# PLANT SUCCESSIONAL RESPONSES TO TOPSOIL THICKNESS AND SOIL HORIZONS[1]

Kent A. Crofts[2], Claire E. Semmer[3] and Clem R. Parkin[4]

Abstract.--The movement and reapplication of topsoil is one of the most expensive aspects of reclamation of strip mined land. The purpose of this study, which was established in 1976 at Colorado Yampa Coal Company (formerly Energy Fuels), was to evaluate plant successional responses to four treatments of segregated respread topsoil horizons and also five treatments of respread topsoil. The segregated topsoil horizon study involved treatments of A horizon only, B horizon only, A over B horizon and A and B horizons mixed. The respread topsoil study consisted of treatments ranging from 0, 10, 20, 30 and 46 cm topsoil depths. Parameters of cover and production were evaluated in 1979, 1981, 1983 and 1985. Data collected in 1985 indicate total plant cover does not appear to be affected by either segregation of soil horizons or thickness of respread topsoil. Plant biomass and species diversity followed a similar pattern. If the results of this study were applied to this operation, or one possessing similar environmental characteristics, substantial cost savings could be realized.

## INTRODUCTION

The two most expensive aspects of mine land reclamation are regrading to approximate original contour and the removal and respreading of topsoil. In today's depressed economic state of the mining industry, it is imperative to examine these two areas for potential operational cost savings. The results of this study can be applied to costs associated with topsoil handling.

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 established the basic criteria for revegetating mined land. In order to restore the land "to a condition capable of supporting the uses which it was capable of supporting prior to mining" and to establish "a diverse, effective and permanent vegetative cover", it has long been assumed such goals could only be obtained with the reapplication of all available premining soil material and with such material being segregated as "subsoil" and "topsoil".

Topsoil is defined by the Office of Surface Mining (OSM 1983) as "The A and E [$A_2$] soil horizon layers of the four master soil horizons". Subsoil is defined as the "B horizon, the layer typically is immediately beneath the E [$A_2$] horizon". Section 816.22 of the OSM Permanent Regulatory Program required separate removal of all available topsoil and subsoil when necessary to achieve revegetation. Almost all western states have identical requirements. In many western states, the common current interpretation of this segregation is topsoil and subsoil must be salvaged and respread in two distinct lifts (Walsh 1985). OSM justified this requirement by stating "to mix the various soil horizons, during removal could be counterproductive to restoration of the disturbed area to a level at least equal to the premining capability" (OSM 1979). Technical documentation to support this requirement relative to attaining success standards within the 10 year bonded liability period is lacking.

Comparatively little research has been conducted relative to horizon segregation. Power et. al. (1979) reported the first year results of topsoil and subsoil segregation studies on sodic mine spoil in North Dakota. As reported, maximum plant yields were obtained when topsoil

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[2]Range Scientist, IME, Yampa, Colorado
[3]Environmental Specialist, Yampa Valley Coal Corporation, Oak Creek, Colorado.
[4]Biologist, San Luis County Department of Agriculture, San Luis Obispo, California.



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and subsoil were segregated during the removal and respreading process. They recommended topsoil and subsoil should not be mixed to avoid dilution of the beneficial properties of the topsoil. Four year results from this study were given by Power et. al. (1981). Yields tended to increase from no topsoil, mixed topsoil and subsoil, and respread topsoil over subsoil. They reported yields obtained from the perennial species in the mixed horizon treatment were within 90% of yields obtained with segregated horizon treatments, and only when crop production (spring wheat) is the proposed post mining land use, does the segregation of topsoil and subsoil appear warranted.

Topsoil handling practices similar to those utilized during mining were evaluated by Biondini et al. (1985). This study reported recovery of dehydrogenase activity and mycorrhizae infection potential after six years was not different between slight and severe levels of soil disturbance. Such findings were not anticipated and are somewhat inconsistent with the strategies for increasing plant community diversity on reclaimed lands reported by DePuit (1984) and Allen (1984). They suggested decreasing levels of soil disturbance should produce increased levels of plant community diversity. The findings of Biondini et. al. (1985) suggest the rate of plant succession is inversely correlated with the level of soil disturbance.

Considerably more research has been conducted relative to plant response on topsoil thickness than horizon segregation. Hargis and Redente (1984) and Doll et. al. (1984) reviewed the extensive literature on topsoil thickness and concluded the optimum depth of topsoil on a given site is a function of spoil characteristics, precipitation and plant forms. Working with materials obtained from the Energy Mine in northwest Colorado, McGinnies and Nicholas (1980) reported a highly significant positive correlation between yields in a greenhouse study as soil thickness increased from 0 cm to 46 cm. Stand ratings in the field during the second growing season were reported to have a similar correlation.

Barth (1984) constructed depth studies at 15 sites which were evaluated for a six year period in the Northern Great Plains. He reported the optimum biomass response of cool season perennial grasses was dependent on the spoil traits of each particular site. The depth of respread soil to achieve optimum production ranged from 0 to 71 cm. A significant increase in production on shallower soil depths was observed during the last years of this study. Barth reported the optimum soil depth requirements become more clearly defined with time. On sodic spoil in North Dakota, Power et. al. (1981) reported optimum crop production four years after planting was associated with respread soil depths of between 75 and 120 cm. Pinchak et. al. (1985) reported on the four year results from a topsoil depth study in Wyoming. Maximum production of seeded species was associated with the deepest soil depth (60 cm) while maximum production of nonseeded species was associated with the 0 and 20 cm topsoil treatments. Maximum biomass by individual species was found to vary across soil depth. Highest species diversity and richness values were associated with the 40 cm soil depth. On the Wyoming study, Schuman et. al. (1985) reported maximum biomass of seeded species shifted from the 60 cm depth to the 40 cm depth five years after seeding.

