LONG-TERM PLANT COMMUNITY RESPONSES TO TOPSOIL REPLACEMENT DEPTH ON RECLAIMED MINED LAND[1]

C.K. Bowen, R.A. Olson, G.E. Schuman and L.J. Ingram[2]

Abstract: The use of topsoil on reclaimed mine lands may enhance plant community development and influence reclamation success. This study assessed the long-term (after 24 years) effects of different topsoil replacement depths (0, 200, 400, and 600 mm) on plant community cover, production, and diversity at a research site established in 1977 in south-central Wyoming. Plant species richness (number of species), canopy cover, aboveground biomass, and diversity were evaluated at the four topsoil depths in 2001. Plants were clipped, by species, to obtain mean biomass and to calculate importance values. Shannon-Weiner diversity indices were calculated for each topsoil depth. Species richness was highest (7.5) at the zero topsoil depth and lowest (5.6) at the 600 mm topsoil depth. Total canopy cover was greatest (average 26.7%) at 400 and 600 mm of topsoil and least (21.5%) at the zero topsoil depth. Seeded species canopy cover and seeded species biomass were also greatest at the 400 mm topsoil depth. Total biomass was similar for the 400 (734 kg/ha) and 600 mm (727 kg/ha) topsoil depths and lower but similar at the 200 mm depth (506 kg/ha) and 0 mm depth (513 kg/ha). Plant species richness and diversity index were highest at 0 mm (7.5 and 2.36, respectively) and lowest at 600 mm (5.6 and 1.87, respectively) of topsoil. Number of species and diversity decreased as topsoil depth increased. Increased plant biomass at the 400 and 600 mm depths and increased diversity at the 0 and 200 mm topsoil depths, indicate that variable replacement depths of topsoil can enhance reclamation success through greater species diversity and by creating a greater mosaic of vegetation. However, the reduced cover observed at these shallower topsoil depths may not be adequate to protect the soil from erosion.

Additional Key Words: plant diversity, rehabilitation, semi-arid climate, rangelands

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Introduction

Much research was initiated in the 1970's to determine the "optimum" topsoil depth replacement on mined lands for establishing a permanent vegetation cover (Barth and Martin 1982, Power et al. 1981, McGinnies and Nicholas 1980, Schuman et al. 1985). Topsoil depth replacement on mined lands was generally dependent upon the amount of soil available and the quality of the spoil material comprising the subsoil. Early studies were generally focused upon soil stabilization and forage productivity, and provided reliable data and recommendations to ensure success of these initial goals. From this research, regulatory agencies developed guidelines and rules that generally required uniform topsoil replacement at a depth representative of resource availability. However, scientists shortly began proposing topsoil management practices that represent natural soil landscapes (Schafer and Nielson 1979, DePuit 1984). DePuit (1984) reviewed the potential topsoil management strategies that might lead to a more natural and varied landscape. He pointed out that the post-mining vegetative community and its diversity can be expected to reflect the physiographic and edaphic conditions of the site. Munshower (1982) also postulated that varying the depth of redistributed topsoil may potentially benefit plant community diversity by simulating the edaphic diversity that is naturally created by erosion and deposition.

These hypotheses led to the initiation of research to assess the role of various topsoil depths upon plant community diversity and succession. However, in most cases these studies were short-term (3-5 years) which generally proved to be an inadequate time frame to assess the long-term natural processes. Therefore, the objective of our research was to evaluate the effects of topsoil depth on plant community diversity, richness, cover, and production on a 24-year-old topsoil depth study established in 1977 by Schuman et al. (1985).

Methods and Materials

The original research study was established spring of 1977 at the Pathfinder Mines Corporation's Shirley Basin uranium mine in south central Wyoming. Elevation of the research site is 2195 m, the long-term average annual precipitation is 259 mm, and the annual frost-free period averages 88 days (Schuman et al. 1985).

The overburden/spoil consisted of a 1-m layer of White River geological material placed over several meters of Wind River material. The White River material is composed of bentonitic arkosic sands interbedded with fine silts and montmorillinitic clays of the Oligocene Epoch. The Wind River spoil is of the Eocene Epoch and characterized by high silt and clay with scattered lenses of arkosic sands in the upper portion of the formation. The replaced spoil material was sloped so that replacement of the topsoil resulted in a relatively flat surface. Overburden was ripped to a depth of 0.5 m after re-grading and before replacing the topsoil. Topsoil used in the reconstruction of the mine soil was a Borollic Haplargid of the fine-loamy mixed family (Young and Singleton 1977). It was spread over the re-graded spoil material in a wedge shape (Fig. 1), ranging in depth from 0 to 600 mm. Topsoil and White River material physiochemical characteristics are presented in Table 1.

