RESTORATION TECHNIQUES FOR ROAD DISTURBANCES IN GRAND TETON NATIONAL PARK[1]

Nicholas R. Cotts and Edward F. Redente[2]

Abstract.-- Landscape distubance usually results in the degradation of any given ecosystem. Disturbed sites must then be manipulated and altered to restore the ecosystem to a functional, self-sustaining community. In 1988, test plots were implemented in Grand Teton National Park to evaluate restoration practices suitable for disturbances commonly found in the park. The overall objective of this research was to determine which restoration techniques could be used to restore the displaced vegetative community on an abandoned homestead road in the park. Bulk density, infiltration and aggregate stability were measured as a means of evaluating the effect of restoration practices on soil physical parameters and subsequent plant community development. Results indicated that scarification facilitated plant establishment on the unaltered roadbase by decreasing surface bulk densities and improving the seedbed environment. The topsoiled and scarified treatments produced the most significant plant community development. Topsoil structural characteristics (large aggregates, macropores) improved initial infiltration rates while presenting a receptive seedbed environment. This research indicates the relative importance of soil physical properties as they relate to successful restoration techniques. These attributes have been shown to dominate the limiting factors controlling vegetation establishment on abandoned roads in Grand Teton National Park.

[1] Paper presented at the American Society of Surface Mining and Reclamation, May 14-17, Durango, CO.

[2] Nicholas R. Cotts is a Research Associate, Department of Range Science, Colorado State University, Fort Collins, CO. Edward F. Redente is a Professor, Department of Range Science, Colorado State University, Fort Collins, CO.

Introduction

The National Park Service strives to maintain a balance between natural environments and public service. Construction projects, intended to facilitate public access, often result in disturbances requiring careful mitigation to restore biotic functions to predisturbed conditions.

Construction projects in National Parks produce soil conditions characteristic of lands disturbed by the mining industry. Soil physical characteristics (bulk density, infiltration, and aggregate characteristics) are altered as a result of compaction and erosion. Chemical properties such as nutrient availability and pH also differ from those levels naturally occurring. Finally, the soil fauna and surface flora capable of existing in the natural environment are reduced or eliminated from the disturbed site.

Physical soil characteristics are often limiting factors governing the success or failure of restoration practices in the semiarid west. Bulk density, infiltration, and aggregate stability are 3 properties greatly influencing soil moisture characteristics which become paramount when establishing a plant community in semiarid regions.

The application of topsoil is a common restoration technique for severely disturbed sites. Topsoil additions to disturbed lands usually provide a renewed source of microbial activity for nutrient cycling, increase infiltration, and soil structural characteristics, as well as providing nutrients not usually present in disturbed soils (Packer and Aldon 1978; Hargis and Redente 1984).

Proceedings America Society of Mining and Reclamation, 1991 pp 511-520
DOI: 10.21000/JASMR91020511
https://doi.org/10.21000/JASMR91010511

Surface manipulation techniques have been frequently studied as to their effect on soil moisture retention, infiltration, and compaction in arid and semiarid lands (Hodder 1975, 1979; Richardson 1979; Verma and Thames 1978). This research suggests that by creating open channels and retention depressions, moisture can enter the soil profile relatively quickly. These manipulations also reduce surface compaction, which may inhibit root penetration. Soil scarification also serves a functional importance in developing a favorable seed germination environment.

The objective of our research was to examine the success of various reclamation techniques as they influenced physical soil parameters. These parameters have a direct influence on the ability of plant materials to develop self-sustaining plant communities on abandoned roads.

Methods and Materials

Study Site

The study was conducted in Grand Teton National Park near Jackson, Wyoming. The test plot was located within the disturbed tracks of an existing, abandoned homestead road at an elevation of 2,075 m.

