LONG-TERM PLANT COMMUNITY DEVELOPMENT IN RESPONSE TO TOPSOIL REPLACEMENT DEPTH ON MINED LAND IN WYOMING[1]

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Abstract: Effects of topsoil replacement depth on plant community development of reclaimed mined lands has been discussed for nearly three decades. Numerous research projects assessing topsoil depth effects were initiated during the 1970s. However, data collection for many of these studies was limited to 3-5 years. Plant community establishment, development, and stabilization through successional processes require considerable time. Only aboveground biomass and plant cover were reported in these short-term studies. In 2001, a research project initiated in 1977 was re-evaluated to assess the long-term effects of topsoil replacement depth (0, 20, 40 and 60 cm) on plant community development in south-central Wyoming. Percent grass cover and aboveground biomass were highest on the 40 and 60 cm topsoil depths, while forb cover was highest on the 0 and 20 cm depths. Percent bare ground was lowest on the 60 cm depth (30%) and highest on the 0 cm topsoil depth (62%). Plant species richness and diversity were significantly higher on the 0 cm topsoil depth and lowest on the 60 cm depth. Many native plant species established naturally in the abundant open space of the 0 cm topsoil replacement treatment. Variable topsoil replacement depth is a good management practice to enhance plant community diversity on reclaimed mined lands. However, placement of variable topsoil depths must consider erosion potential during the early years of reclamation. Areas of shallow topsoil should be limited to sites not prone to erosion, limited in size, and intermingled with other areas of greater topsoil replacement to ensure early stabilization and plant diversity of the reclaimed landscape.

Additional Key Words: plant species diversity, succession, species richness

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Introduction

One of the most difficult aspects of mined land reclamation is achieving the desired plant community species diversity. The effects of variable topsoil replacement on mined lands have been studied since the early 1970's with the primary focus on forage production (McGinnies and Nicholas 1980, Power et. al. 1976, Schuman et al. 1985, Barth and Martin 1984). Researchers later proposed variable topsoil replacement to more closely resemble native landscapes, hypothesizing that this would enhance plant community diversity similar to native landscapes (Schafer and Nielsen 1979, Munshower 1982, DePuit 1984). Several short-term studies (3-5 years) were conducted in the mid-80's to evaluate the effects of variable topsoil replacement on species diversity, richness, and production (Redente and Hargis 1985, Schuman et al. 1985, Pinchak et al. 1985); however, the short-term nature of these studies did not enable evaluation of plant community succession. Therefore, the purpose of this study was to assess the long-term successional development of a plant community influenced by variable topsoil replacement depth.

Methods and Materials

Study Site

The study was conducted at Pathfinder Mines Corporation, Shirley Basin uranium mine in south-central Wyoming on a site established by Schuman et al. (1985) in 1977. Elevation ranges from 2,117 to 2,151 m with a cold, semiarid climate.

The native plant community is dominated by Wyoming big sagebrush *[Artemisia tridentata* ssp. *wyomingensis (*Beetle & Young)], fringed sagebrush (*A. frigida* Willd.), western wheatgrass (*Pascopyrum smithii* Rydb.) A. Löve, bluebunch wheatgrass [*Pseudoroegneria spicatum* (Pursh) A. Love], needleandthread (*Stipa comata* Trin. & Rupr.), and blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths].

Experimental Design

Direct-hauled topsoil (a mixture of A and B horizons) was spread in a wedge, ranging from no topsoil to a depth of 60 cm over 1m of White River spoil overlying several meters of Wind River spoil, resulting in a flat surface. Spoil was ripped to a depth of 45 cm before topsoil replacement.

Experimental design was a completely randomized, split-plot in time (Milliken and Johnson 1996) with topsoil depth as factor A and two mulch treatments (straw mulch and stubble mulch), as factor B. The area was divided into 20 plots (4.9 x 45.7 m), 10 replications, running parallel to the topsoil depth gradient. In the spring 1977, half of the plots were seeded to barley (*Hordeum vulgare* L*.)* to establish the stubble mulch. The remaining ten plots were fallowed. Plots received fertilizer at rates of 67 kg P ha^{-1} (treble super phosphate) and 315 kg N ha^{-1} (ammonium nitrate) at establishment.

