Abandoned Coal Mined-Land Research Program
Project Review Seminar

Fifteenth Project Review Seminar

Casper College, Casper. WY

November 20, 2003

The seminar series is sponsored jointly by the University of Wyoming, Office of Research and the Abandoned Mine Lands Program of the Wyoming Department of Environmental Quality.

Fifteenth Annual ACMLRP Project Review Seminar
Casper College in the Student College Center CE 217, Casper, Wyoming
Thursday, November 20, 2003, 9:45 a.m. - 4:30 p.m

All presentations will be open to the public and there is no charge for participation in the Seminar. The agenda will include a brief review and discussion of the progress that has been made to date on each of these projects with time for questions and answers.

The ACMLRP is designed to support projects, which can aid in the development of practical solutions to some of the concerns that face the State and the Nation with respect to reclamation of coalmines. The projects were selected in open competition.

The seminar series is sponsored jointly by the University of Wyoming Office of Research and the Land Quality Division of the Wyoming Department of Environmental Quality. If you would like to have further information about this seminar series or if you would like to be placed on the mailing list to receive information about the ACMLRP, please call the Office of Research at 307/766-5353 or 766-5320.

Fifteenth Annual ACMLRP Project Review Seminar
Casper College in the Student College Center CE 217, Casper, Wyoming
Thursday, November 20, 2003,

9:45-10:10	**The Effects of Varying Topsoil Replacement Depth on Various Plant Parameters within Reclaimed Areas** **Brenda Schladweiler, Larry Munn, Rose Haroian, Scott Belden**	**Final**	**1**
10:15-10:40	**Relationship of soil organic matter content and sustainable nutrient cycling in reclaimed soils** Peter Stahl, Gerald Schuman, **Lachlan Ingram**, Lowell Spackman	**Final**	**2**
10:45-11:10	**Effects of Variable Topsoil Replacement Depth on Plant Community Development and Soil Ecosystem Development after 24 Years** C.K Bowen, **G.E. Schuman**, R.A. Olson and L.J. Ingram	**Final**	**3**
11:15-11:45	**Evaluate the Effect Detonated Borehole Pressures Have on Adjacent Powder Columns and how that Contributes to Nitrogen Oxide Formation in Cast Blasting** **Charlie Barnhart**	**Interim**	**4**
12:00-1:15	**Lunch break**		
1:20-1:45	**The influence of reclamation management practices on carbon accumulation and soil fertility on coal mine lands in Wyoming** **Peter Stahl**, George Vance, Lachlan Ingram, Snehelata Huzurbazar, Carol Bilbrough	**Interim**	**5**
1:50-2:15	**Impacts of Wildlife Utilization on Big Sagebrush Survival in Reclaimed Mine Lands** Kristene Partlow, **Richard Olson**, and Gerald Schuman	**Final**	**6**
2:20-2:45	**Ecology of the greater sage-grouse in the coal mining landscape of Wyoming's Powder River Basin** Kort Clayton, **Kimberley Brown**	**Final**	**7**
2:45-3:00	**Break**		
3:00-3:25	**Evaluation and Comparison of Hypothesis Testing Techniques for Bond Release Applications** **Carol Bilbrough,** Shay Howlin, Lyman McDonald,	**Final**	**8**
3:30-3:55	**The Effects of Seed Mix Species Composition and Seedling Rates on Attaining Species Diversity for Reclaimed Areas** Lyman McDonald, Shay Howlin, Beth Lack, **Carol Bilbrough**	**Interim**	**9**

THE EFFECTS OF VARYING TOPSOIL REPLACEMENT DEPTH ON VARIOUS PLANT PARAMETERS WITHIN RECLAIMED AREAS

Final Report

Submitted to:
The University of Wyoming Research Office
on behalf of the
Wyoming Abandoned Mined Land Program

Submitted by:
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INTRODUCTION

A project was initiated in 1998 to investigate the effect of varying topsoil depths on various soil and plant parameters on a coal mine in northeastern Wyoming. Soil and vegetation information was collected from 2000 through 2002. Reclaimed treatments included three replacement topsoil depths (15, 30 and 56 cm). Slope positions within two native reference areas were assumed to be reclaimed treatment comparisons. Dependent variables included pH, electrical conductivity (EC), sodium adsorption ratio (SAR), total cover, total vegetation cover, total number of species and average number of species (based on cover sampling) and above-ground production.

METHODOLOGY

Refer to previous AML summary reports for a description of methodology.

RESULTS

Soils

The pH of the 0-15 cm topsoil depth within the 15 cm reclaimed treatment was significantly higher than it was in either the 30 or 56 cm reclaimed treatments in 2001, but the narrow range of pH values may limit the biological significance of these results. The EC of the 0-15 cm topsoil depth within the 15 cm reclaimed treatment was significantly lower than it was in the 56 cm reclaimed treatment in 2000. EC and SAR were significantly higher at the 30-45 cm depth in the 30 cm reclaimed treatment in 2001-2002, compared to the 56 cm reclaimed treatment. This difference occurred in the 30 cm reclaimed because the sample represented backfill compared to topsoil in the 56 cm treatment.

Reduced EC was noted in backfill below the 15 cm reclaimed treatment in 2001 as compared to the 30 cm treatment. The EC of the backfill below the 56 cm reclaimed treatment was intermediate to the other two treatments and not significantly different to either. Several factors could be responsible for these results including mixing of the topsoil in the shallow 15 cm treatment with the underlying backfill during tillage operations, which is not a concern in areas of suitable backfill that lack inhibiting plant growth parameters.

While replaced topsoil depths on reclaimed areas deviated somewhat from designated treatment levels, control depths varied considerably, from what was considered to be the topsoil depths of 15, 30 and 56 cm, on the native areas (Upland Grass and Breaks Grass). This severely limited direct statistical comparison. Comparison of the reclaimed area to the native reference areas suggested numerous differences. Data from 2000, 2001 and 2002 indicated that soil pH, EC and SAR were significantly higher in the upper 30 cm of the replaced soil profile than in the comparable upper 30 cm depth of undisturbed soils in the native reference areas, with the exception of SAR in 2002. Results from 2002 indicated a slight reduction in pH, EC and SAR within the upper 15 cm depth in the reclaimed topsoil treatments with a general increase of EC and SAR in the lower portion of the replaced soil profile. Some differences at depth may have resulted from inclusion of backfill under the reclaimed area treatments, as well as inclusion of paralithic material within the native areas since the bottom of the undisturbed profiles may have been less than the designated treatment comparisons.

No significant gradient of pH, EC and SAR existed on the reclaimed topsoil treatments within this study primarily due to mixing of the original soil profile during topsoil salvage, stockpiling and replacement operations. Some influence is also due to backfill intervals beneath some topsoil replacement treatments being compared to remaining topsoil within other treatments. Inherent gradients for soil pH, EC and SAR were, however, evident on native areas.

Overall lack of topsoil replacement treatment differences may partially be explained by the young age of the reclaimed area, i.e., seeded in 1999, and reduced precipitation over the study time period. Some downward movement of soluble salts within the reclaimed treatments was evident despite low precipitation. In 2002, the 0-30 cm portion of the reclaimed soil profile had reduced pH and EC from 2001 while the 30-60 cm portion increased in EC and SAR. It is anticipated that soil quality differences in terms of pH, EC and SAR between topsoil depth treatments will change with time.

Rill erosion was more common on the 15 cm than the 30 cm topsoil reclaimed treatment depth areas. If erosion is not likely to occur, such as on ridgetops or flat areas, shallow replacement depths could be employed.

Vegetation

Despite the young age of the reclaimed area, differences in vegetation parameters were noted between treatments. However, treatments need to be monitored over time to identify long-term results.

Higher total vegetation canopy cover and above-ground production was achieved at the deeper topsoil replacement depths, but the deeper depths tended to suppress plant diversity. Species richness (average number of species per cover transect) was significantly higher in the 30 cm reclaimed treatment than the 15 and 56 cm topsoil treatments in 2000-2002. The highest total number of species encountered based on canopy cover and above-ground production sampling was in the 30 cm reclaimed treatment, many of which were desirable seeded and volunteer PG and PF. Species richness included AF and AG, but these species were reduced in number and abundance, with the exception of fireweed summercypress (*Kochia scoparia* (L.) Schrad.), due to drought conditions during the study time period. Alternatively, total vegetation cover on the 56 cm reclaimed treatment was significantly greater than the 15 cm treatment, while the 30 cm treatment was intermediate and not significantly different from either. In 2002, more newly germinated Wyoming big sagebrush seedlings were noted in the 15 cm reclaimed treatment than the 30 or 56 cm reclaimed topsoil depth treatments due to more bare ground in the shallow topsoil treatment. Comparison of the current study area to a 1991 reclaimed area indicated a consistent general pattern of species establishment.

Above-ground production was higher in the reclaimed area than the two native reference areas, while total cover and total vegetation canopy cover were lower. CSPG canopy cover was dominant in the reclaimed area for 2000-2002. Absolute cover of WSPG and HS, as well as relative cover of HS, were significantly higher in the native reference areas.

Shannon-Wiener diversity H' indices for absolute total vegetation canopy cover were between 1 and 3 and differed significantly between the reclaimed, Upland Grass and Breaks Grass sites in 2000 and 2001. The 2002 reclaimed and Upland Grass sites were

significantly more diverse than the Breaks Grass native reference area. Shannon-Wiener H' values in 2001, based on total vegetation canopy cover, were significantly greater in the 30 cm reclaimed treatment. Shannon-Wiener H' values in 2000 and 2002, based on total vegetation canopy cover, were also greater in the 30 cm reclaimed treatment, though not significant. Various other indices were examined, but Shannon-Wiener was the only diversity index statistically evaluated based on 2000-2002 cover and 2002 production data. The generalized Shannon-Wiener index for the combined reclaimed treatments compared to the current permitted topsoil replacement depth treatment of 56 cm was always higher, which indicates that the use of a mosaic of topsoil replacement depths enhances the overall diversity of a landscape feature. The evenness of the vegetation pattern, based on Shannon-Wiener calculations, was not significantly different between reclaimed area treatments and was lower than the two native reference area sites in 2000 and 2001.

In summary, from the following observations made at NARM, a mosaic of different topsoil depths, including the shallow 15 and 30 cm depths as well as the mandated 56 cm depth, creates the broadest range of vegetation response under a standard regime of revegetation practices.

- Average number of species was significantly higher in the 30 cm reclaimed treatment than the 15 and 56 cm topsoil treatments in 2000-2002.
- The highest total number of species encountered based on canopy cover and above-ground production sampling was in the 30 cm reclaimed treatment compared to the 15 and 56 cm treatments, many of which were desirable seeded perennial grasses and forbs, as well as volunteer perennial species.
- Shannon-Wiener H' values by treatment, based on total vegetation cover, were significantly highest in the 30 cm reclaimed treatment in 2001 and greater, though not significant, in 2000 and 2002.
- Total vegetation cover on the 30 cm reclaimed treatment was intermediate to the significantly different 15 and 56 cm reclaimed treatments in 2001.
- On a landscape basis, a mosaic of variable topsoil depths that included the 15 and 30 cm replacement depths, collectively provided generally higher diversity than the 56 cm replacement depth mandated in the reclamation plan.
- More newly germinated Wyoming big sagebrush seedlings were noted in the 15 cm reclaimed treatment than the 30 cm or 56 cm reclaimed topsoil depth treatments due to more bare ground in the shallow topsoil treatment.

SUMMARY

Results over the three year study indicated a slight reduction in pH, EC and SAR within the upper 15 cm depth in the reclaimed topsoil treatments with a general increase of EC and SAR in the lower portion of the replaced soil profile. Reduced EC was noted in the backfill below the 15 cm reclaimed treatment in 2001. Soil pH, EC and SAR were significantly higher in the upper 30 cm of the reclaimed soil profile than the native reference areas. Inherent pH, EC and SAR gradients in the native profiles were not present in the reclaimed treatments.

Species richness was highest in the 30 cm reclaimed treatment and, overall, there was an increased number of perennial forbs in the 30 cm reclaimed treatment. Shannon-Wiener index (H') values in 2001 by treatment were significantly greater in the 30 cm reclaimed treatment. On a landscape basis, a mosaic of variable topsoil depths, collectively provided generally higher diversity than the 56 cm permitted replacement depth. Total vegetation cover on the 56 cm reclaimed treatment was significantly greater than the 15 cm treatment. Production on the reclaimed area exceeded the two native reference areas after three years of growth.

In summary, from the following observations made at the North Antelope/Rochelle Mine (NARM), a mosaic of different topsoil depths, including the shallow 15 and 30 cm depths, creates the broadest range of vegetation response under a standard regime of revegetation practices. A limited number of treatment differences may be a manifestation of the low overall precipitation conditions, relatively young age of the reclaimed area and lack of levels of pH, EC and SAR detrimental to plant growth in the backfill.