Redente and Hargis (1984) reported on the third year results of a topsoil thickness study conducted in northwest Colorado. Treatment depths were 15, 30, 45 and 60 cm. Maximum biomass of seeded grasses and volunteer species was associated with the 60 cm depth while maximum biomass of seeded forbs and shrubs was associated with the 15 cm depth. Halverson et. al. (1987) reported increased wheat and corn yields were associated with the 60 cm topsoil depth for the first two years following planting, but during years three through six, maximum wheat and corn yields were usually associated with the 30 cm depth. They also reported little benefit could be obtained by applying more than 15 cm of respread topsoil, and also reapplication of more than 30 cm of coarser textured topsoil over fine textured spoil appeared to reduce the productivity of the reclaimed site.

In western Colorado, Redente and Ruzzo (1979) compared second year retorted oil shale biomass at respread soil depths of 30.5, 61 and 91.5 cm. Maximum biomass was reported for the 91.5 cm depth. These authors reported a highly significant correlation between forage production and soil depth. They also suggested the optimum soil depth to reclaim spent oil shale may change over time. Fifth year results of this study were reported by Biondini et. al. (1984). For the introduced seed mixture, the 30 cm plots were dominated by alfalfa (Medicago sativa) while cool season perennial grasses dominated the 60 cm plots. They reported the rate of succession appeared to be inversely correlated with the thickness of respread soil and management inputs. The plant successional aspects of this study four years after seeding were reported by Biondini and Redente (1986). Species diversity was found to be negatively correlated with increasing biomass production, thickness of respread soil, age of the seeded stand and the presence of certain cool season grasses. They concluded the regulatory goals of high diversity and high production were mutually exclusive and increased species diversity might be achieved by reducing stimulus factors (i.e. irrigation, fertilization and thick layers of respread topsoil).

The purpose of this study is to evaluate long term plant response relative to segregation of soil horizons and varying depths of respread topsoil. The results after nine growing seasons were compared to regulatory success standards of plant cover, annual biomass production and species diversity. Furthermore, the applicability of this study relative to cost savings involving topsoil reapplication, is addressed.

## MATERIALS AND METHODS

### Study Site

The study was conducted at the Energy Mine No. 1 of Colorado Yampa Coal Company (formerly Energy Fuels Corporation) located 32 km southwest of Steamboat Springs, Colorado. Elevation of the study site is approximately 2,250 m and the long term average annual precipitation is 410 mm. Approximately 60 percent of the precipitation is received in the form of snow. The area was surface mined in the early 1970's and reclaimed in 1975. Vegetation on the site prior to mining consisted of scattered mountain shrub, treated sagebrush and aspen (Berg and Barrau 1973). The regraded spoil consisted of a mixture of shale and sandstone strata from the Williams Fork Formation of the Upper Cretaceous Mesa Verde Group. The soils used in these studies were mapped according to standard taxonomic procedures prior to disturbance and sampled for chemical and physical properties prior to mining and again following respreading (Heil 1978).

The predisturbance soil survey revealed the barrow area contained three distinct soils. The horizon segregation plots were constructed with a soil classified as a fine-montmorillonitic family of Typic Argiborolls. The topsoil of this soil was rated "excellent" while the subsoil was rated as being of "good to poor" suitability (Heil 1978). Two azonal soils classified as a fine-loamy, mixed family of Pachic Haploborolls and a fine-loamy, mixed family of Lithic Haploborolls rated as "excellent" suitability were used in the topsoil depth plots. The physical and chemical properties of the topsoils, subsoil and spoil materials used in this study are found in Table 1, Physical and Chemical Characteristics of Soil and Spoil Materials.

Further details of the environmental and climatic conditions of the site during the first two years of the study is described in Nicholas (1979) and McGinnies and Nicholas (1980).

### Plot Construction

The horizon segregation study plots measuring 23 x 61 m were established on A, A over B (A/B), B and AB mix soil horizons. All treatments were placed over regraded spoil material. The A horizon plots were constructed by removing the surface 15 cm layer of the barrow area and

**TABLE 1.--PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL AND SPOIL MATERIALS**

| PARAMETER | TOPSOIL DEPTH A | HORIZON SEGREGATION A | B | SPOIL |
|---|---|---|---|---|
| pH | 6.7 | 6.2 | 6.1 | 7.4 |
| EC | 0.7 | 0.9 | 1.7 | 2.2 |
| SAR | 0.9 | 1.4 | 1.5 | 0.6 |
| Sand (%) | 45.5 | 25.5 | - | 24.0 |
| Silt (%) | 27.0 | 41.5 | - | 47.3 |
| Clay (%) | 27.5 | 33.0 | - | 28.7 |
| Texture | CL | CL | - | CL |
| $NO_3$-N (ug/g) | 27.7 | 43.0 | 26.0 | 5.1 |
| P (ug/g) | 23.6 | 20.0 | 6.0 | 4.5 |
| K (ug/g) | 273 | 282 | - | 122 |
| Fe (ug/g) | 57.3 | 82.5 | 61.6 | 38.3 |
| Zn (ug/g) | 2.3 | 3.6 | 1.1 | 6.8 |
| CEC | 21.9 | 23.4 | 23.7 | 11.3 |
| O.M. (%) | 5.4 | 5.0 | 2.0 | 3.2 |
| 1/3 Bar Water (%) | 22.6 | 28.4 | - | 20.2 |
| 15 Bar Water (%) | 11.5 | 14.3 | - | 10.9 |