Local Climate, Soil and Vegetation

The climate of the area is typically semiarid with hot, dry summers and cool, wet winters. Average annual precipitation is 68 cm (486 cm snowfall) with a mean annual temperature of 2.2° C. Soils characterizing the site are classified as loamy-skeletal, mixed typic Cryoborolls and sandy-skeletal, mixed typic Cryoborolls. The soils have formed on stream terraces and alluvial fans, as well as glacial outwash materials from the Teton Range (SCS 1975). The soils of this area are characterized as being well-drained and having moderate permeabilities. Topography is nearly level to gently sloping. The undisturbed plant community surrounding the study site was described by Sabinske and Knight (1978) as a low sagebrush/big sagebrush mosaic.

Experimental Design

The study was designed as a completely randomized block, with 14 treatments replicated 4 times. The dimensions of treatments 1-8 were 0.6 m by 6 m within the individual road tracks. Treatments 9-14 were 2.5 m by 6 m, or the entire width of the road. The 14 treatments are listed below.

1. Control.
2. Mulch with aspen/ceder woodchips (≈45 metric ton ha^{-1}).
3. Indigenous seed (collected within the park) and brush beating.
4. Commercial seed.
5. Scarifying (30 cm).
6. Scarifying and rock raking.
7. Scarifying, 55 kg P ha^{-1}, indigenous seed and brush beating.
8. Scarifying, 55 kg P ha^{-1}, commercial seed.
9. Topsoil (15 cm), scarifying.
10. Topsoil (15 cm), scarifying, 55 kg P ha^{-1}.
11. Topsoil (15 cm), scarifying, 55 kg P ha^{-1}, indigenous seed and brush beating.
12. Topsoil (5 cm), scarifying, 55 kg P ha^{-1}, indigenous seed and brush beating.
13. Topsoil (15 cm), scarifying, 55 kg P ha^{-1}, commercial seed.
14. Topsoil (15 cm), scarifying, 55 kg P ha^{-1}, indigenous seed and mulch.

P = Phosphorus

Test Plot Construction

The test plot was constructed in October 1988. Vegetation separating the road tracks was removed from those areas designated for treatments 9-14, and topsoil was spread to either 5 or 15 cm. Topsoil was obtained from exposed Jackson Lake bottom soils during reconstruction of the Jackson Lake dam. Soil analyses indicated that topsoil and road substrate materials were similar in both texture and nutrient availability. Respective treatments were scarified (ripped) to a depth of 30 cm with a road grader. Scarification was included as a treatment to reduce compaction.

Phosphorus (triple superphosphate) was applied across all treatments (except treatments 1 and 2, control and mulch) at 55 kg P ha^{-1}. A subset of these treatments received an additional 55 kg P ha^{-1} as a fertilizer treatment. Nitrogen was applied at the rate of 22 kg N ha^{-1} to all treatments to serve as a source of available N for initial growth.

Rock raking was included as a treatment to assess the impact of surface rock on recolonization. A hand rake was used to remove large cobble and rock from this treatment.

The seeded treatments were broadcast by hand at approximately 35 kg pure-live- seed/ha. The seeding treatments consisted of plant materials from indigenous sources of seed and from a commercial source (See Table 1). Indigenous seed came from seed collections and brush-beating operations within the Park in 1988, while the commercial seed was obtained from similar locations (i.e., elevation and climate). Adjacent plant materials were mowed, gathered, and distributed on the test plot as an attempt to incorporate additional seed materials to respective treatments.

Table 1. Seed mixtures - Homestead Plot.

Scientific Name	Seeding Rate
Indigenous Mixture	(kg PLS/ha)
Agropyron trachycaulum	1.80
Artemisia tridentata	0.25
Purshia tridentata	14.40
Bromus carinatus	5.30
Lupinus sericeus	16.70
Poa ampla	0.26
Total	38.71
Commercial Mixture	
Agropyron trachycaulum	1.60
Artemisia tridentata	0.37
Purshia tridentata	7.20
Bromus marginatus	3.30
Lupinus sericeus	14.30
Agropyron smithii	0.87
Achillea millefolium	0.06
Agropyron spicatum	1.80
Artemisia ludoviciana	0.10
Poa compressa	0.07
Total	29.67

Experimental plots were mulched using a woodchip material consisting of 2 parts aspen and 1 part red cedar shredded to approximately 5 cm in diameter. The mulch was applied at the rate of 45 metric tons/ha, equivalent to a 2.5 cm depth.

