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Assessment of Range Planting as a Conservation Practice☆

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ABSTRACT

Natural Resource Conservation Service Range Planting — Conservation Practice Standards provide guidelines for making decisions about seedbed preparation, planting methods, plant materials selection, seeding rate, seeding depth, timing of seeding, postplanting management, and weed control. Adoption of these standards is expected to contribute to successful improvement of vegetation composition and productivity of grazed plant communities. Also expected are some specific conservation effects, such as improved forage for livestock; improved forage, browse, or cover for wildlife; improved water quality and quantity; reduced wind or water erosion; and increased carbon sequestration. The success of specific conservation practices and the magnitude of conservation effects are highly dependent on ecological-site characteristics, the initial degree of deviation from desired site characteristics, and weather, all of which are highly variable in both time and space. Previous research has produced few studies directly linking range planting conservation practices to conservation effects. Assessment of conservation effects attributed to rangeland planting practices must, therefore, be separated into two components: 1) evidence of the degree to which specific management practices have been shown to result in desirable vegetation change and 2) evidence supporting positive conservation effects of alternative vegetation states. The aggregate literature generally supports both 1) the existing conservation practice recommendations for rangeland seeding and 2) the inherent assumption that if these practices are successful, they will result in beneficial conservation effects. High spatial and temporal variability in these systems, however, may limit the success of generic or prescriptive management practices. Current conservation practice recommendations could be improved by incorporating more direct linkages to the ecologically based technical literature, more up-to-date information on adaptive management strategies in highly variable rangeland systems, and integration of monitoring strategies designed to directly test the efficacy of specific conservation practices.

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Introduction

The Natural Resources Conservation Service (NRCS) Range Planting Conservation Practice Standard (CPS 550) is used to develop NRCS management recommendations for improving vegetation composition and productivity of grazed plant communities when the existing ecological state is insufficient to meet management goals and natural recovery toward a more desirable state is not expected. Successful implementation of range planting treatments is assumed to confer some or all of the following conservation effects: improved forage availability for grazing animals; improved wildlife habitat; reduced erosion by wind and/or water; improved water quality and quantity; and increased carbon sequestration.

The relevant spatial domain for CPS 550 includes rangelands in 17 western states that exhibit diverse vegetation types, management priorities, and climatic syndromes and that also vary internally along latitudinal and elevational gradients (Barbour and Billings 2000; Natural Resources Conservation Service 2006). Resource management issues common to all areas, however, are a generally arid or semiarid climatology, high annual and seasonal variability in weather, and intense competition from introduced annual weeds or expanding populations of native woody plants (Hardegree et al. 2012a, 2012b).

The success of specific conservation practice recommendations and the potential ecological outcomes realized are highly dependent on ecological site characteristics, the initial degree of deviation from desired site characteristics, and weather, all of which are highly variable in

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☆ Superscript numbering throughout the text indicates that an expanded list of reference citations may be found.

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both time and space. This variability has perhaps contributed to the relatively short-term and site-specific nature of most rangeland seeding studies, as well as the general lack of longer-term studies directly linking range planting conservation practices and conservation effects per se. This linkage is primarily derived indirectly through 1) evidence of the degree to which specific planting techniques have been shown to produce successful plant establishment and 2) evidence supporting the positive conservation effects of alternative vegetation states. We have, therefore, separated our assessment into two components: 1) an evaluation of the direct benefits of recommended practices from the Range Planting CPS and 2) a brief review of specific conservation effects attributed to alternative vegetation states.

Assessment of the Direct Benefits of Range Planting Practices

The Range Planting CPS includes general recommendations for identification and utilization of site-appropriate plant materials, along with the use of soil preparation and planting techniques for optimization of seedbed microclimate.

Plant Materials Development and Selection

The Range Planting CPS recommends selection of plant materials that are adapted to both climate and microclimate as affected by soil type, landscape position, and range-site characteristics. Gross climatic variability generally determines the historical complement of native species at a site and the suitability of introduced plant materials (Shown et al. 1969; Shiflet, 1994; Barbour and Billings 2000; Vogel et al. 2005; Natural Resources Conservation Service 2006[1]). The general importance of climate is acknowledged in seeding guides in the form of tables that list species and cultivar suitability as a function of mean annual precipitation (Jordan 1981; Jensen et al. 2001; Lambert 2005; Ogle et al. 2008a, 2008b; Bower et al. 2014). Seeding guides may also cite climatic thresholds below which active seeding practices are not recommended (Anderson et al. 1957; Jordan 1981).

Plant material recommendations for both native and introduced species are based primarily on plant materials discovery, screening, and breeding programs by NRCS Plant Materials Centers and other government research and agricultural experiment station programs (Roundy and Call 1988; Asay et al. 2003[2]). Native plant populations that have been identified as possessing superior productivity, vigor, establishment, disease resistance and/or seed-production characteristics, or alternatively have been bred for such traits, are then evaluated and released for commercial use (Schwendiman 1958; Johnson and Asay 1995; Jensen et al. 2001; Asay et al. 2003; Jones et al. 2004a, 2004b; Jones 2010; Robins et al. 2013[3]). More recent efforts in plant material development and evaluation focus on selection for, or comparison of, specific ecological and physiological traits (Aguirre and Johnson, 1991a, 1991b; Johnson and Asay 1995; Arredondo et al. 1998; Jensen et al. 2005; Parsons et al. 2011; Leger and Baughman 2015[4]). These efforts incorporate and report detailed experimental design information but are often based on relatively controlled experimental conditions in the laboratory and greenhouse or an agricultural field environment (Arredondo et al. 1998; Jones et al. 2010[5]). The majority of current plant material recommendations, however, are based on evaluations of field performance that are not accessible through refereed journal publications (Jensen et al. 2001; Lambert 2005; Ogle et al. 2008a, 2008b[6]). In order to be more effective, future plant materials need to be ecologically appropriate for the site (Jones 2013), especially if the site has converted to a novel ecosystem (Jones et al. 2015). Seeding prescriptive genetic diversity to the site to assist natural evolutionary processes has been termed “assisted evolution” (Jones and Monaco 2009). In some cases, it may be advantageous to intentionally develop such material by practicing artificial selection (Chivers et al. 2016) for functional traits that contribute to ecological fitness (Jones et al. 2010).

