-10cm) temperatures for SSWC; (D) xylem pressure potential (Ψ_x) for one- and five-year-old lodgepole pine seedlings in N & P and SSWC fertilization treatments; and (E) xylem pressure potential (Ψ_x) for one-year-old seedlings in N & P and SSWC separated by water conservation treatments. WCT 2 = antitranspirant, WCT 3 = silicone and latex.

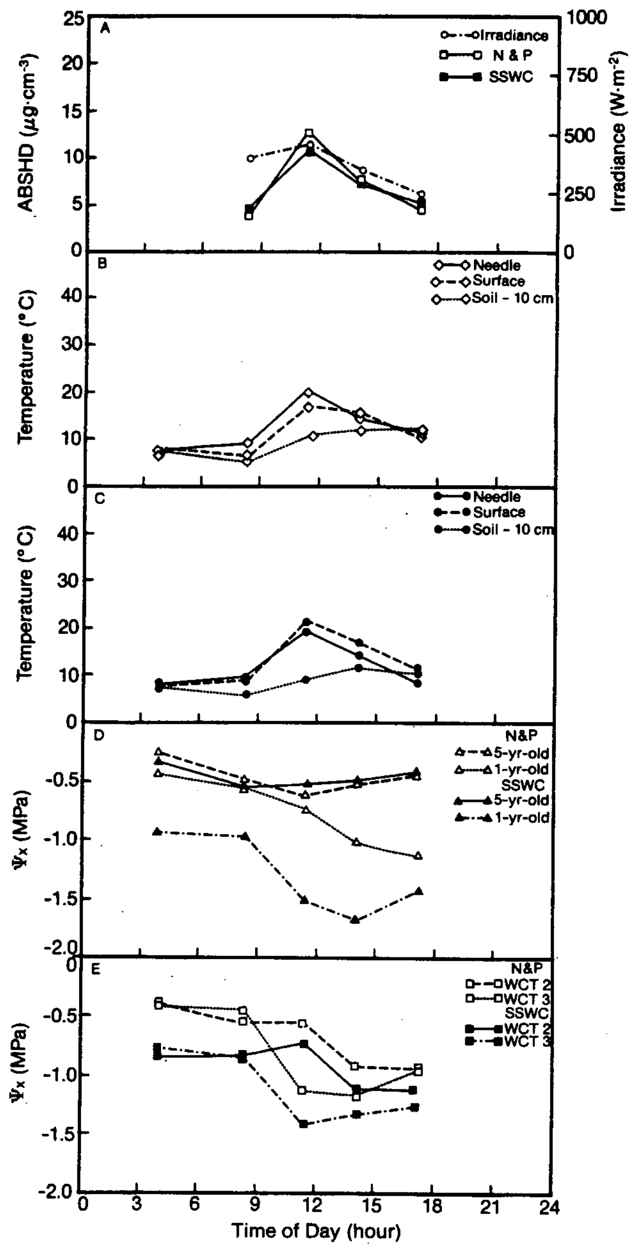

Figure 3. Diurnal patterns for August 12, 1981 of: (A) irradiance and absolute humidity difference between needle and air (ABSHD) for 68 kg N/ha and 90 kg P/ha (N & P) treatment, and sewage sludge and wood chips (SSWC) treatment; (B) needle, soil surface, and soil (-10cm) temperatures for N & P; (C) needle, soil surface and soil (-10cm) temperatures for SSWC; (D) xylem pressure potential (Ψ_x) for one- and five-year-old lodgepole pine seedlings in N & P and SSWC fertilization treatments; and (E) xylem pressure potential (Ψ_x) for one-year-old seedlings in N & P and SSWC separated by water conservation treatments. WCT 2 = antitranspirant, WCT 3 = silicone and latex.

Seasonal measurements of predawn and midday Ψ_x readings.

Predawn Ψ_x readings, Ψ_{soil} at 10 cm, needle temperature and soil temperatures at 10 cm throughout the growing season are shown in Table 1. Soil temperatures taken at 10 cm indicated that during the night hours, soil temperatures were consistently below 8.0°C for the entire growing season. In almost every instance the predawn Ψ_x values for five-year-old seedlings in both fertilization treatment were the least negative. The predawn Ψ_x values for five-year-old seedlings were not found to be discernibly different between fertilization treatments for the entire growing season.

As a whole, one-year-old seedlings in the SSWC fertilization treatment in all WCTs showed the greatest level of predawn water stress (Table 1). The control one-year-old seedlings in SSWC for the most part had the greatest level of water stress. This is reflected in estimates of Ψ_{soil} at 10 cm which were shown to be more negative in SSWC in comparison to N & P throughout the growing season. The application of the silicone and latex water harvesting technique increased the level of soil water at 10 cm in the SSWC treatment. Both the antitranspirant and silicone and latex treatments reduced the level of predawn water stress of one-year-old seedlings in SSWC. But, the silcone and latex treatment was not consistently effective in reducing the Ψ_{soil} and subsequent predawn seedling water stress of one-year-old seedlings in SSWC to levels which are comparable to one-year-old seedlings in N & P. The antitranspirant treatment was also not effective in reducing predawn seedling water stress to levels comparable to one-year-old seedlings in N & P.

As a whole, one-year-old seedlings in the N & P fertilization treatment in all WCTs had more negative predawn Ψ_x readings than five-year-old seedlings in both fertilization treatments, but less negative Ψ_x readings than one-year-old seedlings in SSWC. Only on July 14 were predawn Ψ_x readings comparable between fertilization treatments. On this day Ψ_{soil} in the SSWC treatment were at their highest level of soil water recorded during the growing season. The antitranspirant and silicone and latex treatments were not effective in reducing predawn water stress of one-year-old seedlings in the N & P treatment. The silicone and latex treatment was not as effective in increasing Ψ_{soil} in N & P treatment due to the inherent high levels of soil moisture retained in this soil medium in comparison to the SSWC treatment. June 16, two days after seedlings were planted and WCT applied, was the only day that the WCT were able to significantly reduce water stress in comparison to control seedlings for both fertilization treatments.

Midday Ψ_x readings and environmental conditions of the mine site for the entire growing season are shown in Table 2. Soil temperatures taken at 10 cm indicate that soil temperatures collected on July 14 reflect the point in the growing season when temperatures were at their maximum, 12.7°C and 14.6°C for SSWC. Midday soil temperatures ranged between 6.1 and 10.9°C for the rest of the sample periods. The irradiance and ABSHD data show that July is the peak time for stressful conditions. Both June and August show cooler environmental conditions which is indicative of the growing season found at these elevations.

Table 1. Predawn xylem pressure potential readings of one-year-old lodgepole pine seedlings in response to fertilization or water conservation treatments, and five-year-old lodgepole pine seedlings in response to fertilization treatments on a high-elevation mine site.

Sampling Date	Soil Water Potential at 10 cm (MPa)				Temperature (°C)			Predawn Xylem Pressure Potential (MPa)							
	68kgN/ha & 90kgP/ha		Sewage Sludge & Wood Chips		Air (10cm)	Soil (-10cm)		Five-Year-Old		One-Year-Old					
										68kgN/ha & 90kgP/ha			Sewage Sludge and Wood Chips		
	Control	Silicone & Latex	Control	Silicone & Latex		68kgN/ha & 90kgP/ha	Sewage Sludge & Wood Chips	68kgN/ha & 90kgP/ha	Sewage Sludge & Wood Chips	Control	Anti-transpirant	Silicone & Latex	Control	Anti-transpirant	Silicone & Latex
6/16/81	-0.45	-0.30	-0.70	-0.45	0.5	2.0	2.0	-0.60a*	-0.54a	-1.02c	-0.65ab	-0.64ab	-0.96c	-0.83b	-0.92c
6/30/81	-0.25	-0.25	-0.50	-0.40	5.0	5.1	7.1	-0.40a	-0.40a	-0.48a	-0.58a	-0.52a	-1.02b	-0.91b	-0.84b
7/14/81	-0.20	-0.10	-0.40	-0.35	7.0	7.4	7.2	-0.41a	-0.31a	-0.56c	-0.41ab	-0.51bc	-0.50bc	-0.42ab	-0.41ab
7/28/81	-0.45	-0.40	-1.85	-0.75	7.0	8.0	8.0	-0.24a	-0.34ab	-0.39b	-0.35ab	-0.30ab	-0.91d	-0.82d	-0.63c
8/12/81	-0.20	-0.15	-1.00	-0.85	8.0	7.6	7.6	-0.25a	-0.33ab	-0.42b	-0.38b	-0.41b	-0.94d	-0.85cd	-0.76c
8/28/81	-0.25	-0.15	-1.10	-0.45	5.2	6.1	7.3	-0.33a	-0.38a	-0.48ab	-0.41a	-0.39a	-0.73d	-0.67cd	-0.58bc

* Xylem pressure potential means between fertilization and fertilization-water conservation treatments with a common letter are not significantly different at $p = 0.05$ as determined by Tukey's mean separation test.

Table 2. Mid-day xylem pressure potential readings of one-year-old lodgepole pine seedlings in response to fertilization or water conservation treatments, and five-year-old lodgepole pine seedlings in response to fertilization treatment on a high-elevation mine site.

	Environmental Conditions					Midday Xylem Pressure Potential (MPa)							
	Irradiance	Soil (-10cm) Temperature		Absolute Humidity Deficit (μg.cm^{-3})		Five-Year-Old		One-Year-Old					
								68kg N/ha & 90kg P/ha			Sewage Sludge & Wood Chips		
Sampling Date	(W.m^{-2})	68kg N/ha & 90kg P/ha	Sewage Sludge & Wood Chips	68kg N/ha & 90kg P/ha	Sewage Sludge & Wood Chips	69kg N/ha & 90kg P/ha	Sewage Sludge & Wood Chips	Control	Anti-transpirants	Silicone & Latex	Control	Anti-transpirants	Silicone & Latex
6/16/81	956	6.4	6.1	10.4	12.0	-1.36a*	-1.41a	-1.74b	-1.31a	-1.23a	-1.98b	-1.10a	-1.23a
6/30/81	554	7.6	7.6	12.9	13.6	-1.23a	-1.26a	-1.85b	-1.48ab	-1.60b	-1.76b	-1.74b	-1.70b
7/14/81	1082	12.7	14.6	20.4	23.2	-1.69ab	-1.41a	-2.75d	-2.04bc	-2.17c	-2.40cd	-1.65ab	-2.03bc
7/28/81	1006	7.1	8.6	18.5	21.9	-1.33	1.26a	-2.02bc	-2.21c	-1.68ab	-2.00bc	-2.12bc	-1.87bc
8/12/81	444	10.9	9.1	12.6	11.1	-0.63ab	-0.51a	-0.71b	-0.55a	-0.72b	-1.51d	-1.11c	-1.41d
8/28/81	733	8.3	8.1	14.0	14.7	-1.44a	-1.47ab	-1.72c	-1.52b	-1.37a	-1.81c	-1.58b	-1.46a

*Details as in Table 1.

As was shown with predawn Ψ_X values, the midday Ψ_X values for five-year-old seedlings in both fertilization treatments were the least negative (Table 2). The midday Ψ_X values for five-year-old seedlings were not found to be discernibly different between fertilization treatments for the entire growing season.

In contrast to predawn Ψ_X readings, one-year-old seedlings midday Ψ_X readings did not show a consistent difference between fertilization treatments (Table 2). On all days except August 12, the evaporative demands placed upon the control seedlings was great enough to cause water stress more negative than -1.5 MPa in both fertilization treatments. On August 12 when skies were overcast and intermittent rain showers were occurring, all one-year-old seedlings in SSWC had significantly greater levels of water stress than all one-year-old seedlings in N & P.

The application of WCTs did result in a reduction in midday water stress for one-year-old seedlings, but consistent patterns are not distinguishable (Table 2). On June 16, two days after the application of antitranspirant or silicone and latex treatments, there was a significant reduction in the level of midday water stress for one-year-old seedlings in both fertilization treatments. Two weeks later on June 30, under similar environmental conditions there was no difference between control seedlings and WCT seedlings in either fertilization treatment. Throughout the summer, except on June 16 and August 12, antitranspirant and silcone and latex did result in a reduction in water stress, but the midday Ψ_X readings in these treatments ranged between -1.48 to -2.21 MPa for antitranspirant, -1.37 to -2.17 MPa for silicone and latex in N & P, -1.58 to -2.12 MPa for antitranspirant and -1.41 and -2.03 MPa for silicone and latex in SSWC.

Morphological development of one- and five-year-old seedlings.

By the end of the first growing season on the high-elevation mine site, root development of one-year-old seedlings was dramatically affected by fertilization treatments (Table 3). This impact on root development was still visible after the seedlings had been grown on the mine site for five years. Root dry weight in the container plugs, in the waste material, and total root dry weight of the two were significantly greater in the N & P treatment in comparison to the SSWC treatment for one- and five-year-old seedlings. Root dry weight in waste material is the amount of root biomass that has developed out of the original containerized seedling plug into the amended rock waste material.

A diagrammatic representation of one- and five-year-old seedling root development pattern as influenced by fertilization are shown in Figures 4 and 5, respectively. Root development pattern of one-year-old seedlings was shown to be dramatically affected by the SSWC fertilization treatment. Of special note is the complete lack of root development in the waste material amended with SSWC, except directly below the container plug, while root systems of seedlings in N & P showed moderate development in the 5- to 35-cm region of the rock waste material. Five-year-old seedlings in N & P had

Table 3. Morphological development of one-year-old lodgepole pine seedlings in response to fertilization or fertilization-water conservation treatments, and five-year-old lodgepole pine seedlings in response to fertilization treatments on a high-elevation mine site.

Seedling Age	Water Conservation Treatment	Height (cm)	Stem Diameter (mm)	Shoot Dry Weight (mg)	Root Dry Weight (mg) Container Plug	Root Dry Weight (mg) Waste† Material	Root Dry Weight (mg) Total	Total Root Dry Wt. / Shoot Dry Wt.	Root Dry Wt. (waste material) / Shoot Dry Wt.
				68kg N/ha & 90 kg P/ha Treatment					
	None	2.23a*+	.92a*	208a	186a	40a	227ab	1.10ab	.19a
One-year-old	Antitranspirant	1.76ab	.53a	201a	191a	35a	225ab	1.12ab	.17a
	Silcone & Latex	1.32b	.88a	195a	191a	38a	230a	1.18a	.20a
	Average	1.77a	.78a	201a	189a	38a	227a	1.12a	.19a
				Sewage Sludge and Wood Chips Treatment					
	None	1.54b	.86a	234a	144a	5b	149c	0.66b	.021b
One-year-old	Antitranspirant	1.16b	.92a	222a	158a	1b	159bc	0.76b	.004b
	Silicone & Latex	1.44b	.93a	236a	146a	11b	156bc	0.66b	.047b
	Average	1.38a	.90a	231a	149b	6b	155b	0.67b	.045b
				68kg N/ha & 90kg P/ha Treatment					
Five-year-old	--------	20.0a	5.2a	611a	279a	190a	469a	.73a	.31a
				Sewage Sludge and Wood Chips Treatment					
Five-year-old	--------	21.5a	4.8b	401b	197b	96b	293b	.97a	.24a

† Root dry weight in waste material is the amount of root biomass that has developed out of the original containerized seedling plug into the amended rock waste material.

* Height and stem diameter measurements for one-year-old seedlings represent the mean incremental growth taken from the entire seedling population.

\+ Means between fertilization or fertilization-water conservation treatments for one-year-old seedlings, and between fertilization treatments for five-year-old seedlings with a common letter are not significantly different at p=0.05 as determined by Tukey's mean separation test. No statistical comparisons were done between one- and five-year-old seedlings.

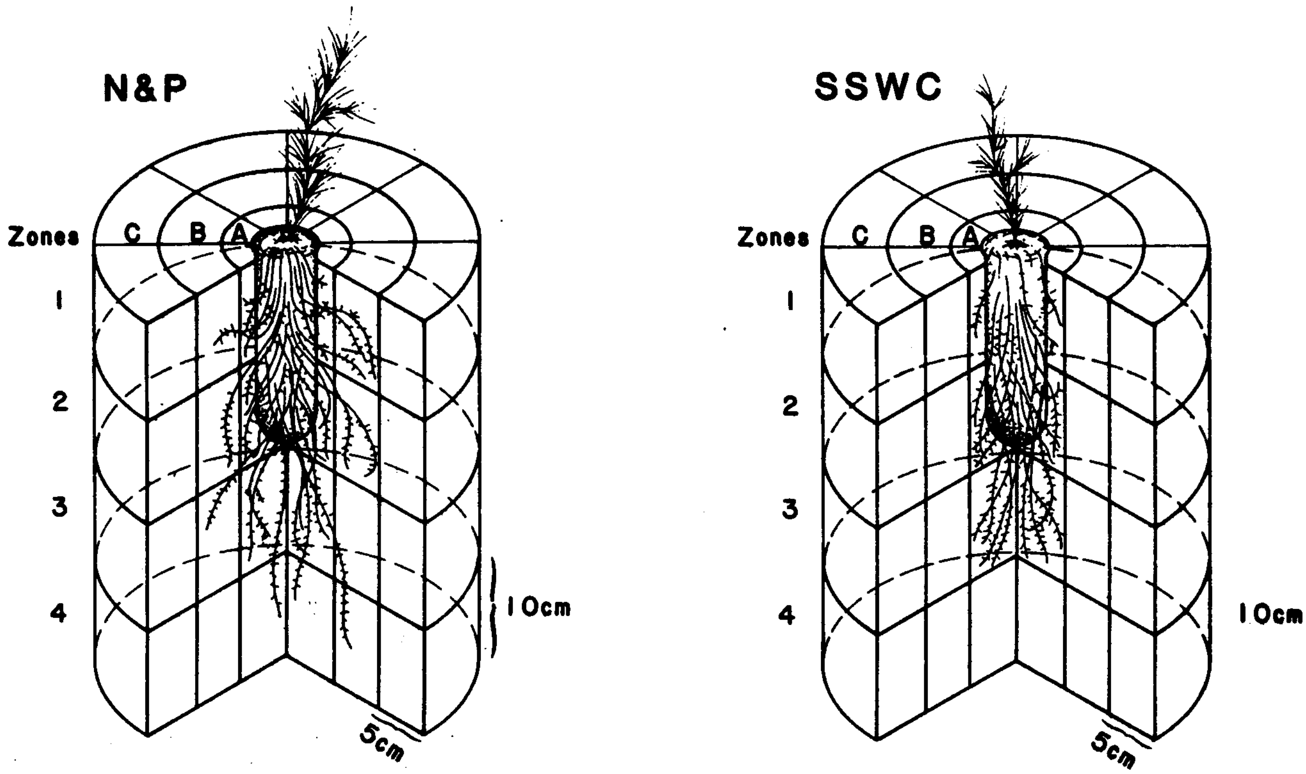

Figure 4. Diagramatic representation of one-year-old lodgepole pine seedling root development patterns as influenced by fertilization treatment on a high-elevation mine site. Composite drawing from 36 seedlings in each fertilization treatment which represent data collected on root number and length in each quadrant. 68 kg N/ha and 90 kg P/ha = N & P, sewage sludge and wood chips = SSWC.

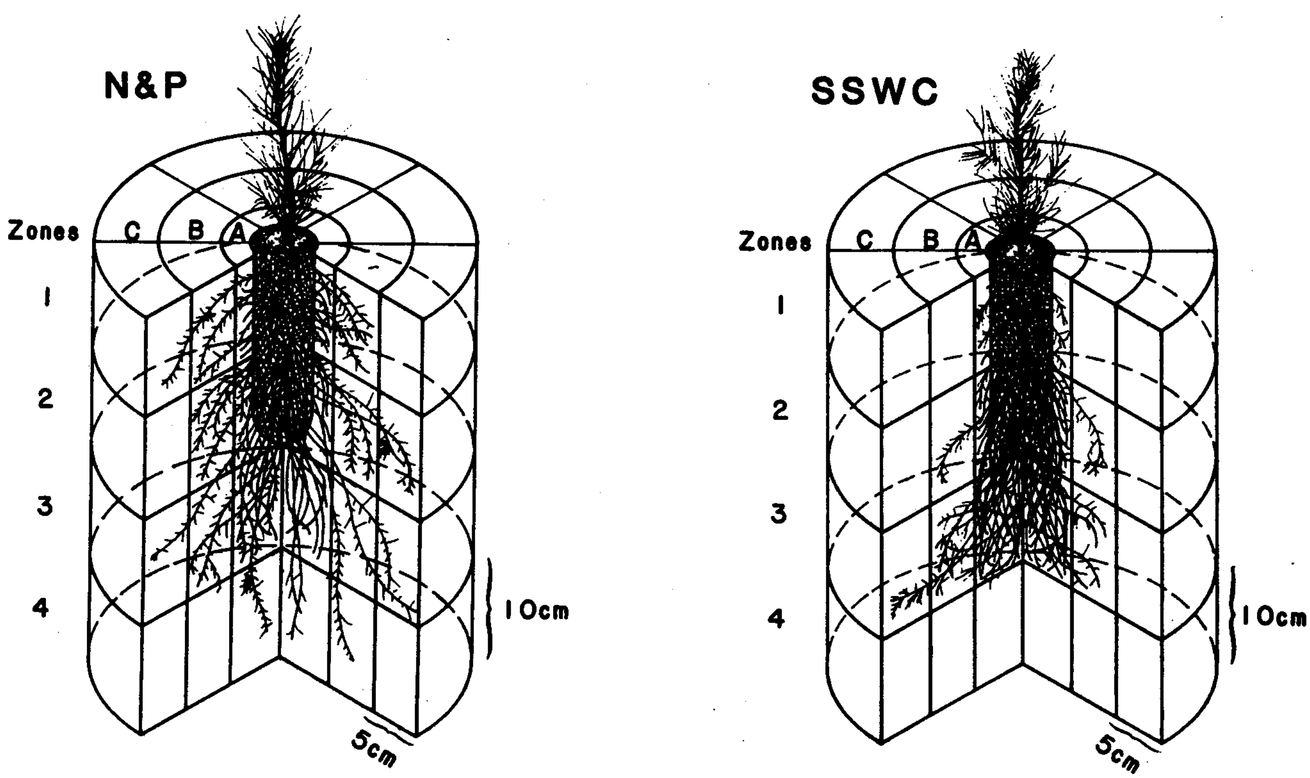

Figure 5. Diagramatic representation of five-year-old lodgepole pine seedling root development patterns as influenced by fertilization treatment on a high-elevation mine site. Composite drawing from 12 seedlings in each fertilization treatment which represent data collected on root number and length in each quadrant.68 kg N/ha and 90 kg P/ha = N & P, sewage sludge and wood chips = SSWC.

extensive horizontal root development from just below the soil surface to a depth of 35 cm, while seedlings in SSWC showed very little horizontal root extension beyond 10 cm, with most root development directly below the initial container plug. Horizontal root development for five-year-old seedlings in both fertilization treatments in zones 1B and 2B were found to be in a semi-circular pattern owing to the presence of the cedar shingle impeding root extension. Cedar shingles had been placed vertically on the southwest side of each seedling to protect them from wind and high solar radiation.

The five-year-old seedlings had significantly greater stem diameter and shoot biomass in N & P in comparison to SSWC (Table 3). The one-year-old seedlings showed no discernable shoot development response to fertilization treatments. Height and stem diameter of one- and five-year-old seedlings utilized in determining plant water status were similar to those seedlings excavated for root development analysis.

For one-year-old seedlings, the root/shoot ratio of total root dry weight/shoot dry weight was significantly larger in the N & P treatment than in the SSWC treatment. For five-year-old seedlings, there was no difference in this root/shoot ratio between fertilization treatments. Comparison between one-year-old and five-year-old seedlings shows that one-year-old seedlings in N & P had the largest total root dry wt./total shoot dry wt. ratio, with five-year-old seedlings in N & P second largest and one- and five-year-old seedlings in SSWC with the lowest ratios.

The root dry weight in waste material (WM)/shoot dry weight ratio was very small for one-year-old seedlings in both fertilization treatments, with one-year-old seedlings in SSWC having a significantly smaller ratio. There were no differences between root dry weight (WM)/shoot dry weight ratios for five-year-old seedlings in either fertilization treatment, and their ratios were much larger than those of one-year-old seedlings.

The main effect of WCT had no statistically significant influence on one-year-old seedling development, and these data are not presented. The interaction of fertilization treatment x WCT combination indicated reduced growth of shoot and roots because of WCT, but it is hard to discern whether reduced growth was a result of the WCT or the overriding influence of fertilization treatments (Table 3).

DISCUSSION

Edaphic conditions of the mine site as influenced by reclamation practices affected seedling plant water status and subsequent root development patterns. Previous work by the author indicated that reduced survival of conifer seedlings in the SSWC treatment was attributable to the seedlings microenvironment, resulting in seedling dessication (Grossnickle and Reid 1982). Findings from this study show that one-year-old seedlings in SSWC exhibited the greatest levels of seedling moisture stress. Inputs of waste organic matter into soil systems have been shown to increase soil porosity, decrease bulk density, and increase saturated hydraulic conductivity (Tiarks et al. 1974; Weil and Kroontje 1979). However, at water contents below soil saturation, additions of sewage sludge have been shown to decrease unsaturated hydraulic conductivity (Gupta et al. 1977). The Ψ_{soil} throughout the growing season was well below field capacity, thus increased water stress in one-year-old seedlings in SSWC can be partially attributed to reduced hydraulic conductivity which resulted in reduced water movement to the roots (Hillel 1974).

The one-year-old seedlings in N & P did not have as great a level of seedling moisture stress as one-year-old seedlings in SSWC. However, they did show greater levels of water stress than five-year-old seedlings in both fertilization treatments when evaporative demands were high.

The silicone and latex treatment was found to increase soil moisture and reduce predawn seedling moisture stress, but it did not have a great influence on soil water availability to enhance seedling growth and reduce seedling moisture stress under conditions of high evaporative demand. Only when moderate evaporative demand and cool temperatures occurred did the silicone and latex treatment result in increased soil moisture and a more favorable plant water status. These findings are in contrast to other studies which have shown improved growth due to increased soil moisture with water harvesting techniques (Packer and Aldon 1978; Carpenter et al. 1978; Sauer 1979).

Antitranspirants were not found to have a long term influence on the plant water status of one-year-old seedlings. Initially this treatment reduced the level of water stress in one-year-old seedlings in both fertilization treatments. However there was no consistent trend of reduction in water stress throughout the study. Film type antitranspirants have limited usefulness on growing seedlings because repeated applications are necessary on seedlings with increasing needle surface and over time a breakdown will occur in the antitranspirant around the guard cell pores (Davenport et al. 1972, Davies and Kozlowski 1974).

The inability of one-year-old seedlings in SSWC to maintain adequate levels of plant water is a possible factor responsible for the reduction of root development in this fertilization treatment. One would expect root growth to be reduced directly by plant water deficits through its effect on cell turgor (Hsaio 1973), and a number of studies have shown roots of gymnosperms and angiosperms to cease elongation and become inactive at Ψ_{soil} more negative than -0.6 to -0.7 MPa (Leshman 1970, Day and MacGillivray 1975, Larson 1980). Predawn xylem pressure potential readings were utilized to indicate the amount of soil water actually encountered by the seedling and to determine the value of plant water at which the seedling begins each daylight period (Hinckley et al. 1978). Throughout the growing season all one-year-old seedlings in SSWC had predawn xylem pressure potential readings which were consistently more negative than -0.6 MPa. The only exception was on July 14 when predawn xylem pressure potential readings recorded were less negative than -0.6 MPa. One-year-old seedlings in N & P had predawn xylem pressure potential readings more negative than -0.6 MPa only on June 16, two days after the seedlings were planted. Five-year-old seedlings in both fertilization treatments had predawn water stress readings which were equal to or less negative than -0.6 MPa during the entire growing season.