Vegetation Sampling

Plant cover was estimated by species during the 1989 and 1990 growing seasons. Sampling was conducted during the periods of peak growth, usually in late July. Plant cover was estimated to the nearest 1% using a 20 cm by 50 cm quadrat ($0.10m^2$) randomly placed along a transect through each treatment. All treatments were sampled until sample adequacy was met.

Statistical Analysis

All vegetative data were subjected to the analysis of variance procedure. Significant differences among treatment means were determined using the Least Significant Difference (LSD) test at the 5% level.

Soil Physical Attributes

Infiltration (Haise et al 1953 and Wani 1987) and bulk density (Blake 1973) tests were conducted to assess the effect of soil scarification and topsoiling on infiltration and bulk density characteristics. The infiltration tests were conducted on treatments that were topsoiled and scarified (5 cm and 15 cm topsoil additions), scarified, and on the control and undisturbed areas along the road. Bulk density tests were conducted on the same treatments as the infiltration tests. Data were analyzed using the single degree of freedom mean separation test.

Aggregate stability analyses were completed on soils from the scarified roadbase and the scarified topsoil treatments. The aggregate analyses employed a soil-wetting technique described by Kemper and Rosenau (1986) and a wet-sieving technique used by Elliot (1986). Statistical analyses were not conducted on the aggregate data. The main goal of this procedure was to understand the relationship between bulk density, infiltration and aggregate size and stability of the soils in question.

Results and Discussion

Soil Physical Attributes

Infiltration and bulk density analyses were conducted to determine if compaction was a problem limiting plant establishment on the abandoned road. These tests also enabled us to determine if the selected experimental treatments of scarification, rock raking, and topsoiling significantly affected the physical parameters of the road substrate. It is important to note that both the road substrate and the topsoil material have identical textural and organic matter characteristics. These factors eliminate the water-holding-capacity advantage of topsoil material over the road substrate.

