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Ground Cover—What Are the Critical Criteria and Why Does It Matter?

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ABSTRACT

This publication is the result of concerns expressed regarding the definition and subsequent use of ground cover in rangeland monitoring. We reviewed 20 monitoring publications. All publications reviewed contained a definition of ground cover and/or direction on how to monitor ground cover. The majority of these publications also defined bare ground. In all cases, bare ground was defined as the opposite of ground cover.

We identified critical criteria of ground cover based on the role it plays in soil conservation as it relates to water and wind erosion. Critical criteria identified included standing and nonstanding live vegetation, standing and nonstanding dead vegetation including litter, and rock. We compared these critical criteria to the 20 monitoring publications reviewed. We found 19 of these publications included the criteria standing live vegetation or similar words and standing dead vegetation or similar words in their definition and/or use of ground cover. The one source where standing live or dead vegetation or similar words were not included was “Indicators of Rangeland Health and Functionality in the Intermountain West.” This publication was produced by the US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ground cover was limited to basal vegetation, litter, moss/lichen, or rock. We also found inconsistencies in the definition and subsequent use of ground cover in *Forest Service Handbook 2209.21—Rangeland Ecosystem Analysis and Monitoring Handbook, Intermountain Region.*

We contend a large volume of literature supports the inclusion of critical criteria as identified in this report as ground cover. These criteria are essential components contributing to resistance of water and wind erosion important to soil conservation. This review demonstrates the importance of accurately defining and subsequently including critical criteria in rangeland attributes including ground cover. This paper addresses standardizing terms and calculations used in determining ground cover.

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Introduction

Maintaining ground cover is one of the most efficient ways of ensuring long-term sustainability of rangelands via soil conservation as 1) ground cover plays a direct role on the condition and trend of soils and 2) ground cover may be directly affected through land management activities including grazing (Bates et al. 2009; Bork et al. 2012). Monitoring ground cover is also advantageous from a cost-benefit point of view as it 1) requires comparatively minimal training to collect data and 2) data can be obtained in a fraction of the time when compared with some other rangeland attributes.

Accurately defining and subsequent monitoring of rangeland attributes is an essential component of rangeland monitoring. Definitions of rangeland attributes that leave out critical criteria or do not implement these criteria can result in data that inaccurately describe conditions and trends of the rangeland attribute being monitored. This could lead to the development of goals and objectives not consistent with the capability of the land. Such is the case with “Indicators of Rangeland Health and Functionality in the Intermountain West” (O’Brien et al. 2003). This publication omits

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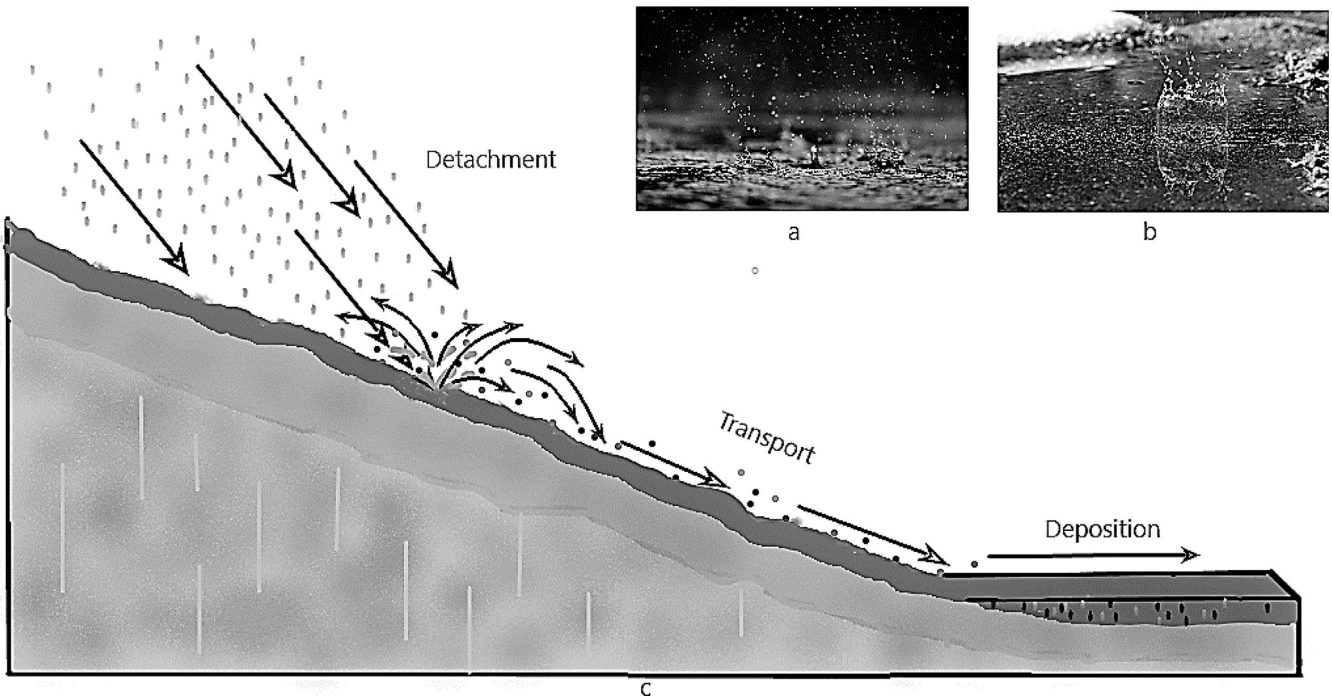

Figure 1. Raindrop splash impact on bare ground and subsequent erosion (Research Gate, 2019). (**A**) Astrid Gast/shutterstock.com; (**B**) TRR/shutterstock.com.

standing live and dead vegetation as factors for soil protection. No explanation is given as to why these factors were omitted. This paper provides rationale as to why standing live and/or dead vegetation herein referred to simply as standing vegetation should be included as critical criteria of soil protection. We contend that critical criteria for ground cover includes rock, litter, and standing vegetation, of which basal vegetation is a component. Dependent upon the ecosystem being monitored, critical criteria can also include biological soil crusts.

Ground Cover—Tool for Soil Conservation

Water Erosion

One of the main roles ground cover plays in soil conservation is protecting soil from rain-drop splash impact (Research Gate, 2019) and subsequent soil displacement (Osborn 1955; Blackburn et al. 1986; Farmer 1999; Weber et al. 2013). Raindrop impact is also a primary sediment contributor to shallow overland flow (Pierson and Williams 2016). Soil surface protection and stabilization via ground cover are paramount in minimizing initial soil displacement and subsequent overland flow. Ground cover, which includes standing vegetation, intercepts rain drops reducing the "energy" of the rain-drop impact and subsequent displacement of soil particles—the first stage of erosion. Ground cover also disperses surface water flow directly (i.e., litter on the soil surface) or indirectly (i.e., standing vegetation), thereby minimizing overland flow (Fig. 1).