reapplying the material approximately 30 cm deep over the spoil. The A/B horizon plots were constructed by applying 15 cm of the B horizon material over the spoil, which was removed from the 30 to 45 cm depth of the barrow area. Fifteen centimeters of the A horizon material was placed over the B horizon to establish a total treatment depth of 30 cm. The B horizon plots were constructed be removing the thickness found in the 30 to 45 cm zone of the barrow area and replacing it to thickness of 30 cm over the regraded spoil. The AB mixed horizons were constructed by removing the undisturbed 15 to 30 cm zone, containing both A and B horizons and replacing this material at a thickness of 30 cm.

The soil thickness plots, 18 x 61 m in size, were constructed by removing A horizon material and respreading it on regraded spoil at depths of 0, 10, 20, 30 and 46 cm. Following topsoiling, all plots of both the horizon segregation and topsoil depth plots were bladed, disked and seeded. The plots were seeded with a diverse seed mixture composed of 13 exotic and 23 natives species. The plant species and seeding rates are depicted on Table 2. All of the plots were seeded in October 1976. Each plot was replicated twice in a block design.

### Data Collection and Analysis

Plant cover data was collected in 1979, 1981 and 1985 using the inclined 10 point frame cover estimate technique. For all years, a sufficient number of randomly located samples were taken within each plot. Each point was recorded as to individual plant species, litter, bareground or rock.

TABLE 2.--SEED MIXTURE (Kg bulk seed/acre) FOR HORIZON AND TOPSOIL DEPTH REVEGETATION STUDY

| COMMON NAME<br>SCIENTIFIC NAME | PLANT SYMBOL | Kg/ha |
|---|---|---|
| GRASSES | | |
| Crested wheatgrass<br>Agropyron cristatum | Agcr | 3.25 |
| Tall wheatgrass<br>Agropyron elongatum | Agel | 1.12 |
| Intermediate wheatgrass<br>Agropyron intermedium | Agin | 3.25 |
| Western wheatgrass<br>Agropyron smithii | Agsm | 1.57 |
| Streambank wheatgrass<br>Agropyron riparium | Agri | 1.34 |
| Slender wheatgrass<br>Agropyron trachycaulum | Agtra | 1.12 |
| Pubescent wheatgrass<br>Agropyron trichophorum | Agtri | 1.23 |
| Regar Meadow brome<br>Bromus biebersteinii | Brbi | 1.23 |
| Manchar Smooth brome<br>Bromus inermis | Brin | 1.90 |
| Orchardgrass<br>Dactylis glomerata | Dagl | 0.56 |
| Russian Wildrye<br>Elymus junceus | Elju | 1.23 |
| Duran Hard fescue<br>Festuca ovina duriuscula | Feov | 1.23 |
| Timothy<br>Phleum pratense | Phpr | 0.56 |
| Sherman Big bluegrass<br>Poa ampla | Poam | 0.90 |
| Kentucky bluegrass<br>Poa pratensis | Popr | 1.12 |
| Green needlegrass<br>Stipa viridula | Stvi | 1.12 |
| Winter wheat<br>Triticum aestivum | Trae | 11.20 |
| TOTAL GRASSES | | 33.93 |
| FORBS | | |
| Aster<br>Aster spp. | Aster | 0.28 |
| Cicer milkvetch<br>Astragalus cicer | Asci | 0.56 |
| Arrowleaf balsamroot<br>Balsamorhiza sagittata | Basa | 0.28 |
| Crownvetch<br>Coronilla varia | Cova | 0.56 |
| Utah sweetvetch<br>Hedysarum boreale var utahensis | Hebo | 0.28 |
| Sunflower<br>Helianthus annuus | Hean | 0.28 |
| Lupine<br>Lupinus spp. | Lupin | 0.28 |
| Alfalfa<br>Medicago sativa | Mesa | 0.56 |
| TOTAL FORBS | | 3.08 |
| SHRUBS | | |
| Saskatoon serviceberry<br>Amelanchier alnifolia | Amal | 0.56 |
| SHRUBS - Continued | | |
| Big sagebrush<br>Artemisia tridentata | Artr | 0.17 |
| Cliffrose<br>Cowania mexicana | Come | 0.22 |
| Fourwing saltbush<br>Atriplex canescens | Atca | 0.56 |
| Winterfat<br>Ceratoides lanata | Cela | 0.56 |
| Rubber rabbitbrush<br>Chrysothamnus nauseosus | Chna | 0.17 |
| Green rabbitbrush<br>Chrysothamnus viscidiflorus | Chvi | 0.17 |
| Morman tea<br>Ephedra viridis | Epvi | 0.17 |
| TOTAL SHRUBS | | 2.58 |
| TOTAL | | 39.59 |

Biomass was determined in 1979, 1981, 1983 and 1985 using a circular metal frame. In 1979, a 1 $m^2$ size was used and plants were clipped at ground level as to grasses and forbs. In 1981, 1983 and 1985 a ¼ $m^2$ circular frame was used. Data for 1981, 1983 and 1985 were collected according to perennial grasses, annual grasses, perennial forbs, annual forbs and shrubs. All samples were dried in drying ovens at 105°C for 24 hours.