The Ψ_x measured throughout the day can vary over a considerable range and above a critical value without marked effect on stomatal aperture (Jarvis 1980). When a critical Ψ_x value is reached stomata begin to close. Stomatal apertures are controlled by a complex mechanism which operates to maintain a variable balance between CO_2 uptake, while restricting water loss from the plant (Schulze and Hall 1982). Thus photosynthesis is affected by stomatal activity since CO_2 assimilation rate is directly influenced by stomatal opening (Farquhar and Sharkey 1982). In lodgepole pine stomata have been shown to close at -1.45 MPa (Lopushinsky 1969). On all days except August 12, measured plant water status of one-year-old control seedlings in both fertilization treatments were more negative than -1.45 MPa. One-year-old seedlings in both fertilization treatments with antitranspirant or silicone and latex treatments had measured plant water status more negative than -1.45 MPa on all days except June 16 and August 12. For five-year-old seedlings, only on July 14, in N & P, did any measured plant water status values greatly exceed the stomatal closure value. These values indicate that throughout the field season all one-year-old seedlings were regularly at water stress levels which would be inhibitory for normal physiological processes related to growth.

Moderate to little root extension into waste material in both fertilization treatments after the first growing season in the field can be partially attributed to the low soil temperatures that occurred throughout the growing season (Tranquillini 1979). Root studies with P.contorta in the mountains of New Zealand showed very rapid root extension only when mean soil temperatures rose well above 10°C (Benecke et al. 1978). The findings show minimum soil temperatures in both fertilization treatments at the effective rooting depth consistently dropped below 8°C through the entire growing season.

The five-year-old seedlings in both fertilization treatments had similar water relations patterns. The lack of water stress in five-year-old seedlings in SSWC may be attributed to root system development into rock waste material below the zone where SSWC had been effectively mixed. Thus, physical characteristics of the soil material in some parts of the root absorption zone were probably comparable to those of seedlings in the N & P treatment.

A balanced root/shoot ratio or, more accurately, the absorbing surface to transpiring surface ratio is important in preventing development of high water deficits caused when absorption lags behind transpiration (Kramer and Kozlowski 1979). The root/shoot ratio based on root dry weight in waste material (WM)/shoot dry weight probably best approximated the actual root absorption/needle transpiration ratio of containerized seedlings. Interpretation of the water relations data indicated that all five-year-old seedlings had the largest root dry weight (WM)/shoot dry weight ratio, and the least amount of water stress. The one-year-old seedlings in N & P had intermediate root/shoot ratios and water stress patterns while one-year-old seedlings in SSWC had the lowest ratios and the greatest amount of water stress. This agrees with the findings of Grossnickle and Reid (1984) who determined that Engelmann spruce seedlings (Picea engelmannii Parry ex. Engelm.) which had the poorest root development out of container plugs had the greatest amount of water stress and lowest needle conductance and transpiration values in comparison to seedlings with a greater development of roots out of the container plug. A study of field-planted ponderosa pine seedlings also showed seedlings with large root/shoot ratios had less negative Ψ_x in comparison to seedlings with small root/shoot ratios (Baldwin and Barney 1976).

A possible explanation for the good relationship between plant water status and the root dry weight (WM)/shoot dry weight ratio is that containerized seedlings planted at this site were previously grown in a soil media of peat and vermiculate (1:2.5 v/v) which created desirable soil characteristics for root growth in the nursery (increased aeration and water holding capacity, and low bulk density) (Tinus and McDonald 1979). However, when planted on the high-elevation mine site, a discontinuity in soil characteristics was created between the peat-vermiculite material and the rock waste material. The waste material-soil plug textural difference may actually impede unsaturated water flow from waste material into the container plug until water accumulates in waste material, and the waste material matric potential increases sufficiently to allow water to enter the large pores of the container plug soil media. In unsaturated conditions, there may even be an outward movement of soil water from the container plug into the surrounding soil medium (Day and Skoupy 1971). Thus, roots in the container plug are not an effective part of the seedlings water absorbing system under low soil moisture conditions.

Previous work by the author determined that the incorporation of SSWC into the rock waste material on the high-elevation mine site increased the nutrient status of the soil medium, which resulted in increased seedling growth (Grossnickle and Reid 1982). Problems occur with the fertilization treatment during the seedling establishment. Findings from study confirm that one-year-old seedlings in SSWC exhibit a greater level of water stress than either one-year-old seedlings in N & P, or five-year-old seedlings in both fertilization treatments. The ability of the seedlings to overcome this problem is through the development of a root system out of the container plug into the waste material. For newly planted seedlings to survive the initial establishment phase in the field the availability of soil moisture and the development of an extensive root system are needed to meet the environmental demands of the site.

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USE OF HUMIC SUBSTANCES IN PLANT GROWTH

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INTRODUCTION

Humic substances, the major constituents of soils and sediments are widely distributed over the earth's surface, occurring in almost all terrestrial and aquatic environments. They are formed from the chemical and biological degradation of plant and animal residue and from the synthetic activities of micro-organisms. The products so formed tend to associate into complex chemical structures that are more stable than the starting materials. Humic substances are dark colored, acidic, polyelectrolyte materials that range in molecular weights from a few hundred to several thousand. The cation exchange capacity of Humic acid varies from 200 to 500 meq. per 100 grams at pH7. Humic acids are generally categorized into three main fractions: (a) Humic acid which is soluble in dilute alkali but is percipitated on acidification and is generally of high molecular weight. (b) Fulvic acid which remains in solution when the humic fraction is acidified. (c) Humin which is the unextractable fraction. The most biochemically active fraction of the three is the alkali soluble portion, Humic acid.

Chemical investigation of humic substances goes back more than 200 years. The capacity of humic substances to absorb water and plant nutrients was one of the first observations.

In the period from 1958 to 1970, the United States Bureau of Mines in Colorado carried out considerable work with Leonardite shale, which is a naturally occurring overlay of most lignite mines. Their work was primarily with those mines located in North Dakota. It is theorized that Leonardite shale originated from trees and other vegetation which grew in the carboniferous period when most of North America was a tropical type forest. Over the ages, the vegetation underwent compaction and heating and slowly carbonized and formed coal. This compaction squeezed out the organic acids and esters present in the vegetation and formed a pool on top of the lignite bed. This pool dried, aged, and eventually formed Leonardite shale. Because of its vegetative origin, this material contains Humic acids. The content of Humic acids is variable with the location of the Leonardite deposits found throughout the world. Those deposits in the North Dakota area contain 80 to 90 per cent Humic acids and are among the most pure deposits in the world. Those deposits of the New Mexico area are largely contaminated with silica and contain 30 to 40 per cent Humic acids. Those of the Texas area contain 45 to 55 per cent Humic acids and are contaminated with pyrites.

Since Leonardite shale is an easily available and concentrated form of Humic acids, much research work and commercial use has been made of it. Other sources of Humic acids are peat, muck, green and animal manures. Any one of these materials is beneficial to plant growth when incorporated into the soil.

RESEARCH DATA

The humates function to increase the water-holding capacity of the soil; thus soils containing humates tend to provide a more drought resistant buffer for crop production. The presence of humates appears to increase soil particle aggregation and consequent soil structure with a resulting increase in aeration, tilth, and workability, as well as better water movement caused by increased soil capilliary and non-capilliary space. This ability of Leonardite shale is being capitalized upon by farmers in the midwest where they combine applications of Humic acids with lime or fertilizers since its use materially reduces the tightness of the soil. Use of Humic acids materially increases the cation exchange capacity of the soil (Freeman, 1969; Miller, etal 1958) thus improving longer term retention of applied or inorganic fertilizers.

A further action of Humic acids in the soil is to increase the buffering property of the soil under alkaline conditions (Freeman, 1969; Senn and Kingman, 1975). Freeman (1969) also states that humic fractions act to effect biological stimulation of growth in that they serve as substrates of micro-organisms as well as causing direct plant growth stimulation by providing a slow release of auxins, amino acids, and organic phosphates.

Fowkes (1975) presented data which demonstrated that increasing the humic fraction of soil reduced the tendency of soil to compact, increased infiltration and retention of water, and increased soil particle aggregation, as well as long term effects of lower soil pH, enhanced nutrient transfer, and increasing micro-organism populations of treated soil.

Humic substances promote the conversion of a number of mineral elements into forms available to plants (Russell, 1961). The increased availability of phosphate in the presence of Humic acids has been shown. This is apparently achieved in that Humic acids are capable of breaking the bond between the phosphate ion and the iron ion in acid soils or the calcium ion in alkaline soils, making those elements more available to the plant. DeKock (1955) showed that Humic acids were effective in the conversion of iron to available forms which protected plants from chlorosis even in the presence of high concentrations of the phosphate ion. Phsophate accumulation in the plant tops was a linear function of increasing concentrations of Humic acids even though the higher rates decreased crop yields. These results were observed by Hajdukovic and Ulrich (1965); Jelenic etal (1966); Hashimoto (1965).

Since humic substances are polyelectrolytes and macro-ionic in nature, they tend to increase the osmotic process and increase ion exchange in a solution. Greenland and Hayes (1978).

Senn and Kingman (1973, 1975), Stevenson (1982), and Schnitzer and Kahn (1978), suggest that an important role is played by the humic substances in which trace elements are linked to the substances in the form of chelates. In fact, toxicants such as aluminum, copper, cobalt, and cadmium are bound so tightly as to effectively take them out of the soil solution.

A number of reports indicated or suggested the presence of auxin type reactions by humic substances. Lee and Bartlett (1976) showed that humic substances were effective in the stimulation of corn seedlings and algae. As with auxins, plant growth tended to be less stimulated by high concentrations of humates and they can decrease plant growth and yield if too high. Recently a good deal of research work has been done with Humic acids and their effect on seed germination and on growth of seedlings. These trials have indicated that seeds treated with Humic acids will germinate more rapidly and uniformly, produce healthier seedlings, and ultimately result in increased yield of plants such as tomatoes, peppers, cucumbers, potatoes, and corn. This technique is being used in fluid gel seeding trials. Here again, low levels of Humic acids stimulate while high levels depress seed germination.

Lee and Bartlett (1976) suggest that on the basis of their data that it might be possible to increase algae populations by the application of Humic extract. Increases in population of nitrogen fixing algae in rice fields could increase the nitrogen content of the soil. Tests have been carried out with Rhizobium organisms by Senn and Kingman (1973, 1975). They found that Humic acids stimulated the activity of Rhizobium organisms in the soybean group. As previously noted, Humic acids generally tend to stimulate most soil microflora. However, unpublished data indicates that it tends to reduce growth of Fusarium solani.

Poapst and Schnitzer (1971) observed that root initiation of hypocotyl segments of beans were stimulated by treatment with low concentrations (up to 60 ppm) of Humic acids. With high concentrations, stem elongation of Alaska pea stems was inhibited (Poapst etal, 1970). Fernandez (1978) also found that low concentrations of Humic acids increased dry matter production in corn plants. Bryan (1976) found the same result by treating seeds of tomato plants which resulted in an eventual increase in yield of the plant. Conover (1978) found that use of Humic acids in potting soil resulted in increased top and root growth of ornamentals. This research may support the idea that more than one mechanism may be involved in effects of humic substances on plant growth.

McCants and Peedin (1971) conducted field tests with addition of humates to fertilizer applied to flue cured tobacco. They concluded that humic substances can influence plant growth and that humates derived from Leonardite shale may increase the yield of commercial plant parts. They further that the magnitude and consistency of increase are variable and determined by unidentified factors.

Freeman (1969) found that using Leonardite as a soil additive in field experiments resulted in greater yields of potatoes and soybeans. He further stated that a great many questions remain to be resolved before a clear understanding of these effects is determined. He suggests that varietal and species differences are evident and must be taken into account. He further suggests the possibility that Humic acids provide the free radicals necessary to stimulate electron transfer and the uptake and transport of iron by plants. Alternatively, the humate-iron complex may provide the bivalent iron necessary to catalyze transport enzymes.

Senn and Kingman (1975) found that lower concentrations (3.6 per cent) of Humic acids stimulated tomato seed germination whereas higher concentrations (greater than 18 per cent) significantly lowered the per cent of germination and that at even higher concentrations of approximately 25 per cent all seed were killed by treatment with Humic acids. Tomato plants treated with humates resulted in an increase in calcium in the plants with an increase in the rate of application.

Tann (1982) found that Humic acids added to calcium enabled the calcium to mobilize downward into the soil profile by one meter after a period of four months, possibly due to chelation of the calcium ion. This in turn would make lower soil profiles more compatible to plant roots and microflora.

SUMMARY

A partial explanation of the growth stimulation effect of Humic acids on plants is by means of the chelation activity of the humates and their ability to break the bond of the insoluble iron phosphate or calcium phosphate molecules in the soil, making their individual elements available to the plant. Iron is a known stimulator or initial plant growth, chlorophyl formation, transport of enzymes and metallic elements within the plant. Phosphate is a known stimulator of seed germination, root initiation, and fruiting of plants.

The second effect of Humic acids is their ability to improve soil structure, increase soil particle aggregation, aeration, and water movement. This contributes materially to better plant growth.

The third effect of Humic acids is to increase availability and absorption of soil nutrients by the plant and to prolong the release of nitrogen and inorganic fertilizers. Humic substances act as suppliers and regulators of plant nutrients, accelerate the respiratory processes, increase cell permeability, and act as growth hormones, thus increasing plant growth.

A considerable market for Humic acid substances is developing all over the world. Humic acid formulations appear to be more effective when combined with fertilizers, lime, or biologicals than when used alone. The liquid formulation seems to be best adapted for use with foliar spray applications, seepage irrigation systems, or other hydroponic applications. The dry formulations seem best adapted for use with dry fertilizer or lime.

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THE AMMONIUM BICARBONATE - DTPA SOIL TEST (AB-DTPA) FOR DETERMINATION OF PLANT AVAILABLE Pb, Cd, Ni, AND Mo IN MINE TAILINGS AND CONTAMINATED SOILS

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INTRODUCTION

Due to increased populations in mountain resorts, expansion of many communities, like Aspen, has encroached upon historic mine dumps. This increased rapid development has raised concern over heavy metal contamination of soils and the possible contamination of vegetables and crops grown on these soils.

In the past, many regulatory agencies have required analysis of trace elements during baseline overburden characterization for surface mining operations. Lead analysis was often required for overburden characterization (Montana, 1981 and WDEQ-LQD, 1981). Contamination of many overburden samples occurred through the use of metal-containing drill stem joint lubricants (Dollhopf et al., 1981). The requirement for routine trace element analysis has been questioned (Munshower, 1983). Montana (1983) has recently deleted certain metals (Pb, Cd, Ni, Cu, Fe, Mn, Zn, and Hg) from their routine overburden analysis recommendations.

The degree of soil, overburden, and regraded spoil characterization varies from state to state (Berg, 1983). As shown in Table 1, this variation includes the use of different soil tests.

Table 1
Current State Requirements for Overburden Analysis

State	Pb	Cd	Ni	Cu	Mo
Colorado*	DTPA	DTPA	DTPA	DTPA	DTPA
Montana	-	-	-	-	A.O.
New Mexico	+	+	+	+	+
North Dakota	-	-	-	-	-
Utah	+	-	-	-	+
Wyoming	DTPA**	-	-	DTPA	A.C.

* Both DTPA and AB-DTPA extracts are acceptable
** Analysis recommended for coal mine operations in Sheridan and Campbell Counties, Wyoming.
\+ Requires chemical analysis but no recommended procedure.
\- Analyses not required.
A.C. Ammonium carbonate
A.O. Ammonium oxalate

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It is doubtful if plant or animal toxicities would result from Pb, Cd, or Ni within the confines of the Northern Great Plains. However, in many of our "high altitude" mining situations these metals (Pb, Cd, and Ni) are frequently encountered. In addition, Colorado has substantial Mo mining operations. The accurate prediction of these elements for "plant availability" is paramount for successful revegetation and environmental concerns.

SOIL CONCENTRATIONS

Soils contaminated with lead and cadmium can be found in many historic mining towns of the Rocky Mountain region. Lead and cadmium values as high as 21,700 and 223 ppm, respectively, have been reported for soils of Aspen, Colorado (Boon and Soltanpour, 1983). These values have been verified by the Colorado State Department of Health.

Soils producing forage plants toxic to cattle have been identified in the Western United States (Kubota, 1975; Stone et al, 1983). Kubota (1975) indicates that molybdenosis in the western states may be a more widespread soil related nutritional problem in grazing animals than has been generally recognized. Disruption of rock and soil during mining can mobilize enough molybdenum to cause pronounced molybdenosis in cattle (Stone et al, 1983).

Although serpentine soils have been identified in the Western United States, none have been located within the Northern Great Plains.

Common ranges and average values for Pb, Cd, Ni, and Mo in uncontaminated soils are outlined in Table 2 (Lindsay, 1979). Table 3 gives average concentrations in soils, overburden, and coal from the Western United States. Average DTPA extractable concentrations for Pb, Cd, and Ni for some Northern Great Plains soils were 0.6, 0.1, and 0.8 ppm, respectively (Severson et al, 1978).

SOIL TESTS

A good soil test should extract nutrients or metals from the same labile pool in the soil that plants do. In addition, a soil test should be cheap, reproducible in different labs, and easily adapted to routine lab procedures. If a soil test can extract more than one element simultaneously then it has a distinct advantage. The DTPA and the AB-DTPA soil tests meet these criteria.

TABLE 2

Common ranges and average values for the elemental composition of soils

(values in ppm)

Element	Common Range	Average Value
Pb	2 - 200	10.0
Cd	0.01 - 0.70	0.06
Ni	5 - 500	40.0
Mo	0.2 - 5.0	2.0

TABLE 3

Average concentrations (geometric means in ppm) of elements in soils, coal and overburden in the western United States.

Element	Bighorn[1] Basin	Wind River[1] Basin	Fort Union Formation[2] Shale	Fort Union Formation[2] Sandstone	Roland[3] Coal Seam
Pb	8.6	13.0	15.0	5.2	13.0
Cd	-	-	-	-	1.4
Ni	22.0	21.0	31.0	16.0	8.0
Mo	4.8	5.0	8.1	5.0	4.0

[1] Severson (1979)

[2] Ebens and McNeal (1977)

[3] Trace metal analysis for the Anderson (Roland) Coal Seam, Campbell County, Wyoming

DTPA Soil Test

The DTPA soil test (Lindsay and Norvell, 1978) was developed to assess Cu, Zn, Mn, and Fe deficiencies in calcareous soils. Numerous researchers are currently using this procedure to evaluate Ni, Cd, and Pb on mined-land soils and on soils treated with sewage sludge.

The extractant consists of 0.005 M DTPA (diethylene triamine pentaacetic acid), 0.1 M triethanolamine and 0.01 M $CaCl_2$, adjusted to pH 7.3. The soil test consists of shaking 10 grams of air-dry soil with 20 mls of extractant for two hours. The leachate is filtered and Zn, Fe, Mn, and Cu are measured in the filtrate.

The theoretical basis for the DTPA soil test has been described in detail (Lindsay and Norvell, 1978). In addition, Sommers and Lindsay (1979) have demonstrated that the DTPA soil test has a sound basis for extracting Cd, Ni, and Pb in addition to the micronutrients it was originally designed to extract.

AB-DTPA Soil Test

For simultaneous multielement determinations, single element extraction solutions are not useful. Soltanpour and Schwab (1977) developed the ammonium bicarbonate - DTPA soil test (AB-DTPA) for simultaneous extraction of macro (P, K) and micronutrients (Fe, Mn, Cu, and Zn) in calcareous soils. This soil test was modified by Soltanpour and Workman (1979) to omit carbon black which sometimes contaminated the sample and absorbed metal chelates. The AB-DTPA soil test is based on the NH_4OAc soil test for K, the DTPA soil test for the micronutrients Fe, Mn, Cu, and Zn and the $NaHCO_3$ soil test for P.

The AB-DTPA extraction solution consists of 1 M ammonium bicarbonate and 0.005 M DTPA adjusted to pH 7.6. The extraction solution to soil ratio is 2:1 and the extraction time is a rapid 15 minutes. After extraction, simultaneous multielement analysis is accomplished using an ICP-AES (Soltanpour et al, 1982).

The theoretical basis for the AB-DTPA soil test has been described in detail (Havlin and Soltanpour, 1981). The Colorado State University Soil Testing Laboratory has routinely used the AB-DTPA soil test in conjunction with an inductively coupled plasma spectrometer (Soltanpour et al, 1979) since July 1977.

Soil Test Correlations

A great deal of emphasis has been placed on the need for all soil testing laboratories to use the same procedure. This would minimize the number of procedures used thus simplifying the process of comparing results on similar soils obtained from different labs. However, a more pressing need is to establish a relationship between different procedures. How the results are obtained is less important than how well they correlate to each other.

Numerous researchers are currently using the DTPA soil test to evaluate Pb, Cd, and Ni on mined lands and soils treated with sewage sludge. Most regulatory agencies that require analysis of these elements recommend the DTPA soil test for evaluating plant availability (Berg, 1983). The AB-DTPA soil test has been recommended for assessing the revegetation potential when concerned with lead and molybdenum on surface coal mine overburden (Sutton et al, 1981). Colorado (Berg, 1983) also allows the use of the AB-DTPA soil test for a wide variety of elements during overburden characterization. As shown in Figures 1 and 2, the AB-DTPA soil test is highly correlated with the DTPA soil test for Pb and Cd.

Vlek (1975) has already demonstrated that the $(NH_4)_2CO_3$ soil test is highly correlated with the molybdenum content of alfalfa. The Wyoming Department of Environmental Quality - Land Quality Division (WDEQ-LQD) recommends the $(NH_4)_2CO_3$ soil test for the evaluation of plant availability of molybdenum in soils and overburden (WDEQ-LQD, 1981). Neuman and Munshower (1983) have correlated the $(NH_4)_2CO_3$ soil test for molybdenum with another widely excepted soil test, acid ammonium oxalate. The soil tests extracted similar amounts of molybdenum (r=0.999) from regraded coal mine spoils in Montana. The AB-DTPA soil test is highly correlated with the $(NH_4)_2CO_3$ soil test (Vlek, 1975) (Table 4).

Total soil analysis is laborious, time consuming, and not amiable to rapid routine analysis. The AB-DTPA soil test in conjunction with an ICP is very rapid and conducive to routine analysis. The Colorado State-Soil Testing Laboratory (CSU-STL) commonly uses the AB-DTPA soil test to evaluate the potential contamination of soils for various elements of environmental concern. For example, take the case of Aspen's contaminated soils. Silver was first discovered in Aspen, Colorado in 1879. By 1896 Aspen's year-round population exceeded 12,000. Mine dumps, ore processing facilities, and smeltors were common sights. Many existing mine dumps are still evident in Aspen today, and are often the playgrounds for young children. The exposure of children to these heavy metal contaminated mine dumps raised concern over potential health problems resulting from the ingestion of contaminated soil (pica). A Boston task force on lead has established that total soil lead levels in excess of 500 ppm are potentially hazardous to human health. A preliminary survey of Aspen soils and mine dumps yielded extremely high lead and cadmium levels (Table 5). The value of 21,700 ppm was verified by the Colorado State Department of Health and

FIGURE 1

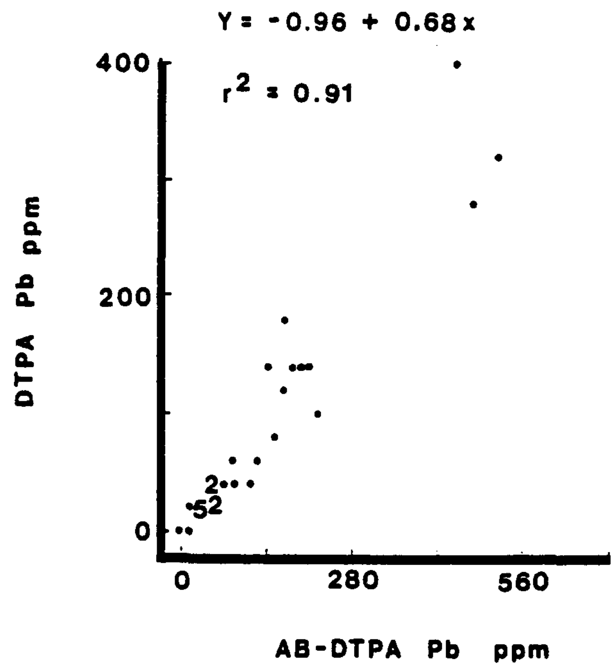

FIGURE 2

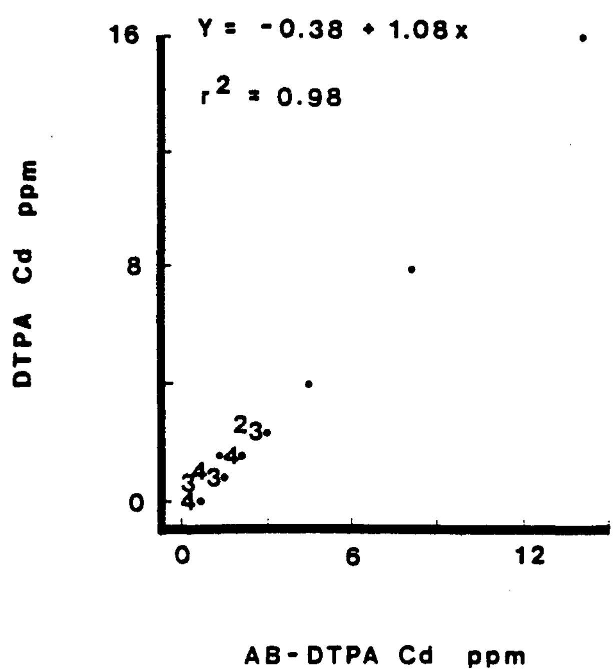

TABLE 4

Correlation coefficients (r values) for
AB-DTPA vs DTPA, $(NH_4)_2CO_3$ and total analysis

	AB-DTPA vs DTPA	AB-DTPA vs Total
Pb	0.9545	0.9295
Cd	0.9935	0.9343
Ni	0.8972	0.8868
Mo	0.9790*	0.6595

* AB-DTPA vs $(NH_4)_2CO_3$

TABLE 5

TOTAL SOIL ANALYSIS

Sample Number	Pb (ppm)	Cd (ppm)
9	2106	21.6
18	2288	-
19	2353	-
20	135	-
100	11455	22.2
104	3132	44.0
105	252	4.1
110	2132	24.0
CDHa	3520	13.3
CDHb	9950	38.3
CDHc	21700	223.0
7157	2625	29.0
7158	12850	29.5
7159	665	19.0
7160	970	25.5
7161	260	19.0
7162	5650	55.0

and came from a residential area, Smuggler Trailer Park. The value of 9950 ppm was obtained from the road in Smuggler Trailer Park. The trailer park was unfortunately built 25 years ago directly on top of the Smuggler mine dumps. As early as 1896 this area was shown on maps as being an extensive mine dump. Total soil lead analysis versus AB-DTPA soil lead yielded a high degree of correlation ($r^2 = 0.86$) as shown in Figure 3. Using the regression equation, an AB-DTPA soil lead value in excess of 100 ppm is equivalent to a total soil lead level in excess of 500 ppm. Currently, the CSU-STL screens all routine analyses for AB-DTPA lead levels in excess of 100 ppm. Customers are notified, free of charge, if safe lead levels are exceeded.

Table 4 gives correlation coefficients (r values) for AB-DTPA versus total analyses for lead, cadmium, nickel, and molybdenum for a wide variety of contaminated soils. Total soil levels should not be used for assessing the amount of plant availability of elements of interest. However, as outlined above, valuable information can be obtained from these types of correlations on a site specific basis.

PLANT ANALYSIS

Decontamination

Plant tissue samples are almost always contaminated with soil, especially if samples are obtained from grazed pastures (Fleming, 1965 and Healy et al, 1974).

Steyn (1959) showed that washing plant tissue with 0.1 to 0.3% detergent solution was satisfactory in removing soil contamination. A variety of detergents and dilute acids have been evaluated for removing soil contamination prior to plant analysis (Askley et al, 1960; Baher et al, 1964; Labanauskas, 1968; Ashby, 1969). More recently, Zimdahl and Foster (1976) developed a plant washing procedure for removing lead contaminated soil from plant roots prior to analysis. Previous studies (Arvik and Zimdahl, 1974) showed that this procedure does remove surface lead but not absorbed lead. Their procedure is outlined in Table 6.

Soil contamination of plant samples can be identified by using any element which is present in relatively large concentrations in soils and relatively low concentrations in plants. Elevated levels of iron and titanium are commonly used to identify soil contamination in plant samples (Fleming, 1965; Cherney and Robinson, 1983). The effects of washing plant tissue collected from soils highly contaminated with lead and cadmium can be clearly seen (Table 7).