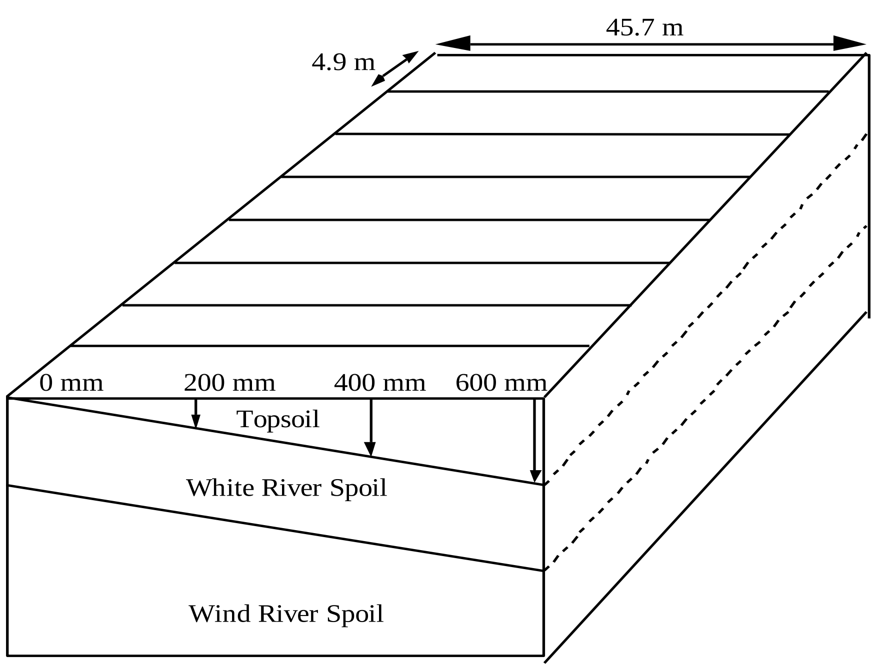

Figure 1. Diagram of a portion of the research plot design showing variable topsoil replacement.

Table 1. Chemical and physical characteristics of topsoil and White River spoil used in constructing variable topsoil depth plot, Shirley Basin, Wyoming (Schuman et al. 1995).

Characteristic	Topsoil	Spoil
pH	7.2	7.0
EC (dS/m)	2.47	0.40
C (%)	1.1	0.1
Kjeldahl-N (μg/g)	900	180
$NaHCO_3$-P (μg/g)	4.4	0.7
Water Soluble Cations (meq/l)		
Na^+	9.41	2.36
K^+	0.80	0.18
Ca^{++}	12.60	1.07
Mg^{++}	1.75	0.35
Particle Size Separates (%)		
Sand	57	45
Silt	30	38
Clay	13	17
Saturation percentage (%)	39	58

The experimental design was a completely randomized design with ten replications of two mulch treatments (straw mulch and stubble mulch). In the spring of 1977, half of the plots were seeded to a dryland variety of barley (*Hordeum vulgare* L.) to establish the stubble mulch.

The remaining ten plots were fallowed for future application of straw mulch. In October 1977, the plots were seeded with a perennial grass and shrub mixture composed of: thickspike wheatgrass [*Elymus lanceolatus* (Scribner & J.G. Smith) Gould], green needlegrass (*Stipa viridula* Trin.), slender wheatgrass [*E. trachycaulum* (Link.) Gould ex Shinners], western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love], Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young), and rubber rabbitbrush [*Ericameria nauseosus* (Pallas ex Pursh) Nesom & Baird]. The grass mixture and shrub component were drill seeded at a rate of 15.5 kg PLS/ha and 0.5 kg PLS/ha, respectively. Straw was hand scattered on the fallowed plots and then crimped into the soil surface to reduce loss due to wind. In 1979, two N fertilizer management treatments were incorporated into the experimental design to assess a single large application (268 kg N/ha) compared to four annual applications of 67 kg N/ha (total 268 kg N/ha) on forage production. For greater detail of the plot and treatment design refer to Schuman et al. (1985) and Schuman et al (1991).