Vegetation diversity was calculated using the Shannon-Weiner index. For all years except 1978, the relative cover by species was used. For 1978, the index was calculated on stand ratings reported by Nicholas (1979). Species richness was calculated by counting the number of plant species encountered in each individual sample transect. Statistical comparisons of species diversity and richness were made using each transect value as an individual datum as suggested by Pinchak et. al. (1985). The data were evaluated by analysis of variance and linear correlation techniques.

## RESULTS

### Horizon Segregation Study

Density and Stand Ratings

Grass seedling density counts for 1977 were given by Nicholas (1979) and ranged from 37.80 to 60.63 plants/$m^2$. According to criteria given by Valentine (1974), all treatments would be considered "excellent" first year stands. The density counts for the B horizon were found to be significantly higher than the other treatments ($P \leq .001$). Stand ratings for 1978 were reported by Nicholas (1979) to range from

2.76 to 3.30 (where 0 equals no stand and 10 equal a full stand). Differences between stand ratings were not significantly different.

Cover

Total plant cover in 1981 was significantly highest on the A horizon (Table 3) while cover on the three treatments containing B horizon material was equal. In 1985, cover was again greatest on the A horizon plots, but the means between treatments were not significant.

**TABLE 3.--PERCENT TOTAL PLANT COVER BY YEAR AND SOIL HORIZON**

| YEAR | A | B | A/B | AB |
|---|---|---|---|---|
| 1981 | 72.8 b* | 61.0 a | 62.5 a | 61.0 a |
| 1985 | 86.7 a | 81.0 a | 85.3 a | 82.3 a |

*Means within a row followed by the same letter are not significantly different at the 0.05 level.

Cover of individual species (Table 4) appeared to be only partially correlated to soil horizon. Analysis of variance of individual cover values by horizon revealed in 1981 no significant differences in species cover across horizons existed. In 1985, differences in cover of intermediate wheatgrass, smooth brome, crested wheatgrass by soil horizon were found (Table 4). Intermediate wheatgrass, crested wheatgrass and smooth brome cover was highest on plots which received segregated A horizon soil. As of 1985, Bromus marginatus (Mountain brome) had successfully invaded the study site. Mountain brome is commonly found in the surrounding native areas.

Production

Since all life forms followed the same pattern as for total biomass, the values for individual life forms were combined in the analysis of the data.

In 1979, the highest biomass was produced on the plots receiving A horizon soil (Table 5). In 1981, 1983 and 1985 greatest production was associated with the A horizon plots. In 1985 horizon, had no significant influence on total forage production.

**TABLE 5.--TOTAL FORAGE PRODUCTION BY YEAR AND SOIL HORIZON (Kg/ha)**

| YEAR | A | B | A/B | AB |
|---|---|---|---|---|
| 1979 | 1406 ac* | 940 a | 1666 bc | 1506 bc |
| 1981 | 3043 bde | 1688 a | 2573 bce | 2294 ac |
| 1983 | 4343 a | 2986 b | 2480 b | 2780 b |
| 1985 | 5134 a | 4318 a | 4840 a | 4552 a |

*Means within a row followed by the same letter are not significantly different at the 0.05 level.

Plant Community Diversity

Stand ratings in 1978 indicated the highest diversity was associated with the B horizon, while the lowest diversity value was associated with the A/B horizon plots (Table 6). A statistical evaluation of the individual transects in 1981 and 1985 suggested the greatest overall diversity was found on the A/B horizon plots. In 1985, there were no significant differences in species diversity among any of the treatments.

**TABLE 4.--PERCENT COVER OF DOMINANT SPECIES BY SAMPLING YEAR AND SOIL HORIZON**

| | A | | B | | A/B | | AB | |
|---|---|---|---|---|---|---|---|---|
| SPECIES | 1981 | 1985 | 1981 | 1985 | 1981 | 1985 | 1981 | 1985 |
| Agin | 16.8 | 3.2 | 13.0 | 1.3 | 16.1 | 5.0 | 14.0 | 1.7 |
| Agcr | 6.3 | 0.3 | 4.8 | 0.5 | 5.6 | 0 | 5.5 | 0 |
| Dagl | 1.0 | 6.7 | 1.3 | 3.5 | 0.9 | 4.5 | 1.0 | 5.2 |
| Brin | 4.9 | 8.8 | 4.4 | 4.0 | 5.9 | 5.3 | 4.8 | 3.2 |
| Brbi | 9.3 | -* | 5.9 | - | 9.8 | - | 7.8 | - |
| Brma | 0 | 7.7 | 0 | 3.8 | 0 | 4.3 | 0 | 5.7 |
| Mesa | 19.1 | 60.2 | 22.9 | 64.5 | 9.9 | 54.3 | 14.0 | 65.3 |
| Weeds | 10.1 | 0 | 0.1 | 0 | 15.6 | 0.3 | 2.5 | 0 |

*In 1985 Brin and Brbi were not differentiated

TABLE 6.-SPECIES DIVERSITY BY YEAR AND SOIL HORIZON

| YEAR | A | B | A/B | AB |
|---|---|---|---|---|
| 1978 | 1.0325* | 1.0728 | 0.9418 | 1.0272 |
| 1981 | 0.7995 ac** | 0.7400 a | 0.8294 bc | 0.8153 ac |
| 1985 | 0.4489 a | 0.3557 a | 0.5149 a | 0.3875 a |

*Duncan's evaluation not conducted on 1978 data.
**Means within a row followed by the same letter are not significantly different at the 0.05 level.