Standing vegetation influences the soil microclimate and the recruitment of soil microbes and microfauna. This aids in nutrient recycling and improves infiltration and water storage (Pierson and Williams 2016). Value of standing vegetation by itself is demonstrated in Pierson and Williams (2016). They showed 1.6× more sediment movement from areas between standing vegetation when compared with areas of standing vegetation. Litter accumulation under standing vegetation is likely a factor in this. However, the standing vegetation is the source of this litter. This reinforces placing value on standing vegetation even when it is not in contact with the soil surface. Plant roots also provide for soil conservation by increasing infiltration rates (Pearse and Woolley 1936). The level of increased infiltration rate varies by the root system. Kincaid and Williams (1966) showed that as crown cover of plants increases, surface runoff decreases significantly. This varied depending on the plant species. For example, Singh (1969) found higher infiltration rates on plots with mules ear (*Wyethia amplexicaulis* [Nuttall] Nuttall) than on plots where other plant species were present. This was attributed to the resistance offered by the broad leaves of this species to raindrop impact.

Ground cover not directly on the soil surface also serves to reduce the velocity of water on the soil surface as the energy of the raindrop splash impact is intercepted by this vegetation. This water then moves from one piece of plant material to another before making contact with the soil surface. This effectively decreases the velocity of water before making contact with the soil surface. Goodrich and Cameron (2014) discussed this process stating: "… plant cover close enough to the soil surface to absorb the impact of rain drops and then release the water without it gaining velocity sufficient to detach soil particles is ground cover." In other words and as stated by Forsling (1931), the amount of plant cover is a primary factor influencing runoff and erosion.

Wind Erosion

Another role ground cover plays in soil conservation is protecting soil from wind erosion. The ease with which soil particles are carried by wind depends on their size, shape, and density (Fig. 2). Soils with a high proportion of fine sand are most susceptible to wind erosion. This is because the particles are small enough to be carried by wind but large enough to not likely bind themselves into larger aggregates not prone to movement by wind. Standing vegetation in particular reduces soil loss via 1) sheltering the soil surface from the erosive force of wind by covering a portion of it; 2) reducing the force of the wind near the ground by extracting momentum from the wind at a height above the soil surface; and 3) trapping soil particles in transport, thus effectively

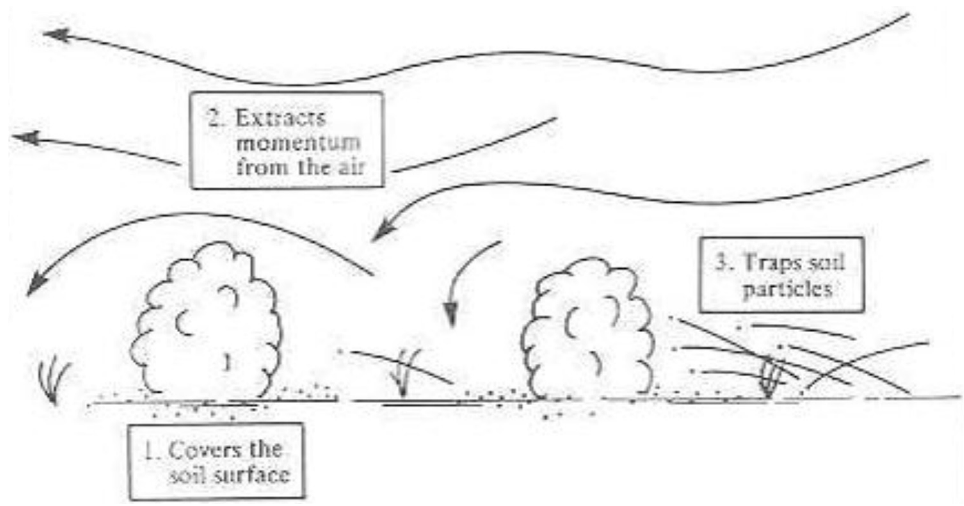

Figure 2. The stabilizing role of vegetation (Wolfe and Nickling 1993).

acting as a catchment for sediment deposition (Van de Ven et al. 1989). In contrast to live vegetation lying flat on the soil surface, standing vegetation has been demonstrated as being several times more effective in reducing soil loss via wind erosion (Siddoway et al. 1965). Standing vegetation also traps snow during the winter months. This increases soil moisture discharge in the spring (Wolfe and Nickling 1993). Dead or partially defoliated vegetation also acts to inhibit soil erosion. This is particularly true when dead material persists for a year or more as this material acts as a sand trap similar to naturally defoliated stems in the spring (Gibbens et al. 1983). Similarly, Brazel and Nickling (1987) found plant cover can act as a suppressant to dust emissions from the soil surface if not destroyed by wind action, abrasion, or human disturbance. This is particularly advantageous during droughts or other times of stress as dead or partially defoliated vegetation is often important in stabilizing the soil surface from wind erosion. Wolfe and Nickling (1993) also discuss the protective role vegetation plays in protecting the soil from wind erosion in arid environments and other places where vegetation is sparse. Numerous publications indicate vegetation cover to be one of the most important controllable factors for limiting wind erosion (Woodruff et al. 1977; Herrick et al. 2005a; Herrick et al. 2009b). The overall effectiveness of wind erosion control via vegetation depends on the quantity, kind, and orientation of vegetation including areal distribution in relation to the soil surface (Chepil 1944; Siddoway et al. 1965; Lyles and Allison 1976).

Methodology

We reviewed 20 monitoring publications (Table 1). Seventeen of these publications are commonly used in rangeland monitoring. Gregory's (1983) publication was also considered due to its relevance to this paper (Bridger-Teton National Forest). We also reviewed and included the two most recent definitions of ground cover provided by the Society of Range Management (SRM 1998; SRM 2005). Glossaries of these publications were reviewed to determine if a definition of ground cover and bare ground was provided. If provided, criteria commonly included in the definition for ground cover were identified. Common criteria were defined as having identical or nearly identical wording within the definition of ground cover. Common criteria for cobble, rock, stone, and/or bedrock were grouped into one criterion. We herein refer to this criterion as "rock." Publications were also reviewed to determine if a size requirement for rock had to be met to be considered ground cover. Common criteria were then summed by publication. We then compared commonly used criteria to critical criteria for ground cover by publication. An appendix to this report that further details findings from Table 1 is available. This appendix is available on request at the Kemmerer Ranger District (308 US HWY 189 North, Kemmerer, WY 83101, USA).