In October 1977, the plots were seeded with a perennial grass and shrub mixture composed of thickspike wheatgrass [*Elymus dasystachyum* (Hook.) Scribn.], green needlegrass (*Stipa viridula* Trin.), slender wheatgrass [*Elymus trachycaulum* (Link.) Gould ex Shinners], western wheatgrass, Wyoming big sagebrush, and rubber rabbitbrush [*Chrysothamnus nauseosus* (Pallas ex Pursh) Nesom & Baird]. The grass mixture and shrub component were drill seeded at a rate of 15.5 kg pure live seed (PLS) ha^{-1} and 0.5 kg PLS ha^{-1}, respectively. Straw was hand scattered on the fallowed plots at a rate of 5 t ha^{-1} and crimped into the soil surface to reduce loss from wind.

Vegetation Sampling

In June 2001, plant canopy cover, frequency, and aboveground biomass were evaluated, within three 0.18 m^2 quadrats, by species at each topsoil depth (0, 20, 40, and 60 cm) within each mulch treatment plot to assess long-term plant community development. Percent cover (vegetation canopy, litter, bare ground) was estimated using a modified Daubenmire (1959) procedure, and frequency of occurrence was recorded for each species. Live aboveground plant biomass was assessed by clipping (by species) all live plant material at ground level, drying at 65^0C for 48 hrs., and weighing.

Relative percent cover, biomass, and frequency were calculated for each plant species within each topsoil depth and mulch treatment, and summed to provide an “importance value” (McCune and Grace 2002). Importance values identify dominant species and composition of a plant community (Curtis and McIntosh 1951).

The importance values were also used to calculate Shannon-Wiener diversity indices, Equation 1, (Krebs 1999). The Shannon-Weiner diversity index was selected because of its sensitivity to rare species in a community (McCune and Grace 2002).

$$H' = -\sum_{i=1}^{S} (p_i)(\ln p_i) \qquad \text{(Eq. 1)}$$

H’ = index of diversity

S = number of species present

P_i = relative importance value of species “i” expressed as a decimal

Data Analysis

A two-way analysis of variance was used to evaluate the effects of topsoil depth and mulch treatment on plant species richness, diversity, cover, litter, bare ground, and aboveground biomass (SAS Institute 1999). Mean separation was accomplished using the least significant difference method (SAS Institute 1999). All statistical analyses were evaluated at $P \leq 0.05$.

Results and Discussion

Topsoil depth significantly influenced aboveground plant biomass and plant species richness, diversity, and canopy cover. Mulch type showed no significant effects. Average aboveground biomass was significantly higher at the 40 (727 kg ha^{-1}) and 60 cm (787 kg ha^{-1}) topsoil depths compared to the 0 (512 kg ha^{-1}) and 20 cm (506 kg ha^{-1}) topsoil depths.

Species Richness and Diversity

Species richness and diversity progressively declined as topsoil depth increased. Greatest species richness and diversity were observed at the 0 cm treatment, but not significantly higher than 20 cm (Table 1). Significantly greater species richness and diversity were observed at 0, 20 and 40 cm topsoil depths compared to the 60 cm depth. Redente et al. (1997) also found greater species diversity at shallow topsoil depths (15 cm). Based on importance values, crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and western wheatgrass were the dominate grass species. The dominate forb, desert madwort (*Alyssum desertorum* Stapf.), was found on all except the 40 cm topsoil depth treatment.

Table 1. Species richness and diversity in response to topsoil depth, Shirley Basin, WY, 2001. (Values with the same letter within a variable, across topsoil depths are not significantly different, P≤0.05.)

