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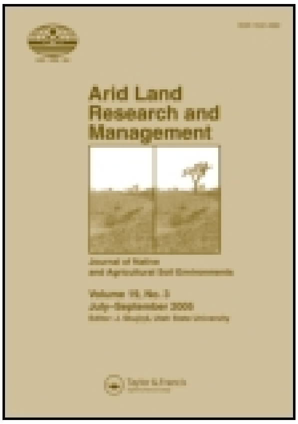

Arid Land Research and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uasr20

Burning and Seeding Influence Soil Surface Morphology in an Artemisia Shrubland in Southern Idaho

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Version of record first published: 30 Nov 2010

To cite this article: Julie H. Hilty, David J. Eldridge, Roger Rosentreter & Marcia C. Wicklow-Howard (2003): Burning and Seeding Influence Soil Surface Morphology in an Artemisia Shrubland in Southern Idaho, Arid Land Research and Management, 17:1, 1-11

To link to this article: http://dx.doi.org/10.1080/15324980301593

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Arid Land Research and Management 17: 1–11, 2003
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1532-4982/03 $12.00 + .00
DOI: 10.1080/15324980390169028

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Burning and Seeding Influence Soil Surface Morphology in an *Artemisia* Shrubland in Southern Idaho

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We compared the morphology of soil surfaces dominated by Wyoming big sagebrush at burned-seeded, burned-unseeded, and unburned sites in southern Idaho. Both burning and seeding resulted in significant changes in soil surface morphology. Unburned sites were dominated by Type I (shrub- and grass tussock-dominant coppice) and Type II (lichen- and moss-covered coppice bench) surfaces, while burned-seeded sites were dominated by Types I, II, and III (bare or lichen-covered microplains between the individual coppices) surfaces. Type V surfaces (severely-disturbed, annual grass-dominant microsites) predominated on the

Received 17 December 2001; accepted 11 March 2002.
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We thank Mark Seyfried and Mike Pellant for their help in designing this study, Jim Hilty for his assistance in the field, Laura Bond and Terry Koen for statistical advice, and Sam Loftin for comments on the manuscript. Funding for this study was provided by the U.S. Department of Defense Legacy Program and the Bureau of Land Management.

burned-unseeded sites. Burning and subsequent conversion of native shrubland to exotic grassland results in a predominance of Type V surfaces unless seeding is used to reintroduce perennials or the surface is allowed to recover in the absence of subsequent fire and disturbance. The benefits of postfire revegetation and subsequent recovery of soil surfaces conducive to germination and establishment of perennial grass and shrub communities outweigh the initial short-term disturbance associated with drill seeding.

Keywords soil surface morphology, post-fire revegetation, sagebrush steppe, biological soil crust, lichens, range seeding

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The potential for natural and artificial revegetation of a disturbed site is affected by the surface-soil morphological types present at a site. Rangeland surfaces are typically patterned, and this patterning is expressed at a range of spatial scales from the landscape scale of tens of kilometres, right down to plant-interplant patches at scales of only a few centimeters (Tongway et al., 2001). At small spatial scales, Eckert et al. (1978) described the morphology of rangeland surfaces based on their microtopographic position and physical characteristics (Table 1). Four of these types are common on loess-mantled soils supporting Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) in northern Nevada, and have been shown to play an important role in the revegetation of big sagebrush communities (Eckert et al., 1986a, b, 1987; Wood et al., 1978, 1982).

Seedling establishment is lower on Type III (intercoppice microplain) and Type IV (playette) surfaces due to the formation of a massive vesicular crust and the inability of seedlings to penetrate the crust (Eckert et al., 1978, Wood et al., 1978, 1982). Higher levels of organic matter in Type I (coppice) and Type II (coppice bench) surfaces prevents the formation of a vesicular horizon that would otherwise impede seedling development and establishment (Wood et al., 1978). The pinnacled and trenched surface associated with Type II surfaces provides favorable microsites (safe-sites, *sensu* Harper et al., 1965) for establishment of native plants. While seedlings may be able to establish in the narrow fissures and cracks within Type III surfaces (Hugie and Passey, 1964), poor soil contact may impede the process (Eckert et al., 1986b). If the surface is trampled, then some seeds may become buried too deeply to germinate.