We also reviewed 22 research papers to determine the use of standing vegetation as an appropriate expression of soil stability.

Findings—Review of Monitoring Publications and Review of Research Papers

Review of Publications—Critical Criteria for Ground Cover

We found 18 of the 20 monitoring publications reviewed included all of the critical criteria for ground cover. The only monitoring publications that excluded one or more critical criteria were Gregory (1983) and O'Brien et al. (2003). Gregory (1983) does not expressly include litter in her definition of ground cover. O'Brien et al. (2003) include only basal vegetation in their definition of ground cover; this is unique as it is the only publication reviewed that specifically excludes standing vegetation as critical criteria for ground cover. It is also the only publication reviewed that was considered a pilot study. No discussion as to why standing vegetation was excluded is provided. In addition, no attempt was made at defining basal vegetation. The Society for Range Management (SRM) defined basal vegetation as, "the cross-sectional area of the stem or leaves of a plant or of all plants in a stand. Herbaceous and small woody plants are measured at or near the ground level; larger woody plants are measured at breast or other designated height" (SRM 1998).

All 20 publications reviewed included rock as ground cover. However, only half of the publications reviewed stated what size rock must be to be considered ground cover. Of these publications, five identified material as having a diameter > 5 mm (≈¼") as adequate for ground cover. The publication *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems* and subsequent versions (Herrick et al. 2005a; Herrick et al. 2005b; Herrick et al. 2009a; Herrick et al. 2009b; Herrick et al. 2015) are used extensively with the Assessment, Inventory and Monitoring Program, a joint monitoring effort between the Jornada–Rangeland Research Program and Bureau of Land Management (BLM). The other publication, *Sage-Grouse Habitat Assessment Framework*, is the identified assessment and monitoring tool for land use plans within sage-grouse habitats on US Forest Service (USFS), BLM, and other public lands (Stiver et al. 2015). Five publications required material to be ≥ 19 mm (¾") in diameter to be counted as ground cover. Three of

Table 1
Comparison of ground cover criteria of commonly use rangeland monitoring publications.

Publication	Citation	Vegetation			Litter	Rock	Biological crusts including cryptograms and related material	Minimal size req. for rock (Y/N)	Other
		Standing live	Basal	Standing dead					
Rangeland Monitoring Trend Studies	BLM 1985	*X*		*X*	*X*	*X*		*N*	
Sampling Vegetation Attributes—Interagency Technical Reference	BLM 1996	*X*		*X*	*X*	*X*		*N*	None
Utilization Studies and Residual Measurements Interagency Technical Reference	Coulloudon et al. 1999	*X*		*X*	*X*	*X*		*N*	None
Subalpine Forb Community Types of the Bridger-Teton National Forest, Wyoming	Gregory 1983	*X*[1]		*X*[1]		*X*		*N*	[1]Vegetation canopy cover interpreted as live vegetation and standing vegetation. Vegetation canopy cover defined as "ground not covered by vegetation canopy cover (p. 7-8). No mention of litter in publication; however, likely included in vegetation canopy cover.
Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems, vol. 1 Quick Start. 2nd ed.	Herrick et. al., 2015	*X*[1]		*X*[1]	*X*	*X*	*X*[2]	*Y* > 5 mm (≈ 1/4")	[1]See Herrick et al. 2009b [2]Biological crusts are only excluded for NRI reporting purposes.
Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems, vol. I and vol. II 1st—reprint	Herrick et. al., 2009a; Herrick et. al., 2009b	X[1]		X	X	X	X	Y > 5 mm (≈ 1/4")	[1]Words "Standing Live" omitted from vegetation (Herrick et al., 2009b). Standing Live vegetation clearly shown to be included in monitoring method (Herrick et al., 2009a)
Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems, vols. I and II	Herrick et al., 2005a; Herrick et al., 2005b	X[1]		X	X	X	X	Y > 5 mm (≈ 1/4")	[1]Words "Standing Live" omitted from vegetation (Herrick et al., 2009b). Standing Live vegetation clearly shown to be included in monitoring method (Herrick et al., 2009a)
Indicators of Rangeland Health and Functionality in the Intermountain West	O'Brien et al. 2003		X		X	X	X	Y > 19 mm (≈ 3/4")	3/4" is ≈ 19 mm.
Interpreting Indicators of Rangeland Health, version 5	Pellant et al. 2018	X		X	X	X	X	N	-None
Interpreting Indicators of Rangeland Health, version 4	Pellant et al. 2005	X		X	X	X	X	N	-None
Interpreting Indicators of Rangeland Health, version 3	Pellant et al. 2000	X[1]		X	X	X	X	N	-[1]Words "Standing Live" omitted from vegetation. Document clearly shown standing live vegetation to be included in ground cover.
Monitoring Rangeland Health …	Riginos and Herrick 2010	X[1]		X	X	X	X	Y > 5 mm (≈ 1/4")	[1]Live or dead plant material" interpreted as including litter.
SRM—Glossary of Terms Used in Range Management	SRM 2005	X		X	X	X		N	None
SRM—Glossary of Terms Used in Range Management	SRM 1998	X		X	X	X		N	None
Sage-Grouse Habitat Assessment Framework	Stiver et al. 2015	X[1]		X[1]	X[1]	X[1]	X[1]	Y > 5 mm (≈ 1/4")	[1]Interpreted using associated Line-Point Intercept Data Form (p. 90-93) with the publication stating, "The HAF site-scale protocol for line-point intercept is the same as the BLM's core method. Directions for the method are given below, but readers can refer to Herrick (2005) or the most current version) for more detail."
Rangeland Ecosystem Analysis and Monitoring Handbook[1]	USDA 2003a	X		X	X	X	X	Y > 19 mm (≈ 3/4")	[1]Subsequent applications of ground cover (USDA 2005) are inconsistent with the provided definition but more appropriately fit the definition provided by O'Brien et al., (2003). 3/4" is ≈ 19 mm.
Soil Management Handbook	USDA 2003b	X[1]		X[1]	X	X		Y > 19 mm (≈ 3/4")	[1]"word "standing" is omitted. 3/4" is ≈ 19 mm.
National Range and Pasture Handbook	USDA 2003c	X		X	X	X		N	
Wyoming Rangeland Monitoring Guide, version 2	UWYO 2008	X[1]	X	X[1]	X	X	X	Y > 19 mm (≈ 3/4")	[1]Live and standing dead vegetation to be counted as ground cover as clarified in cover by lifeform methods and associated worksheet (see pg. 31 to 32). 3/4" is ≈ 19 mm. [1]Live and standing dead vegetation to be counted as ground cover as clarified in cover by lifeform methods and associated worksheet (see p. 31-32). 3/4" is ≈ 19 mm.