Every effort should be made to provide opportunity for diversification within a reclaimed plant community, as well as between communities and on a landscape scale. Without flexibility in topsoil replacement depths, seedbed preparation and seeding innovation, aggressive CSPG tend to dominate the landscape and will not encourage diversification of lifeforms.

Some flexibility must be written into the regulatory system that allows site specific innovation by the operator. Variances should be allowed for operators to reflect natural topsoil placement on sloped areas not prone to erosion or areas with limited replacement topsoil availability. For the operator, it may mean: 1) more detailed classification and definitions of suitable topsoil; 2) more mine planning to accommodate topsoil movement and storage, where needed; and 3) monitoring of reclaimed areas to ensure excess erosion is minimized while maximizing the potential for plant diversity. As with mining operations in other states, opportunity for variations in backfill placement should also be considered as a tool for ultimate diversification.

ACKNOWLEDGMENTS

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NOTE: For more detailed results of project findings, please refer to the final report for the project, the "Effects of Varying Topsoil Replacement Depth on Various Plant Parameters Within Reclaimed Areas".

AML Progress Report

Relationship Between Soil Organic Matter Content and Sustainable Nutrient Cycling in Reclaimed Soils

Final Report

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Introduction

An important aim of mine site reclamation is to ensure that the "reconstructed" ecosystem is self-sustaining, requiring minimal and preferably no additional inputs. It is therefore critical that soils used in mine reclamation are able to provide sufficient quantities of nutrients for plant uptake. Many of the nutrients required for plant uptake, in particular nitrogen (N), are found predominantly in soil organic matter (SOM). Equally important is the large mass of carbon (C) found in SOM, which provides the chemical energy to sustain microbial populations. Microbial decomposition of this SOM makes nutrients available for plant uptake.

The aim of this project is to determine the minimum amount of soil organic C (as a proxy for SOM) in replaced topsoil required to sustain nutrient cycling (i.e. nitrogen-mineralization) in these reclaimed ecosystems. Also, we've been evaluating the use of a potential new method to assess soil quality (Franzluebbers *et al.* 2000) for use with surface mine land reclamation. If successful, this methodology may be useful as a relatively fast, economical and reliable "indicator" of a soil's potential to sustain nutrient cycling.

Methods

Soils were collected during the summers of 2000 and 2001 from reclaimed sites on the North Antelope/Rochelle Complex, Belle Ayr, and Jacobs Ranch coal mines, as well as the Pathfinder uranium mine (sampled in late Autumn of 2002). Samples were analysed for 3- and 21-day microbial respiration; microbial biomass, N-mineralization, organic C and total N. Also in 2001, aboveground biomass was collected and weighed, and sub-samples ground and analysed for total N to determine the annual plant community uptake of N.

Results and Discussion

One of the two major aims of this project was to investigate the usefulness of the 3-day CO_2 flush method (Franzluebbers 2000) as a relatively fast, reliable and economical means to determine soil quality (nutrient cycling potential) in reclaimed coal mine soils.

Generally there where strong ($r^2 > 0.50$) and significant correlations between 3-day microbial respiration and a suite of other standard indicators of soil quality; 21-day microbial respiration, microbial biomass, N-mineralization, organic C, and N (Figure 1). In reclaimed soils, correlations were consistently much tighter than in native soils (data not shown, but native soil correlations where still significantly correlated) suggesting that in these disturbed ecosystems the microbial populations were more sensitive to changes in specific soil environmental characteristics (e.g., organic C and N contents). This disparity between the microbial populations may be the result of differences in the relative availability of C and N between the native and reclaimed soils, with more labile fractions of C and N occurring in the reclaimed soils. While we are unable to quantitatively determine any specific soil biological property (e.g., organic carbon, microbial biomass) on the basis of the 3-day CO_2 flush method alone, we can however, rank soils in regards to their soil biological "health" and associated characteristics (i.e. organic C and total N). This should assist in the determination as how to manage topsoil salvage and replacement to ensure that a minimum threshold level of soil organic carbon is available to maximize the likelihood that the reclaimed plant community established into them will become a productive and functional ecosystem with minimal additional inputs.

One of the major aims of this study was to estimate, on the basis of organic C and from our estimates of potential lab N-mineralization, the minimum concentration of SOM required to supply a sufficient amount of N to the plant community. From our initial sampling of soils in 2000 and 2001, and based on our calculations of *potential* N-mineralization estimate (by extrapolation of our *potential* N-mineralization to a field situation and for two different growing seasons; 1st May to the 31st June and 1st May to the 31st August), it was apparent that the amount of SOM required to provide a sufficient amount of N for plant growth was somewhat lower than what we had measured in our original soil samples. Thus, in the autumn of 2002 we sampled and analysed a reclaimed soil on the Pathfinder uranium mine (located in the Shirley Basin) which had been reclaimed with spoil material containing extremely low amounts of organic C and total N (see Table 1). From this we where able to estimate that the minimum amount of soil organic C required to maintain a healthy plant community was approximately 0.4% organic C or 0.7% soil organic matter to a depth of 30 cm. In general, all the soils sampled during the course of this study,

except the Shirley Basin site, contained sufficient quantities of soil organic matter (and associated total nitrogen) and thus provide sufficient quantities of mineralizable N for plant growth over the course of the growing season. Finally, soil organic matter will continue to increase over time due to above- and belowground litter inputs from the re-established plant community.

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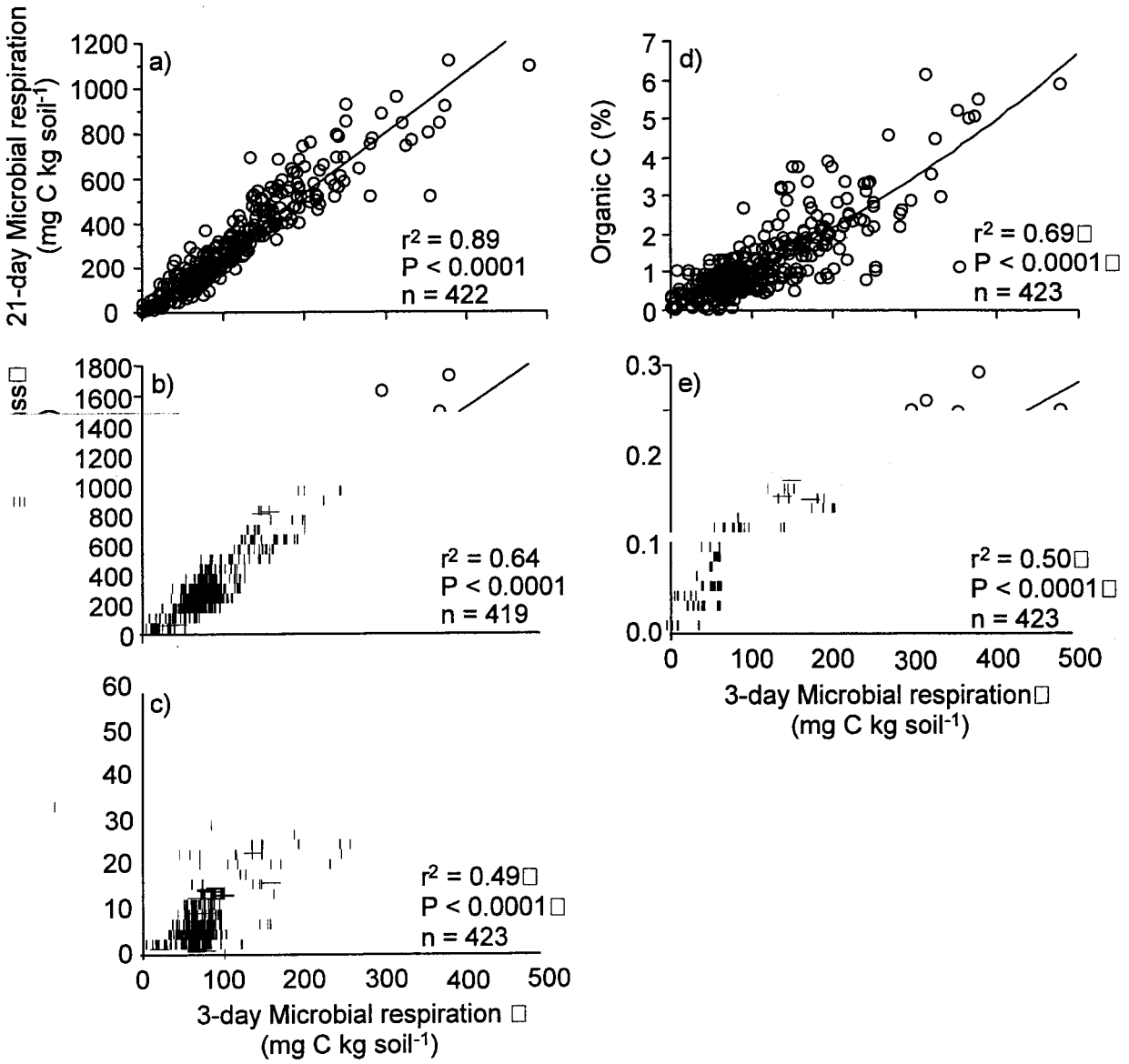

Figure 1. Regressions of 3-day Microbial respiration against: a) 21-day Microbial respiration; b) Microbial biomass; c) Potential N-mineralization; d) Organic C, and; e) Total nitrogen

Table 1. Organic C, total N, and biological data for various reclaimed and native sites from sampling undertaken in 2000, 2001, and 2002. Data was combined as required.

Site#	Dep (cm	Orga C	Tot N	3-day Mic respirat	21-day Mic respirat	Microb bioma	Nitrogen-minerali
		(%)		(mg C kg soil^{-1})			(mg N_i kg so
NA85	0-2	4.3	0.21	346	883	1,202	45
	2.5-	0.8	0.04	73	165	279	8
NA97	0-2	2.6	0.11	197	494	736	13
	2.5-	0.9	0.06	83	199	308	3
NA - Nat	0-2	1.3	0.10	135	368	561	13
	2.5-	0.7	0.07	57	152	239	4
BA55	0-2	1.9	0.14	177	460	842	25
	2.5-	0.7	0.08	70	174	308	8
BA72	0-2	1.3	0.09	131	340	502	17
	2.5-	0.7	0.06	67	146	207	5
BA - Nat	0-2	1.4	0.13	157	468	846	19
	2.5-	0.9	0.09	79	216	353	7
JRSP	0-2	0.9	0.07	149	488	568	10
	2.5-	0.8	0.06	77	204	247	4
JRDH	0-2	0.5	0.05	82	231	222	8
	2.5-	0.4	0.04	33	75	96	1
JR - Nati	0-2	2.8	0.16	140	479	667	26
	2.5-	1.0	0.10	64	208	289	16
PA	0-2	0.3	0.04	60	222	458	21
	2.5-	0.1	0.12	28	47	32	1
PA - Nat	0-2	1.6	0.16	114	374	1083	22
	2.5-	1.0	0.11	66	146	381	8

#NA - North Antelope Coal mine, BA - Belle Ayr mine, JR - Jacobs Ranch mine, PA - Pathfinder Uranium Mine; Native - undisturbed, native.

2003

Abandoned Coal Mine Land Research Program

Effects of Variable Topsoil Replacement Depth on Plant Community Development And Ecosystem Development After 24 Years

Final Progress Report

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Introduction

Achieving plant species diversity is one of the more difficult aspects of today's mining reclamation requirements. Many researchers have examined the affects of variable topsoil replacement on vegetative community attributes, primarily production (McGinnies and Nicholas, 1980; Power et al., 1976; Barth and Martin, 1984). Many professionals in the area believe variable topsoil replacement depths would also contribute to a more diverse plant community. In 1998, a study was initiated to evaluate the short-term effects of variable topsoil replacement depth on plant community diversity (Schladweiler et al., 1998). However, long-term evaluation is needed to evaluate successional changes as affected by variable topsoil replacement depth.

Objectives

Using a study established by Schuman et al. (1985) we examined the long-term (24 years) effects of variable topsoil replacement depths on vegetative community development and soil physical and chemical attributes. Baseline data from the initial 4 years of the study were available for comparison.