Eckert et al. (1986a) demonstrated links between the cover of the four soil surface morphological types and ecological status (or rangeland condition). Types I and II exhibit higher infiltration rates and less surface runoff during heavy snowmelt or precipitation events than do Types III and IV. Late-seral sites have proportionally greater coverage of Type II surfaces stabilized by biological soil crusts, as well as greater cover of bunchgrass-dominant Type I surfaces colonized by disturbance-intolerant ("decreaser") species. Early-seral sites have a higher proportion of Type III surfaces and Type I surfaces associated with shrubs.

Soil surface morphology is of immense interest to ecologists because of its role in the recovery of plant communities, and its usefulness as an indicator of rangeland health. Little is known, however, about the extent to which soil surface microtopography contributes to the recovery of biological soil crusts following wildfire. In this study we extend the four class system described above to include a degraded surface dominated by annual grasses, and compare the occurrence of five soil surface morphological types in unburned Wyoming big sagebrush communities with adjacent burned areas with and without postfire seeding. The objective was to examine links between the health of the plant community and the status of the soil surface.

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TABLE 1 Surface-soil Morphological Types Adapted from Eckert et al. (1978)

Soil-surface morphological type	Microtopographic position	Description
I	Coppice	Semicircular form under single shrubs or grass bunches, or a lobate area up to a few meters long when shrubs or grass bunches are closely grouped. Surface polygons convex-topped, weak to moderate, very fine subangular blocky and uncrusted; separated by about 2 cm wide by 1–2 cm deep, rapidly-narrowing litter-filled trenches. The entire soil surface is covered with litter, lichen, or moss where it is not trampled.
II	Coppice bench	The surface is partly lichen- and/or moss-covered or bare depending on degree of trampling. Occurs as discontinuous, lobate, 0.3–1.5 m wide margins around coppices; or 0.5–3 m wide coppice benches; or on microplains with an A-horizon that has a coarse-loamy texture. Polygons 7–15 cm diameter, prominently convex-topped or frost-heaved into irregular 1–3 cm tall by 2–3 cm diameter pinnacles, separated by 2 cm wide by 1–2 cm deep trenches. Bare surface is smooth or crusted and readily accepts water.
III	Intercoppice microplain	Bare or partly lichen-covered surface depending on trampling. Polygons flat-topped, 13–26 cm in diameter, separated by narrow 1 cm deep by 1 cm wide cracks; polygon top 1–4 cm thick, with a durable, vesicular crust. Pebbles or litter may collect in the cracks around polygons. Microplains form gentle, 0.2–5 m wide slopes around coppices or coppice benches and are flat for 0.3–2 m reaches, forming indistinct steps leading down to playettes or to minuscule drainage ways.
IV	Playette	This surface forms on semicircular or elongated playettes 0.5 to 5 m wide. The surface is barren, lichen- or moss-covered; notably smooth, and light-colored. The flat-topped, 20–36 cm polygons are the largest of all, but are separated by the narrowest, most sharply angular-shouldered cracks less than 1 cm wide. The crust is 4–8 cm thick, coarsely vesicular and massive in its upper part, grading to platy with depth.

(*Continued*)

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TABLE 1 (*Continued*)

Soil-surface morphological type	Microtopographic position	Description
V	Coppice, coppice bench, intercoppice microplain	Severely disturbed, generally flat surface; weakly or no crusting due to abundant, densely-spaced plant roots associated with annual grasses. Cracks are absent or indistinguishable due to density of plants and/or litter accumulation. Subsurface structure is platy. Formation often results from annual grass invasion following disturbance of Types I–III.