Table 1 (*continued*)

Publication	Citation	Vegetation			Litter	Rock	Biological crusts including cryptograms and related material	Minimal size req. for rock (Y/N)	Other
		Standing live	Basal	Standing dead					
Wyoming Rangeland Monitoring Guide, version 1	UWYO 2001	X[1]	X	X[1]	X	X	X	Y > 19 mm (≈3/4")	[1]live and standing dead vegetation to be counted as ground cover as clarified in cover by lifeform methods and associated worksheet (see p. 31-32). 3/4" is ≈19 mm. [1]Live and standing dead vegetation to be counted as ground cover as clarified in cover by lifeform methods and associated worksheet (see p. 31-32). 3/4" is ≈19 mm.
	No. of times used	19	3	19	19	20	12	10	
	Total	20	19	20	20	20	20	20	
	% Used	95%	15%	95%	95%	100%	60%	50%	

HAF, Habitat Assessment Framework.

these publications were produced by the USFS (O'Brien et al. 2003; USDA 2003a; USDA 2003b). The last two publications were produced by the University of Wyoming via the Wyoming Range Service team with member agencies including the USFS (University of Wyoming et al. 2001; University of Wyoming et al. 2008). All of these publications predate those where 5 mm (≈¼") is used as the standard for ground cover.

Biological soil crusts including cryptograms were not identified as a critical criteria of ground cover in this report. However, we recognize the important role they can play in various ecosystems. As such, biological soil crusts may also be considered critical criteria dependent on the ecosystem being monitored. Biological soil crusts, including cryptograms, were referenced 60% of the time in the publications reviewed for definitions of ground cover. We did not focus on biological soil crusts as a critical criterion as they have relatively minor presence in the montane communities that we are currently most interested in.

Review of Research Papers—Applicability of Standing Vegetation as Expression of Ground Cover

We found ground cover that includes standing vegetation has a broad usage in research as an expression of soil stability. This vegetation was commonly described as canopy or foliar cover. In none of the research papers reviewed was standing vegetation excluded as a component of ground cover with the exception of Packer (1963). In addition to ground cover, we recognize the importance other factors play in affecting erosion rates. These include but are not limited to climate, parent material, soil including texture, gradient, aspect, landscape position, species, and production. Hence a one-size fit all approach necessary to provide for soil and hydrologic stability is inappropriate as it relates to ground cover. Rather ground cover objectives should be set on the basis of the potential of the site to produce ground cover and inherent factors influencing erosion rates. The following is a summary of our findings as it relates to ground cover and levels required for soil and hydrologic stability.

Pierson et al. (2007a) found 50–60% ground cover (40–50% bare soil) adequate for hydrologic stability or soil protection in various ecosystems. Pierson et al. (2007b) found an increase from 16% to 36% ground cover greatly reduced rill erosion in western juniper (*Juniperus occidentalis* Hooker) communities. Packer (1951) found 70% ground cover was about equal to 90% for control of overland flow and erosion on perennial wheatgrass sites on gradients of 33–66%. He suggested 70% ground cover as a minimum requirement for watershed protection in perennial wheatgrass sites. Marston (1952), Bailey and Copeland (1960), Packer (1963), and Orr (1970) indicate 60–70% ground cover as adequate to limit erosion levels to less than those of accelerated erosion or to recommended levels for soil protection. Pierson et al. (2007a) cited a literature review in which Gifford (1985) concluded that to maintain soil and hydrologic stability, percentage of bare ground should not exceed 40–50%. In a Patagonian rangeland, Chartier and Rostagno (2006) found 90% plant and litter cover was necessary to sustain soil protection and long-term productivity.

In a sagebrush (*Artemisia* L.) landscape, runoff returned to near preburn levels and sediment yield was greatly reduced when ground cover recovered to 40% at 1 yr post fire. This would exclude large rainfall simulations where accelerated erosion rates were observed until ground cover reached 60% at two growing seasons post disturbance (Pierson et al. 2009). Pierson et al. (2013) reported similar results. Erosion rates stabilized following burning in Ashe juniper (*Juniperus ashei* J. Buchholz)/oak (*Quercus* L. spp.) lands in Texas when vegetative cover reached 63–68% (Wright et al. 1976) and when vegetation and litter cover combined reached 64–72% on slopes of 37–61% (Wright et al. 1982). Figure 3 in Meeuwig (1971) indicates soil erosion on mountain rangelands is greatly reduced as plant and litter cover approached 60% on slopes of < 15%. This figure also indicates it requires about 85% plant and litter cover to achieve the same amount of soil protection on slopes of 35%, as was provided by 60% cover on a 15% slope. On a subalpine range in central Utah, Meeuwig (1965) found ground cover to be more closely correlated with soil eroded than any other measured variable. Meeuwig (1970a; 1971) subsequently found protection of the soil surface from direct raindrop impact proved to be the most important means of controlling erosion on intermountain ranges. The importance of live plant cover in preventing damaging surface runoff was also recognized by Meeuwig (1960). The importance of plant and litter cover in relation to gradient was subsequently demonstrated by Meeuwig and Parker (1976). Pierson et al. (2015) attributed postburn improvement of hydrologic function to recruitment of herbaceous cover. Petersen and Stringham (2008) considered foliar cover a more informative indicator of infiltration than basal cover. Kincaid et al. (1964) and Wilcox et al. (1988) found basal cover a poorer indicator of infiltration than aerial cover.

From a study that included numerous sites across much of the western United States, Pierson et al. (2002) found that when all sites were pooled together, infiltration and sediment production were not correlated with any measured vegetation or soil characteristic. They concluded difficulty in a "one-size-fits all approach for modeling hydrologic response," and they noted a need to develop a rationale tailored approach to different rangeland units. From our review of literature, we have the impression that monitoring basal cover might be more applicable to bunchgrass communities than to shrub and tall forb communities.