In June 2001, plant biomass, cover, diversity and frequency were evaluated on these plots to assess plant community changes after 24 years. Three, 0.18 m^2 quadrats were systematically located at each topsoil depth (0, 200, 400, and 600 mm) within each mulch by fertilizer treatment. Within each quadrat, canopy cover, frequency of occurrence, and aboveground biomass were evaluated for each species. Cover (plant, litter, bare ground) was estimated using a modified Daubenmire (1959) procedure. Live aboveground biomass was assessed by clipping (by species) all live plant material at ground level within a quadrat. The combined samples (three quadrats per treatment) were dried at 65^0C to calculate live aboveground biomass and converted to a kg/ha basis. Frequency of occurrence for each species was also recorded within each quadrat.

A relative value for each species was calculated for cover, biomass, and frequency for each topsoil depth, mulch, and nitrogen treatment. Relative values were summed to provide an "importance value" which identifies species dominance. Relative importance values were used to calculate a Shannon-Wiener diversity index (Krebs 1999), which assesses proportional equivalence of a plant species and heterogeneity in a plant community (Whittaker 1977, Krebs 1999). A three-way analysis of variance was used to evaluate the effects of topsoil depth, mulch type, and N fertilizer treatments on vegetation canopy cover, aboveground biomass, species diversity, and species richness. Mean separation was accomplished using least significant difference methods at $P \leq 0.05$.

Results and Discussion

Topsoil depth was the only treatment that significantly influenced canopy cover, species diversity, species richness, and aboveground plant biomass. Species diversity was significantly reduced as topsoil depth increased from 0 to 600 mm (Fig. 2). The diversity index was significantly lower for the 400 and 600 mm topsoil depth compared to the 0 mm depth. No differences were evident between the 0 and 200 mm depth or between the 200 and 400 mm depths. This trend is likely due to dominance of cool-season perennial grasses at deeper topsoil depths, which resulted in limited inter-space for natural recruitment of native forbs, other grasses, and shrubs. Species richness exhibited an identical trend to species diversity (Fig. 2). In contrast, Pinchak et al. (1985) observed the opposite response in species richness and limited difference in diversity index in 1981 on these plots. The 1981 diversity indices were almost double of those observed in 2001 and the species richness is 20 to 40% greater in 2001 than that observed in 1981. However, Redente et al. (1997) reported similar results to the current study with greater diversity and increased forb production and shrub density at shallower topsoil depths.

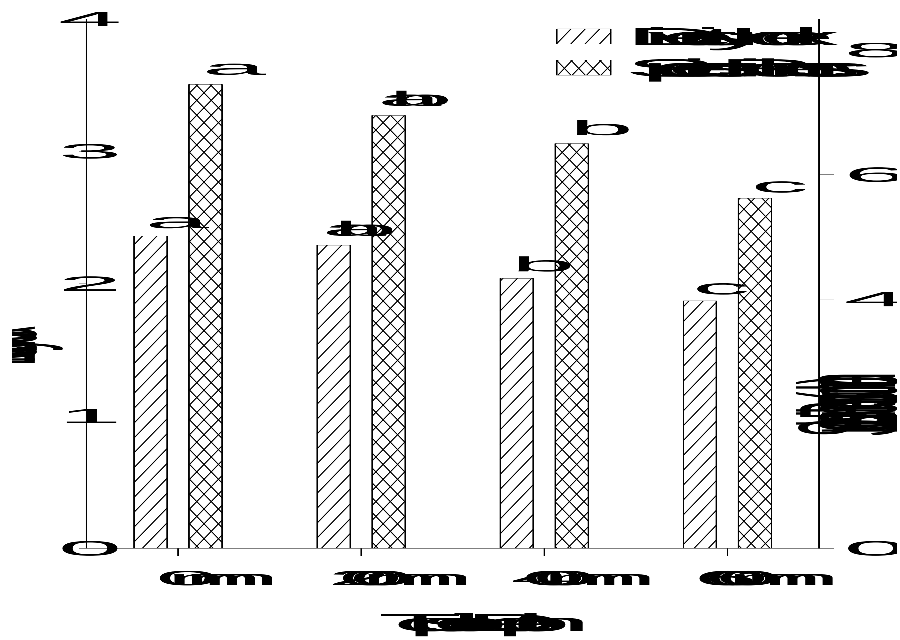

Figure 2. Diversity index and species richness (number of species) in relation to topsoil depth.