Seedbed Preparation and Planting Methods

Seedbed preparation and planting methods are designed to optimize microclimatic conditions for planted species, to increase the number of favorable microsites for germination and establishment, and to mitigate or control competition from undesirable species (Call and Roundy 1991; Sheley et al., 1996, 2006; Roundy and Call 1988; Krueger-Mangold et al. 2006).

Surface Modification

Soil-surface modification is often justified by expectations of increased water availability to the seed, either by improving seed–soil contact, reducing the amount of surface area subject to evaporation, increasing infiltration and water-holding capacity, or creating specific microsites that either receive or retain water more effectively (McGinnies 1959; Roundy et al., 1992; Madsen et al. 2015[7]). In some situations, cultivation without surface firming can increase the surface area subject to evaporation, reduce effective seed–soil contact, reduce seeding depth control, decrease hydraulic conductivity from deeper soil layers, and stimulate weed establishment if seeds are not effectively buried (McGinnies 1962; Kyle et al. 2007; Boyd and Obradovich 2014). Subsequent soil firming from press wheels or cultipackers improves hydraulic conductivity to the seed by reducing soil surface area and soil macroporosity (Hyder and Sneva 1956; McGinnies 1962). The bulk of the range planting literature does not separate treatment effects of soil firming from effects of specific cultivation and planting procedures, which are usually performed together (Bement et al. 1965; McGinnies 1972; Slayback and Renney 1972). Studies that compare multiple seed-bed preparation methodologies often find differences in relative seeding success with different equipment and techniques, but specific inferences can only be made at the treatment level for a given site and year (Hubbard and Smoliak 1953; Hyder et al. 1955[8]). Few studies of this type have been replicated adequately in multiple years or on multiple sites (Bement et al. 1965; Eckert and Evans 1967; Klomp and Hull 1972; Wood et al. 1982; Young et al. 1990; Bakker et al. 2003).

Animal trampling, land imprinting, pitting, furrowing, and rolling treatments have all been used in conjunction with broadcasting to capture or preserve moisture and to press surface-applied seed into the soil (Ethridge et al. 1997; Roundy et al. 1992[9]). Animal ingestion and subsequent deposition of seeds in dung has also been used as a mechanism to disperse seeds into favorable microsites (Akbar et al. 1995; Andrews 1995; Auman et al. 1998; Gokbulak and Call 2004; Kronberg 2015; Ocumpaugh et al. 1996; Traba et al. 2003). Differential establishment success relative to position of soil surface features has been reported and is generally attributed to differences in fine-scale microclimatic conditions (Anderson and Swanson 1949; Hyder and Sneva 1956; McGinnies 1959; Hull 1970; Bragg and Stephens 1979; Hauser 1982; Eckert et al. 1986; Roundy et al. 1992). Surface-modification treatments, however, have also been reported to push small seeds too far into the soil or to cause surface features to fill with soil from wind and water erosion, resulting in seed burial exceeding optimal establishment depth (Hyder and Sneva 1956; Kincaid and Williams 1966; McGinnies 1972; Slayback and Renney 1972; Winkel et al. 1991a).

Positive effects of soil-surface modification may be less relevant in very wet years when water is generally available, regardless of surface treatment, or in very dry years when plantings are unsuccessful regardless of seedbed preparation technique (McGinnies 1968; Stuth and Dahl 1974; Wood et al. 1982; Eckert et al. 1986; Roundy et al. 1990, 1992; Winkel and Roundy 1991; Romo and Grilz 2002).

Mulch Application

Application of mulch is frequently advocated as a mechanism to reduce water loss and moderate soil-surface temperatures, although with the caveat that it is probably not cost-effective for most rangeland applications (Lavin et al. 1981; McGinnies 1987; Ethridge et al. 1997; Young et al. 2013). Relatively expensive soil surface amendments are generally applied only after high-impact disturbance such as mine reclamation or for mitigation of erosion after wildfire on topographically complex terrain (Schuman et al. 1985; Groen and Woods 2008[10]). An exception may be mulch production as a by-product of mechanical shredding for control of juniper and other woody species (Brockway et al. 2002; Stoddard et al. 2008). Establishment of a cover crop to create standing-stubble mulch is usually limited to relatively small areas of major disturbance or higher precipitation zones where grazing lands are being reclaimed from cultivation (Stroh and Sundberg 1971; Stubbendieck et al. 1973; Pinchak et al. 1985; Schuman et al. 1985; Hart and Dean 1986). Justification for mulching practices has been primarily derived from greenhouse, laboratory, and modeling studies, all of which confirm general benefits of water conservation and mitigation of high temperatures near the soil surface (Chung and Horton 1987; Novak et al. 2000[11]), as well as field studies, most of which have been conducted after tillage or on severely disturbed, or otherwise extreme, sites (Schuman et al. 1985; Groen and Woods 2008[11]). Water conservation associated with mulch application may not be ecologically significant in very high or very low precipitation years or on some extreme rangeland sites (Gates 1962; Ludwig and McGinnies 1978; Lavin et al. 1981; Berg and Sims 1984; McGinnies 1987; Bristow 1988; Cione et al. 2002; Fulbright et al. 2006). Regardless of the variable effects of mulch on seeding success per se, the positive effect of mulch for erosion control and soil stabilization is well documented (Meyer et al. 1970; Bautista et al. 1996; Fulbright et al. 2006; Groen and Woods 2008; Stoddard et al. 2008).

Seeding Depth

Successful germination and establishment depend on placement of seeds in favorable soil microsites (Call and Roundy 1991; Roundy et al. 1992; Chambers and MacMahon 1994[12]). A major assumption of many site-preparation treatments is that they increase the number of potential safe sites for germination and establishment by covering the seed, reducing soil-water loss from around the seed, or redistributing and concentrating resources (Anderson and Swanson 1949; Hubbard and Smoliak 1953[13]).