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Methodology

The Study Area

The study area encompassesd the region potentially supporting Wyoming big sagebrush shrub-steppe vegetation communities on the western Snake River Plain south of Boise, Idaho. Three sites, Kuna Butte East (approximately 4.8 km south of Kuna, Idaho, 43°27′ N, 116°26′ W, elevation 884–914 m), Kuna Butte West (approximately 4.8 km south of Kuna, Idaho, 43°27′ N, 116°27′ W, elevation 945 m), and Rattlesnake Creek (approximately 4.8 km northeast of Mountain Home, Idaho, along U.S. Route 20, 43°10′ N, 115°37′ W, elevation 1005–1035 m) were selected for the study. All were located on public lands administered by the Bureau of Land Management (BLM). The three sites had a relatively flat topography and were burned by wildfires between 1980 and 1983, approximately a decade prior to the commencement of the study (Kochert & Pellant, 1996). As the results reported here form part of a larger study of the recovery of biological soil crusts after fire (Kaltenecker, 1997), sites were selected on the basis that they had about a decade of recovery from burning.

Each site contained areas of (1) unburned, (2) burned and seeded, and (3) burned and unseeded shrub-steppe. The unburned (and unseeded; termed "control") sites supported Wyoming big sagebrush with a perennial herbaceous understory dominated primarily by the grasses Sandberg bluegrass (*Poa secunda* J. Presl.) and bottletail squirreltail [*Elymus elymoides* (Raf.) Swezey]. Burned sites which had been revegetated (termed "burned-seeded"), were seeded with perennial grasses using a rangeland drill during the fall following burning. Adjacent burned and unseeded (termed "burned-unseeded") sites were also present nearby. All sites used in this study showed evidence of historical overgrazing, as indicated by the absence of two important perennial grasses for this geographic area: bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Love] and Thurber's needlegrass [*Achnatherum thurberianum* (Piper) Barkworth]. Following burning and seeding, there was minimum use of the sites by domestic livestock, mainly because the areas were close to agricultural fields, residential areas, and/or highways. Although both Kuna Butte sites are popular sites for off-road vehicles and hiking and horse riding from nearby residential areas, we observed that traffic in the area was normally concentrated on established roads and trails and therefore did not impact the study sites.

The soils in the area are predominantly Aridisols, formed on loess and sedimentary deposits covering basalt lava flows (Hironaka et al., 1983). The climate is semiarid, with hot, dry summers and cool, wet winters. Annual precipitation ranges from 178–305 mm, with less than 35% of the moisture occurring between April and September (Hironaka et al.,1983). Mean daily temperatures range from −1°C in January to 24°C in July. Biological soil crusts in the unburned sagebrush stands within the study area were dominated by associations of crustose, squamulose, and fruticose lichens and Pottiaceous mosses (Kaltenecker et al., 1999). Mosses formed short turfs in the interspaces, with lichens interspersed and growing on top of the moss. The moss *Tortula ruralis* (Hedw.) Gaertn. et al. commonly forms thick mats under sagebrush canopies in this shrub-steppe system.

Field Methods

For each combination of the three sites by three treatments (control, burned-seeded, burned-unseeded), we established six 20 m transects, resulting in a total of 54 transects for the study. Each treatment area was stratified to include a relatively homogeneous stand of vegetation 1 to 2 ha in size, and transects were randomly (and permanently) located within the stands.

Between late August and early October 1994, we measured the percentage cover of each of five types of surface morphology along each 20 m transect using the line-intercept method (Canfield, 1941; Eckert et al., 1986a). To the four soil surface morphological types (I–IV) of Eckert et al. (1978) we added a fifth (Type V) in order to describe surfaces which have been altered dramatically by the invasion of annual grasses, particularly cheatgrass (*Bromus tectorum* L.). A detailed description of the five soil surface morphological types is given in Table 1.

Data Analysis

Two-way analysis of variance (ANOVA) was used to test for differences in the percentage cover of soil surface morphologies between the three treatments after checking for homogeneity of variance (Minitab, 1997). The *site* variable was treated as a random effect and *treatment* as a fixed effect in the balanced model. *Post hoc* comparisons of treatment means were performed using Least Significant Difference (LSD) tests using Minitab (1997). Because of the large number of zero values in the Type IV and V categories, when transformation failed to improve the distribution of the data, the nonparametric Mann-Whitney U Test was used to test for differences between means.