TABLE 6

PLANT WASH

1. Tap Water
2. Distilled Water + 0.5% Laboratory Detergent (30 sec)
3. Distilled Water (30 sec)
4. 3N HNO_3 (30 sec)
5. Distilled Water (30 sec)

TABLE 8

Nitric Acid Plant Tissue Digest

(Havlin and Soltanpour, 1980)

1. Weigh 0.5 to 1.0 gm of plant tissue into a 50 ml Taylor tube.
2. Add 10 ml conc. nitric acid. Let stand overnight.
3. Heat samples at 125° C for 4 hours. Let cool.
4. Dilute to 12.5 ml with conc. nitric acid. Dilute to 50 ml with distilled water. Mix and let amorphous silica settle.
5. Aspirate directly into plasma for ICP analysis of P, K, Cu, Mg, Na, Fe, Zn, Ca, Mn.

TABLE 7

Elemental Composition of Washed and Unwashed Spinach Grown on Contaminated Soil, Aspen, Colorado

Element	Unwashed (ug/g)	Washed (ug/g)
Fe	1711	400
Al	830	162
Ti	25	6.8
Pb	118	28.4
Cd	13	8.1

Any plant analysis in excess of 10 ug Ti/g must be strongly suspected of being contaminated with soil. Cherney and Robinson (1983) suggested that the nitric acid digestion procedure (Havlin and Soltanpour, 1980) is ineffective in determining soil contamination by titanium analysis. This inefficiency has not been noted in studies at the Colorado State University Soil Testing Laboratory.

Plant Digestion Procedure

Nitric-perchloric acids have been widely used for the digestion of plant tissues (Blanchar et al, 1965; Behan and Kincaide, 1970; Zososki and Borau, 1977). Wet digestion procedures utilizing perchloric acid have two disadvantages: first, anhydrous $HClO_4$ requires special hoods and very careful handling due to its explosive nature and, second, needle-like $KClO_4$ crystals often form during digestion due to high plant potassium concentrations. To overcome these problems a wet digestion procedure using nitric acid was developed by Havlin and Soltanpour (1980) for simultaneous analysis of P, K, Ca, Mg, Na, Zn, Fe, Mn, and Cu using inductively coupled plasma - atomic emission spectroscopy. The nitric acid digestion procedure is outlined in Table 8. Incomplete oxidation of any organic matter is overcome due to the high temperature (6000 - 10,000°K) of the plasma (Fassel and Knisley, 1974). Analysis of National Bureau of Standard Reference Materials digested with nitric perchloric and nitric acid compared well with the NBS certified values.

This same nitric acid digestion procedure was used to evaluate its effectiveness for plant analysis of Pb, Cd, Ni, and Mo. Spinach grown on lead and cadmium contaminated soil was digested using both nitric-perchloric and nitric acid. A very close agreement between the two procedures can be found in Table 9. In addition, National Bureau of Standard Reference Material 1571 (Orchard leaves) was digested using the nitric acid procedure and the results compared to the NBS certified values (Table 10).

The nitric acid digestion procedure for plant analysis is suitable for determining Pb, Cd, Ni, and Mo when used in conjunction with an ICP. The procedure is rapid, reproducible, and compares well with the nitric-perchloric digestion procedure and NBS Standard Reference Material.

Plant Uptake

It is doubtful that plant uptake of Pb, Cd, or Ni would occur to any significant degree on reclaimed coal mine spoils of the Northern Great Plains. State regulatory agencies prohibit the placement of any acid-producing materials within the plant rootzone (Montana, 1983 and Wyoming DEQ-LQD, 1981). Only under localized conditions of acid-producing spoils would plant uptake be expected since the solubility of these elements is greatest under acid conditions (Lindsay, 1979). However, in many of our "high altitude" sulfide ore deposits substantial plant uptake and toxicity can occur.

Soils producing forage plants with molybdenum concentrations toxic to cattle have been reported for areas of the western United States (Kubota, 1975; Stone et al, 1983). Areas of potential molybdenosis range from the Northern Great Plains to the high altitude Rocky Mountains. Munshower (1983) recommends plant analysis for copper and molybdenum sometime after reclamation and prior to bond release.

Field sampling of contaminated garden soils in Aspen, Colorado resulted in a good correlation between AB-DTPA soil and plant Pb levels (Figure 4). Many residents enjoy gardening as much today as during the late 1800's. Analysis of garden vegetables grown on a range of contaminated soils demonstrated that leafy green portions of plants took up more lead than the roots, and roots took up more than the fruiting portion (Figure 5). However, field sampling and greenhouse experiments have confirmed that certain members of the Brassica family (Brocolli, Cabbage, Collard, Mustard, and Kale) do not take up lead, even when grown on highly contaminated soils from Aspen.

Soils highly contaminated with lead, cadmium, nickel, and molybdenum were used in a modified Neubauer Test (McGeorge, 1946) to correlate AB-DTPA soil levels with plant uptake in Barley and Sweetclover. Although use of the Neubauer Test must be evaluated with caution, it can be used to predict relative uptake into plants when only limited amounts of soil are available. Ranges for AB-DTPA and total soil concentration for Pb, Cd, Ni, and Mo can be found in Table 11. Correlation coefficients for the modified Neubauer Test can be found in Table 12. Also included are correlations for Pb and Cd for Spinach collected from Aspen gardens.

TABLE 9

Elemental Composition of Spinach, *Spinacia oleracea*, Grown on Contaminated Soils, Aspen, Colorado, Determined in Nitric-perchloric and Nitric Digests.

Element	Nitric-perchloric	Nitric
P %	0.63 ± .01	0.65 ± .05
K %	4.33 ± .13	6.95 ± .41
Ca %	1.53 ± .04	1.63 ± .09
Mg %	0.74 ± .02	0.78 ± .03
Na %	0.14 ± .006	0.16 ± .01
Fe ppm	307.40 ± 8.08	307.20 ± 19.5
Zn ppm	329.60 ± 10.6	335.00 ± 10.9
Cu ppm	9.93 ± .33	10.78 ± .59
Mn ppm	27.40 ± .56	28.10 ± .85
Pb ppm	30.72 ± 9.51	30.54 ± 4.23
Cd ppm	7.56 ± .31	7.54 ± .31
Ni ppm	2.54 ± .27	2.28 ± .48
Mo ppm	2.32 ± .46	1.87 ± .17

TABLE 10

Elemental composition of NBS Reference Material 1571 (Orchard Leaves) determined in nitric digests.

Element	NBS[1]	Nitric
P%	0.21 ± 0.01	0.19 ± 0.003
K%	1.47 ± 0.03	1.46 ± 0.05
Ca%	2.09 ± 0.03	2.00 ± 0.03
Mg%	0.62 ± 0.02	0.57 ± 0.01
Na%	.0082 ± 0.0006	0.007 ± 0.002
Fe ppm	300 ± 20	226 ± 2.49
Zn ppm	25 ± 3	22.9 ± 3.09
Cu ppm	12 ± 1	13.7 ± 0.76
Mn ppm	91 ± 4	90 ± 0.78
B ppm	33 ± 3	34.4 ± 1.61
Pb ppm	45 ± 3	47 ± 2.26
Cd ppm	0.11 ± 0.01	0.09 ± 0.04
Ni ppm	1.3 ± 0.2	1.18 ± 0.24
Mo ppm	0.3 ± 0.1	0.32 ± 0.19

[1] National Bureau of Standards, Certificate of Analysis, Standard Reference Material 1571.

FIGURE 3

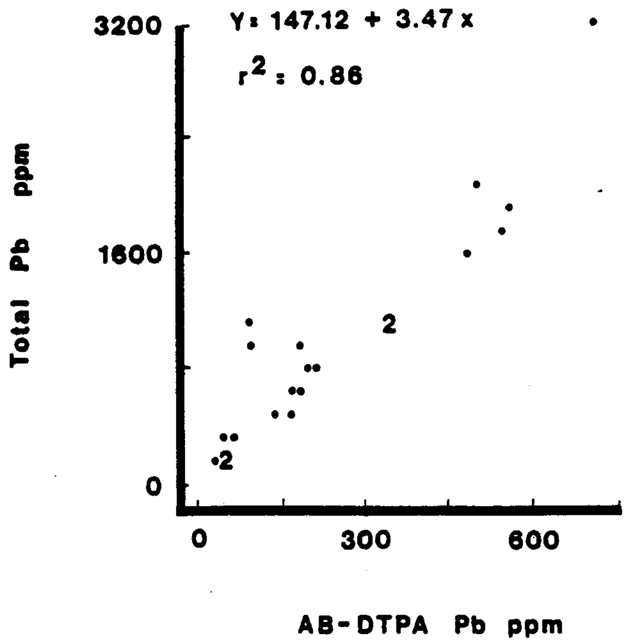

FIGURE 4

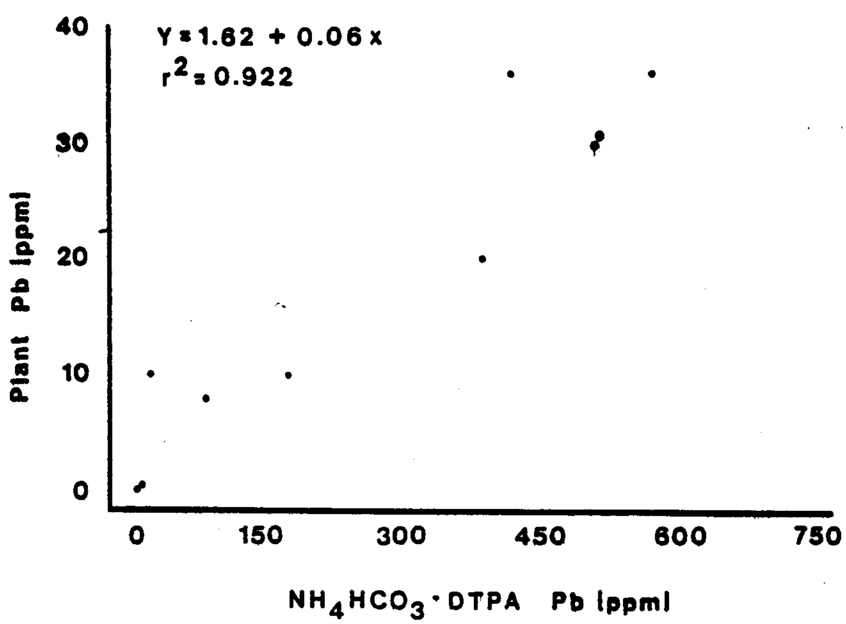

FIGURE 5

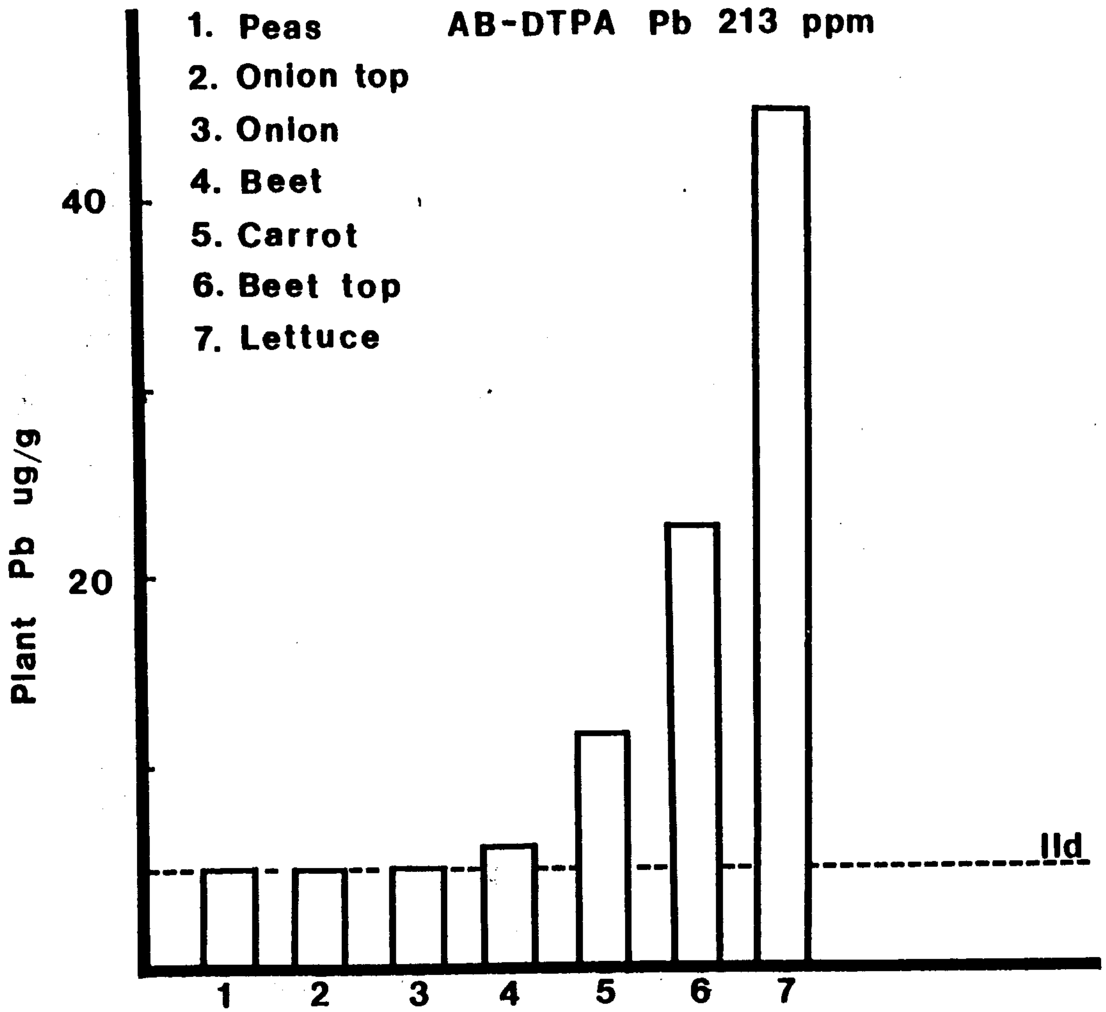
1. Peas
2. Onion top
3. Onion
4. Beet
5. Carrot
6. Beet top
7. Lettuce
AB-DTPA Pb 213 ppm
Plant Pb ug/g
40
20
lld
1
2
3
4
5
6
7

TABLE 11

Selected chemical properties of the soils used in the modified Neubauer Test

			AB-DTPA (ppm)				HF (ppm)			
	pH	EC	Pb	Cd	Ni	Mo	Pb	Cd	Ni	Mo
MIN.	5.9	0.8	0.8	0.03	0.1	0.1	18	1	8	7
MAX.	7.8	10.4	849	17.7	12.1	36.6	3251	32.8	976	254

TABLE 12

Correlation coefficients (r values) for AB-DTPA extractable levels and plant concentrations

Element	Barley[1]	Sweetclover[1]	Spinach[2]
Pb	0.5885	-	0.9602
Cd	0.9575	-	0.8735
Ni	0.5700	0.9043	-
Mo	0.8830	0.8770	-

1 Modified Neubauer Test
2 Contaminated garden soils field samples

Future Research Needs

Soil tests developed for agricultural practices may be suited for topsoil evaluations. However, these same soil tests may be inadequate for overburden characterization. Sommers and Lindsay (1979) demonstrated that in addition to DTPA, several other ligands (EGTA, HEDTA, and EDTA) could be used to extract metals from soils. We cannot be complacent by accepting current soil extraction technology as "best". More soil tests need to be evaluated for predicting plant availability on regraded spoils and replaced topsoil. The accurate prediction of plant elemental uptake is the frontier facing reclamation specialists today.

Many concerns will face the reclamation specialist as the time approaches for bond release on reclaimed lands. Plant analysis, prior to bond release, may be required for molybdenum, copper, and selenium, due to their potential toxicity to grazing animals. Toxicity to livestock must be avoided in meeting regulations concerned with vegetative quality for postmine land use. Various plant washing and plant digestion techniques need to be evaluated for elements of environmental concern.

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Natural Revegetation of Abandoned Spent Shale in Western Colorado

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INTRODUCTION

The oil shale region in Colorado, known as the Piceance Basin, is located in the northwestern area of the state in Rio Blanco, Garfield and Mesa counties. Early efforts at oil shale development during the 1920"s resulted in several spent shale sites abandoned without applied reclamation practices and therefore subjected to only natural processes of weathering and succession. This study examined five of these sites abandoned 50 to 60 years ago. Natural revegetation of surface disposed spent shale as well as drastically disturbed areas surrounding the spent shale was evaluated. Detailed results of the project were summarized in the unpublished report of Mackey (1982); the following paper will summarize major findings of the study.

OBJECTIVES

Specific objectives of this project were:

1) To evaluate the current successional status of abandoned spent shale sites, and
2) To relate defined status to specific physical factors to determine causal relationships.

METHODS

Experimental Design

This study involved vegetation and soil sampling of a series of five nearly equal age (i.e. 50 to 60 years since abandonment) oil shale retort sites. These sites were considered replicates for data analysis. Data on vegetation and soils were collected in three stratified zones at each study site: the immediate area of deposited spent shale, adjacent areas of drastic surface disturbance (termed secondary disturbance) associated with the shale retort and support facilities, and surrounding areas relatively undisturbed by development activity. Undisturbed areas were utilized as a basis for comparison of vegetation and soil development in disturbed areas. The three stratified zones represented study treatments. Thus, three treatments were replicated five times.

Measurements

Vegetation sampling was initiated in early July, 1981 and occured once at each study site. A modified Daubenmire canopy-cover method (Daubemire, 1959) was used to estimate cover of herbaceous species. Shrub species cover was estimated through the line intercept method (Mueller-Dombois and Ellenburg, 1974). For further comparisons among sample zones, Shannon-Wiener diversity indices (Shannon and Weaver, 1973) and the Spatz index of similarity (Mueller-Dombois and Ellenburg, 1974) were calculated among zones. Soil pits were excavated in each zone at each site in August, 1981. Field profile descriptions were made, and samples were extracted from specific depth ranges derived from profile characteristics for laboratory analysis. Laboratory soil tests conducted included electrical conductivity, sodium adsorption ratio, nitrate nitrogen, phosphorus, potassium, calcium, and magnesium.

RESULTS AND DISCUSSION

Current Successional Status and Trends

Determination of general plant community successional trends was confounded somewhat by varying degrees of uniqueness among the five sites in terms of surrounding vegetation, soils and physiography. However, analysis of grouped site data did yield a number of broad relationships between spent shale and secondary disturbance zones and their undisturbed vegetation counterparts.

Table 1 indicates there to have been no significant differences in mean total vegetation cover between secondary disturbed and undisturbed sampling zones. However, spent shale zone plant communities exhibited significantly lower total cover than either of the above two zones. Analysis of cover contributed by various classes of vegetation indicated no significant differences between any of the sample zones for total perinnial grasses, annual grasses and forbs. Total shrub cover was significantly lower on spent shale sites. Therefore, in terms of overall vegetation cover, secondary disturbances had essentially equalled undisturbed sites after 50 years of successional development, whereas cover on spent shale sites was still significantly reduced; primarily due to lower shrub establishment.

However, major differences in individual species cover and composition occurred among all three sample zones. Spatz Similarity Index (Isp) data of Figure 1 indicate both spent shale and secondary disturbance plant communities to have exhibited relatively low percent similarity in species composition/cover to undisturbed vegetation. Secondary disturbance vegetation did prove to be significantly more similar to that of undisturbed sites than did spent shale vegetation. Since secondary disturbance vegetation was essentially equal to undisturbed communities in terms of vegetation cover, the low percent similarity was attributed to differences in species composition. For the spent shale zones, low percent similarity was due to both significantly lower cover and different species composition.

An increasing trend in apparent overall plant community diversity, as evaluated by the Shannon-Wiener Index (H'), occurred from spent shale to secondary disturbance to undisturbed zones. However, differences in H' values were not statistically significant (Figure 1).

Common and unique species plant community composition data, based upon relative cover of such species, are presented in Figure 2. Both spent shale and secondary disturbance plant communities were dominated by plant species which were also components of undisturbed communities. That is, of the total plant cover in both the spent shale and secondary disturbance zones, a high percentage was by plants also found in the undisturbed zones. This may indicate that environmental conditions are harsh enough to limit species involved in natural plant community development to those generally adapted to the semi-arid nature of the area. In addition, spent shale zones had higher relative cover by species that were unique to that zone than did either the secondary or undisturbed zones. This could indicate that spent shale zones had characteristics different enough from surrounding areas to require species specially adapted to those characteristics.

Table 2 presents mean cover of dominant species among sampling zones. Some species exhibited major differences in cover among all three zones, tending to increase from spent shale to secondary disturbed to undisturbed zones. Among these were Ameanchier alnifolia, Cercocarpus montanus, Juniperus utahensis, and Quercus gambelii. These species may thus represent higher seral stage species whose re-establishment has been particularly inhibited by disturbed site conditions. However, their higher cover on secondary disturbances than on spent shale sites may be evidence of higher successional status of the former sites. Certain species, i.e. Artemisia tridentata and Purshia tridentata, exhibited similar cover on secondary disturbance and undisturbed sites but much reduced cover on spent shale. These shrubs may represent species with wider seral amplitude whose establishment may be specifically retarded by conditions unique to spent shale sites. Other species, such as Atriplex confertifolia and Chrysothamnus nauseosus, occurred in roughly equivalent cover on all three zones. These shrubs may represent species with both wide seral amplitude and tolerance of spent shale conditions, and would be likely candidates for inclusion in plant species mixtures for revegetation of spent shale affected lands. One species, Eriogonum corymbosum was unique in that it exhibited highest cover within the spent shale zone and progressively declined within the next two zones. This shrub may therefore be a early seral stage species specifically adapted to spent shale conditions. It thus may have difinite utility as a seeded or transplant species on spent shale deposits. One other species, Atriplex canescens, exhibited highest cover in secondary disturbed zones. This species may have definite utility for seeding in disturbed areas not affected by spent shale. However, persistance of this species may present problems concerning development of species composition comparible to undisturbed vegetation.

To summarize the above results, undisturbed zone plant communities were considered successionally advanced for purposes of this study. Fifty years after abandonment, secondary disturbances had approached undisturbed conditions in terms of total cover, but still were dissimilar to undisturbed sites on an individual species basis. Secondary disturbances may therefore be in middle stages of successional development. Conversely, spent shale sites exhibited both lower total plant cover and maximum individual species dissimilarity to undisturbed communities, and thus can be considered as still in early stages of succession.

Three plant community characteristics were used to evaluate successional development of semi-arid plant communities disturbed by oil shale development. In terms of total vegetation cover, secondary disturbed zones were not significantly different from undisturbed areas. In terms of diversity, as denoted by the Shannon-Wiener index, there were no significant differences among spent shale, secondary disturbed and undisturbed zones. Based upon these two community descriptors alone, secondary disturbances might be judged as adequately developed after 50 to 60 years of succession. Even spent shale zones might be considered successionally advanced in terms of diversity alone. However, the noted differences in community composition were not reflected in comparisons of either total vegetation cover or diversity indices. Therefore, the Spatz index of similarity was used to consider not only cover and diversity, but community composition as well. When both disturbed zones were compared to undisturbed zones using the Spatz index, low similarity values resulted. Similarity indices may represent a more valid means of evaluating disturbed vs. undisturbed site vegetation development than either total cover or diversity indices alone.

Factors Influencing Successional Development

Results of soil analyses (Table 3) provide information on certain edaphic characteristics of disturbed sites which may have influenced vegetation development. Excessive concentrations of salts in spent oil shale have often been reported (e.g., Schmehl and McCaslin, 1973; Berg, 1973), and may comprise a major factor influencing revegetation. In this study, mean electrical conductivity (EC) at spent shale sites was relatively high (i.e., greater than 4 mmhos/cm), and significantly greater than that in either secondary disturbance or undisturbed site soils (Table 3). Mean sodium adsorption ratio (SAR) was significantly higher in spent shale than in undisturbed soils, and was intermediate in secondary disturbance soils.

With respect to soil fertility parameters, several researchers have reported either low concentration or availability of nitrogen (N) and potassium (K) in certain types of spent shale (e.g., Schmehl and McCaslin, 1973; Berg, 1973). Results of soils analyses of this study (Table 3), however, indicated no apparent general dificiency nor significant differences in K concentration among soils of any of the sampling zones. Mean nitrate-N concentrations were in fact significantly higher in spent shale zone soild than in secondary disturbance or undisturbed soils. This effect was also found by Klein (1981), who reported an accumulation of nitrate in soils mixed with greater than 10% Paraho spent shale after a 40 day incubation. High levels of soil nitrate nitrogen are of concern for at least two reasons. The mobility of excess nitrate could pollute water sources, and excess nitrate absorption by plants could result in forage toxicity. However, release of moderate amounts of nitrate could aid in plant establishment and growth.

Magnesium (Mg) concentrations were significantly greater in spent shale zone soils. Antagonistic plant uptake relationships may occur between Mg and calcium (Ca) affecting plant nutrition (Corey and Schulte, 1973). The optimum Ca:Mg ratio is unclear, however, it has been suggested that Ca deficiencies may potentially occur in soils with a Ca:Mg ratio of less than 1.0 (Martin and Page, 1969). Table 4 indicates a mean Ca:Mg ratio approaching 1.0 in spent shale zone soils due to elevated Mg concentration. At certain spent shale sites and/or soil depths ratios were lower than 0.08. Therefore, the possibility of a Ca:Mg imbalance exists in certain spent shale affected soils, which may have influenced plant growth.

CONCLUSIONS

The affect of spent shale appears to have chronically restricted and/or changed the mode of plant community succession. Therefore, initial alleviation of long-term inimical effects of spent shale, such as those demonstrated for certain soil properties, through applied reclamation practices would appear to be necessary on spent shale affected disturbances if attainment of pre-disturbance conditions is to be made possible and/or accelerated.

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Table 1. Mean[1] total vegetation and plant class canopy cover (%)[2] among sampling zones, 1981[3].

	Zone		
	Spent Shale	Secondary Disturbance	Undisturbed
Total Vegetation	16b	46a	55a
Total Perennial Grasses	1a	2a	3a
Total Annual Grasses	3a	5a	8a
Total Forbs	1a	1a	2a
Total Shrubs	14b	35a	47a

[1] For all five sites

[2] Not summed parameters; independently estimated

[3] Values across rows followed by same letter not significantly different at .01 level of significance

Table 2. Mean cover of dominant and/or common shrub species among sites and sampling zones, 1981.