Mechanical disturbance is generally necessary to incorporate seeds into the soil, thus reducing the risk of either desiccation or adverse thermal effects near the surface. Seeding-depth recommendations from commonly cited seeding guides and technical references are relatively specific, but they are based on rules of thumb regarding seeding depth as a function of seed size (Plummer et al. 1968; Roundy and Call 1988; Monsen and Stevens 2004[14]). The physical rationale for depth recommendations usually assumes a trade-off between increased water availability and increased energy requirements for emergence as a function of depth (Call and Roundy 1991; Roundy and Call 1988[15]). In some cases, light or diurnal temperature fluctuation may regulate dormancy to ensure that the seeds germinate at an appropriate depth for a given species (Call and Roundy 1991; Ghersa et al. 1992; Traba et al. 2004). Seed predation has also been documented as a potential problem for surface-sown seeds (Nelson et al. 1970; Longland and Ostoja 2013; Gurney et al. 2015).

Evidence for depth effects is generally limited to studies conducted in a controlled environment, or over very small spatial scales in the field (Kinsinger 1962; Vogel 1963; Hull 1964[16]). A major exception is for studies comparing the relative establishment of broadcast versus planted seeds. The majority of range seeding studies conclude that drill seeding outperforms broadcast seeding, although there is generally no quantification of the specific depth distribution of seeds after planting (Haferkamp et al. 1987; Ott et al. 2003; Davies et al. 2013; Bernstein et al., 2014; Knutson et al. 2014[17]). Relative seeding depth in field studies is often reported only in the context of depth band settings on mechanical seeding equipment, but there are very few studies in which actual seeding depth has been quantified post planting (Winkel and Roundy 1991; Winkel et al. 1991a, 1991b). Laboratory, greenhouse, and field comparisons of surface-sown versus planted seeds generally confirm that very small seeds establish more frequently from near-surface seed placement, larger seeds require soil cover for maximal performance, and seed performance drops dramatically below some threshold depth (Hull 1948; Stewart 1950; Douglas et al. 1960[18]). Indian ricegrass (*Achnatherum hymenoides* [Roem. & Schulte.] Barkworth) has been extensively documented for its ability to germinate and emerge from relatively deep sowing depths, especially in sandy soils (Kinsinger 1962; Jones 1990; Young et al. 1994). Broadcast and planting recommendations are generally not discretionary, as topographic complexity and economic considerations may preclude the use of planting equipment.

Seeding Rate

General seeding-rate recommendations from many technical sources appear to be based on a general standard for what could be considered a hypothetical dominant bunchgrass, planted at optimal depth in a uniform, well-prepared, weed-free seed bed in a favorable establishment year. The standard seeding rate for this hypothetical scenario seems to be roughly equal to a seed density of 1 million seeds per acre or approximately 23 seeds/ft^2 under historical, non-SI units of measure (Jordan 1981; Jensen et al. 2001; Monsen and Stevens 2004; Lambert 2005; Ogle et al. 2008a, 2008b). The most commonly recommended deviation from this hypothetical standard is to increase seeding rate by a factor of 2 to 5 for small seeds or for potential location-specific problems such as inadequate weed control, lack of site preparation, surface application of seeds, probability of drought, nonoptimal seeding season, or high levels of seed dormancy (Jordan 1981; Monsen and Stevens 2004; Thompson et al. 2006). Broadcast seeding rates are generally recommended at two to three times the rates for seed that can be incorporated into the soil (Haferkamp et al. 1987; Ott et al. 2003[19]). Seeding-rate recommendations are also generally adjusted to reflect the total seed-mix ratio and ideal expectations for composition of the desired mature-plant community (Pyke and Archer 1991; Ogle et al. 2008a, 2008b). It is often difficult to assess numerical seeding rates, as the bulk of the literature reports rate in terms of weight of seed planted per unit land area. Weight-based recommendations in the technical literature, however, are generally supplemented by bulk seed density information (Plummer et al. 1968; Jensen et al. 2001; Monsen and Stevens 2004; Lambert 2005; Ogle et al. 2008a, 2008b).

Seeding-rate recommendations are linked to microclimatic considerations, as increased seed numbers increase the probability of seeds reaching safe microsites, irrespective of active depth management (Call and Roundy 1991; Chambers 1995; Harper et al. 1965; Roundy et al. 1992). Relatively few studies reporting effects of seeding rate on establishment success are replicated in such a way to survey annual and seasonal variability in seed-bed microclimate (Masters 1997; McMurray et al. 1997; Williams et al. 2002[20]). Some studies that include variable seeding rates were primarily designed to evaluate competition relative to weed-seed numbers, but in general, the literature supports the concept that higher seeding rates may enhance the likelihood of successful initial establishment (Vogel 1987; Sheley et al. 1999; Wiedemann and Cross 2000; Williams et al. 2002; Schantz et al. 2015).

Seeding-rate impacts remain highly dependent on threshold requirements for water availability in the early stages of establishment, and individual seedling growth can be negatively impacted by both interspecific and intraspecific competition later in development. The majority of the literature pertaining to seeding-rate effects is derived from either controlled environment and greenhouse studies or field studies conducted in years where reported rainfall conditions were either average or above average (Francis and Pyke 1996; Sheley and Half 2006). Eiswerth and Shonkwiler (2006) evaluated a large number of range seeding sites and years in Nevada and determined that increased seeding rates led to higher seedling densities for non-native grasses up to some maximum seeding rate. This study, however, did not analyze or report negative seeding results and did not consider weather and climate conditions during the years that seeding occurred. Eiswerth et al. (2009) evaluated a longer-term field dataset and found less evidence for seeding-rate effects on perennial grasses, but they confirmed benefits of higher seeding rates for planted forbs.