As previously indicated, all of the previously mentioned referenced research papers include standing vegetation as a measure of ground cover except Packer (1963). In addition, standing vegetation, often expressed as canopy and/or foliar cover, was used more as an expression of soil protection when compared with basal cover. This is not to say basal cover does not play a role in rangeland monitoring—only that it is a separate rangeland attribute. For example, basal cover can be particularly useful for aiding in trend determinations of plant species when compared with canopy cover alone due to less variation in annual and season precipitation, other weather events, and use by ungulates (Herrick et al. 2005a; Herrick et al. 2009a; Herrick et al. 2009b; Herrick et al. 2015). This is particularly important when comparing plant species with relatively low canopy covers (Pilloid and Arkle 2013) and when using Line-Point Intercept methodology. However, basal cover is not the total contribution of vegetation to ground cover, and it does not express the opposite of ground cover—bare ground. The numerous references cited above provide ample evidence that standing vegetation is a valid expression of condition and trend as it relates to soil resources. As such, we accept basal cover as having value to rangeland monitoring and more particularly as it relates to its value for determining trend of plant species and other parameters of interest. However, we reject the exclusion of standing vegetation as critical criteria of ground cover.

Discussion

We suggest monitoring programs that do not include all of the critical criteria for ground cover monitoring are misusing the term ground cover and perpetuating an improper rangeland monitoring practice. Furthermore, we contend rangeland monitoring programs that exclude the critical criteria of standing vegetation but include all of the other critical criteria are, in fact, measuring soil, not bare ground—a separate rangeland attribute not directly comparable with ground cover. For example, Herrick et al. (2005a; 2005b; 2009a; 2009b; 2015) states “bare ground occurs only when Top Canopy = NONE, Lower layers are empty (no L), Soil Surface = S” with S being previously defined as soil without any other soil surface codes, such as rock, bedrock, moss, visible lichen crust, embedded litter; or duff.

We recognize researchers commonly treat standing vegetation and on-the-ground cover as separate components in analysis of infiltration and runoff. We recognize this separation is important to this body of research as standing vegetation and on-the-ground surface cover play different roles in soil protection as they relate to soil and wind erosion. However, separation of these components is not an exclusion of one or the other. Two papers we reviewed were based on basal cover only (Johnson 1962; Eckert et al. 1986). In these papers, basal measurements occurred in grassland communities (Johnson 1962) or were limited to grass species (Eckert et al. 1986). However, other research papers reviewed recognized the value of standing vegetation, as well as on-the-ground surface cover for soil protection (Chepil 1944; Marston 1952; Siddoway et al. 1965; Kincaid and Williams 1966; Meeuwig 1970a, 1970b; Tromble et al. 1974; Lyles and Allison 1976; Woodruff et al. 1977; Gibbens et al. 1983; Brazel and Nickling 1987; Wilcox et al. 1988, Van de Ven et al. 1989; Wolf and Nickling 1993; Farmer 1995; Pierson et al. 2015). In addition, Pierson and Williams (2016) include canopy as a factor in soil microclimate, evapotranspiration, antecedent soil water, water transfer and storage, raindrop interception and detachment, infiltration, runoff, sediment transport, and erosion.

Management Implications and Recommendations

Correctly defining and subsequently implementing terms in rangeland management is essential to ensuring rangeland data; (1) are collected consistently; (2) so that they accurately reflect conditions on the ground; and (3) so they can be compared to established goals and objectives. This is particularly important for public lands where grazing is highly scrutinized. If definitions do not include critical criteria, subsequent monitoring efforts may not properly address the why behind monitoring a rangeland attribute—in this case primarily for soil protection. In such a scenario, data collected can be misleading and result in poor range management decisions.

Previous monitoring efforts not using all of the critical criteria for ground cover should be modified to use them. This is particularly important where ground cover goals and objectives are not currently being met and where all critical criteria for ground cover were not included. For example, use of O’Brien et al. (2003), which excludes standing live and dead vegetation in its definition of ground cover, has resulted in areas on the Bridger-Teton National Forest not being at desired condition. Inclusion of standing live and dead vegetation at these areas would likely have resulted in desired conditions being met while still providing for ground cover adequate for soil conservation.

We recommend following protocols that include all of the critical criteria for ground cover and rejecting those that do not. *FSH 2209.21—Rangeland Ecosystem Analysis and Monitoring Handbook’s* Intermountain Region definition contains all of the critical criteria for ground cover (USDA 2003a). However, subsequent application of ground cover in this handbook (USDA 2005) is inconsistent with these critical criteria. This handbook should be updated so that application of ground cover is consistent with its previously provided definition. Methodology for determining ground cover for nested frequency in Chapter 40 of this FSH also does not follow previously produced interagency technical manuals including “Sampling Vegetation Attributes,” of which the Forest Service is a co-author (BLM 1996), and the Rocky Mountain Region Rangeland Analysis and Management Training Guide (USFS 1996). Relevant portions of Chapter 40 of this FSH should also be amended to be consistent with the previously produced interagency technical reference (BLM 1996) and Rocky Mountain Region Rangeland Analysis and Management Training Guide (USDA 1996). Implementing these recommendations would serve to more closely align this handbook with 18 of 20 sources cited in Table 1, including protocols used by the BLM, NRCS, and other agencies.

We recommend following Herrick et al. (2005a, 2005b, 2009a, 2009b, 2015) where components of ground cover and methods of measuring them are well defined. These publications dealing with ground cover are commonly used in recent research papers (Toevs et al. 2011; Pierson et al. 2013; Pilliod and Arkle 2013; Pierson et al. 2014; Roundy et al. 2014; Veblen et al. 2014; Pierson et al. 2015; Stiver et al. 2015; Bybee et al. 2016; Carey and Paige 2016; Ott et al. 2016; Havrilla et al. 2017; Noelle et al. 2017; Ott et al. 2017; Perlinski et al. 2017; Stonecipher et al. 2017; Swanson et al. 2018; and Williams et al. 2017).

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Reference Cited

Bailey, R.W., Copeland, O.L., 1960. Low flow discharges and plant cover relations on two mountain watersheds in Utah. International Association of Science Hydrology Publication 51, 267–278.

Bates, J.D., Rhodes, E.C., Davies, K.W., Sharp, R., 2009. Postfire succession in big sagebrush steppe with livestock grazing. Rangeland Ecology & Management 62, 98–110.

Blackburn, W. H., Thurow, T. L., and Taylor, C. A. 1986. Soil erosion on rangeland. Society for Range Management Symposium Proceedings, 39th Annual Meeting, 12 February 1986; Kissimmee, Florida. p. 31–39.