Species richness in 1978 tended to be higher on plots having B horizon soil (Table 7). In 1981, the highest number of species was associated with the treatments containing some or all A horizon soil. In 1985, the greatest number of species per sampling transect was associated with the A/B horizon plots, but the means were not significantly different.

TABLE 7.-SPECIES RICHNESS BY YEAR AND SOIL HORIZON

| YEAR | A | B | A/B | AB |
|---|---|---|---|---|
| 1978 | 16.0* | 19.0 | 19.0 | 18.0 |
| 1981 | 9.9 a** | 8.5 a | 9.9 a | 9.7 a |
| 1985 | 6.2 a | 7.0 a | 7.2 a | 6.2 a |

*Duncan's evaluation not conducted on 1978 data.
**Means within row followed by the same letter are not significantly different at the 0.05 level.

## Topsoil Depth Study

### Density and Stand Ratings

Grass seedling density counts in 1977 on the topsoil depth study ranged from 21.41 to 31.00 plants/$m^2$. The differences among the means were reported to be nonsignificant. Stand ratings in 1978 ranged from 1.19 to 3.39. The differences among these means were reported to be significant at the $P \leq .02$ level. The 20 cm depth treatment was associated with the highest stand rating of 3.39.

### Cover

Total plant cover in 1979 was found to be greatest on the 30 cm topsoil depth, but the differences among means were not significant (Table 8). In 1981, total plant cover values tended to increase with increasing soil depth, but no advantage in topsoil depth beyond the 20 cm could be documented. Maximum cover in 1985 corresponded to the 30 cm topsoil depth, but all treatment means greater than 20 cm depth were statistically equal.

TABLE 8.--PERCENT TOTAL PLANT COVER BY YEAR AND SOIL THICKNESS

| YEAR | 0 CM | 10 CM | 20 CM | 30 CM | 46 CM |
|---|---|---|---|---|---|
| 1979 | 36.0 a* | 34.5 a | 38.5 a | 57.0 a | 42.0 a |
| 1981 | 64.8 a | 68.0 a | 72.9 ac | 79.9 ac | 86.1 bc |
| 1985 | 87.0 a | 79.7 b | 89.7 a | 92.8 a | 87.5 a |

*Means within a row followed by the same letter are not significantly different at the 0.05 level.

Total plant cover appeared to be partially correlated with soil thickness. The calculated coefficient of correlation for total plant cover and soil thickness for the three monitoring periods yielded values of $r = 0.55$, ($P \leq 0.34$) $r = 0.99$, ($P \leq 0.001$), and $r = 0.42$, ($P \leq 0.48$), respectively. These values are presented to demonstrate over time, there is no consistent correlation between topsoil thickness and total plant cover.

Individual species cover values indicate certain species responded to depth of respread topsoil. Alfalfa cover in 1979 was significantly higher at the 30 cm depth (Table 9). No other species showed responses to soil depth in 1979. In 1981, significant responses in growth for orchardgrass, smooth brome and meadow brome by soil depth were observed. Maximum cover of orchardgrass was observed at the 30 cm depth while cover of smooth brome and meadow brome showed a progressive increase in cover as the depth of respread topsoil increased. By 1985, only alfalfa and smooth brome showed a statistically significant response to topsoil depth. Both species showed trends of increasing cover with increasing soil thickness. Alfalfa cover increased from 0 cm to the 30 cm thickness then declined. Smooth brome showed a progressive increase in cover with each thickness of respread topsoil.

### Production

Biomass production in 1979 was found to increase linearly with increasing topsoil depth (Table 10). The coefficient of correlation for the two variables was $r = 0.97$ ($P \leq 0.007$). In 1981 and 1983, biomass production followed a similar pattern with coefficient of correlation values of $r = 0.96$ ($P \leq 0.01$), $r = 0.94$ ($P \leq 0.017$), respectively. In 1985, no differences among means could be documented, and the maximum biomass production had shifted from the 46 cm topsoil depth to the 20 cm depth. The coefficient of correlation value between total biomass and soil thickness was $r = 0.44$ ($P \leq 0.46$).