Planting Season

Most studies of planting-season effects on establishment success can be linked to climatic variability and often to specific germination and dormancy syndromes of various seeded, nonseeded, and weedy species (Angevine and Chabot 1979). General planting-season recommendations suggest planting to take advantage of the most favorable season for plant establishment (Stoddart and Smith 1955; Plummer et al. 1968; Vallentine 1979; Roundy and Call 1988; Monsen and Stevens 2004[21]). In some cases, fall seeding is recommended well in advance of the optimal growing season to accrue all potential establishment benefits in a highly variable and often arid or semiarid environment (Plummer et al. 1968 et al.; Monsen and Stevens 2004; Boyd and Lemos 2015[21]). Recent studies suggest that many planted species can be expected to exhibit high fall germination and that a principal bottleneck for early plant establishment may be postgermination, pre-emergence mortality during winter (James et al. 2011, 2012; Boyd and James 2013; Boyd and Lemos 2013, 2015; Gornish et al. 2015; Hardegree et al. 2016). Fall seeding, however, is often recommended to avoid use of mechanical planting equipment under wet-spring conditions or to mitigate effects of unpredictable spring weather (Stewart 1950; Douglas et al. 1960; McGinnies 1973; Hart and Dean 1986; Boyd and Lemos 2015). Seasonal timing of seeding may also be dependent on seasonality of weed competition and/or optimal timing of weed control measures (Bement et al. 1965; Robocker et al. 1965; Hull 1972; Klomp and Hull 1972; Schantz et al. 2015).

The most favorable season for establishment varies regionally (Hatfield 1990): spring in Mediterranean-coastal and Intermountain West locations (Douglas et al. 1960; Nord et al. 1971; Hull 1972; Harris and Dobrowolski 1986), summer monsoon in the southwestern desert (Jordan 1981; Abbott and Roundy 2003; Hereford et al. 2006), late spring through early summer in the Great Plains (Robertson and Box 1969; Hyder et al. 1971; McGinnies 1973; Hart and Dean 1986; Ries and Hofmann 1996; Frank et al. 1998; Romo and Grilz 2002), and late spring through early fall in some higher-elevation mountain sites (Hull 1966,1974; Currie 1967; Lavin et al. 1973). Postplanting microclimate must be favorable for growth, but it also needs to remain favorable during the vulnerable period of seedling establishment (Hyder et al. 1971; McGinnies 1973; Frasier et al. 1987; Abbott and Roundy 2003). Eisworth and Shonkwiler (2006) confirmed the relative benefits of fall/winter seeding on Intermountain rangelands in Nevada with the use of meta-analysis of long-term Bureau of Land Management (BLM) fire-rehabilitation monitoring data. Very few experimental studies of seeding-season effects, however, are replicated in more than 1 or 2 years (Hull 1948, 1974; Douglas et al. 1960; Robocker et al. 1965; Ries and Hofmann 1996; Boyd and Lemos 2015).

Weed Control

Seed bed preparation and planting method recommendations are designed to improve microclimatic conditions for desirable species, but also to reduce competition from undesirable plants (Lavin et al. 1973; Gonzalez and Dodd 1979; Ott et al. 2003; Mangold et al. 2007). Chemical or mechanical weed control, before the early stages of establishment, are generally recommended for establishment success of both native and non-native plant species (Evans et al. 1970; Nelson et al. 1970; Klomp and Hull 1972; Stuth and Dahl 1974; Evans and Young 1978; Humphrey and Schupp 2002; Mangold et al. 2007; Davies 2010, Davies et al. 2015; Sheley et al. 2012; Kyser et al. 2013; James et al. 2015). Of the various studies surveyed in this review that included mechanical or chemical weed control, the majority concluded that weed control was either necessary or at least beneficial for successful establishment. Weed competition effects, however, may not dominate depending on the relative degree of abiotic stress (Mangla et al. 2011) and weed-control strategies may require replication over the longer term to be effective (Davies et al. 2015).

Assessment of Specific Conservation Effects

Evidence supporting positive conservation effects of alternative, established plant communities is generally found in a separate body of literature than that examined in the previous section of this paper. The literature supports the concept that seeding, if successful, results in positive conservation effects. There are relatively few studies, however, directly linking rangeland seeding to conservation effects. We have limited our review to conservation effects related to water quality and erosion, water quantity, and soil-carbon sequestration as successful rangeland seeding has previously been primarily defined by metrics associated with increased biomass availability as forage.

Water Quality and Erosion

Very few studies directly link rangeland seeding to conservation benefits from improved water quality and reduced erosion (Wright et al. 1982; Brown et al. 1985; Beyers 2004; Pierson et al. 2007b, Pierson et al. 2010; Petersen and Stringham 2008; Miller et al. 2012; Royer et al. 2012; Roundy et al. 2014). There is an extensive literature, however, documenting the relationship between rangeland soil cover and soil stability (Nearing et al. 2005; Bartley et al. 2006; Gimeno-Garcia et al. 2007; Pierson et al. 2010[22]). Removal of plant-canopy cover by clipping may be insufficient to increase sediment loss in the short term when soil is still protected by basal vegetation cover and surface residues (Giordanengo et al. 2003; Gyssels et al. 2005; Nearing et al. 2005; De Baets et al. 2006). Range planting per se will not have a significant effect on soil stability unless sufficiently successful to provide adequate soil cover (Meeuwig 1965; Gifford 1970, 1972; Wright et al. 1982; Brown et al. 1985; Ziegler and Giambelluca 1998; Aguilera et al. 2003; Beyers 2004; Groen and Woods, 2008; Pierson et al. 2010). Short-term effects of site preparation, fire, or other treatments that precede range seeding or natural recovery, however, can significantly increase potential erosion in the near term (Gimeno-Garcia et al. 2007; Grismer 2007; Pierson et al. 2007a, 2007b; Miller et al. 2012[23]). In most cases, the nature of this cover is less relevant than the issue of soil-surface protection above some threshold level (Aguilera et al. 2003; Mergen et al. 2001; Descheemaeker et al. 2006[24]). Some studies, however, have shown differential hydrologic effects in adjacent plant communities due to differences in growth and litter production, rainfall interception, water-use efficiency, or rooting depth and spread (Dunkerley 2002; Bhark and Small 2003; Kulmatiski et al. 2006[25]). The relative impact of vegetation cover on erosion and runoff is also highly dependent on weather, slope, and soil type (Aguilera et al. 2003; Bartley et al. 2006; Nichols 2006[26]). Major soil loss after vegetation removal can be exacerbated by intense rainfall events (Gifford 1973, 1975; Garza and Blackburn 1985; Takar et al. 1990).