A matrix comprising the percentage of each of the five soil surface types according to the three treatments was converted to a similarity matrix using the Bray-Curtis similarity coefficients contained within the PRIMER (Version 4) statistical package (Clarke & Warwick, 1994). This similarity matrix was subjected to nonmetric Multi-Dimensional Scaling (MDS) using one of the PRIMER (Version 4) routines in order to determine whether sites of a particular treatment were characterized by a unique complement of surface types. Hypothesis tests of differences between the three groups (control, burned-seeded, burned-unseeded), defined a priori, were performed using ANOSIM, which is comparable to a distribution-free two-way ANOVA (Clarke, 1993). Using a number of random permutations on the similarity matrix, ANOSIM produces a test statistic (Global R) with a significance level which we used to determine whether the cover of the surfaces varied significantly between the three treatments.

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Results

There were significant differences in the composition of the soil surface morphological types between burned and unburned sites (Global $R = 0.988$, $P = 0.012$). The first dimension of the MDS biplot (Figure 1) indicated a clear separation between burned and unburned sites based on surface morphology. Average dissimilarity between the burned and unburned sites (77%) resulted from a higher cover of Type V surface at the burned sites, and a higher cover of Type I surface at the unburned sites.

There were significant differences in the percentage of Type I surfaces on all three treatments ($F_{2,4} = 30.0$, $P = 0.004$). Fifty-eight percentage (± 3.1, standard error of the mean) of control sites were dominated by Type I surfaces followed by burned-seeded ($39.6 \pm 3.8\%$) and burned-unseeded ($3.9 \pm 1.2\%$) (Figure 2). The percentage cover of Type II surfaces on the control and burned-seeded plots was significantly greater than that on the burned-unseeded plots ($F_{2,4} = 16.84$, $P = 0.010$). Further, when burned plots were considered separately, seeding resulted in a significantly higher percentage of both Type I and II surfaces and lower percentage of Type V surfaces compared with nonseeding (Figure 2). Both Types III and IV occupied less than 20% of the surface of any site, and there was no significant

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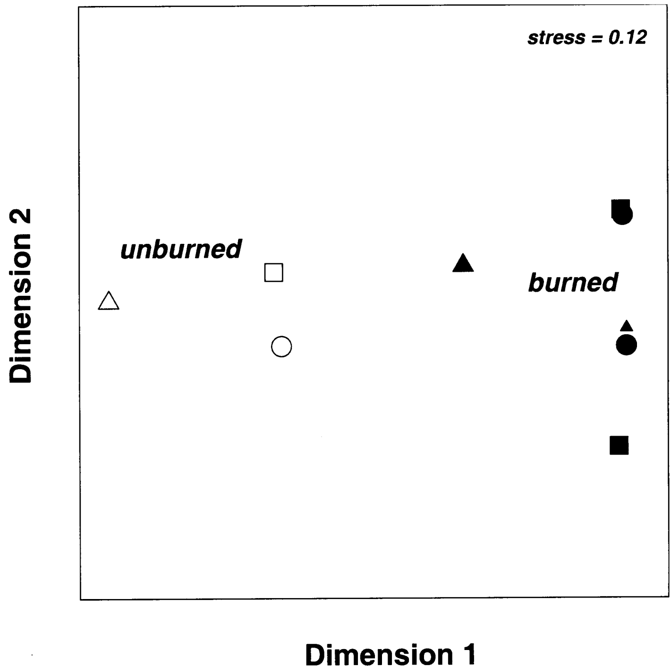

FIGURE 1 The first two dimensions of the nonmetric MDS biplot based on cover of the five surfaces, showing the relative positions of burned (solid symbols) and unburned (open symbols) sites. Kuna Butte East = circles, Kuna Butte West = squares, Rattlesnake Creek = triangles.

difference between treatments ($P > 0.447$). Seventy two percentage ($\pm 4.8\%$) of the burned-unseeded sites comprised Type V surfaces (H = 47.29, df = 2, $P < 0.001$, Figure 2).