[BLM] Bureau of Land Management. 1996. Sampling vegetation attributes. Interagency Technical Reference. BLM/RS/ST-96/002+1730. Bureau of Land Management's National Applied Resource Sciences Center. 163 p.

[BLM] Bureau of Land Management, 1985. Rangeland monitoring trend studies. Technical Reference 4400-4. BLM, Denver, CO, USA, p. 130.

Bork, E., Williams, W., Tannus, S., Alexander, M., 2012. Seasonal patterns of forage availability in the fescue grasslands under contrasting grazing histories. Rangeland Ecology & Management 65, 47–55.

Brazel, A.J., Nickling, W.G., 1987. Dust storms and their relation to moisture in the Sonoran-Mojave desert region of the South-western United States. Journal of Environment Management 24, 279–291.

Bybee, J., Roundy, B.A., Young, K.R., Hulet, A., Roundy, D.B., Crook, L., Aanderud, Z., Eggett, D.L., Cline, N.L., 2016. Vegetation response to pinyon and juniper tree shredding. Rangeland Ecology & Management 69, 224–234.

Carey, A.M., Paige, G.B., 2016. Ecological site-scale hydrologic response in a semiarid rangeland watershed. Rangeland Ecology & Management 69, 481–490.

Chartier, M.P., Rostagno, C.M., 2006. Soil erosion thresholds and alternative states in northeastern Patagonian rangelands. Rangeland Ecology & Management 59, 616–624.

Chepil, W.S., 1944. Utilization of crop residues for wind erosion control. Scientific Agriculture 24, 307–319.

Coulloudon, B., Eshelman, K., Gianola, J., Habich, N., Hughes, L., Johnson, C., Pellant, M., Podborny, P., Rasmussen, A., Robles, B., Shaver, P., Spehar, J., Willoughby, J., 1999. Utilization studies and residual measurements. Interagency Technical Reference. Cooperative Extension Service. US Department of Agriculture—Forest Service; Natural Resource Conservation Service—Grazing Land Technology Institute; US Department of the Interior—Bureau of Land Management. National Applied Resource Sciences Center. National Business Center. BC-650B. 80225-0047, Denver, CO, USA, p. 165.

Eckert Jr., R.E., Peterson, F.F., Belton, J.T., 1986. Relation between ecological-range condition and proportion of soil-surface types. Journal Range Management 39, 409–414.

Farmer, M., Harper, K. T., and Davis, J. N. 1999. The influence of anchor-chaining on watershed health in a pinyon juniper woodland in central Utah. *In:* Monsen, S. B., and Stevens, R. [comps.]. 1999. Proceedings ecology and management of pinyon-juniper communities within the Interior West. 15–18 September 1977; Provo, UT, USA. Proc. RMRS-P-9. Ogden, UT, USA: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 299–301.

Forsling, C.L., 1931. A study of the influence of herbaceous plant cover on surface run-off and soil erosion in relation to grazing on the Wasatch Plateau in Utah. Technical Bulletin No 220. Forest and Range Experiment Station, Branch of Research, Forest Service, Washington, DC, USA, p. 72.

Gibbens, R.P., Tromble, J.M., Hennessy, J.T., Cardenas, M., 1983. Soil movement in mesquite dunelands and former grasslands of southern New Mexico from 1933 to 1980. Journal of Range Management 36, 145–148.

Gifford, G.F., 1985. Cover allocation in rangeland watershed management (a review). In: Jones, E.B., Ward, T.J. (Eds.), Proceedings of watershed management in the 80s. American Society of Civil Engineers, New York, NY, USA, pp. 23–31.

Goodrich, S., and Cameron, A. 2014—Unpublished results. Ground Cover—An Indicator of Condition and Trend and a Measure of Desired Condition. Unpublished Report. Updated 2014-02-01. Vernal, UT, USA: US Department of Agriculture, Forest Service. 14 p.

Gregory, S., 1983. Subalpine forb community types of the Bridger-Teton National Forest, Wyoming. Biology Department. Montana State University, Bozeman, MT, USA, p. 62.

Havrilla, C.A., Faist, A.M., Barger, N.N., 2017. Understory plant community responses to fuel-reduction treatments and seeding in an upland pinon-juniper woodland. Rangeland Ecology & Management 70, 609–620.

Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., Whitford, W.G., 2005a. Monitoring manual for grassland shrubland and savanna ecosystems. Volume II: design, supplementary methods and interpretation. USDA–ARS Jornada Experimental Range, Las Cruces, NM, USA, p. 200.

Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., Whitford, W.G., 2005b. Monitoring manual for grassland shrubland and savanna ecosystems. Volume I: quick start. USDA–ARS Jornada Experimental Range, Las Cruces, NM, USA, p. 15.

Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., Whitford, W.G., 2009a. Monitoring manual for grassland shrubland and savanna ecosystems. Volume I Quick Start. USDA–ARS Jornada Experimental Range, Las Cruces, NM, USA, p. 36.

Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., Whitford, W.G., 2009b. Monitoring manual for grassland shrubland and savanna ecosystems. Volume II: design, supplementary methods and interpretation. USDA–ARS Jornada Experimental Range, Las Cruces, NM, USA, p. 200.

Herrick, J.E., Van Zee, J.W., McCord, S.E., Courtright, E.M., Karl, J.W., Burkett, L.M., 2015. Monitoring manual for grassland shrubland and savanna ecosystems. 2nd ed. Volume I Core Methods. USDA–ARS Jornada Experimental Range, Las Cruces, NM, USA, p. 77.

Johnson, A., 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. Journal of Range Management 15, 79–82.

Kincaid, D.R., Gardner, J.L., Schrieber, H.A., 1964. Soil and vegetation parameters affective infiltration under semiarid conditions. International Association of Science Hydrology Publication 65, 440–453.

Kincaid, D.R., Williams, G., 1966. Rainfall effects on soil surface characteristics following rangeland improvement treatments. Journal of Range Management 19, 346–351.

Lyles, L., Alison, B.E., 1976. Wind erosion; the protective role of simulated standing stubble. Transactions, American Society of Agricultural Engineers 19 (61), 64.

Marston, R.B., 1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. Journal Forestry 50, 303–307.

Meeuwig, R.O., 1960. Watersheds A and B—a study of surface runoff and erosion in the subalpine zone of central Utah. Journal of Forestry 58, 556–560.

Meeuwig, R.O., 1965. Effects of seeding and grazing on infiltration capacity and soil stability of a subalpine range in central Utah. Journal of Range Management 18, 173–180.