Methods and Materials

Topsoil (a mixture of A and B horizon material) was originally re-spread, over regraded spoil material, in a wedge design ranging from 0 to 60 cm. The topsoil material was a fine, mixed Borollic Haplargid, with a pH of 7.1, electrical conductivity of 2.5 dS m^{-1} and a soil organic matter content of 2.4%. Topsoil was direct-applied over 1-m of spoil material derived from coarse-grained sandstone of the White River Formation. Spoil material below the White River material consisted of calcareous and moderately well cemented siltstones and claystones of the Wind River Formation. Organic matter, nitrogen (N), and phosphorus (P) levels were deficient in both spoil types. Neither spoil contained any elements at toxic levels. Plots received fertilizer amendments at rates of 67 kg P ha^{-1} and 315 kg N ha^{-1}. The experimental design was a completely randomized design with ten replications of two mulch treatments (stubble and surface applied straw). The research plot area was divided into 20 plots (4.9 by 45.7 m) running parallel to the topsoil depth gradient. In spring 1977, one-half of these plots were drill seeded with 50 kg ha^{-1} of 'Otis' barley (*Hordeum vulgare* L.) to establish the stubble mulch treatment. The remaining 10 plots were fallowed for future application of the crimped straw mulch treatment. In October 1977, all plots were drill seeded to a mixture of 'Critana' thickspike wheatgrass [*Elymus lanceolatus* (Scribner & J.G. Smith) Gould], green needlegrass [*Stipa viridula* Trin.], slender wheatgrass [*E. trachycaulum* (Link.) Gould ex Shinners], and 'Rosana' western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love] at a total seeding rate of 15.5 kg PLS ha^{-1}. The mixture was composed of equal numbers of seeds for each species. Wyoming big sagebrush *(Artemisia tridentata* ssp. *wyomingensis*) and rubber rabbit brush (*Chyrsothamnus nauseosus*) were also seeded at 0.5 kg PLS ha^{-1}. Barley straw was hand scattered on the previously fallowed plots at a rate of 5000 kg ha^{-1} and crimped into the soil

in two directions (Schuman et al., 1985). In 1979, N fertilizer treatments were added to the study to assess the effects of a single 268 kg N ha^{-1} application compared to four annual applications of 67 kg N ha^{-1} (Schuman et al., 1991). Each N fertilizer treatment was randomly assigned to five stubble and five surface applied straw mulch plots.

In August 2001, three of the five replications of each mulch by fertilizer treatment plots were randomly selected and sampled at each topsoil replacement depth using a hydraulic truck mounted soil sampler. Samples were taken to a depth of 75 cm and separated into four increments (0-5, 5-20, 20-40, and 40-75 cm). The soil cores taken from the 60 cm topsoil depth treatments were divided into the same increments as those obtained from the other topsoil depth treatments except for the lowest depth which was separated at the soil-spoil interface, resulting in a sample that represented the spoil material only, 60-75 cm. The soil samples were analyzed for total nitrogen, organic carbon, clay content, and soluble cations (calcium, sodium, potassium and magnesium).

At the time the soil samples were collected for chemical analyses, additional cores were taken adjacent to these cores to assess soil bulk density. Two of the three replications sampled for chemical analyses were sampled for bulk density.

A three-way analysis of variance was used to assess the effects of topsoil replacement depth, mulch type, and fertilizer treatment on soil chemical and physical attributes.

Results

This research has clearly shown the importance of long-term evaluation of plant community development as influenced by topsoil replacement depth on mined lands. Species diversity, richness, and forb cover were all enhanced by shallower topsoil depths ($\leq$20 cm). Natural recruitment of local native species seems to have been greatest in the open inter-spaces of the plant community on the 0 and 20 cm topsoil replacement depths. Natural recruitment may have been greater; but, the distance of this site from native rangelands (>1.5 km) and topography of the reclaimed area (several hundred meter high spoil dump) undoubtedly influenced the amount of native seed that reached these plots. Limited nutrient availability at the shallower soil depth treatments also limited inter-space recruitment (Woods and Schuman, 1986). Plant communities that developed on the 40 and 60 cm topsoil depth treatments were dominated by highly competitive cool-season perennial grasses that limit natural recruitment of native species. The competitive exclusion hypothesis seem to explain the observed lack of major change in these "new ecosystems" (Huston, 1979). Deeper topsoil depths provided a more conducive environment for cool-season grass production, increasing the competitiveness of these species thus limiting species richness and diversity (Huston 1979). Huston (1979) also hypothesized that limited nutrients and water holding capacity at shallow topsoil depths reduces competition from seeded grasses and is responsible for the increased species diversity and richness at these shallower topsoil depths.

The depth of replaced topsoil on reclaimed mine lands has had a significant effect on nutrient levels and cycling as well as water infiltration. Soil organic carbon and total nitrogen quantity increased with increased thickness of topsoil replacement to a depth of 60 cm. Available phosphorus concentrations increased in the upper 20 cm of the soil as

replaced topsoil depth increased. Some of the responses observed are due to the higher amounts of these constituents in the topsoil used for reconstruction, but primarily in response to increased vegetation production and nutrient cycling at the greater topsoil depths. Topsoil used in the study had higher sand and organic matter content than the spoil material; therefore, water infiltration rates were greater at the 40 and 60 cm topsoil depths compared to the 0 and 20 cm depths. Increased vegetation production, resulting from increased moisture availability and greater nutrient availability, further facilitated water infiltration on the 40 and 60 cm topsoil depth treatments. Water infiltration rates measured on the deeper topsoil depth treatments indicate that these soils are less likely to produce runoff, therefore, decreasing the erosion potential.

Recommendations

This research has shown that varying and reducing topsoil depth replacement on mined lands will enhance plant community diversity and richness and result in the development of a more diverse landscape. Variable topsoil depth replacement appears to be an appropriate tool to enhance mined land plant community diversity. The enhanced community diversity and richness is influenced by community space dynamics and also soil nutrient cycling and soil water infiltration and storage. Designing the pattern of topsoil depth replacement on the landscape will have to be carefully planned to ensure that potentially erodible sites have adequate topsoil replacement to support a plant community that is resistant to erosion. Shallow topsoil replacement depth ($\leq$20 cm) should be placed on landscape positions that are not susceptible to erosion because plant community cover observed on shallow topsoil depths of our study on areas was not great enough to provide good erosional stability/protection. The present idea of replacing shallow topsoil depths on ridge positions may be ill advised as these sites have a high potential for erosion and the result may be an unstable landscape that is not productive and does not meet the desired post-mine land use or cover and production reclamation regulations.

Future Research

Research to assess the effects of topsoil depth replacement on plant community diversity and richness on mined lands will need to be long-term, likely greater than 20 years to enable effective assessment of successional processes as they relate to plant community development. Therefore, future research should be conducted on the numerous research sites that were initiated in the 1970's and 1980's. Initiation of new research will provide only minimal new short-term information while the earlier initiated research can provide much more information as it relates to successional changes and community dynamics.

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Principal Investigator/Project Director: Charlie Barnhart

Institution: Industrial Alchemy

Award Number:

Program: Wyoming Department of Environmental Quality ACMLRP

Project Title: Innovative Blasting to Minimize Nitrogen Dioxide Formation While Maximizing Energy Efficiency in Surface Mining

Solving the Nitrogen Dioxide Problem in Surface Coal Mining

Charles R Barnhart, *Project Director*

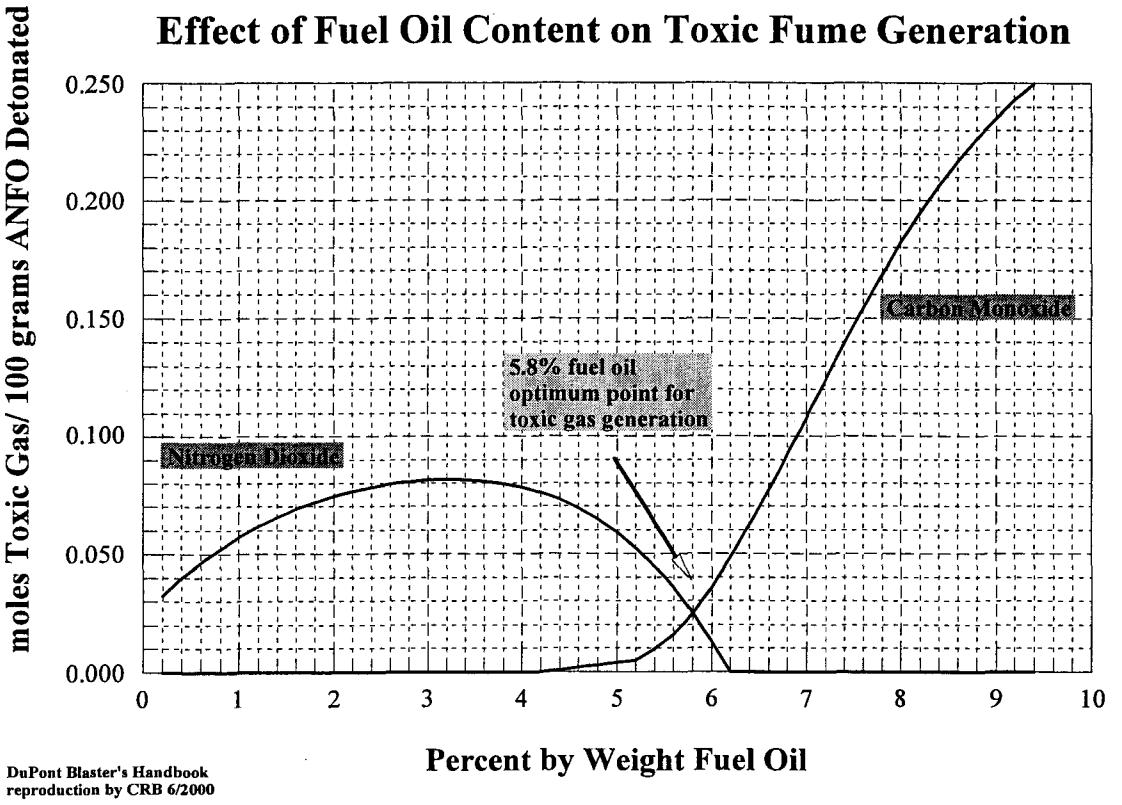
ABSTRACT: Surface coal mining in the Powder River Basin of north eastern Wyoming have employed a blasting technique known as cast blasting, which typically forms an "orange cloud" of Nitrogen Dioxide (NO_2) smoke. The cast blast moves approximately 25% of the 200 feet of sedimentary rock (overburden) off the coal seam. The overburden is moved like a wave of flying rock using an Ammonium Nitrate/Fuel Oil (ANFO) blasting agent. The temperature of the explosion and the confinement of the borehole pressure determine the amount of NO_2 formed and the efficiency of the cast of the overburden. To assure that the large diameter ANFO filled boreholes detonate at maximum velocity, a shaped charge initiation system (CastMax™) has been developed. This plastic capsule is engineered similarly to the shaped-charge technology used in armor piercing military munitions, and can be manufactured at a reasonable cost for the mining industry.

1. INTRODUCTION

Low profit margins on coal have driven the change from relatively expensive truck and shovel overburden removal to dragline removal that can clear to the top of the coal seam in one move of the equipment. To enable this process, cast blasting is used to throw the overburden into the previously mined coal trench. In the early 1990's cast blasting was more or less trial and error and the formation of NO_2 was excessive. During this time, many people were exposed to the toxic gas. This resulted in restrictions being placed on the blasting operations, such as limiting the amount of ANFO used, blasting only under favorable climactic conditions, and blasting only from noon to dusk. These restrictions result in less efficient blasting and increased costs from inefficient use of equipment.

There are three immerging technologies that are showing improvement in lowering NO_2 emissions. A low velocity, non-stoichiometric, solid fuel blasting agent made with cellulose (rice hulls, peanut shells) or styrene is promising because it satisfies the chemical reaction (see chemical reaction in RESULTS AND DISCUSSION). The down side of these blasting agents is that more boreholes have to be drilled to get enough ANFO into the ground to realize a good cast percentage. The Ammonium Nitrate is the chemical that reacts to form gases so replacing it with "inert material" reduces the pressure and heave. For every pound of Ammonium Nitrate detonated, 300 cubic feet of gas will be generated at 4,000

degrees Fahrenheit. The other negative aspect of too much fuel is the generation of Carbon Monoxide (Graph 1) instead of Nitrogen Dioxide. It is also more expensive to ship and blend more components into a blasting agent so there has to be an increased cost per pound.



The use of straight ANFO in plastic sleeves has been successful at reducing NO_2. This blasting system is favorable because ANFO is the least expensive blasting agent available

Graph 1: Fume produced from non-stoichiometric mixtures of Ammonium Nitrate and hydrocarbon. The mining industry uses a low density Ammonium Nitrate to absorb #2 diesel fuel and formulate the Ammonium Nitrate/Fuel Oil (ANFO) blasting agent.

and allows sufficient Ammonium Nitrate to be put in the ground per borehole. The negative of this practice is getting the borehole liners down angled holes without tearing them; obviously, ground water could then get to the ANFO and dissolve areas so that it is non-contiguous. Two other advantages are further realized by sleeving ANFO. Besides the advantage of cost, the powder column is held together by the plastic tube such that ground disturbance from the adjacent borehole blasts do not spread the blasting agent. The other advantage is that ANFO is mechanically sensitized, which is a very important criterion for efficient blasting. Where each sphere of Ammonium Nitrate (prill) contacts another prill there is a gas void. For sympathetic detonation to occur there needs to be void space (1% optimum) for the detonating gas to expand into or the blasting agent will pressure compress

itself to become non-reactive. In blasting agents where the voids between prills are filled with gelatinous blasting agent (emulsion) the system needs to be sensitized with gas. The addition of glass micro-balloons, plastic micro-spheres or chemical gassing agents are used to supply the void volume; however, our experiments show that the pressure waves from adjacent borehole detonation can crush the voids and reduce the blasting agent performance. The porous prill does not seem to be crushed in the blasting agent so straight ANFO should not lose its sensitivity. As mentioned previously, the negative of this blasting system is the added cost of manpower to install the plastic liner, which becomes a challenge with the wind and rain (snow) in Wyoming.