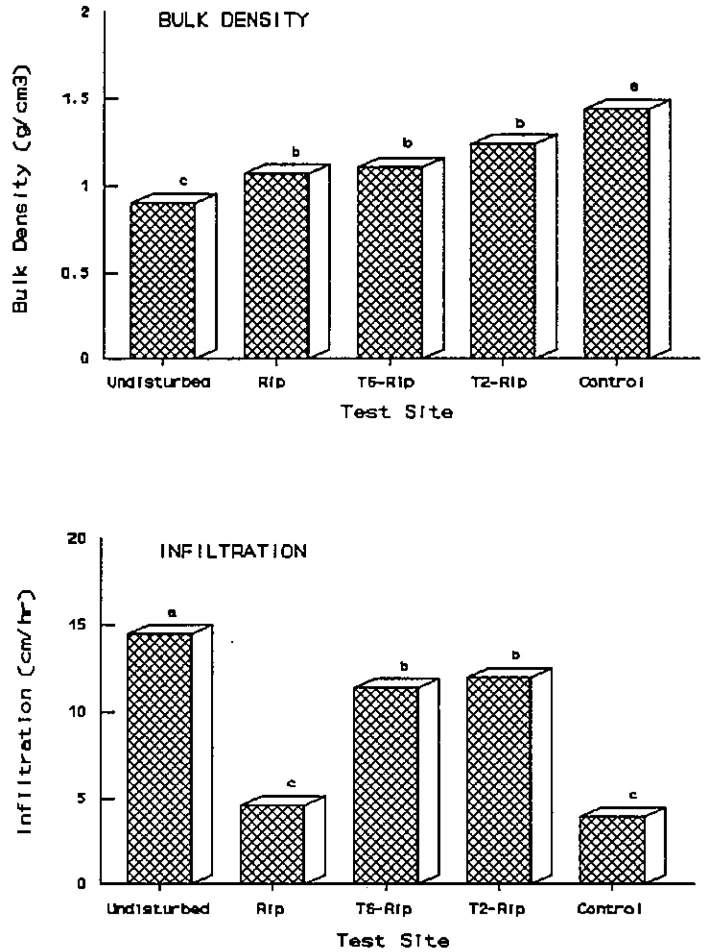

Figure 1. Soil bulk density and infiltration characteristics of the Homestead Plot substrate and undisturbed areas. Treatments with the same letter are not significantly different ($P \leq 0.05$). Undisturbed: soils adjacent to the test plot; Rip: treatments that were scarified; T6-Rip: topsoil (15 cm) and scarification; T2-Rip: topsoil (5 cm) and scarification; Control: undisturbed roadbase.

<u>Infiltration and Bulk Density</u>

Infiltration rates and bulk densities are shown in Figure 1. The bulk density data followed an expected gradient. Natural undisturbed soil had the lowest bulk density, while the untreated road surface (control) had the highest bulk density. This provided evidence that the road surface had been compacted as a result of surface activity over the lifetime of the road.

Infiltration and bulk density may be directly correlated, as bulk density often controls the infiltration rate (Hillel 1982). However, infiltration rates did not parallel the bulk densitiesn in this case. The infiltration rate of the natural undisturbed soil was quite high as expected. The infiltration rates of the topsoil treatments were high as well, due to the fact that this soil has not been compacted. The infiltration rate of the scarified treatment (without topsoil) was not significantly different than the control. This indicates that scarification alone may not improve the infiltration rate of the roadbase soils.

Soil scarification significantly decreased the bulk density of the road substrate, but it did not increase the infiltration rate of these soils. These results suggest that neither the bulk density nor the textural properties of this soil limit infiltration rates (Cotts 1990). Therefore, further structural evaluations were necessary to explain these differences.