Meeuwig, R.O., 1970a. Sheet erosion on Intermountain summer ranges. Research Paper INT-85. US Department of Agriculture, Forest Service, Intermountain Forest and Range Research Station, Ogden, UT, USA, p. 25.

Meeuwig, R.O., 1970b. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. Journal of Range Management 23, 185–188.

Meeuwig, R.O., 1971. Soil stability on high-elevation rangeland in the Intermountain area. Research Paper INT-94. US Department of Agriculture, Forest Service, Intermountain Forest and Range Research Station, Ogden, UT, USA, p. 10.

Meeuwig, R.O., Packer, P.E., 1976. Erosion and runoff on forest and range lands. In: Heady, H.F., Falkenberg, D.H., Riley, J.P. (Eds.), Watershed management on range and forest lands. Proceedings of the Fifth Workshop of the United States/Australia Rangelands Panel, Boise, Idaho, June 15-22, 1975. Utah Water Research Laboratory, Utah State University, Logan, UT, USA, pp. 105–116.

Noelle, S.M., Carr, C.A., Stringham, T.K., Weltz, M.A., 2017. Slash application reduces soil erosion in steep-sloped pinyon-juniper woodlands. Rangeland Ecology & Management 70, 774–780.

O'Brien, R.A., Johnson, C.M., Wilson, A.M., Elsbernd, V.C., 2003. Indicators of rangeland health and functionality in the Intermountain West. United States Department of Agriculture. Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-104, Washington, DC, USA.

Orr, H.K., 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. In: Research Paper RM-60. US Department of Agriculture, Forest Service, Intermountain Forest and Range Research Station, Ogden, UT, USA, p. 12.

Osborn, B., 1955. How rainfall and runoff erode soil. Yearbook of Agriculture 1955 (Water). US Department of Agriculture, Washington, DC, USA, pp. 126–135.

Ott, J.E., Cox, R.D., Shaw, N.L., Newingham, B.A., Ganguli, A.C., Pellent, M., Roundy, B.A., Eggett, D.L., 2016. Postfire drill-seeding of Great Basin plants: effects of contrasting drills on seeded and nonseeded species. Rangeland Ecology & Management 69, 373–385.

Ott, J.E., Cox, R.D., Shaw, N.L., 2017. Comparison of postfire practices for Wyoming big sagebrush. Rangeland Ecology & Management 70, 625–632.

Packer, P.E., 1951. An approach to watershed protection criteria. Journal of Forestry 49, 639–644.

Packer, P.E., 1963. Soil stability requirements for the Gallatin elk winter range. Journal of Wildlife Management 27, 401–410.

Pearse, C.K., Woolley, S.B., 1936. The influence of range plant cover on the rate of absorption of surface water by soils. Journal of Forestry 34, 844–847.

Pellant, M., Shaver, P.L., Pyke, D.A., Herrick, J.E., Busby, F.E., Riegel, G., Lepak, N., Kachergis, E., Newingham, B.A., Toledo, D., 2018. Interpreting indicators of rangeland health, version 5. Tech Ref 1734-6. US Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO, USA, p. 170.

Pellant, M.P., Pyke, D.A., Shaver, P., Herrick, J.E., 2005. Interpreting Indicators of Rangeland Health. Version 4. Technical Reference 1734-6. United States Department of Interior, Bureau of Land Management. National Science and Technology Center. Division of Science Integration. Branch of Publishing Services, Denver, CO, USA, p. 136.

Pellant, M.P., Pyke, D.A., Shaver, P., Herrick, J.E., 2000. Interpreting Indicators of Rangeland Health Version 3. Technical Reference 1734-6. US Department of the Interior Bureau of Land Management United States Geological Survey; US Department of Agriculture Natural Resources Conservation Service, Agriculture Research Service. National Science and Technology Center. Information and Communications Group, Denver, CO, USA, p. 113.

Perlinski, A.T., Paige, G.B., Miller, S.N., Hild, A.L., 2017. Hydrologic response of four ecological sites to natural rainfall events within a semiarid watershed. Rangeland Ecology & Management 70, 675–682.

Petersen, S.L., Stringham, T.K., 2008. Infiltration, runoff, and sediment yield in response to western juniper encroachment in southeast Oregon. Rangeland Ecology & Management 61, 74–81.

Pierson, F.B., Spaeth, K.E., Weltz, M.A., Carlson, D.H., 2002. Hydrologic response of diverse western rangelands. Journal of Range Management 55, 558–570.

Pierson, F.B., Blackburn, W.H., Van Vactor, S.S., 2007a. Hydrologic impacts of mechanical seeding treatments on sagebrush rangelands. Rangeland Ecology & Management 60, 666–674.

Pierson, F.B., Bates, J.D., Svejcar, T.J., Hardegree, S.P., 2007b. Runoff and erosion after cutting western juniper. Rangeland Ecology & Management 60, 285–292.

Pierson, F.B., Moffet, C.A., Williams, C.J., Hardegree, S.P., Clark, P.E., 2009. Prescribed-fire effects on rill and interrill runoff and erosion in a mountainous sagebrush landscape. Earth Surface Processes and Landforms 34, 193–203.