Vegetation affects soil stability and runoff water quality by protecting the soil from rainfall impact, increasing soil infiltration capacity, anchoring the soil mass, and preventing the development of rill erosion by slowing overland flow rates and increasing surface—water flow paths (Tromble et al. 1974; Thurow et al. 1987; Pimentel and Kounang 1998; Aguilera et al. 2003; Imeson and Prinsen 2004; Puigdefabregas 2005). Invasive woody plants have been shown to suppress understory species to the point where insufficient soil-surface cover can result in significant erosion, even under relatively low-intensity storm events (Davenport et al. 1998; Pierson et al. 2007a, Pierson et al. 2010; Petersen and Stringham 2008). Annual-weed cover can affect seasonal patterns of evapotranspiration and soil-water use (Kulmatiski et al. 2006; Prater and DeLucia 2006), but there is little evidence that they increase site runoff or erodibility when they are providing adequate soil cover (Singh 1969; Pierson et al. 2002, 2007b; Wilcox and Thurow 2006; Miller et al. 2012). In the Intermountain West, however, invasive annual weeds can increase the frequency of periods where vegetation cover can be reduced by wildfire (Brandt and Rickard 1994; Knapp 1996; Young and Longland 1996; Whisenant 1999; Pierson et al. 2011). Indeed, the primary objective of most fire-rehabilitation seeding practices is to improve soil stability and reduce erosion (Richards et al. 1998; Beyers 2004; BLM 2007; Grismer 2007).

Application of mulch to improve range-planting success is probably not cost-effective for most rangeland applications (Lavin et al. 1981; McGinnies 1987; Ethridge et al. 1997). Mulch application, litter retention after site preparation, and mulch production as a result of mechanical treatments for woody plant control, however, can have a direct conservation effect of reducing erosion and runoff on severely disturbed or highly erodible range sites or on steep slopes (Fulbright et al. 2006; Groen and Woods 2008; Stoddard et al. 2008; Cline et al. 2010; Pierson et al. 2014[27]).

Water Quantity

Different plant materials and species may have different degrees of water-use efficiency and biomass production, but in arid rangeland systems, plants tend to use all of the available water in the soil profile in most years (Wilcox 2002; Huxman et al. 2005; Wilcox and Thurow 2006; Moore et al. 2012[28]). Seeding grasses after shrub removal can result in increased stream flow in some Mediterranean-type climates, where the principal precipitation season is out of phase with the seasonal peak of evapotranspiration, or in systems where woody plant material has access to groundwater (Hill and Rice 1963; Hibbert 1983; Huxman et al. 2005; Wilcox 2002; Huang et al. 2006; Wilcox and Thurow 2006). Shrubland conversion to grassland is not generally expected to result in an increase in water quantity in arid and semiarid upland rangeland systems, except where vegetation removal may increase overland flow directly to a stream channel (Gifford 1970; Wright et al. 1982; Bergkamp 1998; Wilcox 2002; Wilcox et al. 2003; Wilcox and Thurow 2006) or during extreme rainfall events where runoff may be affected by total plant cover (Weltz and Blackburn 1995; Quinton et al. 1997). The major exception to this would be the relatively large potential increase in overland flow after major vegetation disturbance, which may also generate unacceptable levels of soil erosion (Gifford 1973; Osborn and Simanton 1990; Takar et al. 1990; Johansen et al. 2001; O'Dea and Guertin 2003; Pierson et al. 2007a, 2007b).

Carbon Sequestration

Svejcar et al. (2008) summarized the results of a 6-yr regional experiment that monitored seasonal carbon flux on western US rangelands and found that relatively good condition rangeland generally serves as a carbon sink, except in the driest areas of the Desert Southwest. The degree of carbon sequestration or loss varies primarily in response to seasonal and annual weather patterns (Conant et al. 2001; Flanagan et al. 2002; Jones and Donnelly 2004; Xu and Baldocchi, 2004; Follett and Schuman 2005; Hastings et al. 2005; Derner and Schuman 2007; Svejcar et al. 2008; Bremer and Ham 2010; Brown et al. 2010; Follett and Reed 2010; Gilmanov et al. 2010; Zhang et al. 2010). A change from tillage and annual cropping to perennial grass cover can greatly increase soil carbon sequestration rates, but the effect is less on western rangeland soils than in more mesic areas (Conant et al. 2001; Guo and Gifford 2002; Sperow et al. 2003; Jones and Donnelly 2004; Derner and Schuman 2007). Relatively low sequestration rates, however, are offset by the relatively large land area occupied by rangelands (Scurlock and Hall 1998; Derner and Schuman 2007; Brown et al. 2010; Follett and Reed 2010; Gilmanov et al. 2010). Type conversion from woody plants to grasses can lower carbon sequestration rates if the initial plant community has a higher net ecosystem production, but this would probably not be the case in most upland arid and semiarid rangeland systems (Huxman et al. 2005; Campbell et al. 2012). Restoration of severely disturbed rangeland and activities such as mine reclamation can significantly improve carbon sequestration rates (Follett and Schuman 2005; Derner and Schuman 2007).

Rooting depth and effective water utilization for biomass production can vary considerably among alternative vegetation types (Cline et al. 1977; Cable 1980; Yoder et al. 1998; Huxman et al. 2005; Seyfried and Wilcox 2006). As a significant portion of sequestered carbon can be deposited below ground by root growth (Scurlock and Hall 1998; Jones and Donnelly 2004; Rees et al. 2005; Cleary et al. 2010), depth of rooting may be a consideration in selection of plant materials for rangeland seeding operations.