Species	Mean[1] Cover (%) in Zones: Spent Shale	Secondary Disturbance	Undisturbed
Amelanchier alnifolia	3.2	12.1	23.5
Cercocarpus montanus	0.3	7.8	22.4
Juniperus utahensis	0.0	1.1	2.7
Quercus gambelii	0.2	2.7	8.3
Artemisia tridentata	3.1	14.4	12.8
Purshia tridentata	0.0	6.2	6.8
Atriplex confertifolia	8.5	8.3	8.2
Chrysothamnus nauseosus	1.9	1.3	2.4
Eriogonum corymbosum	2.5	1.6	T[2]
Atriplex canescens	0.0	8.3	0.3

[1] Among sites species present on

[2] T = trace (less than 0.1% cover)

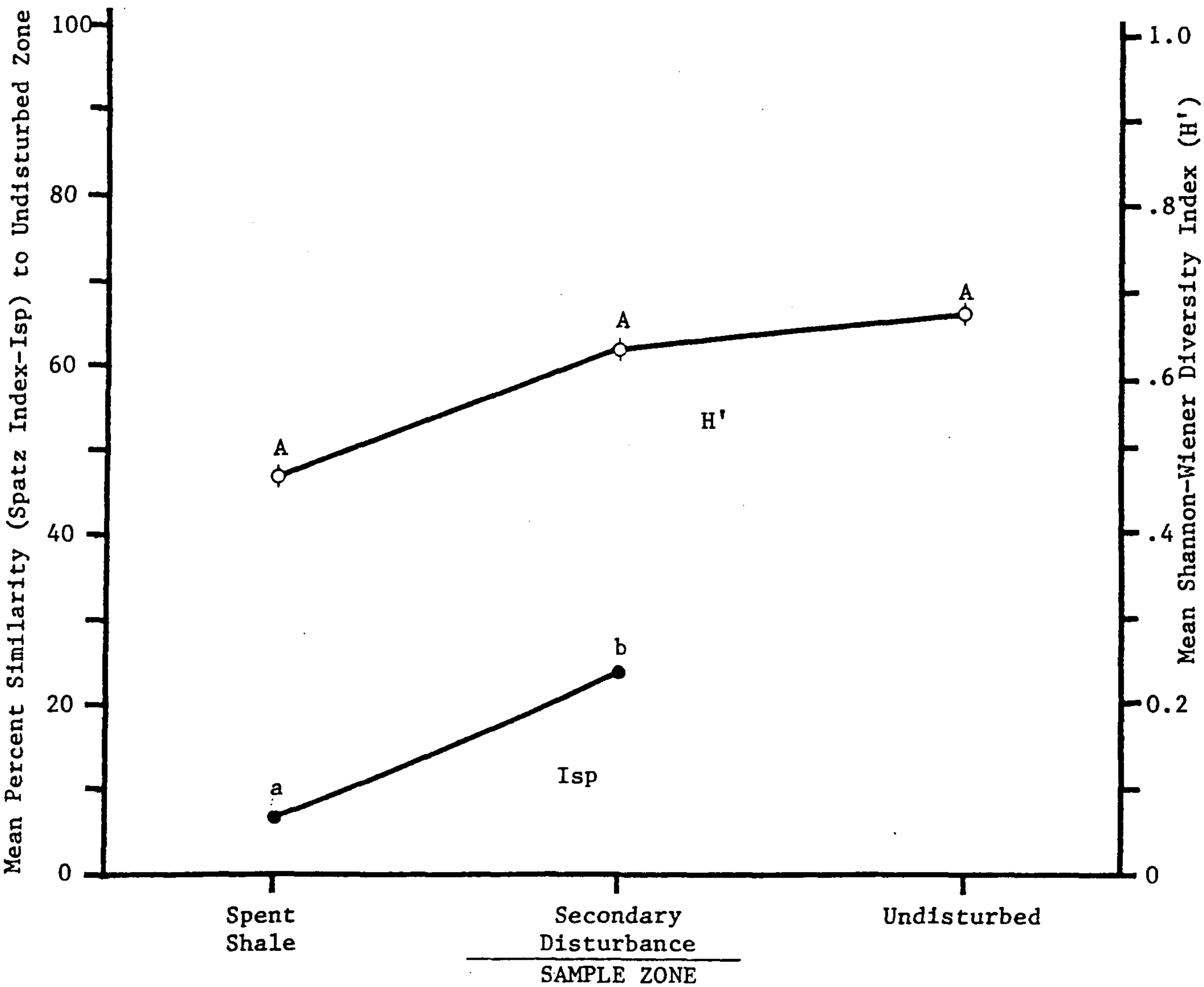
Table 3. Mean data for selected soil parameters among sample zones, 1981[1][2].

Parameter	Spent Shale	Secondary Disturbance	Undisturbed
Electrical Conductivity	5.9a	2.4b	1.1b
Sodium Adsorption Ratio	9.9a	7.2ab	2.2b
Nitrate Nitrogen (ppm)	29.8a	5.4b	4.8b
Phosphorus (ppm)	5.5a	4.1a	2.3a
Potassium (ppm)	541a	305a	200a
Calcium (ppm)	91a	36a	35a
Magnesium (ppm)	74a	14b	9b
Ca:Mg ratio	1.2	2.6	3.9

1 Among all soil depths sampled among all sites

2 Values across rows followed by same letter not significantly different at .15 level of significance.

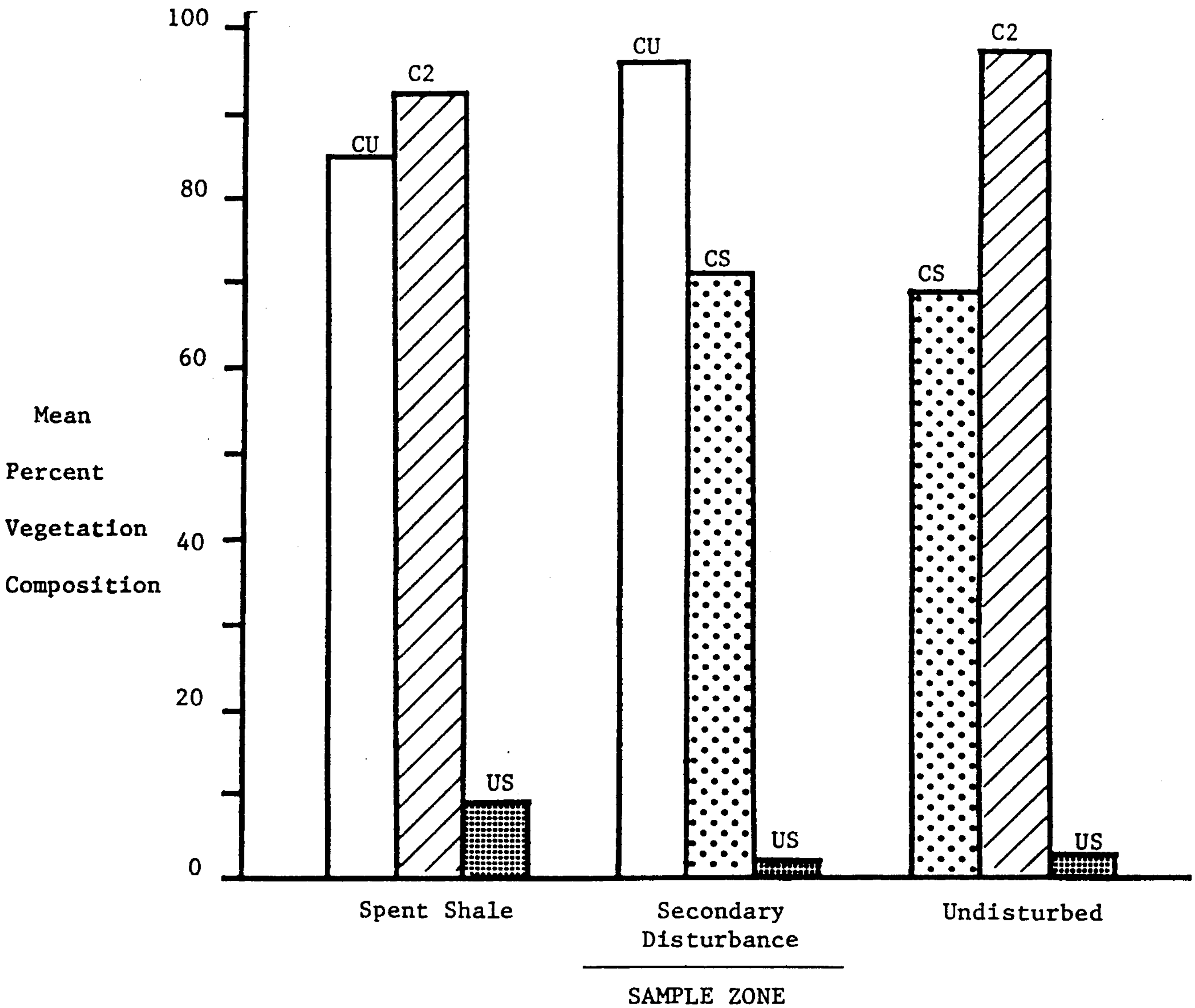
Figure 1. Mean[1] percent similarity (Spatz Index) of disturbed to undisturbed zone vegetation, and diversity indices (Shannon-Wiener Function) among all zones[2].



[1]For all five sites.

[2]Points for each parameter followed by same letter not significantly different at .01 level of significance for Isp and .25 level of significance for H'.

Figure 2. Mean[1] common and unique species plant community composition data for three sampling zones.



Key: CU = Composition by species common to undisturbed zone
C2 = Composition by species common to secondary disturbance zone
CS = Composition by species common to spent shale zone
US = Composition by species unique to given zone

[1]For all sites.

DRYLAND SEED PRODUCTION OF REVEGETATION SPECIES

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INTRODUCTION

Colorado, as well as other western states, has experienced a developmental boom which has created increased demand for seed used in the reclamation of disturbed lands. New seed producers are needed to meet this demand. However, farmers are reluctant to grow unfamiliar crops because of the financial risks involved. Insufficient research has been conducted on dryland seed production of revegetation species in Colorado. Information regarding stand establishment and seed production potential of these species would provide seed growers some of the management tools necessary to produce seed profitably. The San Juan Basin Research Center initiated research in 1982 to answer the aforementioned management questions.

The included data represent the first two years of a long-term study, and should be considered preliminary. The research was funded by the Colorado Commission on Higher Education and Colorado State University.

MATERIALS AND METHODS

The San Juan Basin Research Center is located near Yellow Jacket, in the southwest corner of Colorado, in a region generally referred to as the San Juan Basin or "The Four Corners". The location is near 7000 ft. elevation and is situated in a high, dry basin that receives an average annual precipitation of 14 inches, with at least half of this moisture falling as snow in the winter months. The soil at the study location is a silty clay loam of the Witt series, which represents a major acreage of agricultural land in southwest Colorado. These soils have a high water holding capacity. The success of agriculture in the San Juan Basin is dependent upon winter precipitation that is stored through a major portion of the growing season. The season averages 120 frost-free days per year.

1/ Researcher, Superintendent and Assistant Professor, and Assistant Professor.

The research was conducted in two parts. First was the determination of optimum planting date and depth required for stand establishment among four species. Second was the determination of seed yield potentials among eleven species for two row widths (30 and 60 inch) under dryland conditions. Stand establishment index was determined for each species at both row widths. A difference was not expected in stand establishment for the two row widths. We were interested only in relative stand establishment of the species included under conditions of the study.

The first study, termed the date by depth by species study, was conducted to determine the best combination of planting depth (Tables 1 and 2) and date (Tables 3 and 4) for four species previously deemed difficult to establish in the San Juan Basin. Stand Establishment Indexes were the criteria used to determine optimum planting depth and date for each of the four species. Stand Establishment Index is based on visual observations and rated on a scale of 1-4 where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

A split-split-plot design was used with planting dates as main plots, planting depths as sub-plots and species as sub-sub-plots. Planting depths were one inch and "stratified". All treatments were seeded at a rate of 30 live seed per linear foot of row using a belted cone, spinner type planter. The one inch planting depth was achieved with depth bands. The "stratified" depth placed seed at a range of depth from the soil surface to one inch. Stratification was accomplished by using two drop tubes - one planting in the conventional manner with one inch depth bands - the other drop tube, located just in front of the press wheel, placed seed in the closing furrow slice, thereby distributing seed from the surface to one inch in depth.

Stand establishment was evaluated among the four species planted at three dates in 1982, and three in 1983 (Tables 3 and 4). Stand establishment was also evaluated for depth of planting in 1982 and 1983 (Tables 1 and 2). Yield of seed were not measured.

The second study, termed the row width by species study, was designed to determine whether 60 inch or 30 inch row spacings will produce maximum seed yield among eleven species. Past experience in the San Juan Basin shows that western wheatgrass planted in 30 inch rows would initially yield 200-300 lbs per acre of seed. However, after three to four years of stand, yields would drop to 40-60 lbs per acre. But it was observed that in areas bordering on the edges of the stand, where presumably more moisture is available, seed production would remain high. This observation was our reason for including 60 inch row spacing in the study in an attempt to sustain seed yield for a longer time.

The row width by species study was a split-plot design with row width as main plots and species as sub-plots. All treatments were planted 15 April 1982 at a seeding rate of 30 live seed per linear foot of row. Stand establishment was rated 27 May 1983 as explained for the previous study. Seed was harvested from six of the eleven species in 1983. The other five species did not produce sufficient seed for measurement, or, as in the case of the forbs and shrubs, seed-producing maturity had not been achieved. Seed was harvested by hand during July and August of 1983 as the species matured. A portable head thresher was used to thresh the seed.

RESULTS AND DISCUSSION

Stand establishment was evaluated among four species planted at two depths (one inch and stratified) in 1982 and 1983 (Tables 1 and 2). No significant differences were found in Rocky Mt. penstemon, Lewis flax, Indian ricegrass, or four-wing saltbush for the two planting depths. Based on the results it appears that planting depths up to one inch would be suitable for these species under San Juan Basin conditions.

Stand establishment was evaluated in 1983 for the four species planted at three dates in 1982 (Table 3). Rocky Mt. penstemon and Lewis flax established significantly fuller stands when planted in October vs. April or May. This is presumably a dormancy problem. Apparently seed of these species require exposure to cold temperatures to break dormancy. It is probable that seed of these species could be artificially cold treated to break dormancy if soil moisture or timing considerations make it desirable to plant earlier than the October date. Indian ricegrass established equally well at all three planting dates. Four-wing saltbush established better in May and October than April. This may be a result of the cold, wet spring soils rotting the seed of four-wing saltbush.

The same experiment was conducted in 1983 with similar results obtained. The October planting date will be rated for stand establishment in May or June of 1984. No significant differences exist for date of planting in 1983 (Table 4). These date are incomplete until the October planting date is rated for stand establishment in the spring of 1984. One might anticipate that Rocky Mt. penstemon and Lewis flax will show a significant preference for fall seeding based on 1982 test (Table 3).

The second study was rated for stand establishment among eleven species planted in 30 and 60 inch rows (Table 5). No differences were expected for stand establishment at the two row widths. These species

Table 1) Stand Establishment Index Among Four Species Planted One-Inch Deep and Stratified (1982). *

	Stand Establishment Index **			
	Species			
Planting Depth	Rocky Mountain Penstemon	Indian Ricegrass	Lewis Flax	Four-Wing Saltbush
One-inch	2.00	3.84	2.42	2.17
Stratified	2.00	3.59	2.08	2.00
	n.s.	n.s.	n.s.	n.s.

* Mean values from three planting dates in 1982, evaluated on May 27, 1983.

** Stand index based on visual observations where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

Table 2) Stand Establishment Index Among Four Species Planted One-Inch Deep and Stratified (1983).*

	Stand Establishment Index **			
	Species			
Planting Depth	Rocky Mountain Penstemon	Indian Ricegrass	Lewis Flax	Four-Wing Saltbush
One-Inch	1.00	3.12	1.50	2.00
Stratified	1.00	2.88	1.13	1.65
	n.s.	n.s.	n.s.	n.s.

* Mean values from two planting dates in 1983, evaluated on October 18, 1983.

** Stand index based on visual observations where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

Table 3) Stand Establishment Index Among Four Species for Three Planting Dates (1982).*

	Stand Establishment Index**			
	Species			
Dates of Planting	Rocky Mountain Penstemon	Indian Ricegrass	Lewis Flax	Four-Wing Saltbush
April 16	1.33 a***	3.63 a	1.13 a	1.63 a
May 17	1.25 a	3.63 a	1.83 a	2.63 b
October 21	3.63 b	3.88 a	3.75 b	3.50 b

* Plots rated on May 27, 1983.

** Stand index based on visual observation where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

*** Values within columns followed by the same letter are not different at the 5% level of probability based on Duncans Multiple Range Test.

Table 4) Stand Establishment Index Among Four Species for Two Planting Dates (1983).*

	Stand Establishment Index**			
	Species			
Date of Planting	Rocky Mountain Penstemon	Indian Ricegrass	Lewis Flax	Four-Wing Saltbush
April 20	1.00	2.63	1.00	1.63
June 9	1.00	3.38	1.63	2.00
	n.s.	n.s.	n.s.	n.s.

* Evaluated on October 18, 1983.

** Stand index based on visual observation where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

were rated to determine establishment potential under conditions of the study.

Table 5 indicates a descending order of ease of establishment. Western wheatgrass, with an index rating of 4 (i.e. 75-100% of full stand) is at the top of the list, while winterfat with an index rating of 1 (i.e. 0-25% of full stand) is at the bottom of the list.

Western wheatgrass, Indian ricegrass, small burnet, and tall fescue established equally well at either 30 inch or 60 inch row spacings. As expected, the overall effect of row spacing was not significant in the analysis of variance.

The poorest stands were produced by pine lupine, Lewis flax, Rocky Mt. penstemon, and winterfat. Winterfat did not establish and has been deemed unsuitable for production under local conditions. Rocky Mt. penstemon and Lewis flax show a very low establishment index, but it should be noted that this study was planted in April. Results of the date of planting study showed a significant preference to fall planting for Rocky Mt. penstemon and Lewis flax (Table 3). Pine lupine's poor stand index rating is partially a result of insect damage. Drought and other factors may be contributing reasons. Four-wing saltbush shows an intermediate response to stand establishment. However, shrubs should not be compared directly to forbs or grasses because of difference in plant growth habit. What may appear to be a low index rating for fourwing saltbush may actually need thinning to reduce crowding because of four-wing saltbush's large size at maturity. It is evident that stand establishment is deceiving if one does not consider the particular species growth habit when interpreting the data.

The top four species listed in Table 5 established to very dense stands. It is likely that seeding rates of less than 30 live seed per foot of row would be preferable.

Bulk seed yields were measured for five grass species (Table 6). The species not listed that produced seed in 1983 is the forb small burnet, which had a pure live seed yield of 816 lbs per acre. Tall fescue produced significantly more seed than the other grass species. Indian ricegrass and western wheatgrass produced similar, and desirable, seed yields. Orchard grass produced significantly less seed. Basin wildrye, although adapted vegetatively, produced low seed yield. This is consistent with previous work completed at the San Juan Basin Research Center (R. H. Riley, 1982, unpublished data). Basin wildrye should probably be eliminated as a choice for seed production in the San Juan Basin.

Table 5) Stand Establishment Index Among Eleven Species Planted In 30 and 60 Inch Rows. *

Species - Variety	Stand Establishment Index* Row Spacing 30"	60"
Western Wheatgrass - Arriba (Agropyron smithii)	4.00 a**	4.00 a
Indian Ricegrass - Paloma (Oryzopsis hymenoides)	4.00 a	4.00 a
Small Burnet - Delar (Sanguisorba minor)	4.00 a	4.00 a
Tall Fescue - P.I. 14944 (Festuca arundinacea)	4.00 a	3.75 a
Orchard Grass - Latar (Dactylis glomerata)	3.75 ab	3.75 a
Basin Wildrye - Magnar (Elymus cinereus)	3.25 b	3.75 a
Four-Wing Saltbush - Wytana (Atriplex canescens)	2.25 c	2.25 c
Pine Lupine - Hederma (Lupinus albicaulis)	1.50 d	1.25 c
Lewis Flax (Linum lewisii)	1.25 d	1.25 c
Rocky Mt. Penstemon - Bandera (Penstemon strictus)	1.00 d	1.00 c
Winterfat - N.M. 333 (Eurotia lanata)	1.00 d	1.00 c

* All plots planted on 4/15/82 and rated 5/27/83.

** Stand index based on visual observations where: 1 = 0-25%, 2 = 25-50%, 3 = 50-75% and 4 = 75-100% of full stand.

*** Values within columns followed by the same letter are not different at the 5% level of probability based on Duncan's Multiple Range Test.

Table 6) Bulk Seed Yield Among Five Grass Species Planted in 30 and 60 Inch Rows.

	Seed Yield (lbs/a)		
	Row Width (Inch)		
Species	30	60	$LSD_{(.05)}$
Tall Fescue	606 a *	369 a	66
Indian Ricegrass	253 b	190 b	66
Western Wheatgrass	246 b	169 b	66
Orchard Grass	164 c	126 b	66
Basin Wildrye	59 d	48 c	66

* Values within columns followed by the same letter are not different at the 5% level of probability based on Duncans Multiple Range Test.

All species produced more seed per acre in 30 inch rows than 60 inch rows. The difference was significant only for basin wildrye and western wheatgrass. These results suggest that 30 inch row spacing would optimize seed production in the first year after establishment. However, seed yield in subsequent years will determine which row spacing is best suited for long-term seed production.

Small burnet, which is not in this table, is a forb, that looks very promising in this yield trial. It has an impressive pure, live seed yield of 816 lbs per acre in 30 inch row spacing. Small burnet established with ease and is similar to alfalfa in growth habit, but is much more frost tolerant than alfalfa, and remains green and growing long after alfalfa has gone dormant in the fall. Small burnet is green and actively growing long before alfalfa breaks dormancy in the spring. Small burnet propagates readily from self-seeding, and appears to be a desirable revegetation species in the San Juan Basin.

CONCLUSIONS

Planting depths of one inch and stratified did not significantly influence stand density for the four species tested (Table 1 and 2). Rocky Mt. penstemon and Lewis flax established significantly better when seeded in October vs. April or May plantings. Indian ricegrass established equally well at all dates. Four-wing saltbush showed a preference to May or October plantings (Table 3)

The easiest species to establish under dryland conditions, as tested in this study, were western wheatgrass, Indian ricegrass, small burnet, tall fescue, and orchard grass. Basin wildrye established readily without producing desirable quantities of seed (Table 5).

Tall fescue produced significantly more seed than the other four grass species including Indian ricegrass, western wheatgrass, orchard grass, and basin wildrye (Table 6). Small burnet, the only non-grass that produced seed last year, is a prolific seed producer, with potential as a revegetation seed crop in the San Juan Basin.

COST AND EFFECTIVENESS OF MULCHING PRACTICES

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ABSTRACT

Straw was shown to be the most cost-effective mulch practice to retain soil in artificial rainfall tests. Straw was superior to hydraulic mulches and compared favorably with the expensive fabric products. Some fabrics were inferior to straw. Jute, applied over 3,000 lbs/acre straw, was the most effective. Straw practices are discussed.

INTRODUCTION

The addition of mulch products to the surface of disturbed soils is the most practical way to obtain an immediate degree of protection from surface erosion and to encourage the establishment of plants for additional protection. Mulches control erosion directly by absorbing the impact of raindrops which would otherwise dislodge soil particles. They may also trap soil particles, retain water, and improve infiltration. Plant establishment is encouraged by moderating temperature extremes and retaining moisture.

The cost and effectiveness of mulching practices vary greatly. Therefore, it is important that their relative values be known. Straw was compared in this study to other commonly applied mulching practices for effectiveness in retaining soil under artificial rainfall conditions.

PROCEDURES

Surface applied mulches were tested on 2 ft x 4 ft soil surfaces inclined at 5:1 and/or 2:1 (horizontal to vertical measurement). Artificial rainfall of 0.12 inch diameter drops (3 mm), falling 15 ft at the total amount of 6-inches/hr, was applied to duplicate samples of the surfaces for periods of two to six hours. The boxes containing the soil were designed to allow rapid drainage if water moved through the 6 inch profile. Soil washed from the slope surface was collected, dried, and weighed.

Common mulching practices investigated in this test include hydraulically applied virgin wood fiber mulch (Silvafiber[R]) at rates of 1,500 and 3,000 lb/acre; barley straw at rates of 1,000, 2,000, 3,000 lbs (tacked to the surface with asphalt emulsion at 200 gpa) and 8,000 lb punched into the soil with a shovel to simulate a roller. Erosion control fabrics stapled to the soil were jute, excelsior, paper (Hold/-

Gro[R]), and jute stapled over 3,000 lb of straw. These were compared to no surface protection. The percent of the surface covered with the various straw and fabric treatments was measured with a point frame (100 points/replication), and are listed with weight/acre of various products (Table 1).

Table 1. Percent of surface covered and weight of mulch product.

	lb/acre	Percent cover
Hydraulic mulch	1,500	95
Hydraulic mulch	3,000	100
Straw	1,000	48
Straw	2,000	66
Straw	3,000	78
Straw	8,000	86
Jute	5,050	58
Excelsior	3,300	72
Hold/Gro	850	95
Jute + straw	8,050	96

The eight "soils" used in the tests were often subsoils or mixtures of profiles taken from construction sites. The Arnold fine sand was from a road cut near Prunedale, decomposed granite (DG) from a road cut near Carson Pass, Cieneba gravelly sandy loam from a motorcycle park near Hollister, Dibble sandy clay loam from a brush area in Yolo Co., Los Osos loam from a construction site near Hercules, Yolo loam from Davis farmland, Auburn-Sobrante loam from the surface in the foothills of the Sacramento Valley near Browns Valley, and Altamont clay loam from a motorcycle park near Livermore. Soils were not compacted into the boxes other than by repeated waterings. Bulk density was measured periodically, at or near field capacity to be sure all treatments were comparable. Texture and particle size are shown in table 2.

Table 2. Texture, series name, and particle size of soils tested.

Texture	Name	Clay	Silt	Sand	Gravel
			Percent		
Uncemented fine sand	Arnold	2	3	95	0
Very gravelly coarse sand	Decomposed granite	3	4	41	52
Gravelly sandy loam	Cieneba	9	9	49	33
Sandy clay loam	Dibble	21	18	61	0
Loam	Los Osos	17	48	35	0
Loam	Yolo	22	45	33	0
Loam	Auburn-Sobrante	21	43	36	0
Clay loam	Altamont	29	45	26	0

RESULTS

Erodability of Soils

The unprotected soil surfaces varied considerably in the amount of soil lost (Figure 1). Loss was greater from all soil types when inclined at the steeper angle (2:1 than at 5:1). Least erodable were the soils containing gravel and the soil with the highest clay content. Much of the water flows through the gravelly soil draining out of the bottom of the boxes. Also the surface gravel particles absorb much of the energy from the water drops without being dislodged.

By contrast the montmorillonite clay particles of the Altamont soil are firmly bonded together, and while they don't allow water to readily drain through, they are able to withstand considerable impact energy of the drop sizes used here. Most erodable were the soils with

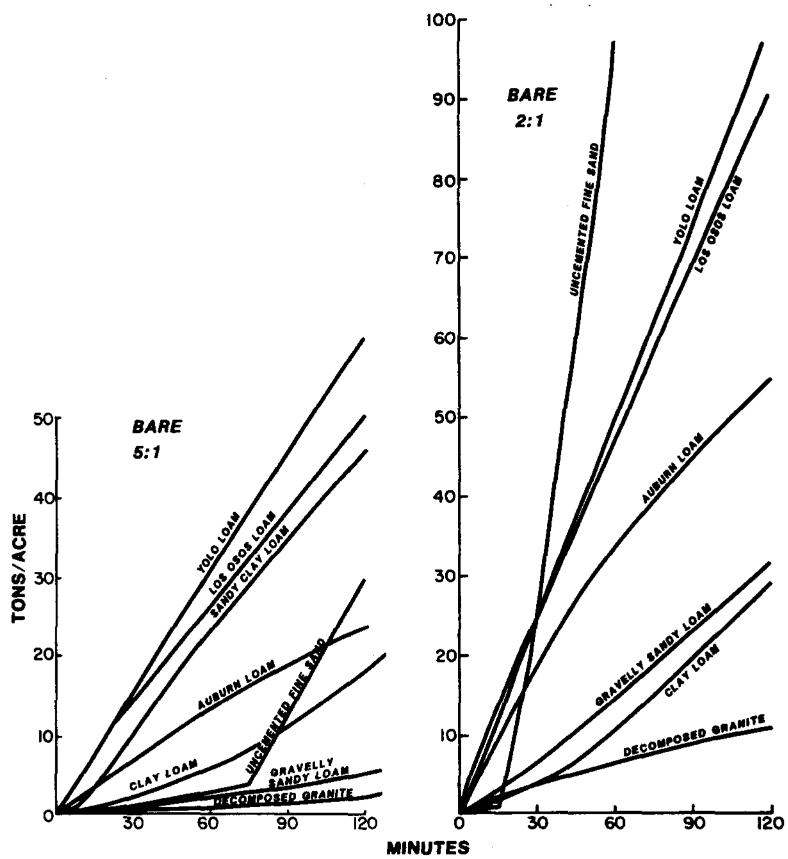

Figure 1. Erosion rates (tons/acre) of unprotected soil surfaces inclined at 5:1 and 2:1.

high percentages of fine sand and silt. The Arnold fine sand allowed some infiltration but soon saturated and liquified. Steepness of the slope then became important in determining how fast the liquified soil flowed from the slope. Also highly erodable are the loams which are particularly important because they commonly occur on coastal sub-division sites.

Straw vs. Hydraulic Mulch

The hydraulic mulch rates were compared to 3,000 lbs of straw on seven soils at both 5:1 and 2:1. The effect on soil loss is shown in figure 2.

Straw provided much greater protection than wood fiber on all soils, but was most dramatic on DG, uncemented fine sand, and clay. The protection was so complete that the regular two-hour test was increased to as much as six hours. The excellent performance of straw on uncemented fine sand was particularly impressive because this soil liquifies and flows if not protected by a mulch. Wood fiber, though inferior to straw, offered some protection. Increasing the commonly used rate of 1,500 lb to 3,000 lb provided additional protection only on a fine sand at 5:1 and DG at 2:1.