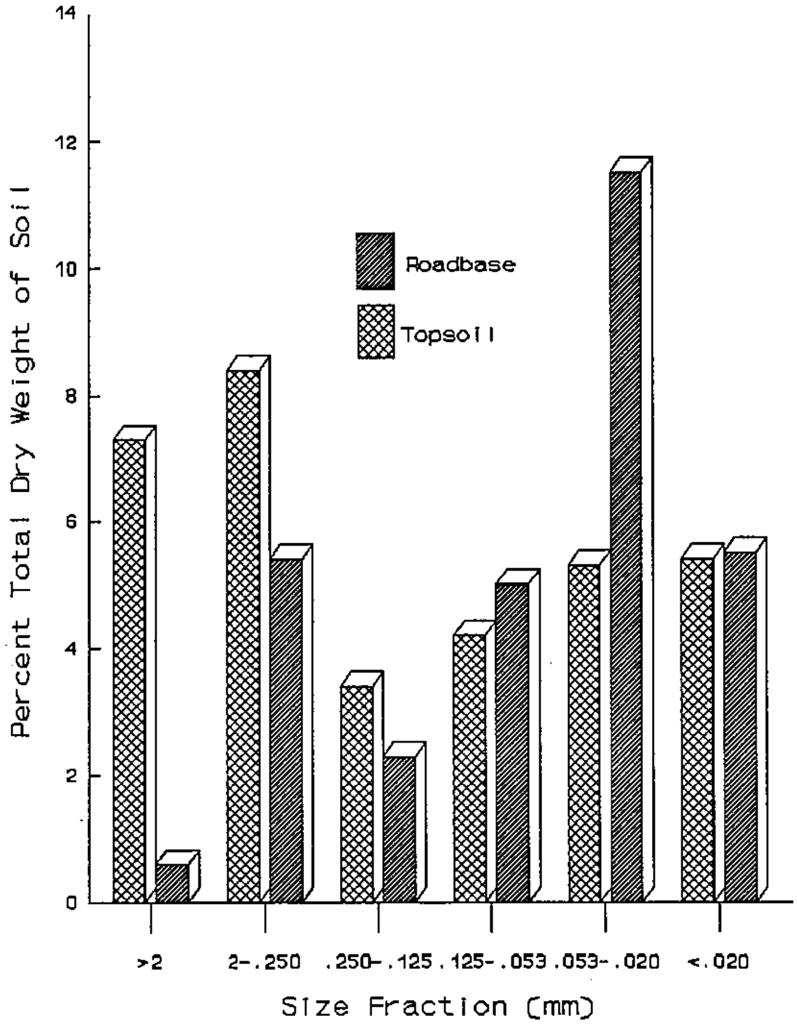

Figure 2. Aggregate stability analyses for soils from the topsoil treatment and the scarified roadbase treatment. Higher percents of soil material in larger size classes indicated greater aggregate stabilities.

Aggregate Stability

Relative aggregate size and stability of roadbase and topsoil materials were tested to evaluate the structural differences between these 2 soils. Aggregate stability analyses were completed on soils from the scarified roadbase and the scarified topsoiled treatments. Results indicated that the topsoil material had more and larger stable aggregates following wet-sieving destruction (See Figure 2) than the roadbase soils. This indicates that soil aggregates in the topsoil material are inherently larger and more resistant to physical destruction upon wetting, and are less likely to break apart. The roadbase soils have more soil particles in the silt-size aggregate range and less soil particles contained in larger, stable aggregates. Aggregates that disintegrate upon wetting result in pore sealing and ultimately decrease infiltration (Hillel 1982).

The aggregate-size relationship between the topsoil and the roadbase soil, including pore size variations, explains the observed differences in infiltration rates, which were independent of soil bulk density. Infiltration may be more dependent on aggregate size, pore size distribution, aggregate stability,

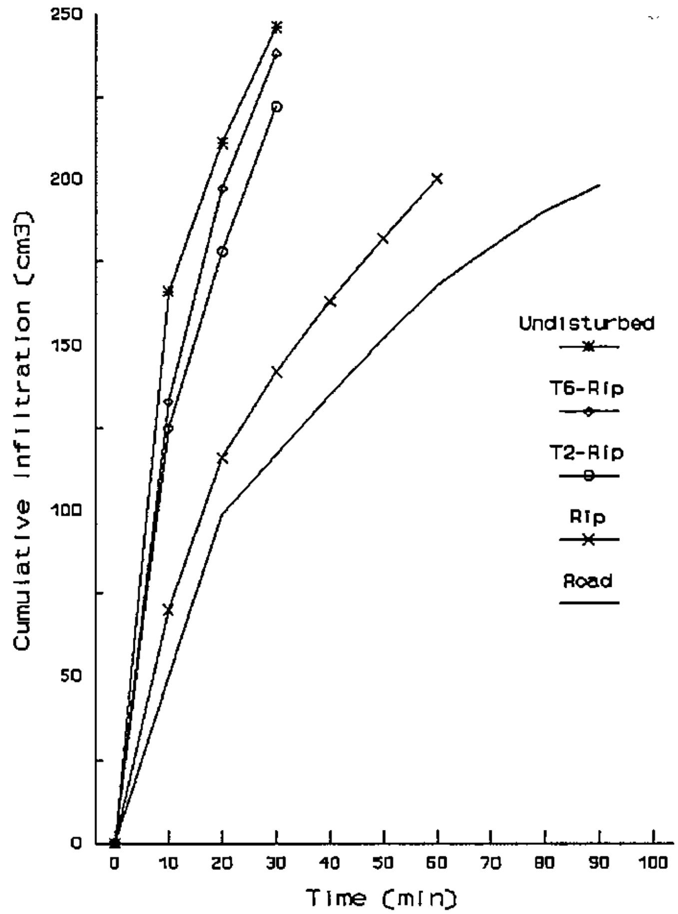

Figure 3. Infiltration curves of various treatments from the Homestead Plot. Undisturbed: soils adjacent to the test plot; Rip: treatments that were scarified; T6-Rip: topsoil (15 cm) and scarification; T2-Rip: topsoil (5 cm) and scarification; Road: undisturbed roadbase.