Millions of acres of sagebrush-bunchgrass rangeland in the Intermountain West have also been invaded by introduced annual weeds such as cheatgrass (*Bromus tectorum* L.) and medusahead wildrye (*Taeniatherum caput-medusae* [L.] Nevski). Annual weed-dominated systems are characterized by more frequent recurrence of wildfire and may resist management actions that are designed to return them to a more desirable ecological state (Brandt and Rickard 1994; Knapp 1996; Young and Longland 1996; Nafus and Davies 2014). Carbon-sequestration rates can be nullified when vegetation is periodically removed by prescribed fire or wildfire (Suyker and Verma 2001; Bremer and Ham 2010; Cleary et al. 2010).

Knowledge Gaps

Explicit Testing of New Conceptual Models for Dynamic Rangeland Systems

Call and Roundy (1991) recommended changes from the predominant site-specific, short-term, empirical-research approach to more directly address the underlying ecological processes driving restoration success and problems associated with high spatial and temporal variability in rangeland systems. A more general scientific understanding of vegetation change may now be achievable through adoption of conceptual models for understanding dynamic rangeland systems (Westoby et al. 1989; Bestelmeyer et al. 2003; Sheley et al. 2006). NRCS has already accepted this paradigm by incorporating state-and-transition-model concepts in the development of Ecological Site Descriptions, but these models are not explicitly incorporated into range planting conservation practice recommendations. These models integrate multiple processes and acknowledge multiple potential trajectories for plant community change and will require new and innovative approaches for validation and testing in the field.

Development and Utilization of Weather and Forecasting Tools

The stochastic nature of weather variability will require adoption of new concepts for evaluating revegetation and restoration success. Expectations for success need to be explicitly linked to the probability of favorable conditions for seed germination, emergence, and establishment (Krzysztofowicz 2001; Bakker et al. 2003). New technologies will need to be developed to use weather information to inform rangeland planting management decisions (Workman and Tanaka 1991; Peters 2000; Rayner et al. 2005; Andales et al. 2006; Hardegree et al. 2012a, 2012b).

The most useful potential technology for enhancing establishment success lies in development and utilization of seasonal weather-forecast technology specific to rangeland planting applications (Barnston et al. 1994, 2005; Garbrecht and Schneider 2007). Seasonal weather forecasts in large portions of the Intermountain West are often merely synoptic descriptions of historical weather patterns and are not based on physical or empirical prediction of future weather conditions. It may be possible, however, to utilize historical weather and seeding data to construct models to assess the potential long-term benefits of adopting forecast/modeling technology in rangeland restoration planning (Batabyal and Godfrey 2002; Schneider and Garbrecht 2003, 2006; Bashari et al. 2008; Hardegree et al. 2013). Similar technology is in relatively common use for more traditional agricultural applications and for some rangeland applications (Schneider and Garbrecht 2003, 2006; Doblas-Reyes et al. 2006; Baigorria et al. 2008; O'Lenic et al. 2008).

Even low-resolution seasonal weather forecasts would increase the probability of successful native plant establishment if seeding decisions in the fall could be based on the anticipation of favorable conditions of seedbed microclimate in the subsequent winter and spring (Hardegree et al. 2003; Hardegree and Van Vactor 2004). Weather forecasts could be used to initiate contingency plans in areas that have been previously identified for restoration, and for which premanagement logistics of equipment, personnel, and plant materials are in place (Westoby et al. 1989; Bakker et al. 2003). Separation of restoration planning objectives from the wildfire cycle would also simplify the problem of predicting management needs for native germplasm (Richards et al. 1998). Historical climate records could provide a relatively stable estimate of the probability of favorable establishment years that could be used to predict acquisition and storage requirements for native seed over the long term.

Biodiversity and restoration planning objectives may require multiple-year strategies for replacement of non-native species only after initial site stabilization and suppression of annual weed competition (Bakker et al. 2003; Cox and Anderson 2004). Weather and climatic limitations require definition of realistic goals when establishing rehabilitation and restoration planning objectives (Call and Roundy 1991; Hobbs and Norton 1996; Ehrenfeld 2000; Jones 2003). Asay et al. (2001) argue that the relatively harsh climatic conditions on many rangelands may preclude the realistic use of many native plant materials in favor of adapted non-native species. In some years, and on some sites, it may be prudent to plant more easily established non-native species, particularly after wildfire or other disturbance, when the principal objective of rangeland planting may be soil stabilization. Biodiversity and restoration objectives could then be addressed in years when climatic conditions are amenable (Holmgren and Scheffer 2001; Bakker et al. 2003; Hardegree et al. 2003; Cox and Anderson 2004; Hardegree and Van Vactor 2004). Seasonal weather forecasts would perhaps improve the probability of successful native establishment if planting were limited to years with a favorable prediction for establishment success.

Plant Materials Program Development and Testing

Previous plant materials development has focused on productivity, vigor, establishment, disease resistance, seed production, and specific ecological and physiological traits deemed to confer superior performance or adaptation. Establishment, persistence, and invasion resistance of seeded plant communities may be enhanced by identification and selection of plant materials with functional traits similar to the various highly competitive invasive species (Arredondo et al. 1998; Pokorny et al. 2005; Funk et al. 2008; Leger and Espeland 2010; Steers et al. 2011; Leger et al. 2014). Functional traits common to many weedy invaders include high relative growth rate, specific leaf area, leaf nitrogen content, and resource-use efficiency (Aguirre and Johnson 1991a, 1991b; Grotkopp et al. 2002; Pokorny et al. 2005; Grotkopp and Rejmanek 2007; James and Drenovsky 2007; Funk et al. 2008; Larson et al. 2015, 2016). This type of functional trait selection, however, may only confer advantages in early seral stages of plant community development. We still need to improve our understanding of abiotic thresholds for plant establishment and persistence at all stages of succession, regardless of the suite of functional traits exhibited (Roundy et al. 1993, 1997; Biedenbender and Roundy 1996; Abbott and Roundy, 2003).