TABLE 9.--PERCENT TOTAL PLANT COVER OF DOMINANT SPECIES BY SAMPLING YEAR AND SOIL THICKNESS

| | 0 CM | | | 10 CM | | | 20 CM | | | 30 CM | | | 46 CM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | 1979 | 1981 | 1985 | 1979 | 1981 | 1985 | 1979 | 1981 | 1985 | 1979 | 1981 | 1985 | 1979 | 1981 | 1985 |
| Agin | 1.0 | 4.9 | 3.2 | 2.0 | 7.5 | 3.5 | 4.5 | 8.0 | 2.0 | 2.0 | 7.5 | 1.2 | 4.0 | 8.9 | 1.8 |
| Agcr | 1.0 | 2.6 | 0.2 | 1.5 | 2.3 | 0 | 2.0 | 2.6 | 0 | 4.0 | 2.6 | 0.2 | 2.0 | 3.1 | 0 |
| Dagl | 0.5 | 0.5 | 2.8 | 2.0 | 0.6 | 6.5 | 1.5 | 0.9 | 7.8 | 2.5 | 2.4 | 4.7 | 1.5 | 1.5 | 6.2 |
| Brin | 1.5 | 2.0 | 5.0 | 2.0 | 2.5 | 3.8 | 4.5 | 2.4 | 3.2 | 3.5 | 4.4 | 7.7 | 2.0 | 7.3 | 14.3 |
| Brbi | 2.0 | 3.1 | -* | 5.0 | 4.6 | -* | 1.0 | 8.0 | -* | 5.0 | 6.4 | -* | 4.0 | 9.9 | -* |
| Brma | 0 | 0 | 1.8 | 0 | 0.4 | 4.5 | 0 | 0 | 2.8 | 0 | 0 | 2.0 | 0 | 0.4 | 0.2 |
| Mesa | 8.5 | 47.1 | 73.8 | 5.0 | 42.1 | 61.3 | 8.5 | 41.3 | 73.2 | 29.5 | 48.6 | 77.0 | 8.0 | 45.6 | 64.8 |
| Weeds | 7.5 | 0.4 | 0 | 10.5 | 4.7 | 0 | 12.5 | 3.6 | 0 | 8.0 | 4.3 | 0 | 13.0 | 3.3 | 0 |
| Others | 14.45 | 4.2 | 0.2 | 6.5 | 3.3 | 0.1 | 4.0 | 6.1 | 0.7 | 2.5 | 3.7 | 0 | 7.5 | 6.1 | 0.2 |
| TOTAL | 36.0 | 64.8 | 87.0 | 34.5 | 68.0 | 79.7 | 38.5 | 72.9 | 89.7 | 57.0 | 79.9 | 92.8 | 42.0 | 86.1 | 87.5 |

-* in 1985 - Brin and Brbi cover values were not differentiated.

TABLE 10.--TOTAL FORAGE PRODUCTION BY YEAR AND SOIL THICKNESS (Kg/ha)

| YEAR | 0 CM | 10 CM | 20 CM | 30 CM | 46 CM |
|---|---|---|---|---|---|
| 1979 | 876 a* | 1237 ace | 1198 ac | 1726 bce | 2053 bde |
| 1981 | 2595 a | 3095 ac | 3596 ace | 4257 bce | 4934 bde |
| 1983 | 2732 a | 3171 a | 3134 a | 3750 a | 5067 b |
| 1985 | 4663 a | 5236 a | 5555 a | 5433 a | 5154 a |

*Means within a row followed by the same letter are not significantly different at the 0.05 level.

TABLE 11.--SPECIES DIVERSITY BY YEAR AND SOIL THICKNESS

| YEAR | 0 CM | 10 CM | 20 CM | 30 CM | 46 CM |
|---|---|---|---|---|---|
| 1978 | 0.9242* | 1.005 | 1.0375 | 1.0413 | 0.9808 |
| 1979 | 0.5223 a** | 0.6620 a | 0.7067 a | 0.6142 a | 0.7014 a |
| 1981 | 0.4615 a | 0.5529 ac | 0.6284 ac | 0.5920 ac | 0.6509 bc |
| 1985 | 0.2626 a | 0.3481 a | 0.2872 a | 0.2697 a | 0.3301 a |

*Duncan's evaluation not conducted on 1978 data.
**Means within a row followed by the same letter are not significantly different at the 0.05 level.

TABLE 12.--SPECIES RICHNESS BY YEAR AND SOIL THICKNESS

| YEAR | 0 CM | 10 CM | 20 CM | 30 CM | 46 CM |
|---|---|---|---|---|---|
| 1978 | 16* | 16 | 16 | 17 | 19 |
| 1979 | 5.5 a** | 6.3 a | 6.8 a | 6.3 a | 6.8 a |
| 1981 | 7.3 acd | 7.6 acd | 8.9 ace | 8.4 ace | 9.5 bce |
| 1985 | 4.8 a | 5.0 a | 4.2 a | 4.5 a | 3.8 a |

*Duncan's evaluation not conducted on 1978 data.
**Means within a row followed by the same letter are not significantly different at the 0.05 level.

Plant Community Diversity

Stand ratings of 1978 were found to linearly increase up to a depth of 30 cm then decline (Table 11). The 1979 and 1981, diversity values appeared to increase up to 20 cm and then level off. In 1985, it appeared optimum stand diversity corresponded to the 10 cm soil depth, but differences among means were not significant. The coefficient of correlation values between diversity and topsoil depth were calculated as r = 0.42 ($P \leq 0.48$) for 1978; r = 0.64 ($P \leq 0.25$) for 1979; r = 0.87 ($P \leq 0.05$) for 1981 and r = 0.27 ($P \leq 0.66$) for 1985.

Species richness in 1978, 1979 and 1981 appeared to increase with increasing soil depth (Table 12). However, in 1985, greatest species richness values were correlated with 0 and 10 cm depths. The coefficient of correlation between species richness and topsoil depth yielded the following values: 1978 r = 0.89 ($P \leq 0.04$); 1979 r = 0.76 ($P \leq 0.14$); 1981 r = 0.91 ($P \leq 0.03$) and for 1985 r = -0.85 ($P \leq 0.07$).