The blasting agent chosen for this research is termed heavy ANFO because it is solid Ammonium Nitrate made water-proof by a thick coating of emulsion. This blasting system is very high energy because it maximizes the amount of Ammonium Nitrate that can be put into borehole. By the very nature of this high energy it is difficult to keep from damaging the adjacent boreholes as the blast proceeds; this aspect of powder column damage was studied extensively. The approach to minimize NO_2 emissions from the 50/50 heavy ANFO was to overdrive the initiation of the blasting agent to make it react as quickly as possible while keeping the entire blast pattern from spreading too far between borehole detonations.

The energetic initiation was accomplished with a new shaped charge detonation system that starts sympathetic detonation with a uni-directional, supersonic fireball of heat and pressure. Confining the blast pressure was made possible by using electronic detonators set at quicker timing between rows than traditional cast blasting. By precise control of the time of detonation in each borehole there is less destruction to adjacent boreholes so the blasting agent stays contiguous; plus, the vaporized hydrocarbon cannot escape the Ammonium Nitrate before it vaporizes and reacts. The overall result of employing both the CastMax capsule and faster timing was a reduction in NO_2 formation and a measurable increase in cast percentage.

2. EXPERIMENTAL

To date the project has measured the parameters of seven cast blasts and visually quantified the Nitrogen Dioxide concentration from each blast by the intensity in color (Table 1). Red is concentrated NO_2 at about 10,000 parts per million by volume, followed by orange in the thousands of ppmv and yellow in the hundreds of ppm.

Correlations between the Nitrogen Dioxide cloud color and other measured parameters are the focus of this experimentation and the basis for judging a successful improvement in the blast. It was realized after the third baseline blast that significant changes in detonator timing were needed for the shaped charge initiation system (CastMax capsule) to be effective in improving the cast blast efficiency.

Testing Location	Blast #	Date of Cast Blast	Nitrogen Dioxide
Arch Black Thunder	Baseline blast #1	August 27, 2002	Red cloud
Triton North Rochelle	CastMax blast #1	December 10, 2002	Light orange cloud

Triton North Rochelle	Baseline blast #2	January 10, 2003	Dark orange cloud
Triton North Rochelle	Baseline blast #3	April 24, 2003	Dark orange cloud
Triton North Rochelle	Baseline blast #4	June 13, 2003	Trace yellow
Triton North Rochelle	Baseline blast #5	July 12, 2003	Slight orange haze
Triton North Rochelle	Baseline blast #6	August 27, 2003	Trace yellow

Table 1: Intensity of Nitrogen Dioxide cloud in tested cast blasts

It was the swell velocity testing in both baseline blasts #2 and #3 that revealed the ground heaved upward before the borehole beneath was being detonated. It became obvious that the initiation of the boreholes had to be faster than the pressure wave moving the overburden so the powder column would not be compromised.

In fact, the pressure front in baseline blast #3 actually blew a seam to the surface between rows D and C to jettison the swell target at a velocity of 90 feet/second. Allowing the pressure front to disrupt the boreholes causes the blasting agent to be non-contiguous and burn rather than detonate, thus producing NO_2. The secondary affect of letting the pressure front move too far before initiation of the next row is loss of confinement so the gas heave is less efficient.

RESULTS AND DISSCUSSION

Deflagration of ANFO (850 °F)

$$\mathbf{3\ NH_4NO_3 + NH_4NO3 \text{ ------ } 2\ NO_2 + 3\ N_2 + 8\ H_2O}$$

Detonation of ANFO (4,750 °F)

$$\mathbf{3\ NH_4NO_3 + [\text{-}CH_2\text{-}]_n \text{---------} CO_2 + 3\ N_2 + 7\ H_2O}$$

There is only one reason for Nitrogen Dioxide to be formed and it results when the Ammonium Nitrate is void of hydrocarbon and reacts with itself. The competing chemical reaction with detonation is termed deflagration. After one year of testing it can be stated that we do know and understand a great deal about why deflagration occurs in cast blasting. Picture 1 is an example of how concentrated the NO_2 can be from a cast blast. It has long been felt that 300 or more milliseconds of timing needs to be put between each row of detonations to allow the rock a maximum time of flight so the cast percentage is high. Our experiments have found that higher cast percentages can be made with timing of 150 to 200 milliseconds between rows. Picture 2 shows a definite improvement in Nitrogen Dioxide concentration and most of that NO_2 was the result of shooting a previously shot end of the cast pattern that had not been dug, thus there was a lack of confinement in several boreholes.

Picture 1: Baseline blast # 3 at Triton North Rochelle on April 24, 2003.

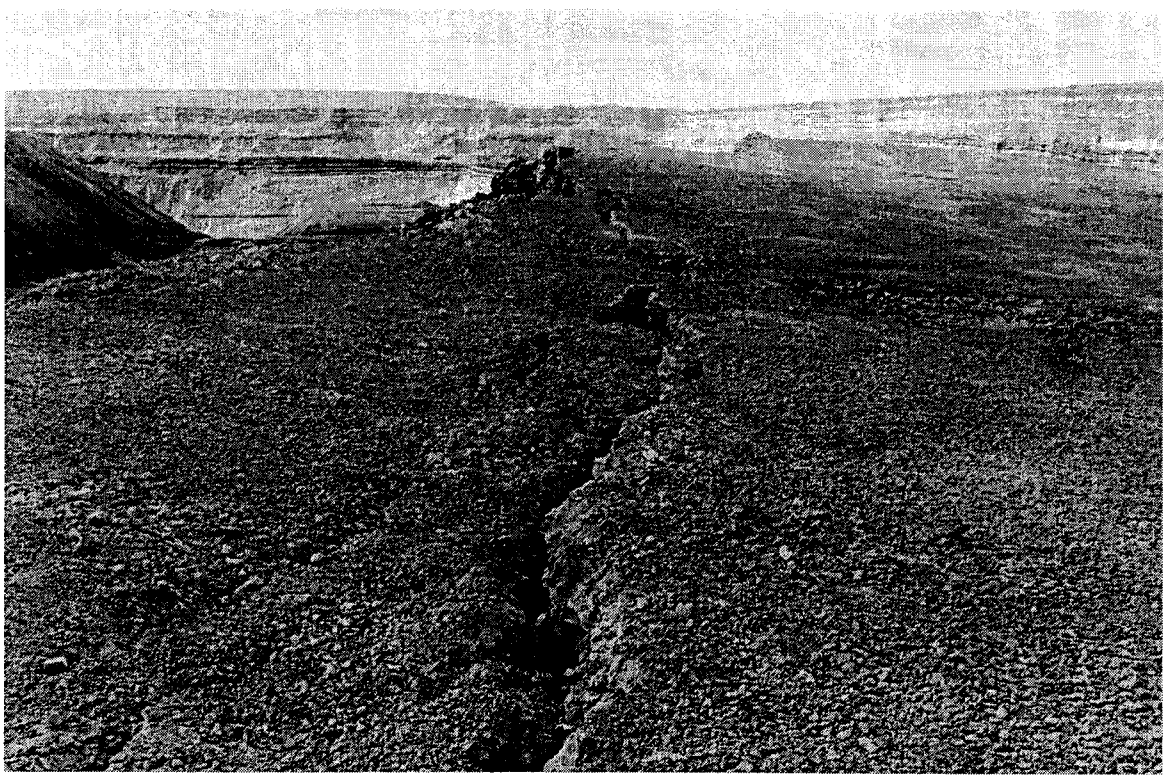
Picture 2: Baseline blast # 6 at Triton North Rochelle on August 27, 2003.

Blast #	Cast #	Hole-to-hole	Row A-to-B	Row B-to-C	Row C-
Baseline blast #1		9 ms	500 ms	300 ms	300 ms
CastMax blast #1	# 73	10 ms	265 ms	295 ms	325 ms
Baseline blast #2	# 76	10 ms	255 ms	285 ms	315 ms
Baseline blast #3	# 87	27 ms	231 ms	278 ms	335 ms
Baseline blast #4	# 91	8 ms	144 ms	144 ms	144 ms
Baseline blast #5	# 95	27 ms	155 ms	180 ms	210 ms
Baseline blast #6	# 98	8 ms	148 ms	148 ms	148 ms

Table 2: Detonator millisecond timing sequences in tested cast blasts.

The millisecond timing of the electronic detonators in each shot is recorded in Table 2 so relationships between timing and NO_2 formation can be made. It is shown by comparing Table 1 to Table 2 that as the timing between rows was decreased the NO_2 also decreased.

The data from these experiments supports the hypothesis that keeping the borehole intact is key to stopping deflagration and increasing the efficiency of the blasting agent; however, new problems arise from initiation of a cast blast that is too fast. The ground

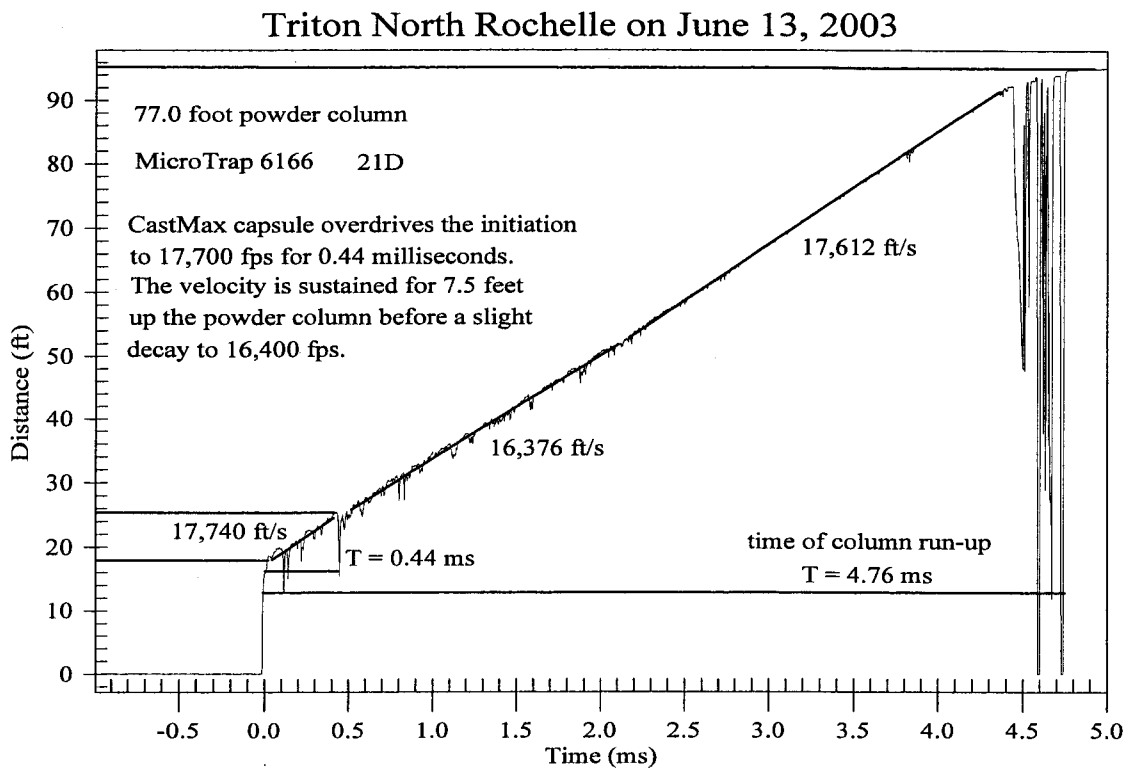


Picture 3: Severe back-break with cast blast timing at 8 ms hole-to-hole and 148 ms row-to-row at Triton North Rochelle on August 27, 2003.

vibration is great because more pounds of blasting agent detonate in an 8 millisecond window of time and the back break into the new high wall is severe; 10 feet further than the anticipated crest line as shown in Picture 3. This leads to high wall instability and requires mechanical digging with track hoes to correct. Good results were obtained when only 14,000 pounds (2 boreholes) of heavy ANFO are allowed to initiate at once.

This quickly timed cast blast was one of the most important experiments performed to date because it was the demonstration that the preferred blasting agent (heavy ANFO) could be detonated with very minimal Nitrogen Dioxide formation. To reduce the severity of the ground vibration, the hole-to-hole timing merely needed to be increased from 8 milliseconds back to 27 ms. This is the point where the frequency of the vibration becomes higher and ground vibration decreases; however, to keep the powder columns intact the row-to-row timing must be slightly less than those in the #5 baseline blast (see Table 2). A suggestion for next cast blast would be 155, 175, 195 milliseconds in row-to-row timing.