Discussion

The soil surface in the control areas was characterized by a rolling microtopography with pedicels 10–50 mm high separated by gently sloping "valleys." The pedicelled Type II surface appeared to be due partly to the occupation of dead clumps of Sandberg bluegrass by mosses and lichens. Distinctive morphological groups of microbiota (*sensu* Eldridge & Rosentreter, 1999) were generally associated with specific positions within the plant community. The distribution of the "tall moss" morphological type (dominated by *Tortula ruralis*) was closely associated with Type I surfaces below the canopies on shrub coppices, while many of the "crustose lichen" group appeared to be restricted to the open interspaces on Type II, III, and IV surfaces. The crustose lichen *Diploschistes muscorum* (Scop.) R. Sant., was often found in a mat on the top of short moss-covered pedicels in undisturbed Type II surfaces. Type III surfaces were most often occupied by lichens that appeared to be early successional types, or have broad ecological amplitudes such as *Collema tenax* Sw. Ach., *Caloplaca tominii* Savicz, and *Placdium squamulosum* (Ach.) Breuss (Johansen et al., 1984; Memmott, 1995; St. Clair et al., 1993). It is possible that unoccupied, gently undulating surfaces provide microhabitat conditions such as shade and enhanced soil moisture resulting in the establishment of short mosses

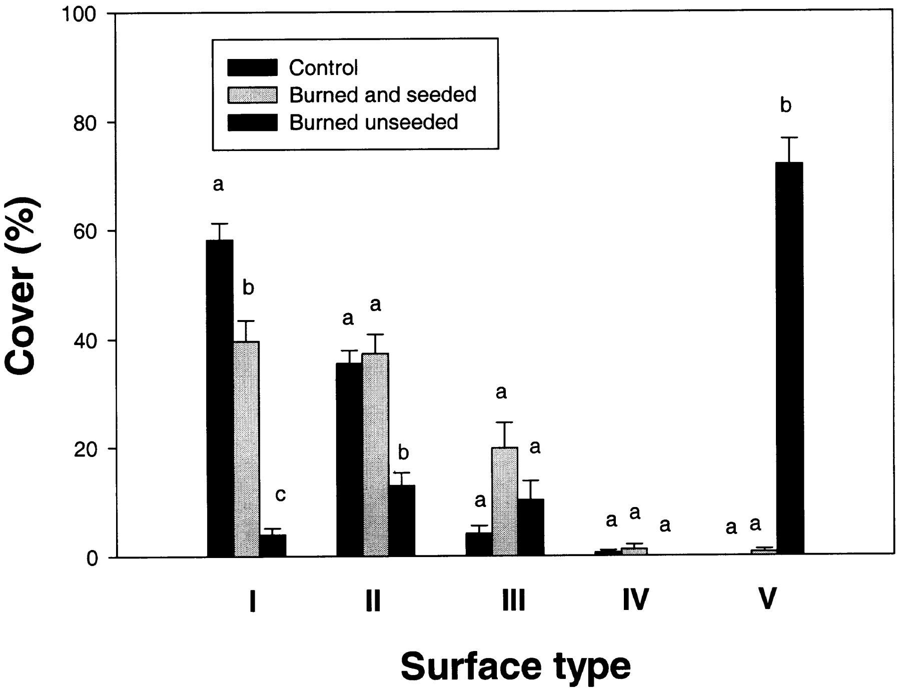

FIGURE 2 Mean (± standard error of the mean) cover of each of the five morphological types in the control, burned-seeded and burned-unseeded treatments. Different letters within a surface type indicate a significant difference at $P < 0.05$.

and later, lichens. As moss cover increases and traps loses (Danin & Gaynor, 1991), the microtopography is typically converted to a gently rolling surface. The shedding of water from the Type III surfaces provides an environment conducive to lichens at the expense of mosses.

On the control plots, the canopy cover of perennial bunchgrasses was approximately 10% and cover of shrubs was about 23% (Kaltenecker, 1997). Type I surfaces can be created by either shrubs or bunchgrasses. At the control sites there was little differentiation between bunchgrass-dominant and shrub-dominant Type I surfaces, and predictably, shrub-Type I surfaces were uncommon in the burned treatments due to the absence of live shrubs. Formation of the bunchgrass-Type I surface is highly dependent on the presence of longer-lived palatable (decreaser) grasses which have larger basal areas, and whose characteristics of litter deposition favor development and maintenance of the Type I surfaces (Eckert et al., 1986a). Type I surfaces in the burned-seeded treatment were primarily associated with the seeded species such as Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski.] Grazing-intolerant species such as bluebunch wheatgrass and Thurber's needlegrass were rare in the control plots, where the understorey was dominated by the more grazing-tolerant grasses Sandberg bluegrass and bottlebrush squirreltail.