Pierson, F.B., Williams, C.J., Hardegree, S.P., Clark, P.E., Kormos, P.R., Al-Hamdan, O.Z., 2013. Hydrologic and erosion responses of sagebrush steppe following juniper encroachment, wildfire, and tree cutting. Rangeland Ecology & Management 66, 274–289.
Pierson, F.B., Williams, C.L., Kormos, P.R., Al-Hamdan, O.Z., 2014. Short-term effects of tree removal on infiltration, runoff, and erosion in woodland-encroached sagebrush steppe. Rangeland Ecology & Management 67, 522–538.
Pierson, F.B., Williams, C.J., Kormos, P.R., Al-Hamdan, O.Z., Hardegree, S.P., Clark, P.E., 2015. Short-term impacts of tree removal on runoff and erosion from pinyon- and juniper-dominated sagebrush hillslopes. Rangeland Ecology & Management 68, 408–422.
Pierson, F.B., Williams, C.J., 2016. Ecohydrologic impacts of rangeland fire on runoff and erosion: A literature synthesis. Gen. Tech. Rep. RMRS-GTR-351. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA, p. 110.
Pilliod, D.S., Arkle, R.S., 2013. Performance of quantitative vegetation sampling methods across gradients of cover in Great Basin plant communities. Rangeland Ecology & Management 66, 634–647.
Research Gate, 2019. Images of raindrop splash impact. Available at: https://www.bing.com/search?q=pictures+of+rain+drop+splash+impact&src=IE-SearchBox&FORM=IENAD2. Accessed 27 January 2020.
Riginos, C., Herrick, J., 2010. Monitoring rangeland health: a guide for pastoralists and other land managers in Eastern Africa, Version II. ELMT-USAID/East Africa, Nairobi, Kenya, p. 96.
Roundy, B.A., Miller, R.F., Tausch, R.J., Young, K., Hulet, A., Rau, B., Jessop, B., Chambers, J.C., Eggett, D., 2014. Understory cover responses to pinyon-juniper treatments across tree dominance gradients in the Great Basin. Rangeland Ecology & Management 67, 482–494.
Siddoway, F.H., Chepil, W.S., Armbrust, D.V., 1965. Effect of kind, amount, and placement of residue on wind erosion control. Transactions, American Society of Agriculture Engineers 8, 327–331.
Singh, T., 1969. Infiltration and soil stability of a summer range. Journal of Range Management 22, 123–128.
[SRM] Society for Range Management), 2005. Glossary of terms used in range management. A definition of terms commonly used in range management, 4th ed. Glossary Update Task Group, 4th ed [eds.], Denver, CO, USA.
[SRM] Society for Range Management, 1998. Glossary of terms used in range management, 4th ed. Edited by the Glossary Update Task Group, Thomas E Bedell, Chairman. Available online at: https://globalrangelands.org/glossary/G?term=. Accessed 27 January 2020.
Stiver, S.J., Rinkes, E.T., Naugle, D.E., Makela, P.D., Nance, D.A., Karl, J.W. (Eds.), 2015. Sage-grouse habitat assessment framework: a multiscale assessment tool. Technical Reference 6710-1. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver CO, USA, p. 114.
Stonecipher, C.A., Panter, K.E., Jensen, K.B., Rigby, C.W., Villalba, J.J., 2017. Revegetation of medusahead-invaded rangelands in the channeled scablands of eastern Washington. Rangeland Ecology & Management 70, 388–395.
Swanson, J.C., Murphy, P.J., Swanson, S.R., Schultz, B.W., McAdoo, J.K., 2018. Plant community factors correlated with Wyoming big sagebrush site responses to fire. Rangeland Ecology & Management 71, 67–76.
Toevs, G.R., Karl, J.W., Taylor, J.J., Spurrier, C.S., Karl, M., Bobo, M.R., Herrick, J.E., 2011. Consistent indicators and methods and scalable sample design to meet monitoring information needs across scales. Rangelands 33, 14–20.
Tromble, J.M., Renard, K.G., Thatcher, A.P., 1974. Infiltration for three rangeland soil-vegetation complexes. Journal of Range Management 27, 318–321.
[USDA] United States Department of Agriculture. 2005. FSH 2209.21—Rangeland Ecosystem Analysis and Monitoring Handbook. Washington, DC, USA: Chapters 20 and 40.
[USDA] United States Department of Agriculture), 2003a. FSH 2209.21—Rangeland Ecosystem Analysis and Monitoring Handbook. Chapter—Zero Code. Forest Service Handbook Intermountain Region (Region 4), Ogden, UT, USA, p. 2.
[USDA] United States Department of Agriculture, 2003b. FSH 2509.18—Soil management handbook. Chapter 2: soil quality monitoring. Forest Service Handbook Intermountain Region (Region 4), Ogden, UT, USA, p. 15.
[USDA] United States Department of Agriculture, 2003c. National Range and Pasture Handbook. Grazing Lands Technology Institute. Glossary. Natural Resources and Conservation Service, Washington, DC, USA, p. 63.
[USDA] United States Department of Agriculture. 1996. Washington, DC, USA: Rocky Mountain Region Rangeland and Management Training Guide. 84 p.
University of Wyoming, 2001. Wyoming rangeland monitoring guide. A cooperative and voluntary approach to monitoring rangelands. Wyoming Range Service Team—member agencies including Bureau of Land Management; Forest Service; Natural Resources Conservation Service; University of Wyoming Department of Renewable Resources; University of Wyoming Extension Service; Wyoming Department of Agriculture; Wyoming Section of the Society for Range Management, Laramie, WY, USA.
University of Wyoming, 2008. Wyoming rangeland monitoring guide. A cooperative and voluntary approach to monitoring rangelands. Wyoming Range Service Team – member agencies including Bureau of Land Management; Forest Service; Natural Resources Conservation Service; University of Wyoming Department of Renewable Resources; University of Wyoming Extension Service; Wyoming Department of Agriculture; Wyoming Section of the Society for Range Management, Laramie, WY, USA, p. 58, Version 2.
Van de Ven, T.A.M., Fryrear, D.W., Spaan, W.P., 1989. Vegetation characteristics and soil loss by wind. Journal of Soil and Water Conservation 44, 347–349.
Veblen, K.E., Pyke, D.A., Aldridge, C.L., Casazza, M.L., Assal, T.J., Farinha, M.A., 2014. Monitoring of livestock grazing effects on Bureau of Land Management land. Rangeland Ecology & Management 67, 68–77.
Weber, K.T., Chen, F., Booth, D.T., Raza, M., Serr, K., Gokhale, B., 2013. Comparing two ground-cover measurements methodologies for semiarid rangelands. Rangeland Ecology & Management 66, 82–87.
Wilcox, B.P., Wood, M.K., Tromble, J.M., 1988. Factors influencing infiltrability of semiarid mountain slopes. Journal of Range Management 41, 197–206.
Williams, R.E., Roundy, B.A., Hulet, A., Miller, R.F., Tausch, R.J., Chambers, J.C., Matthews, J., Schooley, R., Eggett, D., 2017. Pretreatment tree dominance and conifer removal treatments affect plant succession in sagebrush communities. Rangeland Ecology & Management 70, 759–773.
Wolfe, S.A., Nickling, W.G., 1993. The protective role of sparse vegetation in wind erosion. Progress in Physical Geography 17, 50–68.
Woodruff, N.P., Lyle, L., Siddoway, F.H., Fryrear, D.W., 1977. How to control wind erosion. US Department of Agriculture, Agriculture Research Service. Agriculture Information Bulletin No. 354, Washington, DC, USA, p. 22.
Wright, H.A., Churchill, F.M., Stevens, W.C., 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in Central Texas. Journal of Range Management 29, 294–298.
Wright, H.A., Churchill, F.M., Stevens, W.C., 1982. Soil loss, runoff, and water quality of seeded and unseeded steep watersheds following prescribed burning. Journal of Range Management 35, 382–385.