Picture 4: CastMax shaped charge detonation system fitted with one pound booster and electronic detonator. Inexpensive bailing twine is used to lower the capsule on top of 10 feet of heavy ANFO. The use of the CastMax is to guarantee the initiation of the booster contacts 25 pounds of unadulterated high energy blasting agent and send the energy as a uni-direction fireball of heat and pressure upward into the powder column.

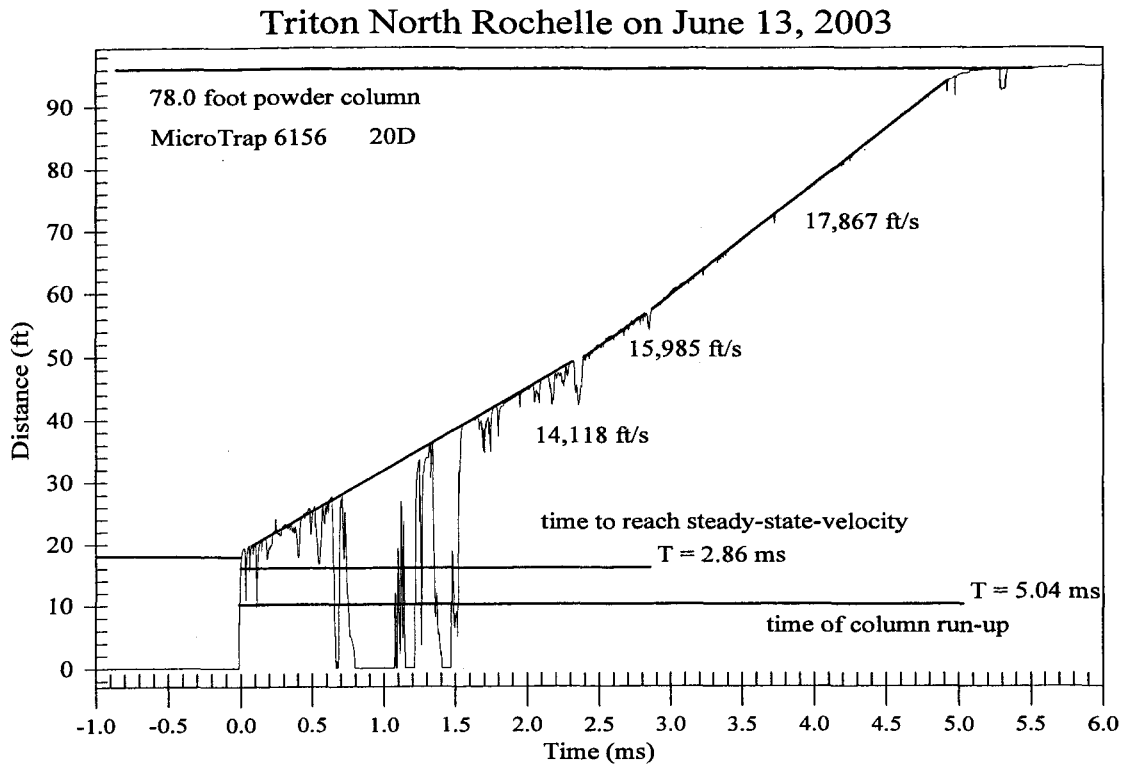


Trace 1: CastMax drives the detonation reaction to hydrodynamic velocity.

The CastMax shaped charge detonation system (Picture 4) has demonstrated that it does overdrive the initiation of the powder column. The velocity of detonation (VOD) data in Trace 1 shows the capsule initiates the powder column at its hydrodynamic velocity.

Only the first row boreholes are not compromised by an initiation of a powder column in front; however, all but a few (maximum 4 boreholes of hundreds) are affected by initiation of a powder column from an adjacent borehole detonation. In the heavy ANFO cast blast the pressure wave from the forward row reduces the VOD of the blasting agent in the next row by 2,000 feet per second (fps). The pressure wave from the adjacent borehole in the same row further degrades the blasting agent by another 2,000 fps as shown in Trace 2. This data is significant proof that lower pressure blasting agents would reduce the production of NO_2 by not compromising the powder columns in adjacent boreholes; however, the true mechanism by which they work is the solid fuel that cannot vaporize away from the oxidizer. Further research with solid fuels that do not produce Carbon Monoxide (Aluminum, Urea) would be of great interest in cast blasting.

The use of CastMax capsules to initiate damaged powder columns is ongoing. The timing has been improved although not optimized, which is not the focus of this research but a necessary effort to demonstrate the performance enhancement of shaped charge initiation.



Trace 2: Interior powder column has been damaged by pressure pulses from forward and adjacent borehole detonations. The heavy ANFO blasting agent initiates 4,000 fps slower than hydrodynamic velocity (14,000 versus 18,000). Approximately 50% of the Ammonium Nitrate in this borehole undergoes some degree of deflagration to produce Nitrogen Dioxide smoke.

Alterations of the heavy ANFO blasting agent to make it withstand high pressure pulses is of great interest but not necessary to continue the evaluation of the CastMax capsule. Industrial Alchemy is looking for a cooperative mine that cast blasts using different blasting agents so we can compare data sets to heavy ANFO.

Efficient cast blasting is like "drag racing" where each contributing factor needs to be optimized for speed. If the powder column detonates it will not deflagrate, which results in maximizing the efficiency of the blasting agent that the mine has spent so much money to put into the ground. We are changing the "mind set" of the blasting fraternity, but there is still much to do. This research will continue if Phase IIB funding can be obtained.

AML Progress Report

Influence of Reclamation Management Practices on Carbon Accumulation and Soil Fertility on Coal Mine Lands in Wyoming

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Introduction

The overall goal of this proposed research is to examine the influence of a number of surface coal mine reclamation management practices on carbon accumulation, organic nutrient pools and soil fertility in reclaimed soils. To accomplish this goal, we are examining the influence of these common management practices (grazing, mulching practices, direct haul/stockpiled topsoiling, and shrub mosaic seeding) on organic carbon and nutrient concentrations in soil. Data collected will be used to determine mechanisms by which organic matter and nutrients accumulate in these soils and evaluate the potential for enhancing carbon and organic nutrient storage in reclaimed surface mine lands.

Information obtained through this research will provide reclamationists with effective strategies for building soil carbon and organic nutrients and contribute significantly to the current scientific understanding of soil carbon and organic nutrient dynamics in reclaimed soils. The observed phenomenon of organic carbon accumulation in reclaimed soils on surface mined lands should be viewed as a mechanism by which

the coal mining industry is contributing to the reduction in CO_2 in the atmosphere through increased carbon storage and improvement in soil fertility.

Progress

This project was initiated during the summer of 2002. Although preliminary arrangements were made with several surface coal mines in Wyoming for research sites during proposal development, field reconnaissance trips were necessary to confirm the suitability of specific research sites. During the summer of 2002, we visited the mines listed in our proposal to assess sites for comparison of reclamation management practices and look for appropriate undisturbed control sites. After discussions with reclamation specialists at the mines, examination of mine reclamation files and maps, and inspection of field locations, research sites were chosen at the mines listed in Table 1 along with the management comparisons to be made at each mine.

Table 1. Mines sampled for field research sites and management comparisons made.

Mine	Management comparison
Belle Ayr, S. of Gillette	shrub mosaic vs. non-shrub mosaic
Dave Johnson, N. of Glenrock	grazed vs. ungrazed
	shrub mosaic vs. non-shrub mosaic
	direct-hauled topsoil vs. stockpiled topsoil
Jacobs Ranch, E. of Wright	grazed vs. ungrazed
Jim Bridger, Point of Rocks	direct hauled topsoil vs. stockpiled topsoil
Seminole 1, W. of Hanna	stubble mulch vs. hay mulch

Sampling of soils at the chosen research sites was initiated in Fall of 2002. We began our fieldwork by collecting soils samples from sites at the Dave Johnson Coal Mine to compare grazed and ungrazed sites as well as shrub mosaic seeded sites with those grassland seedmix sites. During the fall we also collected soil at the Seminole 1 Mine to compare soil characteristics of areas reclaimed with stockpiled topsoil to characteristics of soil in an area reclaimed using direct hauled topsoil. The last mine we worked on in Fall

2002 was the Jim Bridger Mine where we collected soils in another comparison of areas reclaimed with stockpiled topsoil versus directly hauled topsoil.

During the summer of 2003, soils were sampled at the Belle Ayr Mine to compare soil organic carbon concentrations and nutrient pools in a shrub mosaic seeded area versus grassland seeded area. We returned to the Dave Johnson Coal Mine to collect soil samples from areas reclaimed with direct hauled and stockpiled topsoil. Finally, we sampled soil at the Jacobs Ranch Mine to compare soil in a grazed area to soil in an ungrazed area. Also, during this past summer we collected data on soil water infiltration in our study areas and volumetric cores for determination of soil bulk density. As of this fall, we have sampled soils for all of our proposed management comparisons from at least two mines each with the exception of the mulching method comparison. We will be inquiring at the AML Seminar as to the availability of another site for this comparison.

All soil samples collected during fall, 2002 have been analyzed for total C, inorganic C, organic C, microbial biomass N, total N, pH, and electrical conductivity. Soil samples collected during summer 2003 are in the process of analysis for these same properties.

Preliminary Results

The following are some preliminary results based on samples collected in 2002 at the Jim Bridger and Seminole 1 Coal mines.

At the Jim Bridger Mine we compared soil in an area reclaimed using directly hauled topsoil to that of an area reclaimed the same year (1985) using stockpiled topsoil. We also sampled and analyzed soil from a nearby undisturbed area for comparison. Data indicates that there were no significant differences in soil organic carbon content between areas reclaimed with directly hauled topsoil and stockpiled topsoil. Both of these reclaimed soils, however, had significantly greater soil organic carbon content in the 0-5 cm depth than nearby undisturbed soil. Additionally, concentrations of microbial biomass carbon in soil of the two reclaimed areas were not statistically different, but both had greater concentrations of microbial biomass in the 0-5 cm horizon than did the undisturbed soil. In regard to total soil nitrogen content, again, we found no statistically significant differences between the two reclaimed areas, but observed that both reclaimed soils had greater total nitrogen content in the 0-5 cm and 5-15 cm depths than the nearby undisturbed soil. Both reclaimed

areas had significantly greater bulk density in the surface horizon (0-5cm) than the undisturbed soil. No significant differences were found in bulk density of the deeper soil horizons between soils from the three sites. Using the soil bulk density data to calculate amounts of soil organic carbon and total nitrogen across landscapes indicates that soil in the area reclaimed using directly haul topsoil contains 33,600 kg organic carbon per hectare to a depth of 30 cm (15 tons acre^{-1} to a depth of 15 inches), the area reclaimed using stockpiled topsoil contains 28,950 kg organic carbon per hectare to a depth of 30 cm (12.9 tons acre^{-1} to a depth of 15 in.), and the undisturbed soil in the area contains 9,430 kg organic carbon per hectare to a depth of 30 cm (4.2 tons acre^{-1} to a depth of 15 in.).

Preliminary results from the Jim Bridger Mine suggest that soil in reclaimed areas are accumulating carbon at a rapid rate as both reclaimed areas examined had significantly more soil organic carbon than did the undisturbed area sampled. This is also the case with total nitrogen content of soil in these areas. Our data also indicates there are no significantly different effects of the two topsoil salvage and handling methods (direct haul vs. stockpiling) on organic carbon accumulation in reclaimed areas at this mine.

We compared an area reclaimed using stubble mulch methods to an area reclaimed using native hay mulch on the Seminole 1 Mine. Soil from both the stubble mulched area and the hay mulched area had similar organic carbon contents at the 0-5 cm and 5-15 cm depth, but the stubble mulched area had significantly more organic carbon at the 15-30 cm depth. No significant differences were found in soil organic carbon content between the reclaimed areas and the native area except in the 15-30 cm depth where the stubble mulch treatment had a greater concentration than the undisturbed soil as well as the hay mulched treatment. Amounts of microbial biomass carbon in the different soil depths examined were not significantly different between the two mulching methods or between the reclaimed areas and the undisturbed site. Similarly, no significant differences were found in the total soil nitrogen content of the areas reclaimed using the disparate mulching techniques. Soil in the undisturbed area did have a significantly greater concentration of total nitrogen at all depths than did soil in the area reclaimed using native hay mulch, but not the stubble mulched area. Bulk density of soil in the two reclaimed mulch treatments were not significantly different from each other or the adjacent undisturbed site at the 0-5 or 5-15 cm depths. Soil bulk density at the 15-30 cm depth was significantly greater in the hay

mulched area than at the same depth in both the stubble mulched and undisturbed areas. These data indicate that soil in the area reclaimed using stubble mulch contained 41,200 kg organic carbon per hectare to a depth of 30 cm (18.4 tons $acre^{-1}$ to a depth of 15 in.), the area reclaimed using hay mulch contained 30,350 kg organic carbon per hectare to a depth of 30 cm (13.5 tons $acre^{-1}$ to a depth of 15 in.), and nearby undisturbed soil contained 34,030 kg organic carbon per hectare to a depth of 30 cm (15.2 tons acre-1 to a depth of 15 in.).