## DISCUSSION AND CONCLUSIONS

The effect of horizon segregation upon perennial production was evaluated by Power et. al. (1981). Average alfalfa yields were reported to be 1.49 and 1.92 metric tons/ha for mixed topsoil and topsoil over subsoil, respectively. Average perennial forb production for 1985 in our study yielded values of 2.51 and 2.67 metric tons/ha for mixed topsoil and topsoil over subsoil, respectively. Perennial grass yields obtained by 1985 at this study were determined to equal 1.54 and 1.63 metric tons/ha for mixed topsoil and subsoil and topsoil over subsoil, respectively. Crested wheatgrass yields were reported by Power et. al. (1981) to equal 2.38 and 2.42 metric tons/ha respectively. We therefore conclude, as did Power et. al. (1981), to maximize alfalfa production and perennial grass production, topsoil horizons do not need to be segregated.

Forage production in this study indicated during the earlier years of reclamation thicker topsoil depths were most productive. However, by 1985, maximum production was associated with the 20 cm depth. Barth (1984), Doll et al. (1984), Schuman et al. (1985) and Halverson et. al. (1987) all documented in their studies that optimum production over time shifted in favor of shallower soils. Based upon our findings, we would suggest topsoil per se, is not necessary to achieve successful reclamation for similar sites in northwest Colorado. The findings herein are identical to those reported by Parkin et. al. (1980) for nearby nontopsoiled sites.

If one assumes the spoil used in this experiment is suitable as a plant growth medium (in fact, plant performance on this medium documents it is a suitable plant growth medium) then our findings are very similar to those reported by Power et. al. (1981). In their study, they reported alfalfa yields increased up to 20 cm of respread topsoil then declined. Perennial forb production in our study for 1985 was found to equal 3,639, 3,922, 4,312, 3,939 and 3,405 for the 0, 10, 20, 30 and 46 cm soil depths, respectively. We consider the similarity between our findings and those of Power et. al. (1981) to be meaningful. Both studies suggest the optimum thickness of respread topsoil to maximize alfalfa yields is a depth of 20 cm. Redente and Hargis (1985) reported on data collected from a similar site in northwest Colorado. The data indicate significantly higher forb and shrub biomass was associated with the 15 cm depth of respread topsoil than deeper depths.

Yields of crested wheatgrass were reported by Power et. al. (1981) to increase linearly with increasing depth of respread topsoil. Redente and Hargis (1985) reported a similar finding for seeded perennial grasses. In this study, perennial grass yields progressively increased with topsoil depth. Since there is considerable concern regarding the over-establishment of perennial grasses on reclaimed lands with the resultant exclusion of desirable forbs and shrubs, we suggest, based on the results of this study, more life forms and hence greater community diversity might be obtained by reapplying less topsoil.

The responses of individual species on both the horizon segregation and topsoil depth studies were somewhat unexpected. Pronounced declines in cover and composition of intermediate wheatgrass, crested wheatgrass, smooth brome and volunteer species with the exception of mountain brome, were observed over time (Tables 4 and 9). Intermediate wheatgrass dropped from nearly 10% of the stand to 2% of the stand. Crested wheatgrass essentially disappeared from the seeded stand. Composition of smooth brome declined on all treatments over time. In 1985, smooth brome and meadow brome were accidentally combined, but the combined composition of the two continued to decline as well across all treatments. Work in Montana has suggested low species diversity of reclaimed lands could partially be explained by the dominance of crested wheatgrass and smooth brome (Sindelar 1980). Due to the apparent negative efforts of these species on plant community diversity, the composition of these two species was correlated to species diversity values. The coefficient of correlation between composition and species diversity produced no evidence that either species reduced species diversity. Crested wheatgrass was found to positively influence overall species diversity (r = 0.77 $P \leq 0.0001$). Smooth brome grass also was found to positively influence species diversity (r = 0.68 $P \leq 0.008$). The coefficient of correlation calculated from data of Parkin et. al. (1980) for crested wheatgrass and smooth brome was r = 0.997 ($P \leq 0.045$) and r = 0.45 ($P \leq 0.71$), respectively. Working in the Piceance Basin of western Colorado, Biondini et al. (1986) reported species diversity was inversely correlated with the combined composition of crested wheatgrass, pubescent wheatgrass, and intermediate wheatgrass. Analysis of our data failed to confirm such a relationship. In our study, the combined cover of intermediate and crested wheatgrass produced a positive coefficient of correlation of r = 0.89 ($P \leq 0.0001$). Data presented by Parkin et. al. (1980) also indicates a positive correlation where r = 0.883 ($P \leq 0.075$).

Based partially upon studies such as Sindelar (1980) and Biondini et. al. (1986), various state and federal regulatory agencies in the west have effectively banned the utilization of crested wheatgrass and smooth brome due to their perceived negative influence on species diversity. It is our opinion the findings of this study do not substantiate such an adverse relationship between these introduced species and overall plant community development as measured by the species diversity index at this site. The findings from this study parallel previous findings from 15 year old reclaimed spoils in this region (Parkin et. al. 1980). We believe our data are supportive of the findings of Terwilliger et. al. (1974) from a similar high elevation ecosystem in western Colorado wherein he reported crested wheatgrass did not appear to suppress the invasion of indigenous native species on several revegetated sites.