	Topsoil Depth (cm)			
	0	20	40	60
Shannon-Wiener Diversity	2.36a	2.29ab	2.04b	1.87c
Species Richness (# of species)	7.45a	6.95ab	6.5b	5.62c

Grass and Forb Cover

Mean percent grass cover was significantly greater at the 40 and 60 cm topsoil depths compared to the 0 and 20 cm treatments (Figure 1), probably in response to higher nutrient levels and water infiltration and water holding capacity at the deeper depths (Bowen 2003). These findings closely reflect those reported by Syndor and Redente (2000) in northwestern Colorado. In contrast, forb cover was significantly higher at the 0 cm topsoil depth than the other three depths. Forb cover decreased in the 20, 40, and 60 cm treatments as topsoil depth increased; however, these differences were not significant (Figure 1). Increased competition from grasses is believed to be responsible for the deceased forb cover at deeper soil depths. Increased cover at deeper soil depths resulted in increased litter as well, resulting in significantly more bare ground at 0 and 20 cm than 40 and 60 cm of topsoil (Figure 2). There was also significantly more bare ground at 40 cm than at 60 cm of topsoil. Decreased cover at shallower topsoil depths promoted greater natural recruitment of forbs where more bare ground and plant canopy openings exist (Peart 1989). Seeded species cover ranged from 8% at 20 cm to 12% at 40 cm.

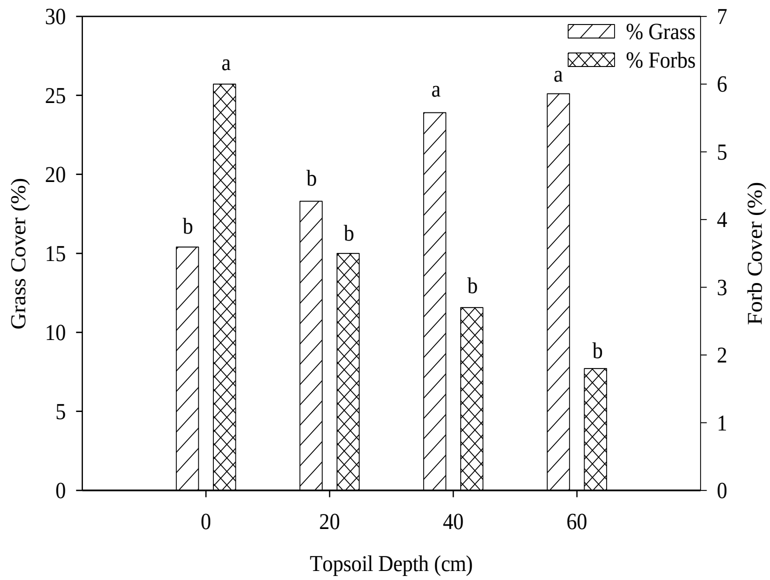

Figure 1. Percent cover of grasses and forbs in response to topsoil depth, Shirley Basin, WY, 2001. (Bars with the same letter within a variable, across topsoil depths are not significantly different, P≤0.05.)

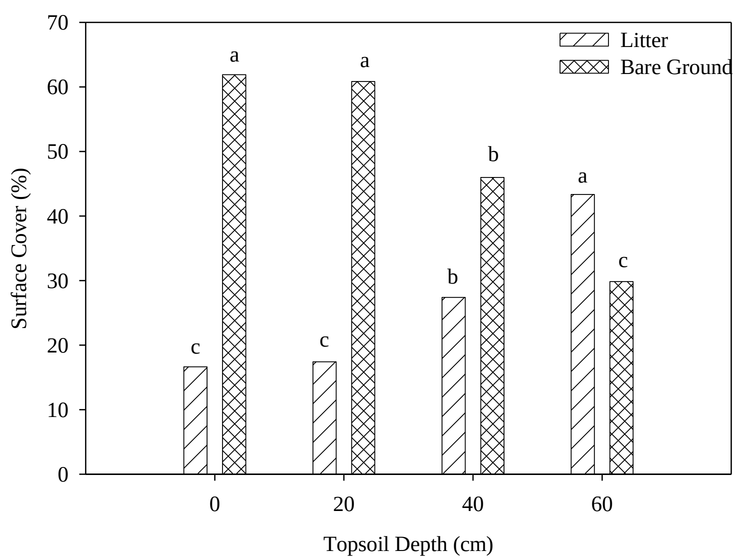

Figure 2. Percent litter and bare ground cover in response to topsoil depth replacement, Shirley Basin, WY, 2001. (Bars with the same letter within a variable, across topsoil depths are not significantly different, P≤0.05).