Straw increased the infiltration rate of water on both DG and uncemented fine sand compared to bare soil as indicated by reduced volume of runoff. Wood fiber, by contrast, increased the volume of runoff on both soils.

Loam and sandy clay loam soils were much more erodable than either coarse textured or clay soils but the same mulch relationships existed. Straw was superior to hydraulic mulch (1,500 lb) on both slopes. Increasing the rate of hydraulic mulch to 3,000 lbs sometimes increased its effectiveness. On Yolo loam at 2:1, 3000 lbs of fiber compared favorably to straw.

Auburn loam was less erodable than other loams. The 3,000 lb of hydraulic mulch was superior to the 1,500 lb rate at 5:1 and comparable to 3,000 lb of straw. However, when the slope was increased to 2:1 straw was much better than the high rate of hydraulic mulch which was still better than the low rate of hydraulic mulch.

Rates of Straw

Because straw is so effective it is important to choose the correct rate. In addition to the 3,000 lb tested above, lesser rates of 1,000 and 2,000 lb were compared on a sandy clay loam soil at 5:1. Also tested was straw punched into the slope at 8,000 lb/acre, a commonly used fill-slope treatment in California.

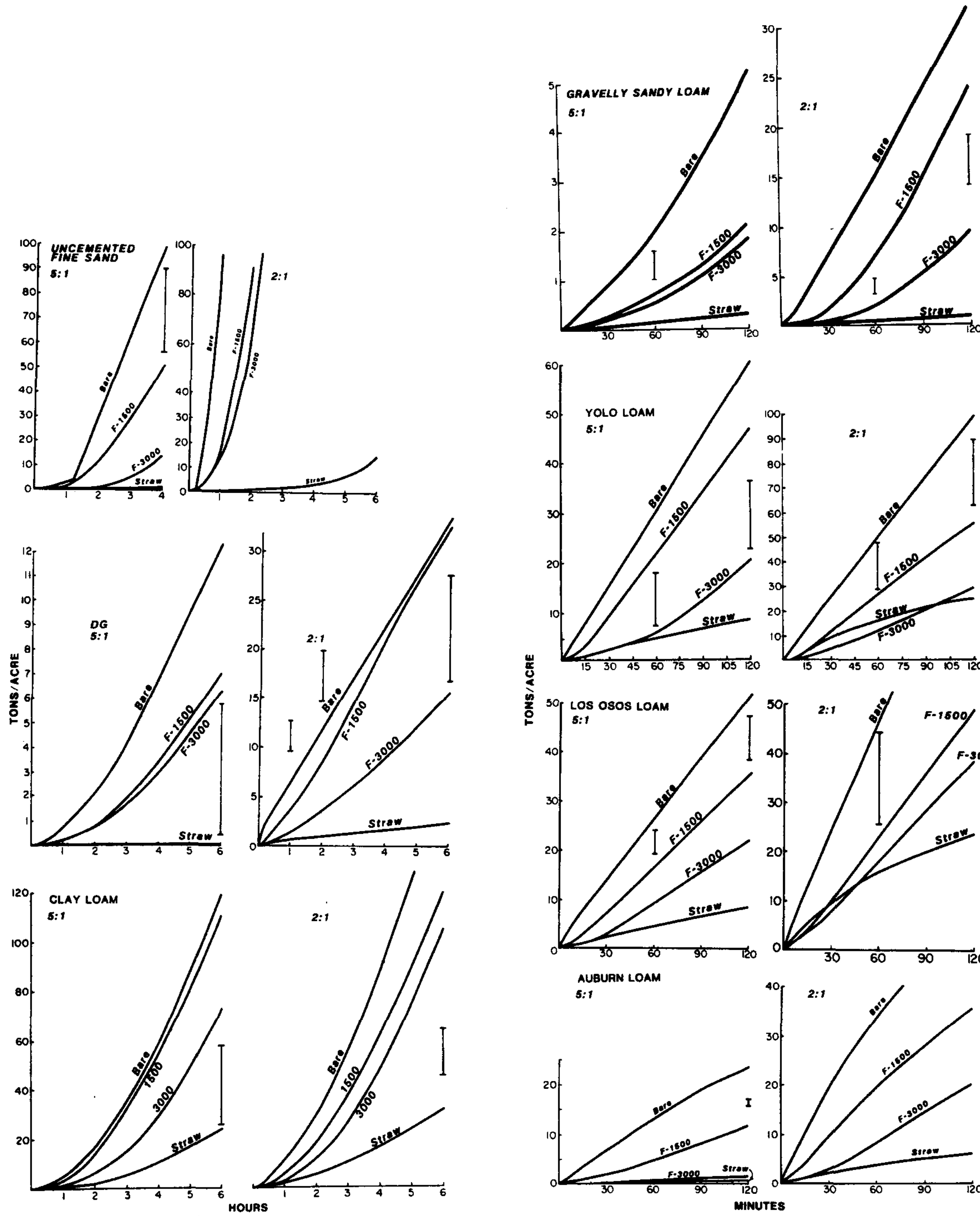

Figure 2. Effects of mulch treatments on soil loss (hydraulically applied wood fiber at 1500 and 3000 lbs/acre and straw at 3000 lbs/acre compared to bare soil) on seven soils at 5:1 and 2:1 slopes. Vertical insets indicate size of significant differences at .05 level.

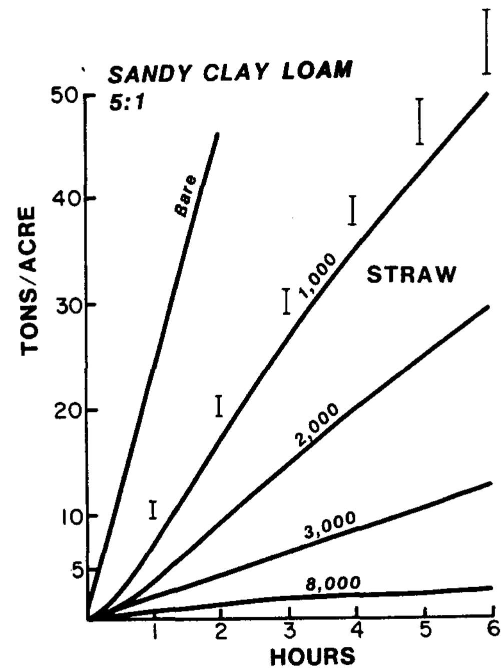

Figure 3. Effect of straw mulch rates on soil loss from 5:1 slopes, sandy clay loam soil. Vertical insets indicate a significant difference at .05 level.

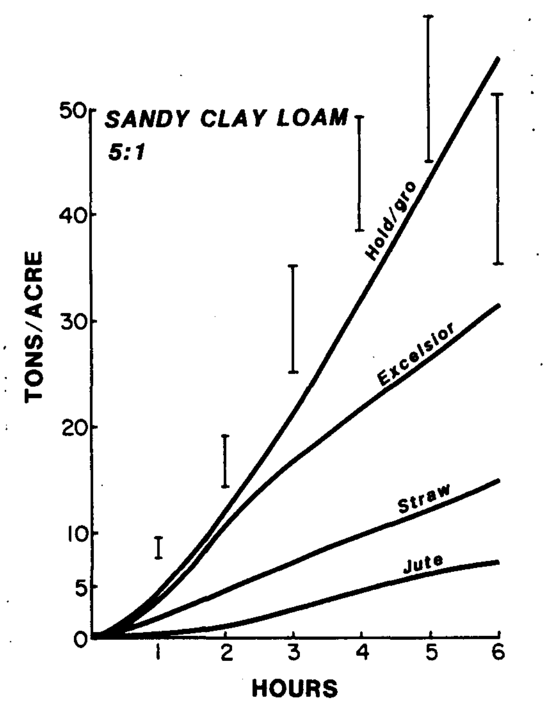

Figure 4. Effect of erosion control fabrics and straw on soil loss from 5:1 slopes, sandy clay loam soil. Vertical insets indicate significant difference at .05 level.

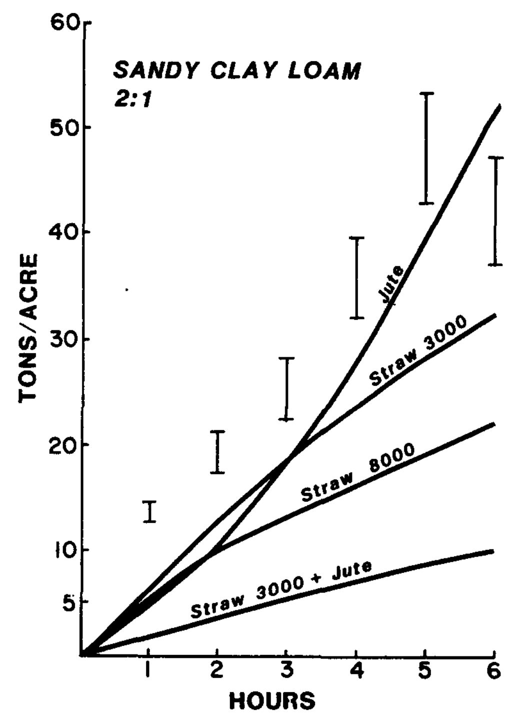

Figure 5. Effect of erosion fabrics or straw on soil loss from 2:1 slopes, sandy clay loam soil. Vertical insets indicate significant difference at .05 level.

All treatments were very successful, allowing us to extend the test to six hours, even though this is a very erodable soil. Each increase in the amount of straw reduced the amount of soil lost (Figure 3).

Straw vs. Fabrics

The most commonly available erosion control fabrics are jute, excelsior, and a paper strip-synthetic yarn product (Hold/Gro). These were compared to straw at 3,000 lb/acre, also on a sandy clay loam at 5:1 for six hours.

Straw and jute were the most effective treatments and not significantly different from each other. Excelsior was less effective but better than the paper product (Figure 4).

Jute is sometimes used on top of straw for added effectiveness. This treatment was therefore compared to the other most effective treatments--straw punched at 8,000 lbs, straw tacked at 3,000 lbs, and jute alone. Because we expected these treatments to be very effective the slope was increased to 2:1.

Jute plus straw was the most effective and better than 8,000 lb of straw which was better than 3,000 lb of straw (Figure 5). Although jute alone was very effective at 5:1 in the previous test, it grew progressively worse during this test. It was as effective as 8,000 lb of straw for over two hours, but then performance deteriorated as soil washed from beneath the fabric.

DISCUSSION OF RESULTS

These tests illustrate the importance of soil texture in erodability and the large differences in the effectiveness of mulch treatments for retaining soil. Also different are the costs of these treatments. Straw, though consistently the most effective treatment, is not expensive. At the rate of 3,000 lb/acre it is comparable in cost to hydraulic mulches at 1500 lb/acre and only 25% of the cost of installed fabrics (Kay, 1978).

Straw has been largely replaced in California by the currently popular hydroseeding techniques (hydraulic slurry applications of seed, fertilizer, mulch fibers, and possibly chemicals). Field and laboratory tests, such as reported here, consistently illustrate that straw is superior not only to retain soil but also to increase the establishment of plants.

The mulch effect of straw can be expected to increase plant numbers. Meyer et al. (1971) obtained fescue-bluegrass establishment of 3, 28, and 42% with respective surface straw mulch treatments of 0, 1, and 2 tons/acre. Straw has been shown to increase plant establishment in decomposed granite (Kay, 1974). Seeding the annual grass Blando brome (Bromus mollis) resulted in 7, 6, 26, 35, and 131 seedlings/ft^2 respectively on the untreated, fiber mulch at 1,000, 2,000, and 3,000 lb/acre, and straw at 2,000 lb/acre on a 2:1 slope. On 1.5:1 the number of plants were 1, 13, 29, 35, and 131, and at 1:1 slopes 0, 10, 27, 20, and 155. Seed coverage with soil also produces superior stands when compared to hydraulic applications (Kay, 1979, Packer and Aldon, 1978). Fertilizer or legume seeding must be applied to compensate for the nitrogen tied up in decomposing the straw.

Size of mulch particles is important because of the mass required to absorb the energy in the water drops. Even though the hydraulic mulches provided the most complete ground cover (Table 1) they were too small to be effective.

Straw length may be important, particularly if it is to be punched into the soil, in which case longer straw is desirable. New agricultural practices are resulting in shorter lengths. The flails used in straw blowers will further shorten straw. The barley straw used in these tests was about 10 inches, ranging from 1 to 23 inches.

Poor soil contact is a problem with some of the fabrics, and frequently allows erosion to occur from beneath them. A layer of straw under the fabric will improve this contact (Figure 4).

Missing from these tests are the glue products, some of which may be expected to be very effective. Among the effective glues are the plastic types, PVA and SBR. Organic glues are of questionable value (Kay, 1978). Properly applied, plastics may be as effective as the best treatments tested here. However, they are expensive and are not as versatile as straw in that they are not self-healing, having curing problems, and in California may inhibit seedling establishment.

DISCUSSION OF STRAW PRACTICES

Cereals are a major crop in dry regions of the United States, and straw left on the site of production is often considered a liability because its decomposition ties up nitrogen needed for the next crop. Straw availability should be increased by current restrictions on removing this crop residue by burning in place. Clean grain straw, free of noxious weeds, is preferred for mulching. The straw can be expected to contain 0.5 to 5.0% cereal seed by weight, which may result in considerable plant cover in the first year. This provides additional erosion protection but may also be prohibitively competitive with the planted erosion-control or beautification mixture. Rice straw is sometimes used because neither the rice nor associated weeds can be expected to grow on most unirrigated disturbed lands. In areas where cereal crops are not common, hay is used but is normally more expensive than straw. Wild-grass hay may be a valuable source of native plant material if cut when the seeds are ripe but not shattered. Both straw and hay are flammable and should be incorporated or sprayed with fire-retarding fertilizer (monoammonium phosphate) if fire is expected to be a problem.

Straw can be applied with specially designed straw blowers or spread by hand. Commercial mulch spreaders or straw blowers advertise a capability of up to 15 US tons/hour and distances to 85 ft. The length of the applied straw may be important and can be controlled in most blowers by adjusting or removing the flail chains. Baled straw may also be relatively long or short, depending on agricultural practices. Straw to be crimped or punched should be relatively long to be incorporated into the soil effectively and still leave tufts or whisker dams. Rice straw is wiry, dirty, does not shatter readily, and may come out of the blower in 'bird nests'. Blown straw (other than rice) lies down in closer contact with the soil than hand-spread straw and is anchored more successfully with a tackifier (substance sprayed on straw to hold it in place). Wind is a serious limiting factor in applying straw, though it can be an asset in making applications downwind. Dust, a problem in urban areas, can be overcome by injecting water into the airstream used to blow the straw.

The amount of straw to be used will depend on the erodability of the site (soil type, rainfall, length and steepness of slope), kind of straw (Grib, 1967), and whether plant growth is to be encouraged. Increasing rates of straw give increasing protection. Meyer et al. (1970) show that as little as 1,000 lb/acre reduced soil losses by two-thirds, while 4 tons/acre reduced losses by 95%. Straw to be crimped is commonly used at 2 tons/acre, while straw punched into fill slopes in California is at 4 US tons/acre in a split application and rolling operation (2 tons/acre each). Straw to be held down with a net should be limited to 1.5-2 tons/acre if plant growth is important. Too much straw may smother seedlings by intercepting all light or forming a physical barrier. Also, some grass straw (notably annual ryegrass, Lolium multiflorum) may contain inhibitors that have a toxic effect if used in excess. A good rule of thumb is that some soil should be visible if plant growth is wanted. Higher rates of straw may of course still satisfy these requirements if the straws are vertically oriented (like tufts) by crimping or punching.

Straw or hay usually need to be held in place until growth starts. The problem is wind, not water. Water puddles the soil around the straw and helps hold it in place. Also, wet straw "mats down" and is not easily moved. If the straw covered area can be irrigated, or if rainfall is imminent, it will not be necessary to anchor the straw.

Common methods of holding straw in place are crimping, disking, or rolling into the soil; covering with a net or wire; or spraying with a chemical tackifier. Swanson et al. (1967) found similar protection from prairie hay applied as a loose mulch or anchored with a disk packer (crimper).

Crimping is accomplished with commercial machines which utilize blunt notched disks which are forced into the soil by a weighted tractor-drawn carriage. They will not penetrate hard soils and cannot be pulled on steep slopes.

Rolling or "punching" is done with a specifically designed roller. Not satisfactory for incorporating straw is a sheepsfoot roller, commonly used in soil compaction. Specifications of the California Department of Transportation contain the following provisions (State of Calif., 1975): "Roller shall be equipped with straight studs, made of approximately 7/8 inch steel plate, placed approximately 8 inches apart, and staggered. The studs shall not be less than 6 inches long nor more than 6 inches wide and shall be rounded to prevent withdrawing the straw from the soil. The roller shall be of such weight as to incorporate the straw sufficiently into the soil so that the straw will not support combustion, and will have a uniform surface."

The roller may be tractor-drawn on flat areas or gentle slopes, whereas on steeper slopes the roller may be lowered by gravity and raised by a winch in yo-yo fashion, commonly from a flat-bed truck. Requirements are soil soft enough for the roller teeth to penetrate, and access to the top of the slope. This is a common treatment on highway fill slopes in California. It can be used on much steeper slopes than a crimper. Punched straw may not be as effective as contour crimped straw, because of the staggered arrangement of tucked straw instead of the "whisker dams" made by crimping (Barnett et al., 1967).

A variety of nets have been used to hold straw in place: twisted-woven kraft paper, plastic fabric, poultry netting, concrete reinforcing wire, and even jute. Price and the length of service required should determine the product used. These should be anchored at enough points to prevent the net from whipping in the wind, which rearranges the straw.

Perhaps the most common method of holding straw, particularly in the eastern U.S., is the use of a tackifier. This method may be used on relatively steep slopes which have limited access and soil too hard for crimping or punching. Asphalt emulsion, the tackifier used most commonly, is applied at 200-500 gal/acre--either over the top of the straw or applied simultaneously with the straw blowing operation. Recent tests (Kay, 1978) have shown that 600 gal is superior to 400 gal. and that 200 gal/acre is not satisfactory. Wood fiber, or new products used in combination with wood fiber, have been demonstrated to be equally effective, similar in cost, and environmentally more acceptable (Table 3). Though wood fiber alone is effective as a short-term tackifier, glue must be added to give protection beyond a few weeks. Terratack I is a gum derived from guar (Cyamopsis tetragonoloba). Ecology Controls M Binder is a gum from plantain (Plantago insularis). The remaining products are emulsions used in making adhesives, paints, and other products. Increasing the rate/acre of any of the materials will increase their effectiveness.

Table 3.--Effects of tackifier products on wind stability of barley straw broadcast at 2,000 lb/acre.

Product	Chemical	Fiber lb	Water gal	Wind speed (mph at which 50% of straw was blown away)
None				9
SS-1 asphalt	200 gal			40
SS-1 asphalt	400 gal			80
SS-1 asphalt	600 gal			84
Fiber only	484			47
Fiber only	736			84
Terratack I	45 gal	150	750	68
Ecology Control M-Binder	100 lb	150	700	84
Styrene butadiene copolymer emulsion (SBR)	60 gal	75	400	84
Polyvinyl acetate (PVA)	100 gal	250	1000	54
Copolymer of methacrylates & acrylates	100 gal	250	1000	76

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WETLAND PROTECTION IN THE ROCKY MOUNTAINS

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INTRODUCTION

In the Rocky Mountains, wetlands are variously known as wet meadows, seeps, riparian habitat, marshes, sloughs, swamps, beaver ponds, bogs, lakes and reservoirs and even by such European terms as carrs, fens, moors, and peatlands. Numerous classification systems have been proposed but the two most often used by wildlifers are the U.S. Fish and Wildlife Services Circular 39 (Shaw and Fredine 1956) and the more recent National Wetlands Inventory system by Cowardin et al. (1979). Officially wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plants and animal communities living in the soil and on its surface. Although other parts of the United States are much more important for wetlands (particularly Alaska, the Lake States, northern prairies, and the Southeast), there is considerable interest in Rocky Mountain wildlife-wetlands relationships. For example, over 30 theses have been written at Colorado State University relating to wetlands wildlife, mainly ducks, geese and beaver but also coots, rails, snipe, herons, pelicans, and moose. Additional graduate studies concerned with wetlands have been in botany, geology, forestry, range management, watershed management, outdoor recreation and zoology.

Of the 127 million acres of wetlands estimated by the Soil Conservation Service to have been present when our nation was founded, at least 45 million acres, or over one-third of the total, had been lost by the mid-1950's (Shaw and Fredine 1956). Losses have continued in the 1960's and 1970's (Frayer et al. 1983). In this paper I intend to summarize some of the values of and threats to wetlands in the Rocky Mountains and discuss some of the more important legislation and other means of protecting and improving these important natural resources.

VALUES OF WETLANDS

Wetlands have many valuable functions such as: flood conveyance, barriers to erosion, flood storage and water supply, sediment and pollution control, fisheries and wildlife habitat, recreation, timber and forage production, historic and archeological values, education and research, open space and aesthetics. These have been well enumerated and discussed by Kusler (1983), Frayer (1983), Good et al. (1978), Greeson et al. (1979), Larson (1982), Richardson (1981), Svedarsky and Crawford (1982), and Weller (1981).

THREATS TO WETLANDS

Man has "battled" wetlands for centuries fearing they harbored disease, insect pests, human enemies, harmful wildlife and interfered with his agriculture, land development and other endeavors. Marshes have been drained (often with government subsidy) to increase crop and timber production and to control mosquitos. Wetlands have been damaged by dredging and stream channelization related to road and reservoir construction, flood control and, at lower elevations, for water-borne transportation. Often the Soil Conservation Service, Corps of Engineers, and Bureau of Reclamation have advocated wetland manipulations opposed by the U.S. Fish and Wildlife Service, various game and fish departments and private conservation organizations. Marshes and swamps have been filled with solid wastes from cities, road and bridge construction, utility line rights-of-way, commercial, residential and industrial developments. Wetlands have been polluted with a variety of biocides from silvicultural and agricultural activities as well as from industry. Mining for sand, gravel, coal, peat and other minerals has eliminated or profoundly altered other wetlands (Kushler 1983, Darnell 1976, Davis and Brinson 1980, Erickson and Camougis 1980, Erickson et al. 1980, Hall 1968, Harris 1980, Hawkes 1980, Horwitz 1978, and Weller 1981).

PROTECTION OF WETLANDS

There has been considerable legislation at both federal and state levels which has evolved in large part to protect wetlands from the above-mentioned threats. The U.S. Fish and Wildlife Service has purchased and manages many wetlands as National Wildlife Refuges largely with so-called Duck Stamp monies authorized by the Migratory Bird Hunting Stamp Act of 1934 (Horwitz 1978). Most state game and fish departments have protected other wetlands using monies authorized by the Pittman-Robertson Act of 1937 (Linduska 1964). The Fish and Wildlife Coordination Act of 1934, the National Environmental Policy Act of 1969, the Clean Water Act of 1977 (especially section 404), and the Endangered Species Act of 1973 have all been invoked at various times to protect wetlands (Kushler 1983 and Barnett 1982). Local zoning regulations have also been utilized (Good et al. 1978). The Water Bank Program of the U.S. Agricultural Stabilization and Conservation Service has made funds available to landowners to maintain, restore, and improve water areas important for migratory waterfowl nesting and breeding (Fish and Wildlife Service 1980). At least 31 states now utilize income tax "check-off" monies to manage nongame wildlife species many of which depend on wetlands (Nongame Wildlife Association of North America 1983). Many private organizations such as Ducks Unlimited, National Audubon Society, National Wildlife Federation and the Nature Conservancy also actively engage in wetlands protection and management (Linduska 1964).

WAYS OF IMPROVING WETLANDS

Wetlands, if totally protected and unmanaged, normally change by natural succession to some other climax form of vegetation such as grassland or forest. Wildlife managers periodically set back succession of wetlands utilizing many of the factors earlier enumerated as threats, such as fire, water fluctuations, herbicides, grazing, plowing and manipulating populations of muskrats and beaver (Rutherford 1964, Bookhout 1979, Beard 1953, Hall 1968, Hopper 1968, Nelson 1954 and Richardson 1981). Thermal waters can be used to make wetlands more available to wintering waterfowl (Ryder 1970). In the high country of Colorado, "early water" spread on wetlands is important for maximum waterfowl production (Anderson 1966, Robinson 1971, and Schroeder et al. 1976). Artificial potholes created by marsh blasting have also improved duck habitat in Colorado (Hopper 1978). Herbicides, fire and mechanical means have been used to control nuisance marsh plants such as cattail (Nelson and Dietz 1966) and common reed (Cross 1983). Rotenone can be used to control overpopulations of carp which reduce valuable waterfowl food plants (Robel 1961). A wide variety of artificial nest boxes, structures, and islands have been used to increase ducks, geese, and other waterbirds (Will and Crawford 1970, Rutherford and Snyder 1983). Techniques for wetland management are well summarized in Linde (1969), Addy and MacNamara (1948), Ratti et al. (1982), Scott (1982), Harris and Sauey (1980) and by the Atlantic Flyway Council (1972).

SUMMARY

Wetlands of the Rocky Mountain area, although limited in total acreage, are very valuable for water regulation and wildlife habitat. A variety of federal, state, and local laws provide protection while numerous management techniques are available to improve and perpetuate wetlands.

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Choosing A Reclamation Contractor

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INTRODUCTION

Many qualified reclamation contractors exist in the western United States. Hopefully this paper will enable those in the mining or construction industry who are faced with selecting reclamation contractors to make the right decisions. However, wrong decisions, if properly managed, can be made to work. This paper does not discuss the advantages/disadvantages of using contractors for reclamation projects. It is assumed that the reader has already decided, for any of a number of reasons, to utilize a contractor to perform the work and is interested in how to choose the best company for the job.

Many companies have well defined bidding/contracting procedures. These are usually flexible and one company's policy may resemble the policies followed by others. Many of the terms in this paper may be referred to by different names but the intent is usually the same. There are five basic steps associated with successful contractor selection:

- Preparation of the Request for Proposals
- Selection of Qualified Bidders
- Procedures for Soliciting Proposals
- Reviewing the Proposals
- Awarding the Contract

Preparation of the Request for Proposals

The "Request for Proposals" (RFP) is the instrument used by the owner to solicit contractor proposals or bids; it is sometimes referred to as an Invitation for Bids or Bid Package. The RFP should be formal and comprehensive for the following reasons: 1) it insures that all bidders receive identical information; 2) it encourages complete and responsive proposals; 3) proposals are more easily comparable; and 4) it facilitates the execution of a definitive, mutually acceptable contract.

A complete RFP consists of five components: an "Invitation Letter", an "Information to Bidders", a "Contract Form", a "Job Description", and "Proposal Forms".

The Invitation Letter is simply a cover letter transmitting the Request for Proposals from the owner to the selected bidders.

The Information to Bidders section contains general background information on the project and instructs the bidders on how to properly prepare and submit their proposals. It describes the other RFP documents, arrangements for site visits, time and place for delivery of proposals, and identifies a contact person in the owner's organization that is able to answer any questions bidders may have. This section also requires the bidders to prepare execution plans, qualification statements, and submit past experience with similar work.

The Contract Form is a sample contract document that has previously been reviewed and found acceptable by the owner. It should set forth all forseeable terms and conditions that must be met by the owner and contractor during execution of the work.

The Job Description is the section that describes the work to be done, the procedures for satisfactory completion of the work, and the services and materials to be provided by the contractor. It serves the same function as a set of drawings and specifications would serve in a construction contract. The Job Description ultimately becomes an attachment to the executed Contract.

The Proposal Forms are used by the bidders to quote their terms, conditions, and prices. If the bidders want to propose alternative methods for conducting the work, the Proposal Forms should be used to recommend these exceptions to the RFP. The Proposal Forms are combined with the Contract Form and Job Description to facilitate contract award.

As the RFP is being completed, the list of prospective bidders should be prepared.

Selection of Qualified Bidders

The objective of bidder selection is to identify the best qualified contractors to participate in the bidding competition. For most contracts, a mix of proven competitive bidders and new bidders is preferred. Experience has shown that new bidders are highly competitive resulting from a strong desire to break into new business. Proven contractors provide the security of having performed satisfactorily on previous jobs.