and surface sealing. Favorable aggregate structure, size, and associated macropores are important soil properties in semiarid environments dominated by high intensity, short-duration precipitation events. These physical qualities are characteristic of the topsoil material used in the study, thereby facilitating initial infiltration in the topsoiled treatments. Soil scarification on non-topsoiled treatments had no immediate affect on structural properties; therefore, the scarified treatments showed no response in terms of increased initial-infiltration rates and are not different than the control (unaltered roadbase). Soil structure and aggregate size is an inherent soil factor dependent on soil development, microbial processes, and weathering. These factors are not enhanced by scarification activites, which explains the lack of infiltration response to scarification.

The relative variations in aggregate size following wet sieving may be explained by the history of each soil. The roadbase soil has been driven on, puddled, and physically disturbed since the road was established. This would result in a soil with smaller inherent aggregate characteristics on the exposed surface. The topsoil material has not been disturbed, as it was taken from exposed Jackson Lake bottom soils. The topsoil material is actually buried alluvial soils, similar to other soils throughout the valley, that were inundated with the creation of Jackson Lake. The inherent aggregate size has not been decreased through disturbance. Therefore, the topsoil treatments have more large aggregates than the roadbase soils prior to wetting, which improves infiltration rates.

The most significant response to topsoil additions are evident when reviewing the infiltration curves for the respective treatments (See Figure 3). As mentioned earlier, initial infiltration rates are extremely important in this environment. High-intensity, short-duration