Development of herbicide-resistant native grass plant materials may be a useful area of future research. In recent years, interest has increased in using acetolactate synthase (ALS) inhibitors such as Imazapic to reduce annual grass competition with desirable perennials (Davies 2010; Hendrickson and Lund 2010; Elseroad and Rudd 2011; Hirsch et al. 2012; Kyser et al. 2012, 2013; Sheley et al. 2012). Imazapic damages fast-growing tissues, especially meristems, so weedy annual grasses and crucifers are controlled with less damage to perennials (Shaner and O'Conner 1991). Some residual activity is present, so annual grass control is still achieved a year following application (Davison and Smith 2007). An advantage of this herbicide is that many desirable nongrass species, particularly legumes and composites, are relatively resistant. Development of ALS-inhibitor resistance has been quite successful in several crop species (Tranel and Wright 2002); thus development of native plant materials with such resistance is likely to be successful. When such materials are developed by traditional plant-breeding methodologies, no special Environmental Protection Agency clearance is required before release.

For many years, the NRCS, US Forest Service, and Agricultural Research Service have routinely evaluated and released experimental materials as part of their ongoing plant-material research and development programs (Roundy and Call 1988; Alderson and Sharpe 1994; Asay et al. 2003). Comparisons between plant species and among plant materials within species are made in order to characterize released plant materials and to justify the release of new plant materials (Jensen et al. 2001; Lambert 2005; Ogle et al. 2008a, 2008b). These trials are typically replicated complete block design experiments subject to statistical analysis, but they are usually analyzed as individual experiments rather than as a collective whole. Because these trials are conducted every year, a large volume of data has been collected. More robust comparisons of species and plant materials could be made if these data were compiled and subjected to meta-analysis.

Adoption of Standard Protocols for Evaluating Success and Development of Meta-Analysis of Field Trials

The majority of range planting studies do not measure critical environmental factors affecting success but only measure relative treatment effects (Call and Roundy 1991; Vargas et al. 2001). Range planting studies also tend to extrapolate results obtained from atypical sites and conditions over larger areas (Cox et al. 1984) and are seldom replicated in multiple seeding years (Casler 1999). Generally, high variability in experimental procedures often produces unique individual studies from a complex combination of unique site preparation, plant materials, seeding rate, soil conditions, and weather during only 1 or 2 establishment years. An important recommendation is adoption of minimum experimental design requirements for publication of range planting studies relative to specific inferences that are of principal interest (Casler 1999; Vargas et al. 2001).

Success metrics are highly variable and often consist of relative ranking of treatment effects, and there has been little research to evaluate alternative criteria for quantification of success (Ries and Svejcar 1991). The majority of range planting studies only consider treatment effects in the first year after planting, and studies that are monitored for longer periods are generally not replicated for planting-year effects (Casler 1999). Many studies that have monitored range planting results in the very long term have noted significant changes from what would have been measured only 1 − 3 years post planting (Bleak et al. 1965; Hull 1971, 1973; Lavin and Johnson 1977; Eck and Sims 1984; Harris and Dobrowolski 1986).

In general, most individual studies within the range planting literature are insufficiently replicated to extract valid inferences about weather and climate effects, site effects, plant-materials effects, and seeding rate. The dominant level for validation in the currently available literature derives from interspersion and within-location replication of seedbed preparation treatments. These studies, as well as a large amount of data contained in conference proceedings, technical reports, and internal-agency documents, might be subject to valuable meta-analysis of treatment effects that are difficult or impossible to replicate in the context of a stand-alone journal publication (Durlak and Lipsay 1991; Gurevitch et al. 1992, 2001; Adams et al. 1997; Michener 1997; Gurevitch and Hedges 1999; Osenberg et al., 1999a, 1999b; Johnson 2006). Much of this information may only be suitable for low-level meta-analysis to document gross treatment effects. It may be possible, however, to develop guidelines for establishing some common experimental design features for future studies that may be amenable to more sophisticated meta-analysis.

Another underutilized research resource is the incorporation of extensive management-level monitoring information into a scientific database format (Pastorok et al. 1997). Eiswerth and Shonkwiler (2006) used a BLM data set to evaluate postfire management treatment effects on seeded non-native grasses, sagebrush, and annual weeds as a function of range site, soil type, and seeding prescription. Unfortunately, this data set did not evaluate impacts of weather and climate variability. More recently, BLM management data contained in the Land Treatment Digital Library have been used to conduct meta-analysis of treatment effects on postfire emergency stabilization and rehabilitation across multiple years and sites in the Great Basin (Gray and Muir 2013; Sankey et al. 2013; Arkle et al. 2014; Knutson et al. 2014; Leger and Baughman 2015). Effective utilization of these data may also require some degree of coordination within and between management agencies to adopt similar monitoring protocols. NRCS Conservation Practice Standards could be improved by establishing standard monitoring requirements to assess both the effectiveness of specific management recommendations and conservation effects of successful practices. Monitoring requirements, however, should be based on an explicit experimental design that would facilitate future meta-analysis.

Recommendations

The aggregate literature generally supports both the existing conservation practice recommendations for rangeland seeding and the inherent assumption that if these practices are successful, they will result in beneficial conservation effects. Current conservation practice recommendations, however, are relatively prescriptive in that they do not effectively address site- and year-specific variability, provide no mechanism for evaluating or adapting to unsuccessful or partially successful treatments, are oriented toward short-term management, and are not fully integrated with current ecologically based models for management of alternative vegetation states. Current conservation-practice standards could be improved with references to more ecologically based technical literature and by providing specific guidance for both monitoring and adaptive management in rangelands with an inherently high level of annual and seasonal weather variability.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.rama.2016.04.007.

References

Abbott, LB, Roundy, BA, 2003. Available water influences field germination and recruitment of seeded grasses. J. Range Manag. 56, 56–64.

Adams, DC, Gurevitch, J, Rosenberg, MS, 1997. Resampling tests for metaanalysis of ecological data. Ecology 78, 1277–1283.

Aguilera, MO, Steinaker, DF, Demaria, MR, 2003. Runoff and soil loss in undisturbed and roller-seeded shrublands of semiarid Argentina. J. Range Manag. 56, 227–233.

Aguirre, L, Johnson, DA, 1991a. Influence of temperature and cheatgrass competition on seedling development of two bunchgrasses. J. Range Manag. 44, 347–354.