Type II surfaces were equally abundant on the control and burned-seeded surfaces (Figure 2) and were almost entirely dominated by lichens and mosses (Kaltenecker, 1997). The lack of domestic livestock use over the past decade almost certainly accounts for the abundance of Type II surfaces in both treatments. Repeated trampling by livestock can crush Type II surfaces and convert

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them to smooth Type III surfaces (Eckert et al., 1986a). Trampling of microphytic biological soil crusts is known to reduce their cover and composition (Warren & Eldridge, 2001), leading to increased erosion and ultimately altered landscape function. The formation of the Type V surface, which was dominant in the burned-unseeded treatment, appears to occur due to invasion of Type I, II, and III surfaces by annual exotic grasses. This surface type is characteristic of large areas of the western United States which have become invaded by cheatgrass over the past century (Pyke & Novac, 1994).

Favorable microsites for seedling establishment are restricted to the noncrusted Type I and II surfaces, trenches in Type II, and cracks in Type III surfaces (Eckert et al., 1986b). A combination of burning and trampling leads to the conversion of Type I–III surfaces into a Type V surface, and a possible mechanism for this is as follows. Following site disturbance by fire, the cover of live microbiotic crust cover is frequently reduced (Eldridge & Bradstock, 1994; Johansen et al., 1984). Cheatgrass readily invades the site, establishing in the favorable sites of Type I and II surfaces, now unprotected by live vegetation, and in the cracks in Type III. Litter accumulation from the first and subsequent year's crops provides additional microsites for further cheatgrass establishment (Evans & Young, 1970). The increased depth of litter and high density of grass reduces raindrop impact, and prevents physical crusting of the soil surface. Type V surfaces might provide temporary favorable hydrologic characteristics for the site, at least in the short-term, but competition from cheatgrass excludes establishment of other vascular plants, preventing the reformation of Type I surfaces. Recovery of the biological soil crust is limited by a dense litter layer resulting from annual grass invasion, and the increased frequency of repeated fires. Removal of the cheatgrass litter by fire leaves the soil surface vulnerable to raindrop impact, splash erosion and sheet flow (Seyfried, 1991), resulting in erosion and the formation of Type III surfaces. This process, along with loss of native species due to cheatgrass competition, results in perpetuation of the processes that contribute to landscape degradation.

Implications for Range Seeding

Type I and II surfaces are likely to reform following disturbance if bunchgrasses and shrubs are reintroduced (by seeding), or if cover is allowed to increase without repeated trampling by livestock. Our results indicated significantly greater cover of Types I and II surfaces on seeded burned sites compared with sites which were unseeded (Figure 2). Seeding is likely to lead to a positive feedback on the soil surface increasing further favorable microsites (Type II) for bunchgrass and shrub establishment, and reestablishment of the perennial community structure may then enhance the recovery of the biological soil crust (Danin et al., 1989; Johansen et al., 1993). Wood et al., (1978) suggested that cover of Type III surfaces increases as a result of overgrazing and loss of herbaceous cover. Low levels of livestock use following rehabilitation probably contributed to the relatively low cover ($<20\%$) of Type III surfaces in the seeded treatment (Figure 2).

Revegetation to prevent cheatgrass invasion presents a significant challenge to land managers. Rangeland seed drilling is often necessary to establish perennial grasses in interspace soils (Wood et al., 1982). Although Types I and II combined may account for nearly two-thirds of the surface in early-seral communities, thus providing potential sites for natural revegetation to occur, lack of seed sources for native species and competition from annual alien grasses and forbs may limit recovery.

The detrimental effects of drilling which will reduce the cover of Type I and II surfaces are largely offset by subsequent perennial grass and shrub establishment. Reestablishment of perennial plant cover adds organic matter to the soil, protects the

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surface against the formation of a Type III or V surfaces (Wood et al., 1978), moderates soil temperature, and increases the length of time that moisture is present near the soil surface (Wight et al., 1992). These factors contribute to a favorable environment for plant establishment and improve the potential for successful revegetation.

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