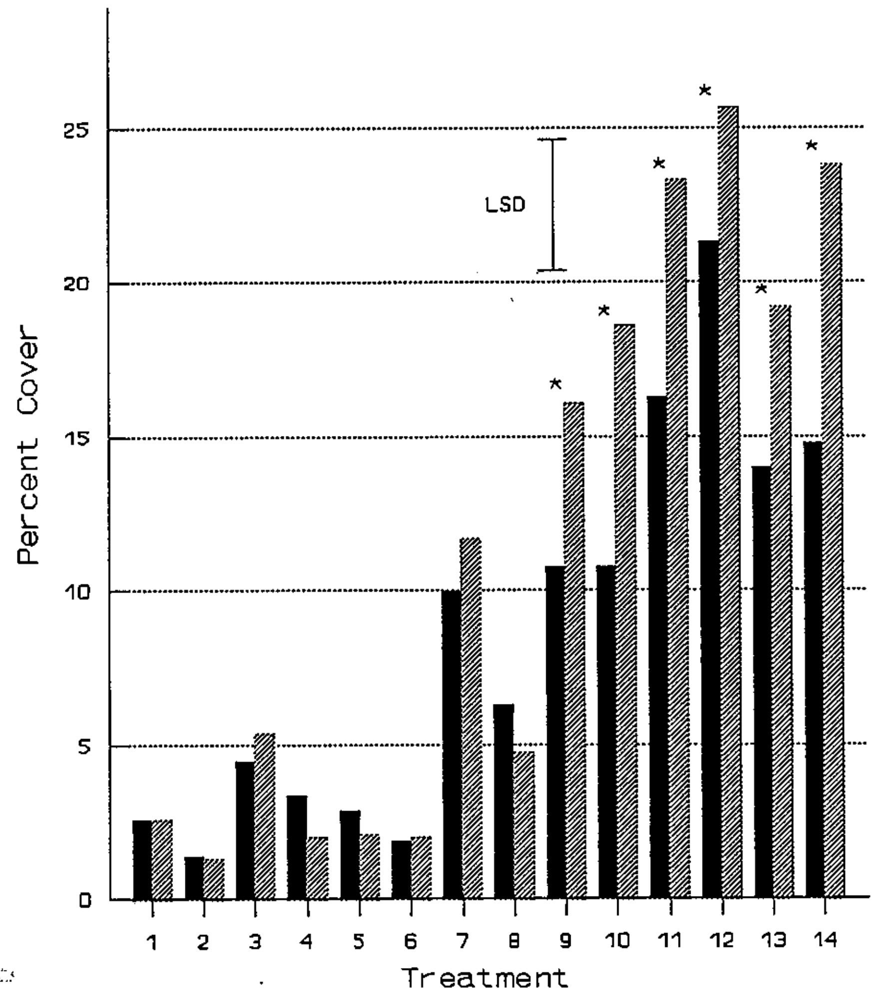

Figure 4. Total plant cover comparison between 1989 and 1990. Treatments with an (*) express significant differences between 1989 and 1990 cover values at the P≤0.05 level. Rip: Scarifying (30 cm); T15: Topsoil 15 cm; T5: Topsoil 5 cm; P: Phosphorus.

1. Control
2. Control and mulch
3. Indigenous
4. Commercial
5. Rip, no seed
6. Rip, rock raking
7. Rip, P, indigenous
8. Rip, P, commercial
9. T15, Rip
10. T15, Rip, P
11. T15, Rip, P, indigenous
12. T5, Rip, P, indigenous
13. T15, Rip, P, commercial
14. T15, Rip, P, indigenous, mulch

precipitation events translate into large volumes of water being added to the soil profile in a short period of time. Soils with improved surface structure are better able to infiltrate and store this water in the soil profile. Soils with poor infiltration characteristics tend to pool water on the surface. This water is then lost to runoff and evaporation and never becomes available for plant growth.

Plant Community Development

Correlations between physical soil parameters and plant community development throughout the Homestead Plot substantiates the importance of physical soil qualities in restoration practices. Plant cover data were collected during 1989 and 1990 to assess plant development in response to varying treatment intensities (See Figure 4).

Scarification

Treatments 3 versus 7 and treatments 4 versus 8 provide evidence supporting plant response to scarification and direct seeding. Although infiltration rates were not dramatically altered (Figs. 1 and 3), scarification did positively influence community establishment. A significant response to scarification was associated with seedbed preparation. Soil scarification improves the probability of adequate seed burial (Richardson 1979), which is necessary to ensure seed germination. Treatments 7 and 8 clearly illustrate this response. In both cases, there were dramatic increases in total plant cover over similar treatments that were not scarified (treatments 3 and 4). These differences were significant in the case of the indigenous seed mixture, which is apparently better-suited to the growing conditions present on the road surface. Seeding without scarification did not produce an acceptable plant community.

Scarification had little effect on treatments which were not seeded (treatments 5 and 6), indicating minimal plant establishment from natural seed rain. This comparison, in part, explains the limiting factor controlling natural community development. Seeds from intact communities on the periphery are not able to establish due to the limiting physical soil characteristics of the roadbase soil.

Topsoil Response

Historically, topsoil has been used to increase nutrient availability, moisture holding capacity and improve the soil tilth of disturbed sites. Treatments receiving topsoil in this study (treatments 9-14) showed the most significant plant community development. However, topsoil materials applied to the Homestead Plot were physically and chemically similar to roadbase soils. These soil similarities eliminate the liklihood of a plant response to a change in textural or chemical conditions.

Topsoiled treatments showed positive plant growth responses with and without seeding. Treatments 9 and 10 represent natural invasion from surrounding, intact plant communities along the roadway. Topsoiling practices improved the seedbed conditions, which presented a more suitable environment for seed germination.

The success of natural invasion indicated the importance of seedbed quality. Improved physical soil characteristics presented a better seed environment when compared to treatments 3 and 4, which received no physical alteration. Data indicate that the propensity for natural invasion is high if a suitable seedbed environment can be achieved.

The significant increase in plant cover between topsoiled and non-topsoiled treatments may also indicate a difference in plant-available water between these treatments. The topsoiled treatments had high initial infiltration rates as well as overall cumulative infiltration. These treatments were able to take advantage of the high-intensity, short-duration precipitation events by infiltrating larger volumes of water with subsequent storage deeper in the soil profile. Non-topsoiled treatments suffered water loss through the lack of deep percolation and surface evaporation. Plant response indicated that topsoiled treatments had more available soil moisture, which significantly increased overall plant cover values.