Canopy cover of grasses and invading species varied significantly between topsoil depths (Fig. 3 & 4). Canopy cover of all grasses was significantly higher at $\geq$ 400 mm of topsoil compared to $\leq$ 200 mm of topsoil replacement (Fig. 3). Among the seeded grasses, western wheatgrass exhibited the greatest mean canopy cover and production across all topsoil depth treatments. Canopy cover of invading species was significantly greater at the 600 mm topsoil depth compared to the 0 and 200 mm depth (Fig. 4). These observed responses are mainly attributed to the invasion of crested wheatgrass (*Agropyron cristatum* L. Gaertn.). Crested wheatgrass seedlings are very competitive and aggressive. Crested wheatgrass seed has been scattered by wildlife and livestock from a small planting made at the mine in the early 1970's.

Forb canopy cover decreased with increasing topsoil depth. The observed trend in canopy cover is directly related to increased diversity and species richness at the shallower topsoil depths.

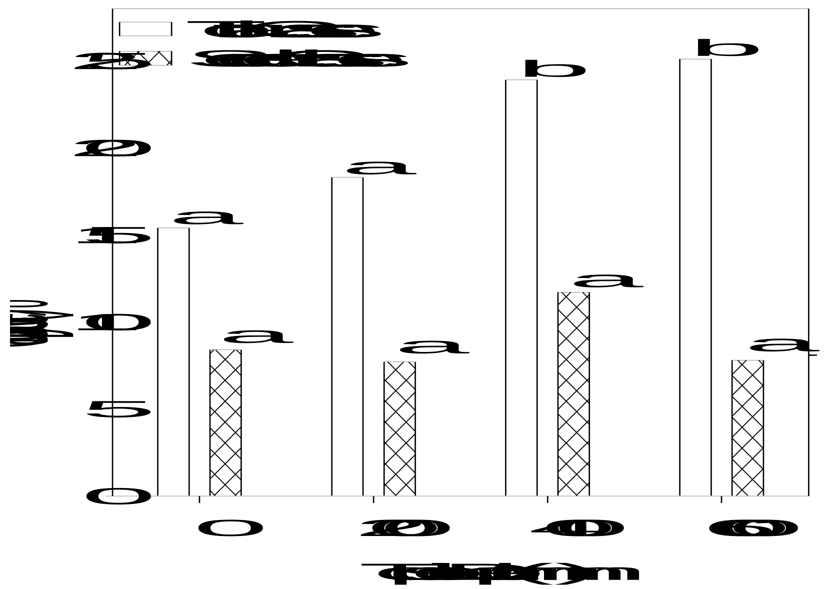

Figure 3. Canopy cover of total grasses and seeded grasses as affected by topsoil depth.

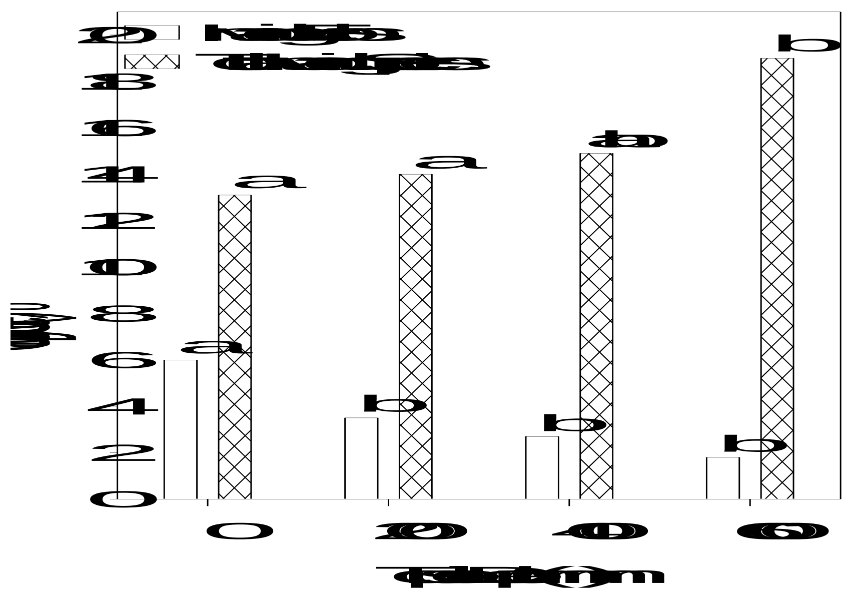

Figure 4. Canopy cover of invading forbs and total invading species as affected by topsoil depth.