Ideally, all bidders should be prequalified before being invited to bid. Thus, any bidder submitting the low conditioned bid can be recommended for contract award, provided that bidder submits a technically acceptable proposal. Unfortunately, an adequate and equitable screening and prequalification program is sometimes difficult to conduct and may require significant time. Minimizing the number of bidders that the owner is unfamiliar with will facilitate contract award. It is unfair to send a Request for Proposals to a bidder that will not be seriously considered. Excessively large bidder lists may discourage the better contractors from bidding because they judge their chances of success to be too low.

Once the RFP is approved and a bidders list is prepared, the RFP is ready for release.

Procedures for Soliciting Proposals

The RFP should be made available to all bidders at the same time. All bidders should receive identical RFP's with the same submittal requirements.

All communications with the bidders should be channeled through a single contact named in the Information to Bidders section of the RFP. Bidders will often have questions concerning the job or bidding procedures. These questions should be answered quickly and, in some instances, may result in a revision to the RFP.

In addition to revisions resulting from bidders' questions, revisions may result from new information, regulatory changes, weather, and a variety of other causes. Revisions should be minimized. If revisions are required, all bidders should be notified and the revised documents sent to all bidders as quickly as possible.

Since reclamation involves extensive field work, all bidders should be required to visit the work site. Some owners prefer separate site visits for each bidder. This writer prefers that all of the potential contractors attend a common site visit. This insures that each bidder hears the same questions and comments and sees the same conditions.

The last step in soliciting the proposals is to assure that the proposals are delivered on or before the due date. This should be done to reduce the chances of delaying the bid review. The date and time of proposal receipt should be noted on the unopened proposal by the owner and documented to insure fair and equal treatment of all bidders.

Reviewing the Proposals

Bid review involves the comparison of many factors. An organized evaluation process is essential in weighing these factors for each bidder.

There is usually significant pressure, once proposals have been received, to complete the review and award the contract quickly. Regardless of the complexity of the bid review, prime responsibility for the overall effort should be assigned to a single individual so that the review can be properly coordinated.

The personnel required for the bid review team will depend on many factors, including the scope of work, type of contract, and contract value. Most reclamation bid review teams are comprised of only two or three individuals. Each of the review team members should develop a list of criteria/factors for use in evaluating the proposals. The team leader must then combine these factors and assign each a relative value before the bids are opened.

An example proposal review is shown to facilitate this discussion. The following is a summary of four proposals submitted for a job involving the propagation and outplanting of over 40,000 containerized plants on approximately 100 acres. The costs shown are not representative and are included only as examples. Note that five general factors were used to evaluate the four proposals used for this example and the relative value of each has been established by the numbers in the Factor Value column.

Contractor A submitted a bid of $2 million. They proposed using a small nursery inexperienced in growing containerized stock for reclamation plantings. Past work by this contractor was satisfactory but their execution plan was not entirely complete.

Contractor B submitted a bid for $2.4 million. They proposed using a small nursery inexperienced in growing containerized stock for reclamation plantings. Past work by this contractor was very satisfactory but their execution plan did not address some important concerns.

Contractor C submitted a bid of $1.5 million. They proposed using a mid-sized nursery experienced in growing containerized stock for reclamation plantings. Past work by this contractor was outstanding and their execution plan was very thorough. Contractor C proposed an attractive alternative to the work for $1 million.

Contractor D submitted a bid of $0.9 million. They proposed using a large nursery experienced in growing containerized stock for reclamation plantings. Past work by this contractor was very satisfactory and their execution plan was complete. Contractor D proposed an attractive alternative to the work for $1 million.

The contractors' proposals are then ranked, recognizing the factors discussed above. Each contractor's rank for any particular factor is subjective. The actual rank value is not as critical as the relationships between the contractors' ranks. For instance, Contractor D is assigned a rank of 10 for the cost factor, signifying the lowest bid. Contractor D could have been assigned a rank of 8, provided that the other contractors' rankings were similarly reduced. Multiplying each factor's value times

EXAMPLE - PROPOSAL REVIEW

FACTOR	FACTOR VALUE	CONTRACTOR A		CONTRACTOR B		CONTRACTOR C		CONTRACTOR D		CONTRACTOR C Conditioned		CONTRACTOR D Conditioned	
		RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE
1) Cost	50	5	250	4	200	7	350	10	500	9	450	9	450
2) Nursery, Materials, Containerized Stock Quality	10	5	50	5	50	7	70	7	70	9	90	10	100
3) Personnel, Superintendent, References	10	7	70	7	70	10	100	7	70	10	100	7	70
4) Execution Plan	10	7	70	6	60	10	100	8	80	10	100	10	100
5) Owner Confidence/ Recent Experience	20	7	140	8	160	10	200	8	160	10	200	10	200
TOTAL	100		580		540		820		880		940		920

each contractor's rank for that particular factor equals each contractor's score. The addition of the five factor scores equals the contractor's total score.

In this example, Contractor C's proposed alternative scored the highest with a total score of 940. Contractor D's proposed alternative followed closely with a total score of 920. Total scores that are this close to one another should be considered identical; additional comparisons may be needed to make the final determination of the successful bidder. Based on the above analysis, a recommendation is made to the owner's management to execute a contract with the bidder that is judged to be most capable of performing the work satisfactorily and economically.

Awarding the Contract

After management approval of the award recommendation, the final contract terms are negotiated. These are best handled "across the table". As issues are resolved with the contractor, the contract documents are revised by the owner to ensure that the owner's understanding of the resolution is accurately stated. When all revisions have been agreed to by the owner and contractor, the contract is typed in final form and then signed by both parties, concluding the award. All unsuccessful bidders should then be notified in writing.

Summary

This paper outlines a recommended approach to selecting reclamation contractors. This approach can be easily adopted for other contract work. An organized process for selecting reclamation contractors expedites the contracting process, treats bidders impartially, and generally results in more satisfactory work.

ECOLOGICAL ASPECTS OF CONTRACTING SEED COLLECTION, GROWING AND TRANSPLANTING ON THE GLENWOOD CANYON HIGHWAY PROJECT

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Glenwood Canyon, located some 160 miles west of Denver, is a steep walled, river carved gorge that has served as a transportation corridor for one hundred years. This is one of two uncompleted sections of rural Interstate 70 left in Colorado. Because of the "scenic" designation given to it, Glenwood Canyon has received a design solution that goes far beyond normal engineering efforts. Along with this has been the desire to successfully revegetate not only the disturbances created by this construction, but also to help rehabilitate some of the old scars left from previous roadbuilding efforts.

Due to the rocky nature of the canyon, many of the naturally occurring species simply are not commercially available. Because of these facts, the Colorado Department of Highways (CDOH) in 1979 tried to write contractual documents for seed collection of various species to be used in revegetation. This proved to be much more difficult and involved than anyone anticipated, because of the little known species being required, and partly because the standard format and specifications are for construction jobs of ten thousand to several million dollars, not seed collection or plant growing. I view the opportunity to present this paper as a challenge and hope that others may benefit from our "learning experience".

Consultants were retained to perform a vegetation inventory from within Glenwood Canyon and develop a list of species needed and quantities desired. This first list of species and quantities was reviewed in house as well as sent to several companies involved in this sort of work. They were requested to submit comments and a very preliminary estimate of costs involved.

Although the industry people were pleased that CDOH was going to this much effort to revegetate, they did not care for our contract documents. Comments such as, "We find the idea of daily charges for late completion unacceptable since they are not standard practice in industry", and "Many of the species listed will incur more damage in cleaning than any bacterial degradation and should not be cleaned by normal standards". The comment that really got my attention was "I could give you many examples of very gross problems with many species if you need further information of such". It seemed from these comments that maybe we were off the track. It appeared I needed to do some "homework" and become more involved with these contracts. Although my background was not as a specification writer, I knew a little bit more about plants, seeds and the canyon vegetation than the squadleader or the cost estimator in our Denver office.

Definition of terms seemed to be a point of contention, and there were as many opinions of what it should be as there were responses. Terms such as ripeness, stratification, method of cleaning and improper storage were a few of those we tried to define. These are things that are problems partly because this is a pioneer type contract and partly because there are no "accepted horticultural practices" for the species in question. We spent many hours trying to evaluate what American Nursery Standard Category plants such as Greasewood (Sarcobatus vermiculatus), Gambel Oak (Quercus gambelli), and Fourwing Saltbrush (Atriplex canescens) fit into, if any.

More in the ecological aspect were the problems with determining how much constraint to use when it came to difference in collection sites. In which states could we collect before there were genetic or phenological differences in what appeared to be the same plant. Most of the published data at that time seemed to be oriented to the forestry industry and conifers. Could or should we apply the same guidelines to the shrubby decidious plants we were working with? If we allowed collection in Montana, would there by a "day-length problem" with the seed? These are the kinds of things various people brought up in our deliberations about these contracts.

The need for very precise wording was pointed out by the fact that everyone who reviewed the plans thought they must collect all of the required seed from the north slope of the canyon itself. This was the first choice, if there was sufficient quantity to make it an economical site to collect from. However, provision was made to collect from sites of similar environmental conditions in a five state area. A provision was added that the contractor may purchase seeds from commercial sources as long as they met the environmental constraints of:

(a) annual precipitation (10"-20")
(b) elevation - 6,000 feet above sea level ($\pm$ 1,000 feet)
(c) states - Colorado, Idaho, Utah, Wyoming, and New Mexico

We felt this would cover most of the seed collection areas. The species that were grown under these conditions would probably be named varieties of grasses that have known genetic traits, and their origin would not be as critical.

One of the most significant changes that was made was to use named varieties of grasses versus using native stands that were harvested. The way I understand this is that a named variety will keep its genetic qualities intact whether it is grown in North Dakota or New Mexico. The advantage of this is that it reduces the cost and allows for commercial harvesting. I do not feel there is enough difference between the existing native stands of Indian Ricegrass (Oryzopsis hymenoides) and Nezpar Indian Ricegrass (Oryzopsis hymenoides"Nezpar") to destroy the integrity of the canyon.

In the original draft contract (that never went to bid), there was wording to the effect that the seed must be stored in such a manner that when the seed comes out of storage, it would be stratified and ready to germinate. This placed an unusual burden on the collector. They needed to determine what was proper storage for 20 some different species, and have the facilities to provide that treatment. Most seed collectors are not set up to offer special seed treatment and storage facilities. Even the larger wholesalers of seed do not offer pre-germination treatments. This wording was eliminated in subsequent drafts of the contract. Our stratification is now done by Mother Nature as most of our seeding is done in the late fall and not expected to germinate until the following spring.

There was a great deal of evolution that took place between the first list of species and quantities, and that list as it went to bid. I found it hard to believe anyone would be able to collect 725 purelive seed (pls) pounds of Needle-and-Thread Grass (Stipa comata), 590 pls pounds of Bottlebrush Squirreltail (Sitanion hystrix), or 660 pls pounds of Galleta (Hilaria jamesii). This is probably the whole western United States' collection in a good year. At prices ranging from 28-70 dollars/pls pound, it seemed rather extravagant. Galleta is now being produced and would not be the problem that it was in 1980.

There were also many changes in the herb/forb list that was generated originally. After trying my hand at collecting some of these species, I was convinced that any minor ecological benefit could not be justified by the costs incurred. One example that comes to mind is Tufted Evening Primrose (Oenothera caespitosa) at 400 dollars/pls pound, for a plant that most people would not see while traveling the highway. I believe in the use of the herb/forb type plants in our mixtures, but I have a hard time dealing with these dollar amounts and some of the suggested species.

I would like to state here that I do not fault the original consultant's recommendations, and that we have all learned a great deal from going through this process. What would really be sad to me is if we had not learned anything from this exchange of ideas.

When CDOH finally got the seed collection contract printed, advertised, and let out for bids, the response was interesting. Four or maybe five companies picked up plans and only two submitted bids. The two bids were a factor of 2x apart with the Engineers' estimate somewhere in the middle.

Since the low bid was so much lower than the estimated cost, the bidder's bonding company would not bond them. To make a very long story short, no contract was ever awarded. The most common complaint heard, concerning this contract, was the companies having to pay their people according to the Davis-Bacon wage scale. The fact that they had to be bonded an put up collateral in case of default seemed very objectionable to most of them also. The manner in which we finally obtained our seed was through a purchase order. This proved to be less than desirable in the end. I received bags of seed that were short on quantity, that were of questionable identification and could have come from almost anywhere. This was pretty much conducted on the honor system as far as knowing where the seed was collected from. Several attempts to contact the collector proved to be futile. I made appropriate price adjustments to the contract and had it closed out. Unless you know the collector you are working with and trust him, I would not recommend this method of obtaining seed.

Other hindsight items that come to mind concerning the seed collection contract are: I thought it would be good to stake out the stand of seed to be harvested for approval. This would make sense only if there were very large pure stands of certain species. A USGS map was suggested to show where collection took place for a certain species. This works for the areas that have been mapped at the small scale. A herbarium specimen with the pertinent data may also be a beneficial item. This still pretty much leaves it on the honor system for the collector to harvest where it was stated the specimen came from.

Except for a few increases/decreases in quantity, not much changed in the woody plants portion of the contract. Once a palette of plants was established, the idea of growing contracts seemed like the next step. Several meetings had been held prior to this, with interested growers, to develop the best way to proceed with the problem of contract growing of plants. It was quickly apparent that we could not rely on the open market for our plant materials, because the species CDOH needed were not normally grown, and because of the quantities needed and the schedule that had to be met. ie(large quantities of fall availability plants)

New types of problems developed with the growing contracts. When entering into long term (3-5 years) growing contract, many things should be taken into consideration. Especially in the Intermountain West where weather is such a factor. Drought, spring freeze and many unforeseeables can affect the grower's ability to produce the desired plants. Because of the weather, maybe no seed is produced or the seed is of low viability. Insects can infest the seed or can eat the pods or capsules before they are ripe. This is when you hope you can scout around and find a pocket to meet your requirements for the following year. These Acts of God cannot be used to penalize the grower but they do not allow you to utilize the plant materials which have been proposed and put into the plans. This is why you need an "alternate plan B" if at all possible. Things such as a list of acceptable plant substitutes, growers who may have the substitute plant species in stock, and a pool of larger or smaller sized plants to draw from may be viable options.

Since seed crops are very fickle, it may be prudent to collect extra seed on the years when there are good crops and store it away for future use. Not all seed will allow you to do this. Know what the limitations are.

Seeds such as Gambel Oak is best when planted immediately after collection. Winterfat (Eurotia lanata) and Rubber Rabbitbrush (Chrysothamnus nauseosus) will generally keep for two years before a decline in viability. Seeds from Saltbrush and Indian Ricegrass may actually germinate better when held in storage for several years, due to an afterripening process where the embryo matures fully.

We have had to accept plant materials not meeting the top growth requirement because of weather and rabbit damage. However, the root systems were healthy and this may be more important that if a plant has two caned and a minimum height of eight inches. In late May of 1983, a snowstorm come out of the Rockies and dumped 6-8 inches of slushy snow on our plants. The Saskatoon Serviceberry (Amelanchier alnifolia) seemed to show the most severe response. These plants dropped all their leaves and returned to budset. It remaind in budset, even with our grower giving it high nitrogen fertilizer, until September. The plants were only 3-6 inches tall but had 3/8 inch caliper stalks and a good healthy root system. My best guess is that they may just be some of our best plants by next year, even though "technically" they did not meet our specifications. I think our grower summed it up pretty well with the statement, "Growing trees is different from making ball bearings. We can't guarantee that every one will turn out just right".

One of the biggest problems we have right now is the original schedule of production is no longer valid. This is due to funding for particular portions of the highway project not being available when scheduled. Therefore, we have plants being grown which are salt, drought tolerant types for the east end which will not be needed for several years. Several options are available to us: dump them now while they are small and inexpensive or overplant areas of high visual impact or repot them into larger containers. Experience has shown us that the survival rate of plants decreased proportionately as the size gets larger. We have not resolved this problem ourselves.

Transplanting in Glenwood Canyon is very difficult due to the extremely rocky nature of the canyon and poorly defined soil strata. Even in pockets where some soil exists, it is extremely rocky and difficult to maintain a ball of soil around plant roots. We have tried two step transplanting with root pruning as the first step. This was to encourage more fibrous roots to be produced to hold together better. Although this procedure is done in the nursery industry with success, ours was very marginal. The species we tried it on included Chokecherry (Prunus virginiana), Trumpet Gooseberry, (Ribes leptanthum), and Gambel Oak.

Our grower has been able to lift wilding from some areas in the canyon successfully. He cuts them back severely and places them in a half shade situation while nuturing them along. In most cases these develop into good, usable plants by the following year at a larger size than those started from seed at the same time. The supply of these is somewhat limited and takes some searching to find.

From our experience, I would say study the available literature and know what is reasonable. Do not expect the industry to change a great deal to fit your needs. Be as clear and concise in the text as possible; do not leave much to interpretation. Follow your contract through, from specification writing to delivery of goods, if at all possible. Keep good notes; you never know when you may be called upon to present a paper.

RESPONSES OF SEEDED NATIVE GRASSES TO REPEATED FERTILIZER APPLICATIONS ON ACIDIC ALPINE MINE SPOILS

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INTRODUCTION

One of the main concerns in revegetation is maintaining the level of soil fertility during the critical phases of plant establishment and growth to insure adequate production and surface cover. Unfortunately, in the alpine zone the number of applications and the length of time that artificial refertilization of the soil is required after seeding or planting remains unknown. In most revegetation efforts fertilizer is applied at the time of seeding or planting followed by one additional application, but rarely is fertilizer re-applied more than once. It is still not known if repeated applications of fertilizer in the years following seeding will help establish a more desirable and stable vegetation cover sooner than would fewer applications.

Fertilizer increases productivity and cover on most disturbed alpine sites, but the length of time these attributes are maintained after the discontinuation of fertilizer is unknown. For alpine disturbances site productivity and cover changes in floristic composition after fertilization is discontinued are poorly understood. If fertilization were continued over a long period a heavy grass sward would probably be sustained, but the impact of this on the invasion and establishment of other species has not been studied in the alpine zone. Perhaps site diversity is being restricted with frequent refertilization by favoring grasses and inhibiting forbs or other growth forms. Generally grasses are widely used in revegetation because they respond well to treatments such as fertilizer, and they tend to provide a rapid source of ground cover. However, we are still uncertain whether thick grass swards are desirable on revegetation sites, or if diverse mixtures of grasses and forbs would be more desirable.

In alpine environments, fertilization studies have not yielded much usable information. Faust and Nimlos (1968) found that nitrogen exists primarily in the organic form in Montana alpine surface soils. Cool summer temperatures restrict microorganism activity in these soils, resulting in low levels of nitrogen available for plant growth. Plant nutrients such as nitrogen, phosphorus, and potassium are usually found to be either low or limiting for plant growth in alpine soils (Lunt 1972, Grubb 1965, Smith 1966, Webber 1974, Retzer 1956). Fertilizer was found to be useful in several alpine revegetation efforts (Brown and Johnston (1976, 1978, 1980), but little data are available that quantify the limits of nutrient deficiencies found prior to revegetation.

The concepts of alpine revegetation and the impacts of the alpine environment on revegetation have been described by Johnston et al. (1975), Brown and Johnston (1976, 1978, 1980), and Marr et al. (1974). Appreciable success has been achieved in revegetation using techniques that consume intensive levels of resources on alpine disturbances. However, the minimum requirements needed to establish a protective plant cover on disturbed alpine sites are still not known, particularly the amounts of fertilizer required over time. Industries and most State and Federal agencies tend to rely on relatively minimal revegetation efforts in order to satisfy legal and agency regulations, primarily for economic reasons. It would be highly valuable to know what levels of refertilization are needed to provide the levels of surface protection required to meet these regulations.

The primary objective of the present study was to determine how effective various fertilizer reapplication schedules are for the development of a protective plant cover on acid mine spoils in the alpine zone. Also, we wished to determine what role various reapplictions may have on ultimate species composition, cover, plant density, and above-and-below ground productivity or standing-crop.

METHODS AND PROCEDURES

The study site is located on the McLaren Mine in the Beartooth Mountains in southwestern Montana, situated about 5 miles north of Cooke City. This surface mine has been inactive since about 1952, but the large spoil piles still contain high concentrations of copper, iron pyrites, and other heavy metals. The mine is on a highly mineralized intrusion on a southwestern exposure at 2956 m (9,700 ft.) elevation, and occupies an area of about 12.5 ha (30 acres). Water draining from the mine site into the head-waters of the Stillwater River is very acidic and contains high concentrations of heavy metals, including copper, iron, aluminum, and others. This toxic drainage not only seriously impacts the aquatic ecosystem for several miles downstream from the mine site, but also has destroyed many off-site plant communities.

In 1976 a 0.7 ha (1.7 ac.) site on the north side of the mine was selected for a revegetation demonstration area. The spoil piles in this area were contoured to the same shape and slope as the adjacent undisturbed landscape. The study site is located on a southwest exposure with a slope of about 15 percent, and microsite variations are numerous. For example, a small swale near the center of the area becomes a late snow-melt pocket that in some years creates quite different environmental conditions than otherwise exist on the area. In addition, some variation in the characteristics of the spoil material exists resulting from original placement of spoil piles. The details of the revegetation methods used were described by Brown and Johnston (1978), but in general the site was treated in order to raise the spoil pH from its original level of 3.5 to about 5.5 and to increase water-and nutrient-holding capacities. Lime and manure, both at the rate of 2,200 kg/ha (2,000 lbs /ac.), and a granular 16-40-5 fertilizer at the rate of 112 kg/ha (100 lbs/ac.) nitrogen, 280 kg/ha (250 lbs/ac.) phosphorus, and 35 kg/ha (21 lbs/ac.) potassium, were incorporated into the upper 15 cm (6 in.) of the spoil. The area was seeded with a mixture of native grasses and a single sedge (Table 1) , and then mulched with straw at the rate of 2,500 kg/ha (2,200 lbs/ac.). The mulch was held in place with an asphalt emulsion surface tackifier.

Table 1. Summary of species and seeding rates used on the McLaren Mine demonstartion area in 1976.

Species	Seeding Rates	
	kg/ha	lbs/ac.
Agropyron scribneri	1.6	1.4
A. trachycaulum	8.6	7.7
Carex paysonis	7.8	6.9
Deschampsia caespitosa	45.2	40.2
Phleum alpinum	5.2	4.6
Poa alpina	12.7	11.3
Trisetum spicatum	1.9	1.7
Total	83.0	73.8

The entire site was refertilized in 1977, 1978, and 1979 using the same fertilizer and application rate described above. Beginning in 1980 the demonstration area was divided into four approximately equal-sized subplots. The plots were oriented such that surface runoff and fertilizer movement between plots would be minimized. Because of slope orientation and the possibility of fertilizer contamination from one treatment plot to another it was not possible to employ a more sensitive statistical design, such as a split-plot layout. In 1979 treatment 1 (the upper subplot) was fertilized for the last time, but the other three subplots were all refertilized. Then, in 1980 treatment 2 was given its final fertilizer application, followed by treatment 3 in 1981, and finally by treatment 4 in 1982 (Table 2). Thus, 1983 was the first year that no fertilizer was used on the study site.

Table 2. Summary of re-fertilization treatments on the McLaren Mine Demonstration Area by year. "X" refers to fertilizer applications.

Year	Treatments 1	2	3	4
1976*	X	X	X	X
1977	X	X	X	X
1978	X	X	X	X
1979	X	X	X	X
1980		X	X	X
1981			X	X
1982				X

* Year of installation

Each treatment was assessed late in the growing season of each year after the plants had obtained maximum vegetative production (usually mid-to-late August). The variables measured included: cover (percent vegetation, litter, cryptogams, and rock), density by species(number of plants per quadrat), and total above-ground production or standing-crop. A total of 15 quadrats, each 0.1 m^2 (20 x 50 cm), were systematically located over the area of each treatment. Prior to 1981 above-ground production was measured by lumping all species, but in 1981 and in all subsequent years, above-ground production was measured for each species individually. Beginning in 1979 soil-root cores to a depth of 10 cm (4 in.) were collected from each treatment to assess below-ground biomass. Soil-root cores were collected with a 10 cm diameter (4 in.) coring tool from the center of one-half on the clipped quadrats.

The clipped above-ground plant samples were ovendried at 80°C (176°F) until constant weight was achieved, and then weighed. Roots from the soil-root cores were separated by washing and screening and then oven-dried.

In 1982 and 1983 we estimated cover from vertical photographs collected at the time of sampling in the field. A 35-mm camera was mounted on a tripod and positioned over each quadrat for each photograph. Later, the slides were projected onto a grid pattern so that percent cover of vascular plants, bare ground, rocks larger than 2 mm (0.08 in.) diameter, litter, and cryptogams could be estimated. Prior to 1982 these estimates were made in the field by ocular estimates at the time of sampling. These estimates led to some variation by different workers that could not be re-checked when the data were analyzed. Hence, it is felt that cover estimates using photographs as permanent records can be made more accurately.

During the first year of sampling (1977) the assessment was generally performed visually, but too few numbers of quadrats were examined over the entire area to be statistically valid. Consequently, the data were not analyzed with those of later years and are not reported here (these data are reported in Brown and Johnston 1978)

A two-way analysis of variance (treatment vs. year) was used for each variable to assess the data. The analyses were separated into two groups, one for the pooled data before treatment differences were applied (1978 to 1979), and the other for the years after treatments were imposed.

RESULTS AND DISCUSSION

The results were dramatically different than expected. Generally, the factors of plant density, cover, and production did not show obvious increases with repeated applications of fertilizer over time, nor did they show consistent trends from treatments 1 through 4. Also, plant species composition did not change dramatically for the four treatments or over time from 1977 to 1983.

A summary of the data (means and standard errors) collected from the demonstration area from 1978 through 1983 for the four treatments is presented in Appendix 1.

Cover

A summary of total cover partitioned into percent total vegetation, litter and cryptogams, rock, and bare ground by treatment and year is illustrated in Figure 1a, b, c, and d. Generally no strong treatment effect is noticeable, but treatment 4 (Figure 1d, receiving the longest period of refertilization) had a higher percent vegetation cover since 1979 than any other treatment. In general, the average vegetation cover was greater than about 35 percent (1982 had the least) over the entire area, whereas in most years it was greater than 50 percent. This is in contrast to an average vegetation cover of 21.7 percent in 1977 (Brown and Johnston 1978). It appears that plant cover percent declined from 1978 through 1982, and then increased in 1983. We suspect that local climatic fluctuations may have been significant in creating this response because all four treatment areas responded similarly. Treatment 2 (Figure 1b, receiving 4 years of refertilization) consistently showed higher plant cover percentages than treatment 3, even though the latter area was refertilized an additional year. This response strongly suggests there were large site differences among the four treatments that may have been stronger than the refertilization treatments themselves.