Results obtained thus far from the Seminole 1 Mine indicate that soil in the reclaimed areas examined contain at least as much organic carbon as nearby undisturbed soil. This may represent an accumulation of organic carbon in these reclaimed soils since replacement as they typically become depleted from predisturbance levels during time they are stockpiled. Our data also suggest that stubble mulching may increase organic carbon levels at the 15-30 cm depth over the hay mulched area, probably through root growth into this soil depth by the small grain species used.

To close, our preliminary results from both of these mines suggest organic carbon is accumulating in reclaimed soils and that stubble mulching may lead to greater inputs of organic carbon to soil at the 15-30 cm depth. Since we have made this mulch method comparison at only one mine so far, we will be looking for another mine with suitable sites to sample for additional data.

2003

Abandoned Coal Mine Land Research Program

Impacts Of Wildlife Utilization On Big Sagebrush Survival On Reclaimed Mined Lands

Final Progress Report

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Introduction

Wyoming big sagebrush (*Artemisia tridentata* Nutt ssp. *wyomingensis* Beetle & Young), if present in pre-mined ecosystems, is required to be re-established according to the Surface Mining Control and Reclamation Act of 1977 and the Wyoming Environmental Quality Act of 1973 (Wyoming Department of Environmental Quality 1996). The process of re-establishing this shrub has been difficult for reclamation specialists. In 1990, Schuman et al. (1998) demonstrated the positive benefits of direct-placed topsoil compared to stockpiled topsoil and of mulch treatments on re-establishment of big sagebrush seedlings at North Antelope Coal mine south of Gillette, Wyoming.

However, ensuring big sagebrush survival remains a challenge years after initial establishment. Reclamation specialists are now exploring the potential impacts of wildlife browsing on big sagebrush survival. Severe browsing on some mines may be a major influence on big sagebrush survival. Newly reclaimed coal mine lands often provide young, highly palatable and nutrient-rich plant communities that attract wildlife species such as mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), cottontail rabbits (*Sylvilagus audubonii baileyi*), and jackrabbits (*Lepus townsendii* and *L. californicus melanotis*). Since adjacent native rangelands often contain older, mature shrubs of lower palatability and nutrient value, wildlife are attracted to reclaimed areas where greater herbaceous material and young shrubs are present. Cool-season grasses and some shrub species, including big sagebrush, generally dominate seeding mixtures used for reclamation. Restrictions on public access and prohibited hunting on mine property encourages wildlife to habitually utilize these reclaimed areas.

To investigate the influence of wildlife utilization on big sagebrush growth and survival, a game-proof exclosure was constructed on a portion of the original North Antelope study site established by Schuman et al. (1998) to provide comparative data on browsed versus unbrowsed big sagebrush. Differences in plant community composition and diversity were also evaluated inside and outside the exclosure.

Past research has enabled reclamation specialists to successfully establish big sagebrush on reclaimed mine lands. Reclamation specialists must now develop successful post-reclamation management practices to increase big sagebrush survival. Quantitative information on utilization levels of big sagebrush by wildlife and browsing impacts on long-term seedling survival are needed.

Objectives

Specific objectives were to (1) determine long-term big sagebrush survival, including data from the original study, (2) evaluate recent effects of wildlife browsing on big sagebrush survival using inside versus outside exclosure comparisons, (3) assess the influence of location (inside/outside exclosure) and grass seeding rates on sagebrush density (plants m^{2}), (4) evaluate differences in seasonal (spring/summer, fall/winter) utilization rates of big sagebrush leader growth between grass seeding rates, inside/outside the exclosure, (5) determine percent cover of plant species, litter, and bare ground at various grass seeding rates, inside/outside the exclosure, and (6) evaluate differences in plant diversity and species similarity between various grass seeding rates inside/outside the exclosure.

Methods and Materials

The original big sagebrush establishment study design (Schuman et al. 1998) was utilized in the current project. The original study was initiated in August 1990, on approximately 1.2 ha of leveled coal mine spoil and included the following treatments: topsoil management (fresh stripped and 5-year-old stockpiled topsoil), mulch type (stubble mulch, surface-applied straw mulch, stubble and surface-applied straw mulch, and no mulch), and grass seeding rate (no perennial grass seeded, 16 kg PLS [pure live seed] ha^{-1}, and 32 kg PLS ha^{-1}). All treatments were randomly located in a randomized block, split-split plot design with 3 replications. Topsoil treatment plots were 15 by 60 m with mulch subplots measuring 15 by 15 m and grass seeding rate sub-subplots

measuring 15 by 5 m. Each of the 4 mulch types occurred within each of the 3 replications of fresh and stored topsoil treatments. The stockpiled topsoil plots were excluded from study in this project because of the noted benefits of fresh topsoil. The 3 grass seeding rates were randomly established within each of the 4 mulch treatments. Nine quadrats (1 m^2) were permanently staked in each of the grass seeding rate sub-subplots in 3 belts of 3 quadrats, lying in an east-west direction and located 1 m from the edge of each subplot. Permanent belt transects (2 by 12 m) were also established in the center of each grass seeding rate sub-subplot. The only other alteration to the original study was the addition of a game-proof exclosure, constructed June 4, 2001. Dimensions of the exclosure are 90 by 30 m and 3.05 m tall. The exclosure protects half of each of the 3 replicated topsoil treatments. Therefore, the same number of mulch treatment subplots and grass seeding rate sub-subplots are located inside and outside the exclosure. The fence is constructed of woven wire with chicken wire extending along the ground surface and about 0.5 m high along the fence to exclude rabbits.

Big sagebrush density was evaluated from the original quadrats and newly established belt transects. Density was summarized as the mean number of plants m^2 in each grass seeding rate, inside and outside the exclosure. Density of big sagebrush was determined in June and September 2001, and April and September 2002.

Percent cover of vegetation, bare ground, and litter were determined using a 10-pin point frame placed every 1.2 m along the permanent transects for a total of 100 pin-hits per transect. Mean percent cover was calculated for each grass seeding rate, inside and outside the exclosure. Mean plant species cover was converted to relative cover and used in calculating community diversity and similarity indices. Percent cover was determined in June 2001 and 2002.

In June 2001, 4 big sagebrush plants were selected within each grass seeding rate sub-subplot and marked by attaching plastic zip-lock ties at the plant base. In June and September 2001, and April and September 2002, marked plants were recorded as browsed or unbrowsed. In April and September 2002, type of browser (big game species or rabbit) was also recorded for marked plants outside the exclosure. Current leader growth was also measured on marked big sagebrush plants. Leader length was summarized as the mean leader length per plant for each grass seeding rate, inside and outside the exclosure. The difference in mean leader length provided percent seasonal utilization.

In September 2001, April 2002, and September 2002, pellet groups of big game (antelope and mule deer) were counted, recorded, and removed from the permanent belt transects. Big game pellet group densities (number m^{-2}), along with percent utilization of big sagebrush at the various grass seeding rates, provided trends of use and preference by big game. Rabbit fecal pellets were recorded (presence or absence) and removed from belt transects.

Analysis of variance (ANOVA) was used to evaluate differences in big sagebrush density, percent vegetative cover, diversity indices, number of pellet groups, percent big sagebrush plants browsed, mean leader length, and percent seasonal utilization between grass seeding rates, inside and outside the exclosure. Mean separations were evaluated using Tukey's pairwise comparison test ($\forall = 0.10$).

Results

Big sagebrush density (plants m^2) from permanent quadrat data displayed increases the first 2 years (1993 and 1994) following seeding (1992), but then declined during subsequent years across grass seeding rate and mulch treatment (Schuman and Belden 2002). Although big sagebrush density was significantly greater in the 0 kg PLS ha^{-1} grass seeding rate in 1992, these differences were not significant in later years, but were equivalent to the 16 and 32 kg PLS ha^{-1} by 2000-02, reflecting a greater magnitude of reduction in density across the long-term project period. More big sagebrush seedlings successfully germinated in the 0 kg PLS ha^{-1} grass seeding rate initially, but we suspect they experienced more intraspecific competition and subsequent wildlife browsing resulting in higher overall mortality compared to the 16 and 32 kg PLS ha^{-1} grass seeding

rates.

Big sagebrush density from belt transect data during 2001-02 was significantly higher in the 32 kg PLS ha^{-1} grass seeding rate compared to the 0 and 16 kg PLS ha^{-1} inside the exclosure, and significantly higher inside versus outside the exclosure within the 32 kg PLS ha^{-1} grass seeding rate. Likewise, big sagebrush density for all grass seeding rates combined was significantly higher inside compared to outside the exclosure in the second sample year (2002) but not in 2001. A total of 24 marked big sagebrush plants died outside the exclosure compared to 8 plants inside the exclosure during the 2001-2002 study period. Outside the exclosure, the number of dead marked big sagebrush plants was lowest in the 32 kg PLS ha^{-1} grass seeding rate (5) compared to the 0 (10) and 16 (9) kg PLS ha^{-1} grass seeding rates. These data suggest a higher survival rate of big sagebrush seedlings in the 32 kg PLS ha^{-1} grass seeding rate.

Percent of big sagebrush plants browsed was significantly different outside (100%) compared to inside (0%) the exclosure during 2002. Likewise, mean percent shrub cover was significantly lower outside compared to inside the exclosure by 2002. Rabbits were the primary browsers of big sagebrush rather than big game, as determined by characteristics of severed leaders. Pellet group analysis (fecal deposits) indicated presence of rabbits in all grass seeding rates outside the exclosure. Big game pellet groups were considerable less prevalent among sample plots.

Mean current annual leader lengths (mm) were significantly longer across all grass seeding rates inside (0 kg PLS ha^{-1}, 45.1 mm; 16, 39.5 mm; 32, 48.4 mm) versus outside (0 kg PLS ha^{-1}, 16.6 mm; 16, 17.6 mm; 32, 16.2 mm) the exclosure across the total sampling period. Mean leader lengths progressively decreased outside the exclosure and increased inside the exclosure with each successive sampling period during 2001-2002. Mean percent seasonal utilization was consistently higher during winter across all grass seeding rates (0 kg PLS ha^{-1}, 53.7%; 16, 43.2%; 32, 23.6%) compared to summer (0 kg PLS ha^{-1}, 20.7%; 16, 14.9%; 32, 20.1%). In addition, mean percent winter utilization was significantly lower (23.6%) in the 32 kg PLS ha^{-1} grass seeding rate compared to the 16 (43.2%) and 0 (53.7%) kg PLS ha^{-1} grass seeding rates. We hypothesize that significantly lower percent winter utilization, higher percent survival of initially established seedlings, and lower overall percent mortality of big sagebrush in the 32 kg PLS ha^{-1} grass seeding rate in this study suggests a beneficial relationship between big sagebrush re-establishment long-term success and higher grass seeding rates.

Mean percent cover of grasses and total vegetation across all grass seeding rates inside and outside the exclosure were greater in 2001 (grasses, 35.6%; total vegetation, 47.2%) compared to 2002 (grasses, 19.3%; total vegetation, 29.9%), probably due to below average precipitation in 2002 (242 mm compared to 333 mm mean annual precipitation, 1978- 2002). Plant species diversity and similarity indices were comparable within and between grass seeding rates, inside and outside the exclosure.

Recommendations

Since intense wildlife utilization suppressed big sagebrush survival on this mine site, reclamation specialists should consider post-reclamation management practices to reduce herbivore impacts. Habitat on adjacent, native rangeland may be improved to attract wildlife away from reclamation sites, and therefore, potentially enhance big sagebrush survival. Prescribed burning, mechanical practices (mowing, chaining, cabling, roto-beating), and chemical applications (herbicides, fertilizers) that increase woody and herbaceous plant production, improve forage quality, and enhance plant diversity on adjacent native rangeland may help distribute wildlife across the landscape (Emmerich 1982, Bainter 1982). Inter-seeding perennial grasses and forbs, combined with pro-active management of over-mature big sagebrush stands, would enhance adjacent native rangelands and improve big sagebrush survival on reclaimed areas by improving wildlife distribution.

Improving wildlife distribution and enhancing rangeland forage quality may not be

appropriate or acceptable to the regulatory agency and mining companies, or may not be entirely adequate for reducing wildlife use on reclaimed areas. In some situations, where feasible and practical, wildlife population management may need to be considered. Allowing limited harvests (hunting) under strictly enforced and supervised situations, where compatible with the mine environment and safety considerations, may be an additional management option.

If hunting is an undesirable solution, rabbit utilization of big sagebrush could be reduced by using repellents, toxicants, or traps on reclaimed areas (Craven 1983a, Knight 1983). Another suggested management practice to control rabbit populations is erection of raptor roosts near reclaimed areas and removing rockpiles that attract rabbits. Big game could be temporarily discouraged by using non-lethal damage control techniques as frightening (fireworks, propane zon guns) or repellents (smell, taste aversions) (Craven 1983b, Schemnitz 1983). These approaches are labor-intensive, however, and require frequent change in approaches to be successful.