Summary

Our research indicates variable topsoil replacement influences plant community composition. Shallower topsoil depths (0 and 20 cm) exhibited greater species richness, diversity and forb cover due to natural recruitment and establishment of native species in the open inter-spaces of these topsoil depth treatments. However, plant communities that developed on the 40 and 60 cm topsoil depths were dominated by higher producing, highly competitive cool-season perennial grasses that limited recruitment of native species (Huston 1979). Variable topsoil replacement depths clearly enhance more diverse plant communities on mined lands. Care must be taken to ensure adequate plant cover is initially established to avoid excessive soil erosion when creating shallow topsoil depths (<20 cm). Deeper soil replacement on potentially erosive sites, such as slopes, may help to establish a more robust vegetative community in these areas.

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Literature Cited

Barth, R.C. and B.K. Martin. 1984. Soil depth requirements for revegetation of surface mined areas in Wyoming, Montana, and North Dakota. Journal of Environmental Quality. 13: 399-404. http://dx.doi.org/10.2134/jeq1984.00472425001300030016x

http://dx.doi.org/10.2134/jeq1984.133399x

Bowen, C.K. 2003. Influence of topsoil depth on plant community and soil attributes of reclaimed mine land after 24 years. M.S. Thesis, Department of Renewable Resources, University of Wyoming, Laramie.

Curtis, J.T. and R.P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 32: 476-496. http://dx.doi.org/10.2307/1931725.

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 Proceedings, Symposium on Surface Coal Mining and Reclamation in the Great Plains (Billings, MT, March 19-21, 1984). 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.

McCune, B. and J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR.

McGinnies, W.J. and P.J. Nicholas. 1980. Effects of topsoil thickness and nitrogen fertilizer on the revegetation of coal mine spoils. Journal of Environmental Quality. 9: 681-685. http://dx.doi.org/10.2134/jeq1980.94681x http://dx.doi.org/10.2134/jeq1980.00472425000900040028x.

Milliken, G.A. and D.E. Johnson. 1996. Analysis of mesi data. Volume I. Chapman and

Hall, New York.

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

Peart, D.R. 1989. Species interactions in successional grassland. III. Effects of canopy gaps, gopher mounds and grazing on colonization. Journal of Ecology 77: 267-289. http://dx.doi.org/10.2307/2260929.

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. Journal of Range Management 38: 262-265. http://dx.doi.org/10.2307/3898981.

Power, J.F., R.E. Ries, and F.M. Sandoval. 1976. Use of soil materials on spoils-effects of thickness and quality. North Dakota Farm Research 34: 23-24.

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.

Redente, E.F. and N.E. Hargis. 1985. An evaluation of soil thickness and manipulation of soil and spoil for reclaiming mined land in northwest Colorado. Reclamation and Revegetation Research 4: 17-29.

SAS Institute. 1999. SAS/STAT user's guide, release 8.0. Cary, North Carolina.

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., F. Rauzi, and B.A. Pinchak. 1985. Revegetation of mined land: Influence of topsoil depth and mulching method. Journal of Soil and Water Conservation 40: 249-252.

Syndor, R.S. and E.F. Redente. 2000. Long-term plant community development on topsoil treatments overlying a phytotoxic growth medium. Journal of Environmental Quality 29: 1778-1786. http://dx.doi.org/10.2134/jeq2000.00472425002900060007x http://dx.doi.org/10.2134/jeq2000.2961778.