Total canopy cover and total ground cover were significantly greater at the 400 and 600 mm topsoil depths compared to the 0 and 200 mm depths (Fig. 5). Deeper soil depths exhibited significant litter accumulation from high density and production of the cool-season grasses that dominated these topsoil depth treatments.

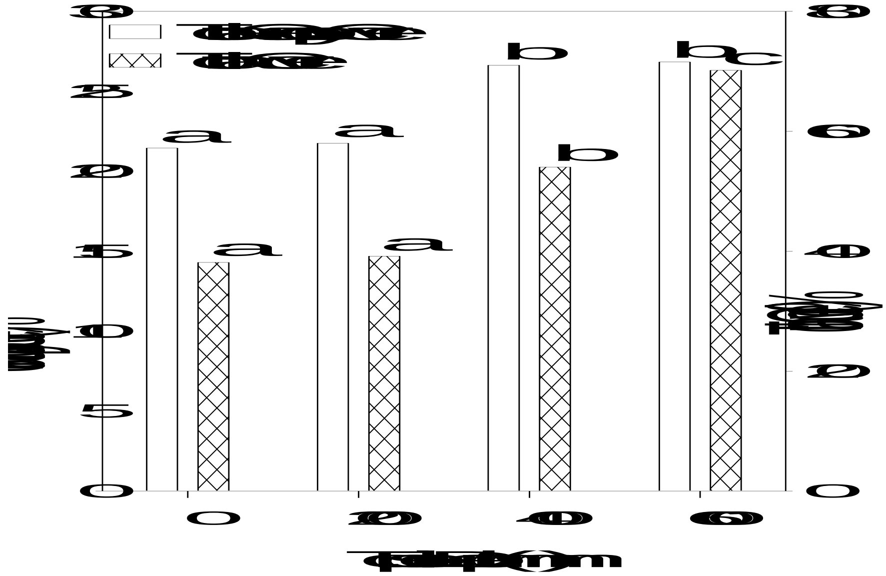

Figure 5. Total canopy cover and total ground cover as affected by topsoil depth.

Total biomass was significantly greater at the 400 and 600 mm topsoil depths compared to the shallower topsoil treatments (Fig. 6). However, seeded species biomass was significantly greater at the 400 mm topsoil depth than at any other depth. Pinchak et al. (1985) also observed this trend in 1981. This long-term response in aboveground biomass to topsoil depth is not understood; however, it is likely that some edaphic characteristics are influencing production of these seeded species and/or plant community development. The results of this study contrast with the study by Redente et al. (1997) who reported no difference in aboveground production between 150 and 600 mm of replaced topsoil after 10 years in northwestern Colorado.

Summary

These findings clearly show the importance of long-term studies to evaluate plant community development as influenced by topsoil depth replacement on mined lands. Species diversity, richness, and forb cover were all enhanced by shallower topsoil depths ($\leq$ 200 mm). Natural recruitment of local native species appears to occur in the open inter-space of the plant community on the 0 and 200 mm topsoil depth treatments. However, plant communities that developed on the 400 and 600 mm topsoil depths were dominated by highly competitive cool-season perennial grasses that limit natural recruitment of native species (grasses, shrubs, and forbs). Competitive exclusion hypotheses seem to explain the observed changes or lack of changes in these "new ecosystems" (Huston 1979). Recommendation of shallow topsoil

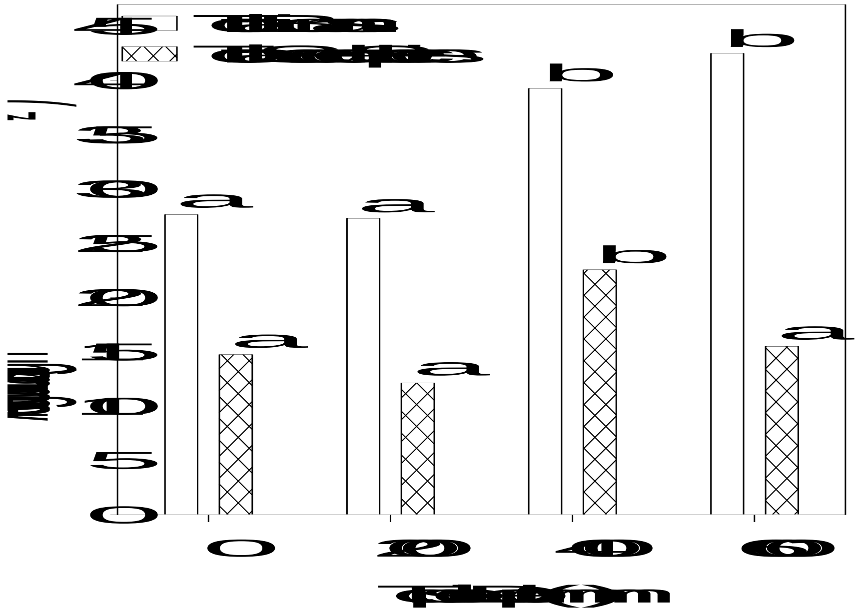

Figure 6. Total aboveground biomass and seeded species biomass as affected by topsoil depth.