Project data indicates that wildlife densities are impeding successful long-term survival and growth of big sagebrush on reclaimed areas at North Antelope Coal Mine. Both proactive wildlife management and habitat manipulation may be necessary for successful reclamation of these impacted sites. Without proper wildlife and habitat management, big sagebrush densities could decline to less than 1 plant m^{-2} on these sites, and not satisfy the required density for bond release (Wyoming Department of Environmental Quality, Land Quality Division 1996).

Future Research

Our data suggests that a higher grass seeding rate atthe time of initial reclamation may lead to greater big sagebrush re-establishment success and prolonged survival, however, the specific ecological relationship between seeding rate and big sagebrush seedling response cannot be fully explained with this data set. Future research should focus on the ecological aspects of this relationship to fully understand this process, and subsequently, develop management practices to enhance big sagebrush re-establishment.

From a landscape perspective, research is needed to evaluate the feasibility of manipulating/enhancing adjacent native rangeland plant communities using various range improvement practices to attract wildlife away from newly reclaimed sites and improve herbivore distribution. In addition, animal damage management techniques, particularly focused on rabbits, should be explored for their feasibility in reducing impact to big sagebrush seedlings and young plants. Holistic wildlife and habitat management practices need to be incorporated in a post-reclamation resource management strategy.

Publications

Partlow, K.A., R.A. Olson, G.E. Schuman, and S.E. Belden. (In Press). Effects of wildlife utilization and grass seeding rates on big sagebrush growth and survival on reclaimed mined lands. pp. __, *In:* Hild, A.L.; Shaw, N.L.; Meyers, S.E.; Schupp, E.W.; and Booth, T.D. (compilers). Seed and soil dynamics in shrubland ecosystems: proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-000. Ogden, UT; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.(In press)

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Ecology of the greater sage-grouse (*Centrocercus urophasianus*) in the coal mining landscape of Wyoming's Powder River Basin

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Final Report, November 2003

Introduction

The greater sage-grouse (*Centrocercus urophasianus*) has been extirpated from peripheral portions of its range and populations have declined in most other areas (Connelly and Braun 1997). Habitat loss, degradation, and fragmentation have been major factors contributing to population declines.

In the Powder River Basin of northeast Wyoming, sage-grouse occur in close proximity to coal mines. Such large-scale surface coal mining has the potential to negatively affect grouse populations in many ways including: behavioral disturbance, vehicle collisions, habitat loss, and habitat fragmentation. Some authors have investigated the effects of mining and made recommendations for mitigating impacts and reclaiming sage-grouse habitat after mining. However, few studies have examined the movements and habitat preferences of grouse in the vicinity of active mines.

In light of long-term conservation concerns for sage-grouse and the continued expansion of coal mining in the Powder River Basin, it is important to understand how grouse use the landscape in the vicinity of active mines and how lands can be reclaimed after mining to benefit those local populations. To address those issues, this three-year investigation of the movements, habitat preferences, and demographics of sage-grouse in the vicinity of several active coal mines in the southern Powder River Basin was initiated in spring 2001.

This research will help define which vegetation parameters are preferred by sage-grouse during different seasons throughout the year in the southern Powder River Basin. Such local information, combined with previously published data from other regions, will provide a clearer picture of how well current reclamation practices provide habitat for sage-grouse and how practices might be improved. Spatial data collected during this study will reveal areas that are consistently used by grouse and may help to define the potential impact of mining on this population and delineate priority areas for post-mining shrub establishment. This study will also lend valuable data to the Wyoming Game and Fish Department's (WGFD) planning and management efforts, particularly towards development of the upcoming Powder River Basin Sage-grouse Conservation Plan. State-wide and local conservation plans and their resulting management are needed to prevent federal listing of the sage-grouse under the Endangered Species Act. Such a listing would significantly impact coal mining operations in Wyoming.

Study Area

The focus of this study is the Rochelle lek complex sage-grouse population. Leks comprising that complex are located approximately 25 km southeast of Wright, Campbell County, Wyoming. Recent counts from the two active leks in the Rochelle complex yielded a conservative population estimate of fewer than 100 birds. Predominant habitats within

the ~1,200 km^2 study area include: herbaceous rangeland (~63%), sparse big sagebrush (~20%) moderately dense big sagebrush (~14%), and ponderosa pine (~1%). Portions of five active coal mines occur within the study area. Other significant activities in the area include pervasive livestock (cattle and sheep) grazing, conventional oil and gas extraction, and coal bed methane development.

Methods

Methodology for capturing and radio tracking grouse, measuring vegetation, and assessing nest success follow procedures used by most contemporary sage-grouse researchers (Connelly et al. 1991, Fischer et al. 1993, Gregg et al. 1994, Sveum et al. 1998).

Grouse were captured during spring 2001 through 2003 in the vicinity of two active leks using spotlights and either a long-handled fishing net (Geisen et al. 1982) or a net gun. They were fitted with 14-24 g necklace-style radio transmitter (Advanced Telemetry Systems, Isanti, MN) and released at the point of capture. Collared grouse were re-located approximately every 10 days using both hand-held and vehicle mounted receiving systems. Specifically, biologists "homed in" with the vehicle from roads and then walked until the grouse were seen. Precautions were taken to avoid flushing incubating hens from their nests or dispersing young broods.

Data collected at all relocation sites included: UTM coordinates, notes on group size and composition (age/sex), canopy cover and height of big sagebrush, and maximum droop height of grasses. During spring, summer, and fall, we also measured canopy cover of grasses, forbs, cacti, litter, and bare ground. Sagebrush canopy cover was measured along two 10 m perpendicular, intersecting transects (Canfield 1941). Percent cover of other variables was estimated within nine 20 x 50 cm plots (Daubenmire 1959) spaced equidistantly along the sagebrush cover transects. Sagebrush and grass height were also measured at nine points along the sagebrush cover transects. During winter months, snow depth was measured at nine points along those transects.

Additional variables measured at nest sites included: the species, height, and crown volume of the nest shrub, and big sagebrush density (stems/m^2) within a 25 m^2 plot centered on each nest. Measurements were not taken at nest sites until after hens and broods had dispersed from the area. Nest fate (hatched or depredated) was determined from the condition of the eggs and shell membranes.

To facilitate an analysis of habitat preferences, in July 2002 we sampled the previously described habitat variables at 97 sites that were selected through a stratified-random process based on digital land-cover data provided by the WGFD.

Results

Thirty-nine grouse (28 hens and 11 males) were captured and radio-collared (10 in 2001, 19 in 2002, and 10 in 2003). Over the approximately three-year study period (April 2001 through October 2003), radio-collared grouse ranged over 421.9 km^2 (100% minimum convex polygon, Mohr 1947, Table 1). Ninety percent of those grouse locations were within 8.0 km of either of the two active leks. Grouse were found within portions of three coal mine permit areas, and used reclaimed grasslands at one mine. Population seasonal ranges overlapped considerably, suggesting that the population is non-migratory.

Of grouse that were relocated at least 13 times after being captured (n = 22), individual home ranges varied from 0.9 to 237.8 km^2, and averaged 31.3 km^2. The median individual home range was 12.4 km^2.

Over the study period nest initiation by radio-collared hens averaged 96.9%. Nests (n = 33) averaged 2.73 km from the closest active lek. Nests were located 0.08 to 28.46 km (mean = 3.11 km) from lek of capture. Clutch size (n = 28) ranged from 5 to 10, and averaged 7.3. Over the three nesting seasons, nest success ranged from 35.7% to 75.0%. All but two nest failures

Table 1. Seasonal population range (100% Minimum Convex Polygon) statistics of radio collared sage-grouse from the Rochelle lek complex in southern Campbell County, Wyoming.

Season	n	Seasonal range (km
Breeding/pre-nesting (16 March-30 April)	13	121.67
Nesting/early brood rearing (1 May-15 July)	18	349.37
Summer/late brood rearing (16 July-31 Augus	13	236.19
Autumn (1 September- 31 October)	9	317.22
Winter (1 November-15 March)	10	315.63
Overall	66	421.9

were attributed to predation: one hen abandoned and one was killed away from the nest. Of depredated nests in all years, only one hen ever re-nested.

Annual and seasonal survival estimates (Heisey and Fuller 1985) were calculated for all grouse (Table 2). No significant differences were found either within or between years, probably because of limited sample size. However, survival was lowest during winter 2001-2002, and from nesting through late brood rearing 2003. Although the cause of death could not be determined with certainty in all cases, it appeared that 72% of mortalities were the result of predation, 16% from the effects of West Nile Virus, and 12% other (fence, vehicle, fight).

Table 2. Annual survival of radio collared sage-grouse from the Rochelle lek complex in southern Campbell County, Wyoming.

Period	n	2001-20	2002-20	2003
Breeding/pre-nesting	(0,18,1	---	0.900	0.947
Nesting/early brood rearing	(10,17,1	0.854	0.940	0.782
Summer/late brood rearing	(9,16,1	0.891	0.876	0.730
Autumn	(8,14,8	0.868	0.926	0.806
Winter	(7,13)	0.697	0.913	---
Annual	(10,16,1	0.432	0.567	0.432

Statistical comparisons of used and available habitats have not yet been conducted. However, summary statistics suggest that grouse are nesting and otherwise using sites with taller and denser sagebrush than is generally available within the study area (Table 3). Seasonal summaries of habitat use are presented in Table 4.

Future Analyses

Field work has been completed for this project and we are in the process of analyzing and interpreting data. Productivity, survival, and home range data will be qualitatively compared with published information from populations in less industrialized landscapes. We will analyze habitat preferences using sampled vegetation parameters and digital land-cover data. Spatial analyses will also be conducted to assess landscape variables and habitat suitability within the range of both the Rochelle grouse population and the southern Powder River Basin in general. Such analyses would facilitate habitat and population models that could address the potential impacts of future mining.

We will present and make the results of this project available to a wide audience of industrial, governmental, and private entities. We are currently collaborating with researchers from Wyoming, Montana, and Alberta on a manuscript for the journal *Science*.

Table 3. Summary of vegetation parameters (mean and SE) at 33 nests and 460 use-sites of radio collared sage-grouse, and at 97 random locations in southern Campbell County, Wyoming.

Parameter	Nest site	Use sites	Random site
Sagebrush canopy cover (%)	22.9 (1.8	14.5 (1.0	5.5 (0.8)
Sagebrush height (cm)	30.9 (2.0	31.4 (1.6	18.9 (1.5)
Nest shrub height (cm)	56.3 (2.0	---	---
Nest shrub crown volume (m^3)	1.6 (0.2	---	---
Sagebrush density (stems/m^2)	1.1 (0.1	---	---
Grass height (cm)	20.2 (1.7	17.5 (1.1	13.3 (0.4)
Grass cover (%)	34.8 (2.8	35.7 (2.2	28.9 (1.8)
Forb cover (%)	6.1 (1.0	4.9 (.71)	2.4 (0.5)
Litter cover (%)	16.7 (1.3	35.2 (2.4	32.7 (1.4)
Bare ground (%)	37.8 (3.8	24.3 (2.6	32.5 (2.1)

Table 4. Summary of vegetation parameters (mean and SE) at 460 use-sites of radio collared sage-grouse during five biological seasons, and at 97 random locations in southern Campbell County, Wyoming.

Parameter	Breeding/pr nesting (58	Nesting/early b rearing (12	Summer/late b rearing (11	Autumn	Winter (1	Random s (97)
Sagebrush cano cover (%)	15.8 (1.3)	15.5 (1.1)	13.3 (1.0)	14.5 (1.	13.9 (0	5.5 (0.8
Sagebrush height	30.2 (1.2)	33.5 (1.0)	38.7 (1.1)	31.9 (1.	27.6 (0	18.9 (1.
Grass height (c	12.1 (0.7)	20.8 (1.1)	23.0 (1.4)	16.8 (0.	10.8 (0	13.3 (0.

Snow depth (cm	4.9 (1.9)	---	---	---	4.3 (0.	
Grass cover (%	31.5 (4.0)	38.4 (1.9)	38.5 (1.7)	28.9 (2.	---	28.9 (1.
Forb cover (%	2.6 (0.5)	5.4 (0.6)	5.4 (0.7)	4.3 (0.8	---	2.4 (0.5
Cactus (%)	1.2 (0.2)	1.6 (0.3)	0.9 (0.2)	1.1 (0.2	---	1.4 (0.3
Bare ground (%	28.4 (3.7)	35.8 (2.4)	35.2 (1.9)	36.0 (2.	---	32.5 (2.
Litter cover (%	33.5 (4.4)	19.9 (2.4)	24.0 (2.2)	29.3 (2.	---	32.7 (1.