Summary

This research was initiated to provide information regarding restoration techniques to successfully modify past and current anthropic disturbances found in Grand Teton National Park. The research has provided several guidelines relative to the intensity of cultural manipulations needed to produce varied degrees of plant community development. Examination of treatments following 2 years of growth indicated that different levels of manipulation resulted in varying rates and directions of plant community development. These observations may continue to change over time, but inferences can be made regarding their potential utility as a means of altering disturbed landscapes.

It was determined that soil physical properties were the limiting conditions preventing establishment of plant communities on the abandoned road. Topsoiling and scarification were suitable techniques that amended surface conditions and facilitated plant establishment.

Our research has provided the National Park Service with a set of desired conditions necessary to facilitate plant community development on disturbed sites. Plant community development is then dependent upon the available resources (i.e., topsoil, plant materials) and the ability to recongize the limiting conditions of a given site.

ACKNOWLEDGEMENTS

This research was funded by the National Park Service under grant number PX1200-8-0932. Special thanks to Robert Schiller and William Beavers for their administrative support, and to the University of Wyoming National Park Service Research Center for providing logistical support.

Literature Cited

Blake, G.R. 1973. Bulk Density. In: Black et al, (eds) Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9, Chapter 13. American Society of Agronomy-Soil Science Society of America, Madison, WI.

Cotts, N.R. 1990. Evaluation of Restoration Techniques for Grand Teton National Park. M.S. Thesis, Colorado State University. 98 p.

Elliot, E.T. 1986. Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. Soil Science Society American Journal 50(3):627-633.
http://dx.doi.org/10.2136/sssaj1986.03615995005000030017x

Haise, H.R.; W.W. Donnan; J.T. Phelan; L.F. Lawhon; and D.L. Shockley 1956. The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils. USDA-ARS 41-7. USDA, Washington D.C.

Hargis, N.E. and E.F. Redente 1984. Soil handling for surface mine reclamation. Journal of Soil and Water Conservation 39(5):300-305.

Hillel, D. 1982. Introduction to Soil Physics. Academic Press, Inc. 364 p.

Hodder, R.L. 1975. Montana reclamation problems and remedial techniques. pp. 90-109. In: M.K. Wali (ed) Practices and problems of land reclamation in western North America. The University of North Dakota Press.

Hodder, R.L. 1979. Rapid soil stabilization and perennial vegetation establishment with use of annual species, irrigation, and seedbed treatments. Montana Agricultural Experiment Station, Research report 141. Montana State University, Bozeman.

Kemper, W.D. and R.C. Rosenau 1986. Aggregate stability and size distribution. In: Klute (ed) Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9, Chapter 17. American Society of Agronomy-Soil Science Society of America, Madison, WI.

Packer, P.E. and E.F. Aldon 1978. Revegetation techniques for dry regions. pp. 425-450 In: F.W. Schaller and P. Sutton (eds) Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Madison, WI.

Richardson, B.Z. 1979. Site preparation. pp. 27-34 In: User Guide to Vegetation. USDA General Technical Report INT-64. Forest and Range Experiment Station, Ogden, UT.

Soil Conservation Service 1975. Soil Survey - Teton County, Wyoming.

Sabinske, D.W. and D.H. Knight 1978. Variation within the sagebrush vegetation of Grand Teton National Park. Northwest Science 52(3):195-204.

Verma, T.R. and J.L. Thames 1978. Grading and shaping for erosion control and vegetation establishment in dry regions. pp. 399-409 In: F.W. Schaller and P. Sutton (eds) Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Madison, WI.

Wani, B.A. 1987. Physical and chemical aspects of an infiltrations study on a shortgrass prairie ecosystem. Ph.D. Dissertation, Colorado State University. 118 p.