Other components of total cover include the presence of litter, cryptogams (moss, lichens, and other), and rock greater than 2 mm in diameter. Litter and cryptogams were lumped together and the percent cover contributed by them is also illustrated in Figure 1 above vegetation cover. Generally, these variables do not vary significantly ($p = 0.05$) even though the two combined components increased dramatically in 1981 and 1982. We suspect that the litter and cryptogam increases in these years were related to the decrease in vegetation cover witnessed in the same years. As vegetation cover declines, more

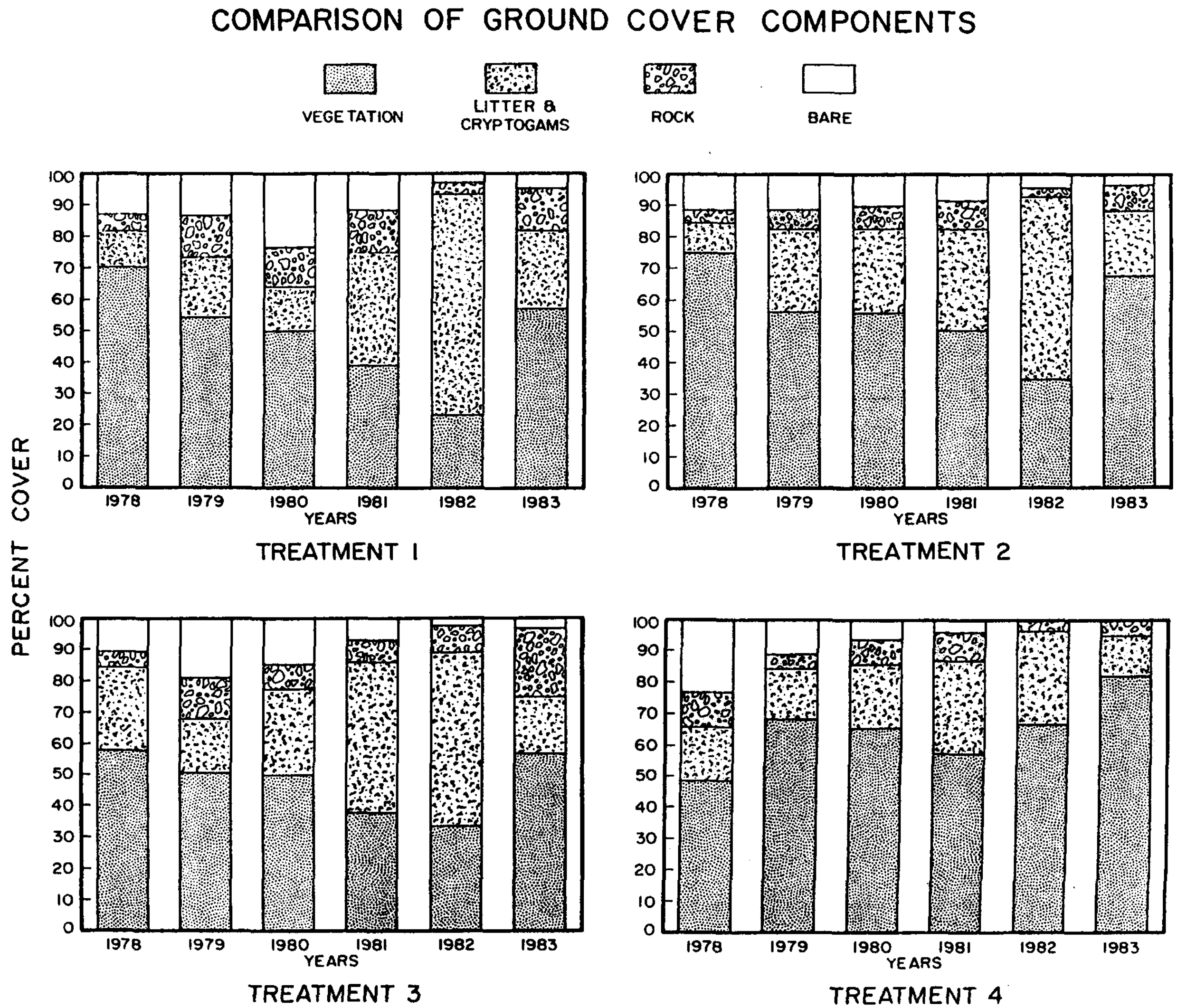

Figure 1. Summary of total cover partitioned into percent vegetation, litter and cryptogams, rock, and bare ground for the four treatments (a, b, c, and d) by year from 1978 to 1983.

litter and cryptogams become visible and are thus included in the total estimate of cover.

Percent cover provided by rocks greater than 2 mm diameter is illustrated in Figure 1 above litter and cryptogams. The apparent high degree of variability in rock cover is suspected to be due to the fluctuating vegetation cover observed over the years. Generally, rock cover varied from about 2.5 to nearly 14 percent.

Percent bare ground on the study area is summarized by treatment and years in Figure 1. The percentage of bare ground decreases with time, and generally the treatment receiving the most fertilizer (treatment 4, Figure 1d) has less bare ground than other treatments. In 1977 we observed that bare ground was about 29 percent (Brown and Johnston 1978), but in subsequent years it decreased from about 15 to less than 5 percent. These data show that fertilizer reapplications may have a positive effect on site protection, but generally the differences among treatments are variable and not significant ($p = 0.05$). The strongest variable apparently affecting bare ground is time after seeding.

Plant Density

A summary of mean plant density for all species on each treatment from 1978 to 1983 is illustrated in Figure 2. These data show that total density (number of plants per square meter) do not vary significantly with treatment or year ($p = 0.05$). Total plant density decreased slightly from 1979 through 1981, and then increased again in 1982 and 1983, but these differences were small. The very high density shown in treatment 2 for 1980 is an apparent error in the data and should be considered with caution. We attempted to record the density of seedlings and mature plants separately that year, hence, some confusion by crew members may have resulted in large errors. However, the data from the other treatments do not reflect this in 1980. Interestingly, the 1977 plant density (Brown and Johnston 1978) was found to average 399 plants / m^2, only slightly higher than that found in succeeding years.

Generally, the total density on all four treatments is composed of five species out of the seven originally seeded on the area. All four treatments had about the same species composition in 1983, regardless of the fertilizer applications used. These five species, in order of decreasing density, include: *Deschampsia caespitosa*, *Poa alpina*, *Phleum alpinum*, *Agropyron trachycaulum*, and *Trisetum spicatum*. The other two species performed poorly: *Agropyron scribneri* has never been encountered, and *Carex paysonis* has been detected only rarely. Other species have invaded the area from surrounding plant communities, but none of them are abundant. Of the five major species on the area, none shows a significant treatment, time, or interaction effect ($p = 0.05$).

Above-ground Production (Standing Crop)

Figure 3 summarizes the results of total dry-weight production of plants in g/m^2 (1 g/m^2 = 8.9 lbs/ac = 10 kg/ha) for each treatment by

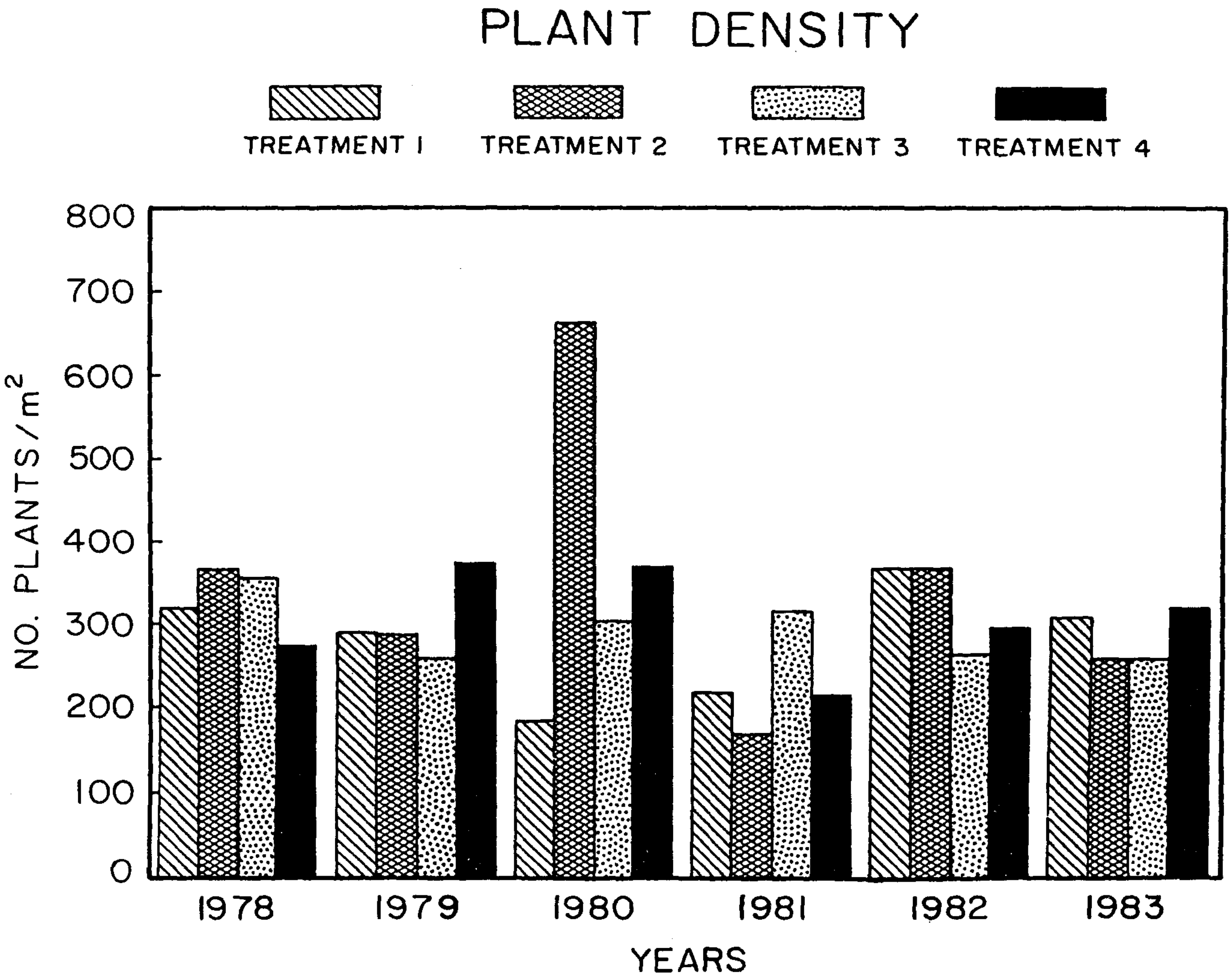

Figure 2. Summary of total plant density (number of plants per m^2) for the four treatments from 1978 to 1983.

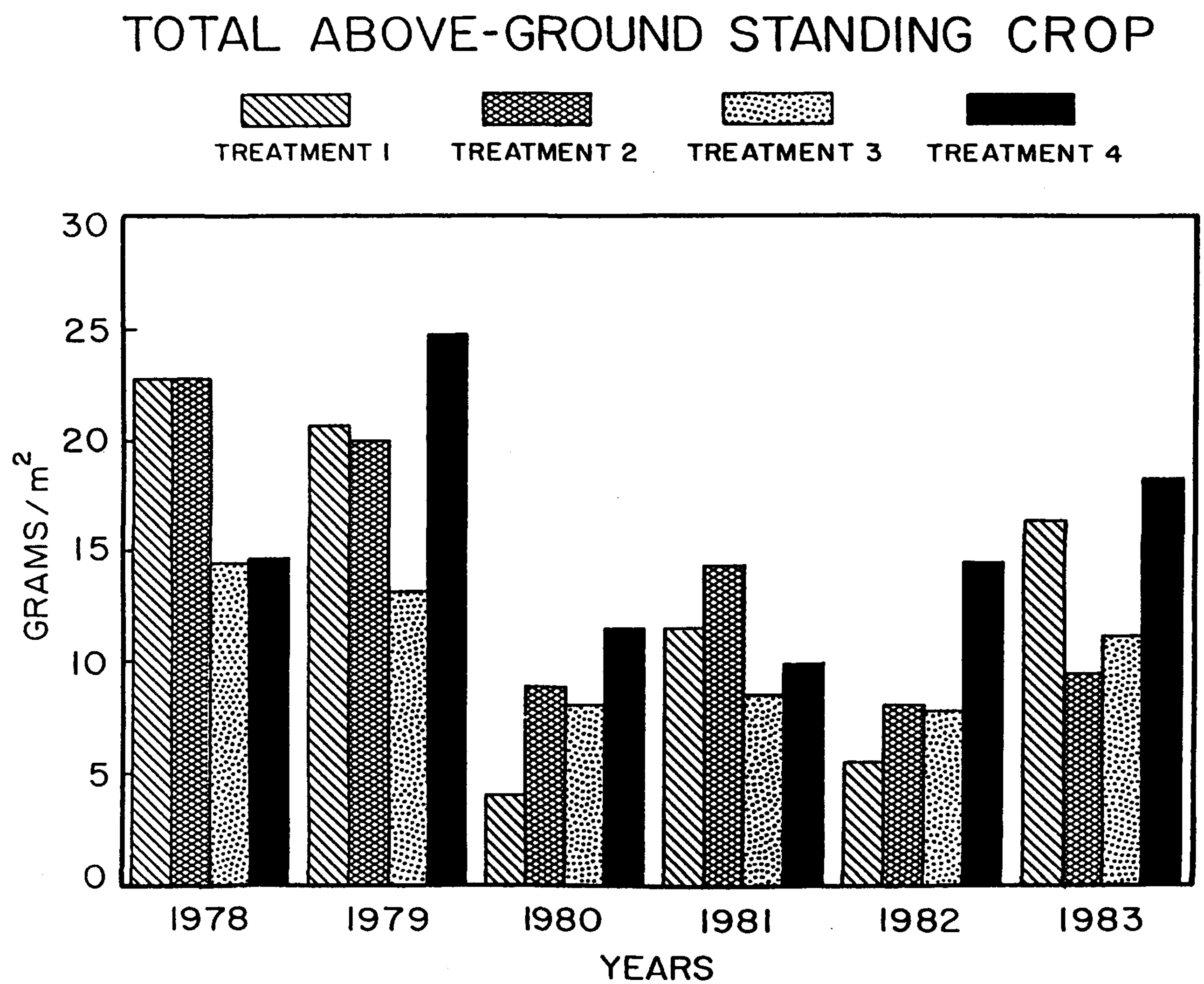

Figure 3. Summary of total above-ground plant production (standing crop) expressed as g/m^2 for the four treatments from 1978 to 1983.

year. A similar trend as was noted for vegetation cover was observed for total vegetation production. Production of shoot material decreased from 1978 through 1982 and then increased slightly in 1983. Also, treatment 4 had slightly higher levels of above-ground production than the other areas, but not in all years. From the study design, one would expect that treatment 1 would have a lower standing crop than the other areas following its removal from the refertilization scheme, but from Figure 3 and the analysis of variance it is evident this response was not consistently observed. As with the other variables measured on the area, standing crop appears to be influenced by yearly fluctuations in climate and site variability more than by the applied fertilizer treatments.

Although not illustrated, above-ground standing crop of individual species (collected from 1981 to 1983 only) shows results similar to total standing crop. *Deschampsia caespitosa* had consistently higher levels of standing crop in all 3 years and on all four treatments than the other species, comprising about 70 percent of the total production on all treatments. *Poa alpina* and *Phleum alpinum* together usually comprised between 10 and 20 percent of the total standing crop on the four treatments, with other species making up the difference. These figures are not surprising considering the rates of seeding used in 1976 (Table 1). The order of decreasing standing crop for the various species is almost identical to that shown above for plant density. Also, treatment 4 had higher levels of standing crop for each species than other treatments, but these results were highly variable and statistically insignificant ($p = 0.05$). Strong shifts in species production from year to year and on the various treatments are difficult to explain, but appear to reflect the effects of climate and sampling procedure.

Of particular concern is the apparent slow rate of change in species composition on the demonstration area as a whole. We expected that after seven full growing seasons a shift in total resource consumption would occur, with later successional species beginning to invade and compete more vigorously with the early seral species that were originally seeded on the area. However, it appears that these early seral species are more firmly established than expected, and that enrichment of species diversity will require longer periods of time than anticipated. We may have influenced this pattern by applying high rates of fertilizer for so many years following seeding, which may have favored the early seral species over further successional development.

Below-ground Production (Standing Crop)

Root production for all species is illustrated in Figure 4 for the four treatments from 1979 to 1983. This quantity was calculated as g/cm^3 for the total sample. Root biomass standing crop declined sharply and steadily from 1979 through 1983. The much higher levels of production in 1979 are strongly suspected to be an error in sampling, and should be considered with caution. Only three samples were collected in each treatment in 1979, whereas eight were collected in later years. These responses were totally unexpected, but may reflect the early seral nature of these alpine species. Perhaps most of the

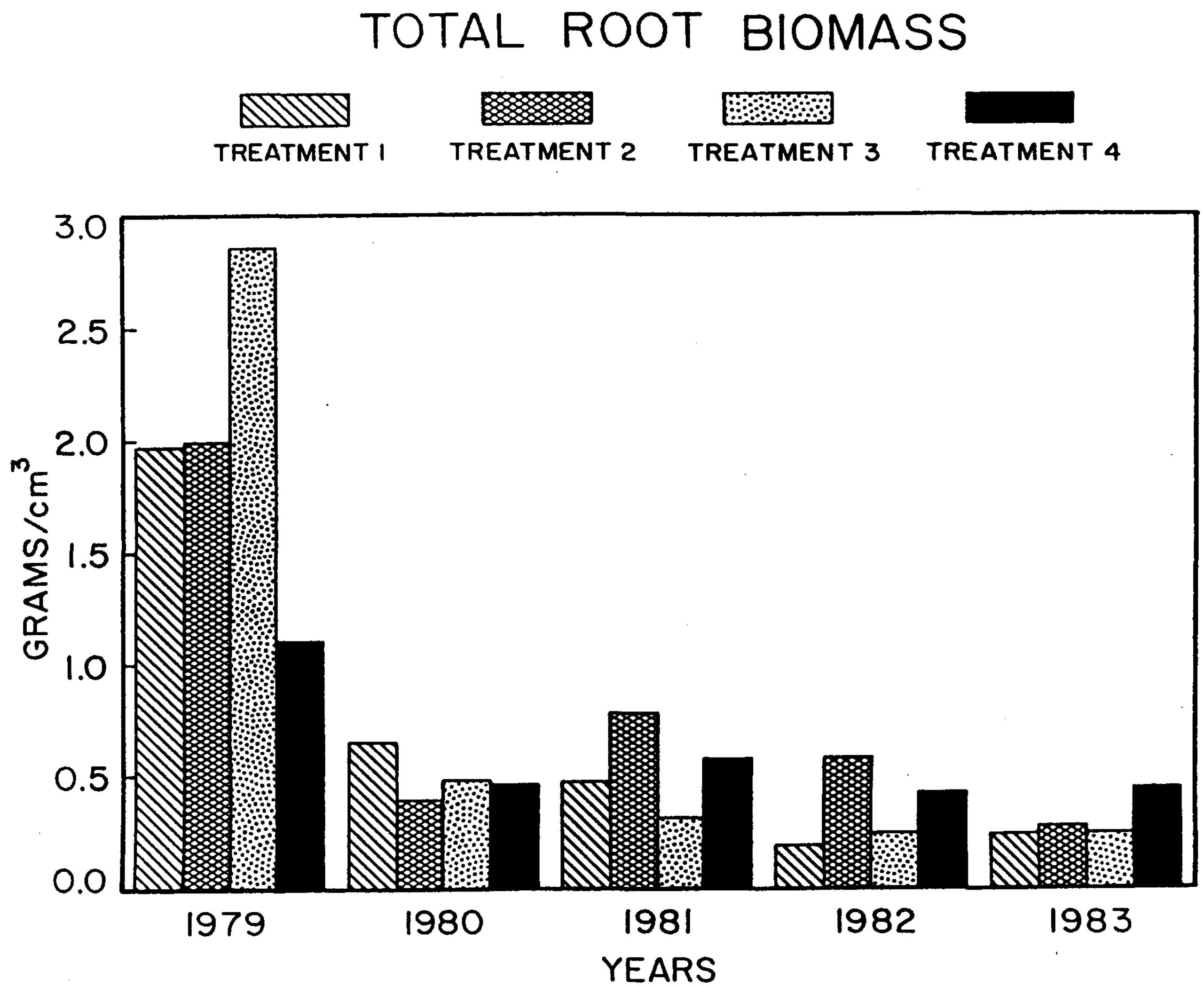

Figure 4. Summary of total root biomass expressed as g/cm^3 for the four treatments from 1979 to 1983.

growth and development of these species is directed toward shoot and reproductive tissues as maturation is reached rather than firm deep root systems.

Perhaps the most disturbing aspect about these data is that root biomass, considered as a factor of site protection, is declining while total cover and above-ground production is either stabilizing or increasing. Soil stabilization is a primary concern in revegetation, but these data indicate that it may be jeopardized at the expense of shoot growth and cover. Whether shoot growth and cover alone are sufficient to provide site stabilization in the long-term is still not known.

Sources of Error

The analyses of variance tests show significant differences among treatments for the variables studied (p = 0.05) for data collected before treatment differences were applied, but not necessarily for data after treatment refertilizations were begun. These results strongly indicate that site conditions are significantly different and that these differences masked the effects of the fertilizer treatments.

Also, the data appear to indicate strong variability in climatic conditions from year to year on the study area. When the data from any one treatment are examined over time, the variations in response are sufficiently great to suspect that precipitation, snowpack accumulation, and perhaps temperature during the growing season may influence them more than did the fertilizer treatments.

Of additional concern is the original study design that was intended to display the effects of continued refertilization. We may have waited too long after seeding (3 years) to initiate the treatments. Had the treatments been implemented in the second year after seeding, perhaps the results would have been more firmly established. We suspect that after three growing seasons the plants in all treatments were so well established that site differences and climatic variation had more effect on plant responses than any further fertilizer manipulations.

Also, we are concerned that a poor choice of fertilizer type was made in the beginning of the study. The 16-40-5 fertilizer used may have not been suitable to show marked differences in such factors as plant density, cover, and production. We feel that additional research is needed to clarify the types of fertilizer best suited for alpine plants, its application rate, and how frequently reapplications are needed to establish suitable levels of site protection and enhancement of successional development.

CONCLUSIONS

The data from this study show that site differences among the four treatment areas were sufficiently large that they masked any effect of the fertilizer treatments. Also, they suggest that climatic variables differ significantly from year to year and have a profound effect on species growth responses that may also help mask treatment effects. Observations of similar vegetation characteristics on adjacent reference areas in this and other alpine plant communities, suggest that large variation occurs routinely in plant growth responses in the alpine zone. A third possible source of variation may stem from the sampling procedure and its application from year to year. Extreme care is required not only to insure a large statistical sample, but also to insure that each sample unit is precisely collected.

Based on these data it appears that long-term refertilization of revegetation areas on acid spoils in the alpine zone is unwarranted. Cover, plant density, and production after the third growing season appeared to change more in response to site and climatic variables than to fertilizer.

Of concern relative to the practical application of these results are the apparent effects of local climatic variations on bonding restrictions imposed by State and Federal regulatory agencies. Severe climatic conditions appear to have large impacts on vegetation responses in some years, which may unfairly influence the interpretation of bond release policies. Even though the McLaren Mine demonstration area is deemed to be a highly successful revegetation effort, there are years when conditions are harsh enough to cast doubt on its stability. However, in other years the vegetation responses are more favorable, and site stability appears to be solidly established. Because we do not have the solution to this anomaly, we feel further research is needed.

The choice of fertilizer used in revegetation areas in the alpine zone appears to require more research. The influence that nutrients have on native alpine species is virtually unknown, particularly under field conditions on acid spoils. In addition, the role played by plant succession in revegetation is poorly understood. The primary objectives of revegetation, namely maximizing production and surface cover, are contrary to successional development. High seeding rates and heavy applications of fertilizer may tend to produce closed communities that resist further successional development and enrichment of species diversity. This may be particularly true in alpine environments where seedling establishment is a relatively rare event requiring specific conditions. Obviously, additional research is needed to enhance our knowledge of alpine revegetation.

ACKNOWLEDGEMENTS

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Appendix 1. Summary of means (left) and standard errors (right) of revegetation data for the McLaren Mine Demonstration Area by treatment and year. See Table 2 for explanation of treatments.

		Treatment							
Year	Variables	1		2		3		4	
1978	Cover: Percent								
	Vegetation	70.3	9.5	75.0	7.7	57.9	7.0	48.5	6.8
	Litter/Cryptogam	11.4	6.9	9.6	5.1	26.6	8.8	17.9	4.1
	Rock	5.5	2.6	4.1	1.7	4.8	2.2	10.8	2.9
	Bare ground	12.8	5.5	11.3	4.5	10.7	2.8	22.8	4.6
	Density: no./m^2	318.0	43.3	367.0	28.3	356.0	46.4	275.0	34.2
	Production: g/m^2	22.4	6.8	22.7	4.3	14.4	1.8	14.6	3.5
1979	Cover: Percent								
	Vegetation	54.0	4.3	56.0	6.6	50.4	9.6	68.2	7.4
	Litter/Cryptogam	19.3	6.0	26.5	5.9	17.6	6.8	16.1	4.9
	Rock	13.3	3.1	6.1	2.3	12.9	3.9	4.5	1.3
	Bare ground	13.4	4.2	11.4	5.1	19.1	6.7	11.2	5.1
	Density: no./m^2	291.0	43.9	290.0	44.8	260.0	38.2	375.0	35.9
	Production: g/m^2	20.6	1.4	19.9	2.3	13.1	2.7	24.7	4.2
	Root biomass: g/cm^3	2.0	0.5	2.0	0.5	2.9	1.5	1.1	0.5
1980	Cover: Percent								
	Vegetation	49.7	6.3	55.7	6.6	49.9	7.2	65.5	4.7
	Litter/Cryptogam	14.2	2.1	26.8	5.1	27.4	5.6	20.1	3.3
	Rock	12.6	4.1	7.2	1.8	7.7	3.5	7.8	3.7
	Bare ground	23.5	3.9	10.3	3.9	15.0	4.1	6.7	2.1
	Density: no./m^2	184.7	20.4	663.3	152.9	304.7	49.3	370.7	51.8
	Production: g/m^2	4.0	1.0	9.0	1.9	8.0	1.1	11.5	1.3
	Root biomass: g/cm^3	0.7	0.1	0.4	0.0	0.5	0.1	0.5	0.2
1981	Cover: Percent								
	Vegetation	38.7	4.5	50.3	6.1	37.7	4.3	57.3	5.7
	Litter/Cryptogam	35.9	4.6	32.2	6.2	48.0	5.1	29.5	4.4
	Rock	13.6	3.9	9.1	5.4	7.0	3.0	8.9	4.5
	Bare ground	11.9	4.2	8.5	3.6	7.3	2.5	4.3	1.6
	Density: no./m^2	222.0	18.2	170.7	24.2	316.6	51.1	216.7	23.2
	Production: g/m^2	11.5	1.1	14.3	1.7	8.5	0.9	10.0	1.0
	Root biomass: g/cm^3	0.5	0.1	0.8	0.2	0.3	0.2	0.6	0.2
1982	Cover: Percent								
	Vegetation	22.9	2.5	34.4	3.9	33.2	3.6	66.7	5.3
	Litter/Cryptogam	70.4	2.3	58.2	4.5	55.7	3.9	29.6	4.9
	Rock	3.7	1.0	2.8	1.2	8.4	3.1	2.7	1.9
	Bare ground	2.9	1.0	4.6	4.3	2.7	1.0	1.0	0.4
	Density: no./m^2	369.3	53.6	370.0	45.9	266.0	37.3	298.0	28.6
	Production: g/m^2	5.5	0.4	8.1	0.5	7.8	0.7	14.5	1.3
	Root biomass: g/cm^3	0.2	0.0	0.6	0.1	0.2	0.1	0.4	0.1
1983	Cover: Percent								
	Vegetation	56.9	3.5	67.5	4.2	56.7	6.5	82.0	4.4
	Litter/Cryptogam	24.8	4.0	20.6	3.4	18.0	3.5	13.0	2.8
	Rock	13.4	2.9	8.3	3.0	21.7	8.0	4.5	1.9
	Bare ground	4.9	1.2	3.7	1.8	3.6	0.9	0.5	0.4
	Density: no./m^2	311.3	34.3	262.0	42.9	261.3	49.9	323.3	45.3
	Production: g/m^2	16.4	1.7	9.5	1.2	11.2	1.4	18.3	1.9
	Root biomass: g/cm^3	0.2	0.1	0.3	0.1	0.2	0.2	0.4	0.2

Examination of Plant Successional Stages in Disturbed Alpine Ecosystems: A Method of Selecting Revegetation Species

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INTRODUCTION

A limited number of plant species have been successfully used for revegetation of alpine disturbances (Brown et al., 1978). Information concerning such plant materials is becoming increasingly important as demands on alpine ecosystems accelerate. An examination of the successional processes in these ecosystems can provide crucial insight into the selection of species for revegetation. Only a limited pool of species adapted to the extreme environment exists, and species used in alpine revegetation must necessarily be members of that pool (Eaman, 1974). The alpine flora includes few annuals (Bliss, 1962), and seldom are species successfully introduced from more temperate ecosystems (Eaman, 1974). Our concern here is with species that are capable of long-term survival and reproduction in alpine ecosystems. Therefore, our focus is on native alpine species.