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Evaluation and Comparison of Hypothesis Testing Techniques for Bond Release Applications

by

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Statistically valid tests must be used on quantitative data to determine if reclaimed areas have successfully revegetated. Under current Wyoming regulations, mine operators first determine that they have sampled the reclamation adequately using a sample adequacy formula before conducting a statistical test. Appendix A of the LQD Coal Rules and Regulations contains a sample adequacy formula, but does not specify statistical methods for testing revegetation success. The purpose of this project was to provide a scientific basis for statistical methods used for bond release, and to develop recommendations the LQD may use for revisions to Appendix A.

We used bond release data to examine how different statistical procedures performed using real data from Wyoming, or from plant communities similar to those found in Wyoming. We used simulated data to evaluate properties of statistical testing methods to determine how statistical tests performed under different scenarios by varying effect size (the difference between reclaimed and reference means/technical standard) and the coefficient of variation (variance expressed as a percentage). The results of this study are presented in a final report, and recommended bond release statistical procedures are provided in Appendix 1 to the final report. This appendix is written in a format similar to the Statistical Procedures appendix to the New Mexico Rules, and is intended for Wyoming LQD use. We developed two flow charts for Appendix 1 that guide the user through the procedures necessary to determine the appropriate statistical test.

Objectives

The objectives of this project were to evaluate sample adequacy formulas and potential statistical tests that may be appropriate for bond release assessment, specifically:

1. To explore and illustrate the relative merits of different statistical tests commonly used to help evaluate if bond release is warranted, including standard t-tests, reverse null tests, and nonparametric tests.
2. Review and evaluate sample adequacy formulas for one sample and two sample tests.
3. Evaluate the influence of sample size, data distribution, and variance on the outcome and validity of each statistical test.

4. Develop recommendations for sample adequacy calculations and bond release testing procedures, including a "road map" to determine recommended statistical tests and methods.

Statistical Tests for Bond Release

Statistical tests used in evaluating bond release take two general forms, one-sample and two-sample tests. One-sample tests are used when the reclamation vegetation parameter is tested against a technical standard. The value of the reclamation vegetation parameter is estimated using data collected from the reclaimed area. Because the value (e.g. arithmetic mean) is an estimate of the "true" mean, there is error associated with this value (variance). In contrast, a technical standard is a predetermined fixed value of the vegetation parameter, with no associated error, and "one-sample" test procedures are appropriate.

When vegetation parameters from both reclaimed and native reference areas are estimated, a two-sample test is used. The two-sample test takes into account that the parameters of both populations are estimated with associated errors. The statistical method most often used by coal and noncoal operators in bond release comparisons in Wyoming is a one-sample t-test. In those cases where comparisons are made with reference areas, use of this method incorrectly assumes that the vegetation parameters on the reference area are measured without error. The one-sample t-test and other one-sample procedures are not appropriate unless the reclaimed area statistic is being compared to a fixed "standard" value.

The most commonly used test in Wyoming for evidence concerning bond release, the *classic t-test*, tests a null hypothesis that the mean of the reclamation is greater than or equal to the mean of the reference (Reclamation mean $\geq$ reference mean (or technical standard)). Evidence for bond release is achieved when the null hypothesis is accepted. T-tests were developed for experiments designed to test a hypothesis by disproving (rejecting) the null hypothesis. Failing to reject, or accepting, the null hypothesis does not prove this hypothesis to be true, only that the test did not prove the null hypothesis <u>is not</u> true (the result may be a "false negative"). Therefore, acceptance of the null hypothesis is not considered as scientific proof that the null hypothesis is true. High variation due to inadequate sample size, variation in experimental units, or imprecise measurement techniques can yield data for which the null hypothesis is accepted when an important difference truly exists. Therefore, it is inappropriate to use the classical hypothesis test without consideration of sample sizes and variance when the desire is to show the null hypothesis is true. In Wyoming and other western states, this problem with the classical test of a null hypothesis has led to stringent sample adequacy requirements to assure that the tests have sufficient power to reject the null hypothesis when an important effect exists (e.g., an important

difference between reference and reclaimed areas (or technical standard)). In this manner, the state is protected from the possibility of failing to reject the null when an important effect exists. If a data set does not meet sample adequacy, alternative test procedures must be used in order to provide evidence that the reclamation really does meet bond release criteria.

One of the alternative tests used by other states is a *reverse null t-test*, which simply reverses the inequality sign. The null hypothesis is that the mean of the reclamation is less than or equal to some proportion of the reference mean (Reclamation mean $\leq$ proportion of reference mean (or technical standard)). Evidence for bond release is obtained when the null hypothesis is rejected. In this case, the test allows for a definitive conclusion that the null hypothesis is not true, rather than inconclusive evidence that the null hypothesis is true, as is the case with the classic approach. This is a more defensible test because the test concludes the reclamation mean is $\geq$ the reference mean, having proven it is not less than the reference mean. Because the state is protected by this hypothesis testing method, there is no sample adequacy requirement for reverse null procedures.

Alternatives to t-tests are *nonparametric procedures*, which do not require the data to follow a normal distribution or have equal variances. These tests are not sensitive to high variance or heavily skewed data, and perform better than the t-tests for classical null hypotheses in some situations. Nonparametric methods typically have less efficiency and therefore power, given the same sample size than their parametric t-test counterparts (if the data are approximately normally distributed).

Sample adequacy for bond release is directly tied to the use of classical null hypothesis testing for bond release data. Sample adequacy requirements are a necessary part of classical statistical methods, ensuring the tests have sufficient power to detect biologically important effects. Classical hypothesis tests for one sample or two sample data have different requirements for sample adequacy. Though in both cases, it is the size of the variance of the estimate that determines the sample size and not the size of the area to be sampled. Large sample sizes will be required for areas with large variance, regardless of the size of the area. Sample adequacy calculations are inaccurate when the data distribution is extremely non-normal. Under circumstances where the data are extremely non-normal, the better choice is a nonparametric statistical test that does not require normally distributed data.

Summary of statistical tests recommended for evaluation of data for bond release

The final report and Appendix 1 provides procedures for bond release tests of one-sample and two-sample data. A one-sample classic t-test, a one-sample reverse null t-test, and a nonparametric reverse null sign test are proposed for one-sample data. Similarly, a two-sample classic t-test, a two-

sample reverse null t-test, and a nonparametric reverse null test are proposed for two-sample data. The authors recommend using the reverse null approach for bond release evaluations. If the data meet the assumptions of normality and equality of variance (two-sample data), the reverse null t-test approach is appropriate. If the data do not meet the assumptions, a reverse null nonparametric test is appropriate. In all cases, the reverse null nonparametric test for one-sample or two-sample data is appropriate. It is only acceptable to use the classic t-test when sample adequacy has been met, in addition to the other assumptions regarding data distribution.

The appropriate test is determined by the ability of the data to meet sample adequacy and the applicable assumptions of normality and equality of variances. We developed separate flow charts for one- and two-sample data. The user tests the data assumptions and sample adequacy in the order indicated on the flow chart, and follows a "yes" or a "no" pathway to the next procedure, ultimately ending at an appropriate statistical test. The number of procedural steps to determine the appropriate statistical test range from one to three. At each juncture, the user may choose to follow the "no" pathway to a statistical test or the next procedure, without testing the assumption to determine if the data meet that assumption. These flow charts are the decision tools essential for determining the appropriate statistical test to be used for bond release evaluation.

Sample adequacy formulas are presented for situations where one data set is involved (one-sample), or where two data sets will be used in a statistical test (two-sample). Sample adequacy using a one-sample test is appropriate when sample size is calculated for one data set to be compared to a technical standard. This calculation is also appropriate for baseline data sets, when no statistical comparison between the proposed affected area and a reference area is planned. When two data sets are collected and are to be compared (reclaimed and reference), then it is necessary to calculate the sample size for both areas. This can be done using one equation, where the variance of the two data sets are pooled, and the calculated sample size applies to both data sets. This approach is described in the final report, but not included in the statistical procedures appendix. Alternatively, a sample size may be calculated for each data set individually. Although the formula for this calculation is similar to the one-sample formula, the alpha level is adjusted (alpha/2) because the two criteria are satisfied simultaneously. This results in a higher sample size for comparison of means from two data sets, as compared to a similar calculation for one data set.

2003 ANNUAL PROJECT REVIEW SEMINAR

ABANDONED COAL MINE LAND RESEARCH PRORAM

The Effects of Seed Mix Species Composition and Seeding Rates on Attaining Species Diversity for Reclaimed Areas

Interim Progress Report
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Introduction

LQD Rules and Regulations specify diversity as a requirement for revegetation success for surface coal mining operators. The LQD is developing technical standards for species diversity that operators must meet to achieve bond release. In order to achieve success, it is essential to understand the effect of seed mixes and seeding rates on species establishment and persistence. Many factors contribute to the successful establishment of a persistent, diverse plant community. However, the seed mix is the key determinant for species composition, and strongly affects species relative composition through seeding rates. A quantitative assessment of the relationship between seeding rates, seed mix species composition, and observed cover through time in revegetated areas of Wyoming will help identify species that consistently dominate, persist at low levels, or do not persist. Investigation of the seeding rates will attempt to identify subordinate species that can coexist with dominants if certain combinations of seeding rates are planted. This information will also be used to design seed mixes to obtain diversity in reclaimed areas.

The first objective of this project is to analyze the seed mixes and seeding rates used in Wyoming to assess how individual species perform, and how this performance is affected by the composition of the seed mix, seeding rates, and other factors. We will incorporate factors such as climate, topsoil depth, and management practices such as mulching and timing of seeding. The outcome of this study will be a final report that may be used by LQD to develop guidance documents for designing seed mixes. The second objective is to develop a product for LQD to use to continue to build knowledge and understanding of seed mix performance through time. This product will include an Access data base and analysis methods for LQD to continue the investigation on seed mix performance as additional vegetation monitoring data becomes available.

Methods/Progress

Our study plan involves conducting a literature review, selecting mines for the analysis, acquiring vegetation data and reclamation history information, designing the database, entering the data, Phase I analysis, Phase I review, Phase II analysis, Phase II review, and the development of an analysis tool for LQD.

We have started an extensive literature review on reclaimed mine land revegetation techniques. This literature review is being conducted to locate studies which have investigated the relationships between plant establishment and seed mix composition and seed rates.

We have also started acquiring data and developing the database to house and manage interim monitoring and bond release vegetation data for this project. Our ability to obtain data from a broad range of ecological conditions, seeding mixes, and seeding rates will directly influence the applicability of the results. The selection of the mines used in the analysis has taken several factors into account including: seed mix variety, completeness of reclamation record, and mine operator interest. We have limited our scope of study to the Powder River Basin and intend to involve at least 5 mines in the study.

The database has been designed using Microsoft Access and involves several tables linked together. The analysis depends on the ability to link the interim vegetation monitoring data with the seed mix planted and any other actions performed on a reclamation unit.

We have started data entry for the Belle Ayre Mine. We are using interim monitoring and bond release vegetation data from hard-copy reports housed at LQD's Cheyenne office. Several sources of information, including the annual reports, mine permit and maps, are being used to link the vegetation monitoring locations with the reclamation history. After the data has been entered for each mine selected for this study and before analyses begin, we will perform a quality assurance/quality control (QAQC) check on the data.

The Phase I analysis will be a broad analysis to look for general patterns in the data at the level of the individual species. This analysis will assess species establishment and persistence through time, independent of the other species present in the seed mix. An assessment of the relationship between observed cover of each species to seeding rates, mine location and other factors will be conducted. This phase is designed to identify patterns that will provide reliable predictors of species presence on a reclamation unit. There are four major categories of patterns we will investigate in Phase I: Persistence, Patterns of Dominance, Patterns of Subordinance, and Invasions.

The results of the Phase I analysis will be reviewed by all investigators. Feedback from LQD, mine operators, and consultants will also be solicited. During the review, we expect the Phase I results will lead us to refine the specific analysis questions for the Phase II analysis.

The Phase II analysis will be a detailed multivariate analysis to look for specific patterns in the data. This analysis will investigate the relationship of observed cover of each species to the cover and seeding rates of the other species in the seed mix. When the data are adequate, we will investigate the influence of other environmental factors such as aspect, slope, precipitation, climate, mulch type, mulch depth, topsoil depth, seeding method, planting time (month), deer density, and other land management characteristics. The second phase is designed to identify explanations for the patterns identified in the first phase of the analysis and we expect specific research questions will be identified after the review of the phase I analysis. In addition, this phase will have an exploratory component that will look for patterns that were not apparent in Phase I, particularly the effect of seed mixes. There are three major categories of investigations we will pursue in Phase II: Community Response, Discrete Influences, and Continuous Influences.

The results of the Phase II analysis will be reviewed by all investigators. Collaborations between the biometricians and ecologists will facilitate the identification of ecological explanations for the results obtained by the data analysis. Feedback from LQD, mine operators, and consultants will also be solicited. During the review we will compare the results documented by this analysis with results obtained by more experimental approaches to the same questions. It is expected the experimental results will support the patterns observed in this project.

The final piece of this project will be to develop a protocol (guidelines and programs) for a systematic analysis of the new data available after this project is finished. The analysis will be based on the results we determine to be most useful during Phase I and II of this project.