replacement may be premature until we are able to ensure the ground cover and plant community present on these shallower topsoil depths are adequate to protect the soil from erosion and are self-sustaining. However, this study and Redente et al. (1997) clearly demonstrate that topsoil depth replacement on mined lands will significantly influence plant community diversity, richness and production. Both studies found that the deeper topsoil resulted in a community dominated by cool-season perennial grasses which limit colonization by other desired native plant species.

Literature Cited

Barth, R.C. and B.K. Martin. 1982. Soil depth requirements to reclaim surface-mined areas in the Northern Great Plains. Colorado School of Mines Res. Institute, Golden, CO. 182 p.

Daubenmire, R.F. 1959. A canopy-coverage method of vegetation analysis. Northwest Science. 33: 43-64.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. p. 258-272. In: Proc., Symposium on Surface Coal Mining and Reclamation in the Great Plains, March 19-21, 1984, Billings MT. Reclamation Research Unit, Montana State University, Bozeman. http://dx.doi.org/10.1007/bf02043991.

Huston, M. 1979. A general hypothesis of species diversity. American Naturalist. 113: 81-101. http://dx.doi.org/10.1086/283366.

Krebs, C.J. 1999. Ecological Methodology. Second Edition, Benjamin/Cummings Publishers, Menlo Park, CA. 620 p.

McGinnies, W.J. and P.J. Nicholas. 1980. Effects of topsoil thickness and nitrogen fertilizer on the revegetation of coal mine spoils. J. Environmental Quality. 9:681-685. http://dx.doi.org/10.2134/jeq1980.00472425000900040028x.

Munshower, F.F. 1982. Problems in reclamation planning and design. p. C-7(1) - C-7(17). *In*: Proc., Symposium on Surface Coal Mining and Reclamation in the Great Plains, March 19-21, 1984, Billings MT. Reclamation Research Unit, Montana State University, Bozeman.

Pinchak, B.A., G.E. Schuman and E.J. DePuit. 1985. Topsoil and mulch effects on plant species and community responses of revegetated mined land. J. Range Management. 38: 262-265. http://dx.doi.org/10.2307/3898981.

Power, J.F., F.M. Sandoval, R.E. Ries, and S.D. Merrill. 1981. Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Science Society of America Journal. 45: 124-129. http://dx.doi.org/10.2136/sssaj1981.03615995004500010027x.

Redente, E.F., T. McLendon, and Q. Agnew. 1997. Influence of topsoil depth on plant community dynamics of a seeded site in northwest Colorado. Arid Soil Research and Rehabilitation. 11: 139-149. http://dx.doi.org/10.1080/15324989709381467.

Schafer, W.M. and G.A. Nielsen. 1979. Soil development and plant succession on 1 to 50 year old strip mine spoils in southeastern Montana. p. 541-549. In: M.K. Wali (ed.) Ecology and Coal Resource Development, Pergamon Press, New York, NY. http://dx.doi.org/10.1016/B978-1-4832-8365-4.50076-4.

Schuman, G.E., E.M. Taylor, Jr., and F. Rauzi. 1991. Forage production of reclaimed mined lands as influenced by nitrogen fertilization and mulching practices. J. Range Management. 44: 382-384. http://dx.doi.org/10.2307/4002404.

Schuman, G.E., E.M. Taylor, Jr., F. Rauzi, and B.A. Pinchak. 1985. Revegetation of mined lands: Influence of topsoil depth and mulching method. J. Soil and Water Conservation. 40: 249-252.

Whittaker, R.H. 1977. Evolution of species diversity in land communities. Evolutionary Biology. 10: 1-67. http://dx.doi.org/10.1007/978-1-4615-6953-4_1.

Young. J.F. and P.C. Singleton. 1977. Wyoming general soils map. Research Journal No. 117, Wyoming Agricultural Experiment Station, Laramie, 40 p.