We define succession as a change in species composition, or proportion of species on a plot of ground, over time following a disturbance (MacMahon, 1980). In alpine succession, early colonizing species are also members of the climax community. This type of succession has been termed autosuccession (Muller, 1952) or autogenesis. However, distinct seral stages do exist on most disturbed alpine sites, (Churchill and Hanson, 1958; Bliss, 1962), and early seral dominants are most often graminoids, although several species of the Brassicaceae and Asteraceae also appear in early seral stages (Webber and Ives, 1978). Succession in alpine ecosystems follows the same processes as those observed in more temperate ecosystems, only the changes in species and life form following disturbance are less apparent (MacMahon, 1981). MacMahon (1981) has suggested that Clements (1916) correctly categorized the major successional processes exhibited in ecosystems. Clements described the development of a "climax formation" through secondary succession as beginning with the "initiation" of a site. The processes involved depend upon the type of disturbances (nudation), the propagules remaining in the soil following disturbance, the colonizers that reach the site (migration), the success of the propagules and colonizers in establishment and growth (ecesis), and the alteration of the abiotic environment by these individuals (reaction). Clements further suggested that a "continuation" phase exists in which species compete with one another (competition) and that this results in an additional alteration of the environment. The end result of the process, the climax stage, occurs when the species on the site arrive at an equilibrium among themselves and with the environment.

The time required for the completion of succession in alpine ecosystems is largely dependent upon the type and size of disturbance. On 25- to 30-year-old nonphytotoxic disturbances in the Beartooth Mountains in Montana, successional processes range from active colonization to competition and closure of the site to new species.

Disturbances in numerous alpine areas have led us to believe that early colonizer species have many characteristics that are desirable for revegetation: they often exhibit an obvious ability to establish and grow on harsh phytotoxic sites; they frequently have large ecological amplitudes; and they are distributed over wide geographic areas. Of course, late colonizing species also have desirable characteristics for revegetation, but the desirable characteristics of the early colonizing species are immediately apparent because of their occurrence on distured sites. The frequency of occurrence and the abundance of early colonizers on disturbed sites suggest adaptations for reaching and/or surviving on disturbances that late colonizers may lack. This could involve any combination of several factors that are typical of early colonizers: (1) large and/or more consistent seed production; (2) effective seed dissemination; (3) high germination percentages; and (4) large tolerance limits for seedling establishment on disturbed sites (Harper, 1977).

White (1979) suggested that disturbances are frequently occurring events in all ecosystems and that floras have numerous disturbance-adapted species. Specialization for a certain seral stage following a disturbance may have an important role in species-isolating mechanisms and may give rise to characteristic species compositions for individual seral stages (Loucks, 1970; White 1979). Commonly occurring disturbances in alpine areas include cryopedogenic movement and frost heave, windstorms, temperature fluctuations, precipitation variability, and biotic disturbance (MacMahon, 1981; White, 1979). It is not surprising, therefore, to find a large number of disturbance-adapted species in alpine ecosystems.

Four unreclaimed alpine disturbed sites in the Beartooth Mountains of Montana were examined to identify the early colonizer species. We addressed three specific questions. Which species occurred consistently on all of the disturbed sites? Which species exhibited the greatest abundances on the disturbed sites? Which species occurred infrequently on the disturbed sites?

METHODS

Site Description

The four study sites selected had been disturbed 20 to 30 years previously, and represented a range in elevation, disturbance type, and geologic material (Fig. 1). The environmental characteristics of each site are summarized in Table 1. The McLaren Mine site, a severe mining disturbance in the upper subalpine zone, is on an intrusion of pyritic materials high in heavy metals and related chemical constituents. The Goose Lake site, similar geologically to the McLaren Mine, is also a mining disturbance, but is slightly higher in elevation than the McLaren site and

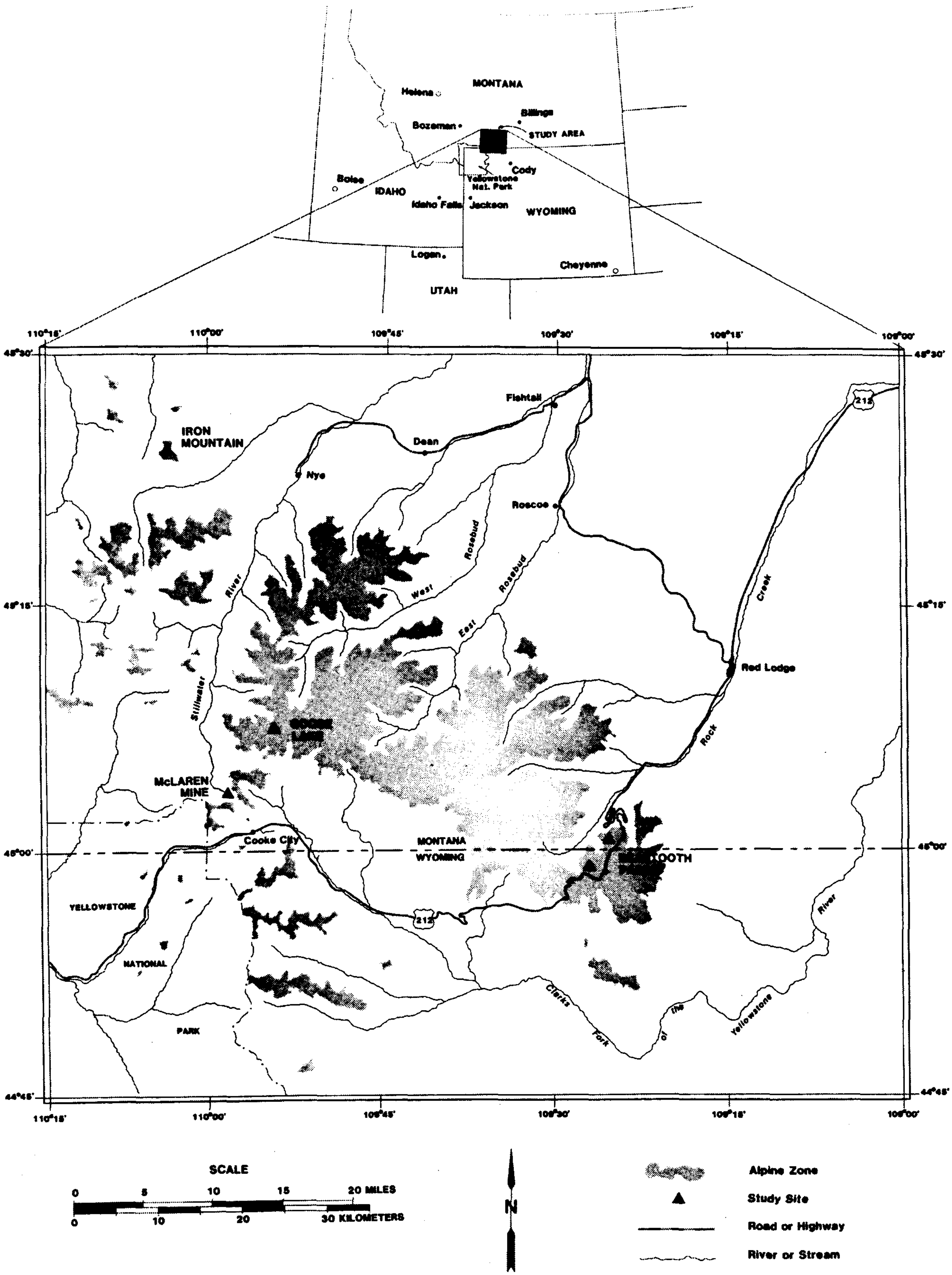

Figure 1. Location of study sites.

Table 1. Summary of Environmental Characteristics of the Four Study Sites

Site	Elevation ft (m)	Soil type	Vegetation type	Exposure
McLaren Mine	9,700 ft (2,956 m)	clay loam pH = 2.5-4.0	subalpine grass-forb krummholz	SW
Goose Lake	10,000 ft (3,047 m)	clay loam pH = 2.5-4.0	alpine forb-sedge-grass	SE
Iron Mountain	10,000 ft (3,047 m)	silt loam pH = 4.5-6.0	alpine forb-sedge-grass	SW-E
Beartooth Pass	10,350 ft (3,155 m)	sandy loam pH = 4.5-6.5	alpine forb-sedge-grass	N-E

is located in the true alpine zone. The Iron Mountain site is a mining disturbance in the alpine zone on a concentrated metal intrusion of nonpyritic materials that do not produce acid spoils. The Beartooth Pass site resulted from highway construction and is representative of disturbances in granitic materials in true alpine ecosystems. This site is characterized by gravelly subsoils that, when disturbed, exhibit lower nutrient and water-holding capacities than the soil of the area.

Sampling Methods

A complete list of colonizer species was compiled for each site. Initial species identification was made using Hitchcock and Cronquist (1973) as a reference. Voucher specimens of each species were collected and verified in the Intermountain Herbarium at Utah State University.

Estimates of relative abundance were made for each species by classifying them on a ranked scale from 1 to 3 (1 = rare, 2 = common, 3 = abundant). Although subjective, this scheme provided a rapid and reasonably quantitative method of determining the frequency expected for each species on each site. The species lists and estimated abundances for all sites were compiled from 1976 to 1980. The observations of individual species, therefore, were independent of yearly climatic fluctuation.

Data Analysis

Hierarchical cluster analysis of the ordinal or ranked species abundance data was used to determine species relationships between the four sites (Table 2). Average Euclidean distance, a dissimilarity coefficient, was used to compute the resemblance matrix, and clustering was performed using the "unweighted pair-group method using arithmetic averages" (UPGMA) (Sneath and Sokal, 1973). CLUSTAR and CLUSTID, computer programs for

Table 2. Cluster analysis of ranked relative abundance of colonizer species on four alpine disturances in the Beartooth Mountains (0 = absent, 1 = rare, 2 = common, 3 = abundant). Order was determined using Euclidean distance, a dissimilarity coefficient, and UPGMA.

Species	McLaren Mine	Goose Lake	Beartooth Highway	Iron Mtn.
Carex paysonis Clokey	3	3	3	2
Deschampsia caespitosa (L.) Beauv	3	2	2	2
Sibbaldia procumbens L.	2	2	3	1
Draba spp.	2	2	2	2
Trisetum spicatum (L.) Richter	2	2	2	2
Polygonum bistortoides Pursh	2	2	2	2
Potentilla diversifolia Lehm.	2	2	2	2
Antennaria spp.	1	2	2	2
Poa alpina L.	2	1	1	2
Phleum alpinum L.	1	1	1	1
Carex phaeocephala Piper	0	2	3	2
Arenaria obtusiloba (Rydb.) Fern.	0	2	2	2
Senecio fremontii T. & G.	2	2	2	0
Arabis spp.	2	2	2	0
Veronica wormskjoldii Roem. & Schult.	2	1	2	0
Achillea millefolium L.	2	0	1	1
Solidago multiradiata Ait.	2	0	1	1
Taraxacum spp.	2	0	1	1
Oxyria digyna (L.) Hill	2	1	1	0
Erigeron spp.	1	1	0	1
Aster alpigenus (T. & G.) A. Gray	1	0	1	1
Luzula spicata (L.) DC.	0	1	1	1
Carex nigricans C.A. Meyer	3	3	0	0
Juncus drummondii E. Meyer	3	2	0	0
Epilobium alpinum L.	3	2	0	0
Poa fendleriana (Steudel) Vasey	3	2	0	0
Arenaria rubella (Wahlenb.) J. E. Smith	3	0	0	2
Carex pyrenaica Wahlenb	0	3	2	0
Carex haydeniana Olney	0	2	2	0
Hieracium gracile Hook.	2	2	0	0
Agropyron scribneri Vasey	0	0	2	0
Silene acaulis L.	0	0	2	2
Agoseris glauca (Pursh) Raf.	2	0	2	0
Smelowskia calycina (Steph.) C.A. Meyer	0	2	1	0
Arnica longifolia D. C. Eaton	2	1	0	0
Mertensia alpina (Torr.) G. Don	0	0	2	1
Senecio canus Hook.	0	0	2	1
Poa secunda Presl.	2	0	1	0
Geum rossii (R. Br.) Ser.	0	0	1	1
Androsace septentrionalis L.	0	0	1	1
Erigeron simplex Greene	0	0	1	1
Erigeron peregrinus (Pursh) Greene	0	0	1	1

Table 2. (con.)

Species	McLaren Mine	Goose Lake	Beartooth Highway	Iron Mtn.
Pinus albicaulis Engelm.	1	0	0	1
Juncus mertensianus Bong.	3	0	0	0
Luzula parviflora (Ehrh.) Desv.	3	0	0	0
Cearastium beeringianum Cham. & Schlecht.	0	0	3	0
Senecio crassulus A. Gray	2	0	0	0
Senecio triangularis Hook.	2	0	0	0
Epilobium angustifolium L.	2	0	0	0
Poa nervosa (Hook.) Vasey	2	0	0	0
Polygonum douglasii Greene	2	0	0	0
Rumex paucifolius Nutt.	2	0	0	0
Spraguea umbellata Torr.	2	0	0	0
Lomatium cous (Wats.) Coult. & Rose	0	0	2	0
Stellaria longipes Goldie	0	0	2	0
Carex microptera Mack.	0	0	2	0
Oxytropis campestris (L.) DC.	0	0	2	0
Trifolium parryi A. Gray	0	0	2	0
Polemonium pulcherrimum Hook.	0	0	2	0
Phlox spp.	0	0	2	0
Carex albonigra Mack.	0	0	0	2
Carex scirpoidea Michx.	0	0	0	2
Lupinus argenteus Pursh	0	0	0	2
Calamagrostis purpurascens R. Br.	0	0	0	2
Arnica latifolia Bong.	1	0	0	0
Arnica rydbergii Greene	1	0	0	0
Descurainia richardsonii (Sweet) Schulz	1	0	0	0
Phyllodoce empetriformis (SW.) D. Don	1	0	0	0
Vaccinium scoparium Leiberg	1	0	0	0
Phacelia sericea (Grah.) A. Gray	1	0	0	0
Abies lasiocarpa (Hook.) Nutt.	1	0	0	0
Bromus inermis Leyss.	1	0	0	0
Deschampsia atropurpurea (Wahl.) Scheele	1	0	0	0
Poa compressa L.	1	0	0	0
Poa reflexa Vasey & Scribn.	1	0	0	0
Salix arctica Hook.	1	0	0	0
Salix monticola Bebb.	1	0	0	0
Bupleurum americanum Coult. & Rose	0	0	1	0
Artemisia scopulorum Gray	0	0	1	0
Agropyron trachycaulum (Link) Malte	0	0	1	0
Poa pattersonii Vasey	0	0	1	0
Poa rupicola Nash	0	0	1	0
Polemonium viscosum Nutt.	0	0	1	0
Lewisia pygmaea (Gray) Robins	0	0	1	0
Castilleja pulchella Rydb.	0	0	1	0
Erigeron compositus Pursh	0	0	0	1
Lloydia serotina (L.) Sweet	0	0	0	1
Poa interior Rydb.	0	0	0	1
Dryas octopetala L.	0	0	0	1

hierarchical cluster analysis, were used for all computations (Marshall and Romesburg, 1981). Final ordering of the data was performed manually and is from highest to lowest abundance and from maximum to minimum similarity between sites.

RESULTS AND DISCUSSION

Ordering of the colonizer species according to their relative abundance and frequency of occurrence on the four disturbed sites (Table 2) allows a generalized interpretation of the types of adaptations of the individual species and of their successional role. Species that occurred on three or four sites, with an abundance rating of "common" on two or more of those sites, have many of the attributes classically ascribed to early colonizer species, including a wide geographic distribution and large ecological amplitude. Carex paysonis, Deschampsia caespitosa, and Sibbaldia procumbens are examples. Species that occurred on two sites with similar edaphic or environmental characteristics may have similar growth requirements or tolerance limits. For example, species that occur on both the McLaren Mine and Goose Lake sites may exhibit a tolerance to acidic soils. Similarly, species that occur only on the Beartooth Pass and Iron Mountain sites may not be able to tolerate acidic soils. Species found on only one or even two sites may also require the specific edaphic or environmental conditions that exist on that site. However, an alternative explanation is that these species represent differences in the vegetation types that surround individual disturbed sites. The McLaren Mine, for example, consists of a transition zone between subalpine and alpine ecosystems, and many of the colonizer species, such as Arnica latifolia and Vaccinium scoparium are subalpine in origin. These species, therefore, are not found on the other three disturbances that are true alpine sites.

In interpreting species occurrences on disturbed sites, it should be remembered that a species' or an individual's presence on a site is dependent on the ability of the propagules to reach the site and on the ability of the propagules to establish and survive. The ability of the rarer species in a flora to reach a disturbed site is often dependent upon chance, and the presence of a species on a site may not be a function of its ability to survive on the site but of its propagules to reach the site.

Based on this study, it appears that certain species occur consistently and in relatively high abundances on alpine disturbed sites. Johnson and Billings (1962) found many of these species to be persistent if relatively minor components of late successional alpine ecosystems in the Beartooth Mountains. This first category, then, we propose to call early seral dominants. This includeds all of the species that occurred in relatively high abundance on three or four of the disturbed study sites. The most obvious examples of this category include Carex paysonis, Deschampsia caespitosa, Sibbaldia procumbens, Trisetum spicatum, Polygonum bistortoides, and Potentilla diversifolia.

Late seral dominants, the second category, are those species that comprise a major component of late successional ecosystems but that also occur as colonizing species on disturbed sites. Late seral dominants are most often colonizers on sites that have the proper edaphic characteristics and that are close to the seed source. Examples of late seral dominants are Geum rossii and Artemisia scopulorum.

Species that are a rare, but persistent, component of late successional ecosystems and that occasionally exist as colonizers on disturbed sites, we classify simply as rare. The majority of the species on the bottom of Table 2 could be placed in this third category.

A few notable exceptions to these three proposed categories exist. Deschampsia caespitosa has been described here as an early seral dominant. However, Johnson and Billings (1962) found it to be the major component of the Deschampsia meadow vegetation type. Depending upon the individual ecosystem, D. caespitoa may exist either as an early or late seral dominant. A second exception is those species that inhabit extremely harsh sites. All alpine species are adapted to low temperatures, but those found on ridges and open fell-fields exhibit even higher tolerances to drought and low temperature (Billings and Mooney, 1968). On sites that have these conditions, only a few species can survive, and there is no species replacement over time (del Moral, 1983).

Classification of species as early or late seral dominants or rare greatly facilitates a discussion of the use of alpine species for revegetation. Use of the three successional categories involves interpretation of the characteristics of the species in each category and of the type of disturbance to be revegetated. Early seral dominant species are probably better suited to more types of disturbances than either late seral dominant or rare species because of their large ecological amplitude and widespread geographic distribution. Establishment trials and revegetation efforts have concentrated on early seral dominants (Brown et al., 1978; Brown and Johnston, 1979; Selner and King, 1977). Early seral dominant grasses (D. caespitosa, T. spicatum, Poa alpina, Phleum alpinum) have been successfully used in revegetation trials on all disturbed sites in this study (Brown and Johnston, unpublished data). However, depending upon the management goals for a particular area, late seral dominant and rare species are potentially valuable revegetation species. Inclusion of these species in the seed mixture may increase both the species diversity and structural diversity of a site. It may also be possible to accelerate the rate of succession on a revegetated site that includes late seral dominants and rare species.

Only a small number of late seral dominant and rare species have been evaluated in actual alpine revegetation trials. That these species usually occur in low abundances on disturbed sites and in localized areas suggests that their use may be restricted to specific edaphic or environmental conditions. Late seral dominants and rare species potentially could be used on those types of disturbed sites where they have been observed to establish as early colonizers.

Until we have more specific information about the ability of late colonizer and rare species to establish on phytotoxic and/or acidic spoil and to respond to standard revegetation treatments, early seral dominants will most frequently be the best choice for revegetation. However, certain early seral dominants may have specific requirements for establishment. For example, Carex paysonis, a highly abundant early seral dominant requires light for germination and can not be established using standard revegetation procedures in which the seeds are buried beneath the soil surface (Haggas et al., 1983).

RESEARCH NEEDS

An assessment of species occurrences on disturbed alpine sites is an initial step in the selection of species for alpine revegetation. Revegetation research is still needed on early seral dominant forbs and late seral dominant species. Specifically, ease of establishment, tolerance limits for various types of disturbances, and ecological amplitudes of the different types of species need to be determined. Once this information has been obtained, the interactions of the species when planted in mixtures will need to be examined.

Increasing our knowledge of the characteristics of individual species and of species interactions could help us select the optimal mixture of species for reclaiming specific types of disturbances. It could also help us increase species diversity in alpine revegetation efforts, and possibly, enhance natural successional processes.

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ASPEN MANAGEMENT ON THE NATIONAL FORESTS IN COLORADO

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Aspen (Populus tremuloides Michx.) is the most widely distributed tree species in North America (Folwells, 1965). Throughout its natural range, aspen grows under a wide variety of climatic conditions and occurs on a great variety of sites. In the East, its distribution is relatively continous; in the West it is discontinous and is restricted to relatively moist sites on mountains and high plateaus. On most sites throughout its natural range aspen is considered as seral to conifers. It is a pioneer species that invades sites that have been drastically disturbed, such as after fire or clearcutting. Maximum biomass production usually occurs between 50 and 100 years after stand establishment (DeByle, 1981). Aspen grows very rapidly and is considered to be mature at 70 to 100 years in the Lake States (Perala, 1977) and at slightly older ages in the West. If left undisturbed, these aspen stands will be replaced by longer-lived and more stable plant communities (DeByle, 1981). In the West, seral aspen stands may be replaced by conifers beginning as early as 50 to 120 years after initial stand establishment. Some stands of aspen in the West are considered to be stable. In these stands, aspen will regenerate itself through more than one generation. A few stands are considered to be decadent, and aspen in these stands will not regenerate itself nor be replaced by conifers, but will be replaced by brush, forbs, or grasses (Harnis, 1981).

In the West, aspen stands can be managed for multiple-uses including forage, recreation, water, wildlife habitat, and wood (DeByle, 1981). Succession of all aspen stands to conifers is undesirable because the aspen contribute significantly to species diversity. The interconnected root systems of aspen clones help stabilize the soil and reduce erosion. Because they are less susceptible to fire damage than conifers they form natural firebreaks in extensive conifer forests. New aspen shoots are a nutritious food source for big game, as well as, nongame wildlife species. Diversity of wildlife is ensured with aspen as a component of the forests and over 100 species of vertebrate wildlife species utilize the aspen for feeding, nesting, and cover during some time of the year (Shields, 1981). Vegetation under aspen stands provides valuable forage for cattle and sheep and six times more forage is produced in an aspen stand than in a mixed conifer stand. The aspen also provide numerous opportunities for recreation, and the esthetic value is extremely important to both Coloradans and the visitor alike.

In the Rocky Mountains aspen is not currently being utilized to a great extent as a wood source. Most management of aspen in this area emphasizes esthetics, forage production, recreation, and wildlife (Shepperd and Engelby, 1983). Effective management of the aspen resource in Colorado for all of these uses has been prevented because of tradition, the relative low dollar value of its wood products, its inaccessability in many areas, and because of the relative lack of markets for aspen products.

PRESENT SITUATION

The Rocky Mountain aspen forest cover type occupies about 4 million acres of commercial forest land in eight Rocky Mountains states (Shepperd and Engelby, 1983). About 2 million acres of aspen currently exist on nonwilderness National Forest lands in Colorado and Wyoming (Table 1). Of this total only three percent (67,273 acres) occurs in Wyoming, while 97 percent (1,929,412 acres) occurs in Colorado. About 28 percent of the aspen in Colorado occurs on the National Forests on the front range while 72 percent is found on west slope Forests. The Arapaho and Roosevelt National Forests on the front range has the fewest acres (91,378) and lowest percentage (5 percent) of forest lands in aspen. In comparison, the Grand Mesa, Uncompahgre, and Gunnison National Forests on the west slope have the greatest acreage (629,453 acres) in aspen. Table 1 shows a preponderance (42 percent) of 80 to 160 year old aspen on the National Forests in Colorado. The majority of these stands are considered to be seral, but until research by the Rocky Mountain Forest and Range Experiment Station on habitat classification (Hoffman and Alexander, 1983) has been completed we will not know the percentage of aspen stands that are seral, climax, or decadent.

Because of the abundance of seral aspen stands in the mature to overmature age classes, many of these stands are in need of treatment if they are to be retained in aspen and to increase the age distribution of the aspen stands. Ultimately, the acreage of aspen desired in each age class will be determined by individual Forest land management objectives.

As a typical aspen stand develops, its shade will inhibit new aspen shoots from developing. Generally aspen is intolerant of shade and requires full sunlight to grow. Shady conditions, however, are favorable to fir and spruce development and these conifers often become established under the aspen and take over when the existing aspen shoots die. Although aspen occassionally reproduces by natural seeding, Rocky Mountain aspen reproduces almost exclusively by suckering, whereby a number of stems are reproduced asexually by sprouting from a single parent root system to form a clone (Shepperd and Engelby, 1983). This usually happens when the original parent shoots are destroyed which usually occurs as a result of fires or cutting. When a portion of the shoots in a clone are destroyed, the root system will support the remaining portion of the shoots. Regeneration of the destroyed portion of the clone will be much less than if the entire clone had been destroyed. Consequently, when aspen

Table 1 - Aspen on National Forest Lands in Colorado and Wyoming

(Nonwilderness lands)

Average Tree Size (inches, DBH)	Average Age (years)	Colorado Total (acres)	Wyoming Total (acres)	CO and WY Total (acres)
1 - 5	10 - 80	338,713	31,500	370,213
5 - 9	60 - 120	768,007	16,504	784,511
9+	80 - 160	822,692	19,269	841,961
	TOTAL	1,929,412	67,273	1,996,685

are to be regenerated they are usually treated by clearcutting or fire to regenerate the entire clone or stand of aspen.

National Forsts in the Rocky Mountain Region have been treating between 1500 and 2000 acres of aspen annually for the last 5-10 years. These treatments have yielded about 9 million board feet of forest products annually. Most of the treatment has been on the San Juan National Forest through commercial timber sales. Since 1948, the San Juan has cut aspen regularly and studies of aspen regeneration on two-to 20-acre clearcut blocks have indicated that sprouting was adequate to perpetuate the aspen (Crouch, 1983). The remainder of the treatments have been carried out on other National Forests and these treatments have been accomplished through timber sales, firewood, and wildlife programs.

Aspen can be used for a wide variety of products such as lumber, veneer, paneling, and pulp. In Colorado, however, where the aspen is generally less than nine inches in diameter at breast height, aspen markets have been relatively small in scale and specialize in small wood products such as match sticks, excelsior, and shakes. Although the uses of apsen from Colorado are restricted by the size, decay rate, and high moisture content of the tree, new uses are constantly being developed, including waferboard.

In 1983, the Louisiana-Pacific Company announced that it was interested in developing a commercial outlet for waferboard constructed from aspen and wood waste from conventional sawmills. Development of this market would provide the opportunity to accomplish part of our land management objectives relative to managing stands of aspen.

FUTURE MANAGEMENT

The Rocky Mountain Region of the USDA Forest Service will be expanding its aspen program five to six fold, beginning in fiscal year 1984. This will result in the treatment of 10-12 thousand acres and a volume of aspen timber offered of approximately 70 million board feet annually. Most of these activities will be accomplished through the commercial timber sale program. The Louisiana-Pacific Company is currently building a waferboard plant at Kremmling and is planning on construction of another plant at Olathe, Colorado, in the near future. Each plant may utilize up to 25-30 million board feet of aspen annually in the production of waferboard. Because of these needs, it is anticipated that Louisiana-Pacific will compete for timber sales offering aspen. The Rocky Mountain Region's expansion of aspen sales will be located primarily on the Routt, Grand Mesa, Uncompahgre, and Gunnison National Forests. These are the Forests that have the greatest acreages of aspen (Table 1) and are most in need of treatment. There will also be additional opportunities to treat aspen on these and other National Forests through our firewood and wildlife programs.

The increased market for aspen that will be provided by Louisiana-Pacific is not being utilized solely to increase our timber sales, but as an opportunity to increase our treatment of aspen on a more efficient and economically sound basis. The aspen on National Forests in Colorado will continue to be managed for multiple-use purposes including forage, recreation, water, wildlife, and wood. Our field experience and research conducted by the Rocky Mountain Forest Experiment Station has indicated that we can manage aspen with a minimum of adverse effects and provide benefits to all of these resources.

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