The species which appeared to correlate best with species diversity was alfalfa. The coefficient of correlation for species diversity and alfalfa composition was determined to equal r = -0.97 ($P \leq 0.007$). To verify such a relationship, we tested the results from previous work in this area (Parkin et. al. 1980). The coefficient of correlation here was calculated at r = -0.995 ($P \leq 0.06$).

Since previous documentation (DePuit and Coenenberg 1980) has shown grazing increases species diversity and lowers alfalfa dominance in reclaimed stands, we suggest the low species diversity levels on these reclaimed sites may be more attributable to management than to the presence of introduced species or alfalfa. In 1980 and 1981, this operation attempted to gain regulatory approval to graze the area, however, because of the state regulatory interpretation, that reclaimed areas could not be grazed until the ninth and tenth year of the liability period, the area was not grazed. We suspect the reduction of species diversity is due more to the exclusion of grazing than the use of introduced species. This concept is further supported by Parkin et al. (1980) where nontopsoil spoils were dominated by identical species, but progressively increased in diversity under grazing from 1970 to 1980.

If this information were being used to apply for bond release at the CYCC operation, the revegetation success stand for the ungrazed mountain shrub community would apply. The production standard for the area would be 886 Kg/ha for production and 64.5 percent cover. The species diversity would be 1.046, with 6 major species accounting for 64 percent of the diversity index total (Energy Fuels Corporation, 1979). Based upon our production (Tables 5 and 10) and cover estimates (Tables 3 and 8), topsoil is not necessary to achieve either the production or cover standards. The species diversity standard would not be attained even though an extremely diverse mixture of 36 species was planted. It is unlikely the species diversity or species richness standards could be achieved, either with or without substantial depths of topsoil.

It is our opinion, based upon nine years of monitoring data, the optimum depth of respread topsoil on regraded spoil on this site for maximum forage production, total plant cover, overall species diversity and richness is between 10 and 20 cm. This figure parallels the recommendation of Power et. al. (1981) who recommended 20 cm; Redente and Hargis (1985) and Halverson et. al. (1987) wherein they recommended 15 cm; and Barth (1984) who recommended 14 cm as the optimum depth of respread topsoil for microbial activity. Previous research at this site (Skaptason 1978) has documented no difference in microbial populations between raw spoil, respread topsoil and undisturbed soils Barth's estimate may be overly conservative for this site. Hydrologic research on this site (Striffler and Rhodes, 1981) has shown essentially no difference in erosion between spoil and respread topsoil, but suggests a greater depth of wetting with topsoil. Greater wetting depth might provide some advantage to topsoiling. DePuit (1984) reviewed the literature on seed reserves in connection with topsoil depth and concluded most seed reserves were confined to the upper most 5-7 cm of the profile. With regard to the inoculation of mycorrhizae, Allen (1984) suggested respreading 2-3 cm fresh topsoil onto regraded spoil or poor quality topsoil might be more advantageous towards long term reclamation than reapplication of a thick layer of biological inert stored topsoil. Based upon these recommendations and findings from our study, and considering the topsoil and spoil quality of this area, we believe there is little justification to reapply more than 10 to 20 cm of topsoil onto regraded spoil.

We believe the most notable finding from this evaluation is the response of vegetation characteristics to respread topsoil is extremely dynamatic over time. Since existing regulations require bond release for reclaimed areas be obtained from data collected during years nine and ten following seeding, it appears, based upon our findings and examination of all long term topsoil depth studies, data obtained from studies monitored for shorter periods of time might not be representative of conditions which may exist at a later date. We suggest this concern is particularly pertinent to the existing regulatory requirements to segregate topsoil horizons and in establishing recommended topsoil thicknesses. The available evidence indicates the existing regulatory requirements to salvage all available topsoil and segregate topsoil and subsoil horizons are based upon short term studies of questionable applicability to the bonded liability period. The removal and segregation of all available topsoil has in many instances resulted in a situation, as suggested by Biondini and Redente (1986), wherein the ultimate goals of revegetation cannot be achieved because the regulatory standards preclude such a possibility. The results of this study and others indicate considerable amounts of money have perhaps been unnecessarily spent on topsoil handling.

Significant cost savings could be achieved by implementation of these findings at this and other similar sites. Bonding data from this particular operation (Yampa Valley Coal Cooperation, 1987) reveal topsoil handling costs to replace 37.8 cm of soil average $7,114/ha. Using this operation as an example, we would conservatively estimate approximately $1,779/ha could be saved for similar operations by combining horizons during removal and a corresponding amount could be saved during laydown. The total approximate cost savings could be $3,557 per hectare. These costs are based on increased operating costs of approximately 25 percent to remove and reapply segregated topsoil. Where topsoil has already been stockpiled, it is doubtful if any cost savings could be realized, but for operations where topsoil removal is being conducted, we believe significant cost savings could be achieved.

Implementation of the findings from this study to this mine operation would result in a significant cost savings. According to the current bond, Yampa Valley Coal Corporation has a commitment to replace an average of 37.8 cm of topsoil on all reclaimed areas. The bonded liability of this commitment amounts to $3,055,048. If this operation were able to implement the findings of this study, potential cost savings of between $3,350/ha to $5,232/ha, totalling between $1,440,000 and $2,250,000, could be realized. We strongly suspect other operations having similar soil and spoil properties and environmental factors, could achieve corresponding cost savings.

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