Aguirre, L, Johnson, DA, 1991b. Root morphological development in relation to shoot growth in seedlings of four range grasses. J. Range Manag. 44, 341–346.

Akbar, G, Call, CA, Wiedmeier, RD, 1995. Cattle dungpat microenvironmental effects on germination and establishment of crested wheatgrass. Arid Soil Res. Rehabil. 9, 409–422.

Alderson, J, Sharp, WC, 1994. Grass varieties in the United States. Washington DC, USA: USDA Agricultural Handbook No. 170 296 pp.

Andales, AA, Derner, JD, Ahuja, LR, Hart, RH, 2006. Strategic and tactical prediction of forage production in northern mixed-grass prairie. Rangel. Ecol. Manag. 59, 576–584.

Anderson, D, Swanson, AR, 1949. Machinery for seedbed preparation and seeding on southwestern ranges. J. Range Manag. 2, 64–66.

Anderson, D, Hamilton, LP, Reynolds, HG, Humphrey, RR, 1957. Reseeding desert grassland ranges in southern Arizona. Tucson, AZ, USA: Arizona Agricultural Experiment Station Bulletin 249 32 pp.

Andrews, TS, 1995. Dispersal of seeds of giant *Sporobolus* spp. after ingestion by grazing cattle. Aust. J. Exp. Agric. 35, 353–356.

Angevine, MW, Chabot, BF, 1979. Seed germination syndromes in higher plants. In: Solbrig, O.T., Jain, S., Johnson, G.B., Raven, P.H. (Eds.), Topics in plant population biology. Columbia University Press, New York, NY, USA, pp. 188–206.

Arkle, RS, Pilliod, DS, Hanser, SE, Brooks, ML, Chambers, JC, Grace, JB, Knutson, KC, Pyke, DA, Welty, JL, Wirth, TA, 2014. Quantifying restoration effectiveness using multi-scale habitat models: implications for sage-grouse in the Great Basin. Ecosphere 5, 31. http://dx.doi.org/10.1890/ES13-00278.1.

Arredondo, JT, Jones, TA, Johnson, DA, 1998. Seedling growth of Intermountain perennial and weedy annual grasses. J. Range Manag. 51, 584–589.

Asay, KH, Chatterton, NJ, Jensen, KB, Jones, TA, Waldron, BL, Horton, WH, 2003. Breeding improved grasses for semiarid rangelands. Arid Land Res. Manag. 17, 469–478.

Asay, KH, Horton, WH, Jensen, KB, Palazzo, AJ, 2001. Merits of native and introduced Triticeae grasses on semiarid rangelands. Can. J. Plant Sci. 81, 45–52.

Auman, BS, Call, CA, Wiedmeier, RD, 1998. Crested wheatgrass establishment in livestock dung deposited on degraded rangeland vegetation types in the Intermountain West, USA. Arid Soil Res. Rehabil. 12, 317–333.

Baigorria, GA, Jones, JW, O'Brien, JJ, 2008. Potential predictability of crop yield using an ensemble climate forecast by a regional circulation model. Agric. For. Meteorol. 148, 1353–1361.

Bakker, JD, Wilson, SD, Christian, JM, Li, XD, Ambrose, LG, Waddington, J, 2003. Contingency of grassland restoration on year, site, and competition from introduced grasses. Ecol. Appl. 13, 137–153.

Barbour, MG, Billings, WD, 2000. North American terrestrial vegetation. Cambridge University Press, New York, NY, USA 708 pp.

Barnston, AG, Kumar, A, Goddard, L, Hoerling, MP, 2005. Improving seasonal prediction practices through attribution of climate variability. Bull. Am. Meteorol. Soc. 86, 59–72.

Barnston, AG, Vandendool, HM, Zebiak, SE, Barnett, TP, Ji, M, Rodenhuis, DR, Cane, MA, Leetmaa, A, Graham, NE, Ropelewski, CR, Kousky, VE, O'Lenic, EA, Livezey, RE, 1994. Long-lead seasonal forecasts—where do we stand? Bull. Am. Meteorol. Soc. 75, 2097–2114.

Bartley, R, Roth, CH, Ludwig, J, McJannet, D, Liedloff, A, Corfield, J, Hawdon, A, Abbott, B, 2006. Runoff and erosion from Australia's tropical semiarid rangelands: influence of ground cover for differing space and time scales. Hydrol. Process. 20, 3317–3333.

Bashari, H, Smith, C, Bosch, OJH, 2008. Developing decision support tools for rangeland management by combining state and transition models and Bayesian belief networks. Agric. Syst. 99, 23–34.

Batabyal, AA, Godfrey, EB, 2002. Rangeland management under uncertainty: a conceptual approach. J. Range Manag. 55, 12–15.

Bautista, S, Bellot, J, Vallejo, VR, 1996. Mulching treatment for postfire soil conservation in a semiarid ecosystem. Arid Soil Res. Rehabil. 10, 235–242.

Bement, RE, Barmington, RD, Everson, AC, Hylton, CL, Remmenge, EE, 1965. Seeding of abandoned croplands in the central Great Plains. J. Range Manag. 18, 53–59.

Berg, WA, Sims, PL, 1984. Herbage yields and water-use efficiency on a loamy site as affected by tillage, mulch and seeding treatments. J. Range Manag. 37, 180–184.

Bergkamp, G, 1998. A hierarchical view of the interactions of runoff and infiltration with vegetation and microtopography in semiarid shrublands. Catena 33, 201–220.

Bernstein, EJ, Albano, CM, Sisk, TD, Crews, TE, Rosenstock, S, 2014. Establishing cool-season grasses on a degraded arid rangeland of the Colorado Plateau. Restor. Ecol. 22, 57–64.

Bestelmeyer, BT, Brown, RR, Havstad, KM, Alexander, R, Chavez, G, Herrick, J, 2003. Development and use of state-and-transition models for rangelands. J. Range Manag. 56, 114–126.

Beyers, JL, 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. Conserv. Biol. 18, 947–956.

Bhark, EW, Small, EE, 2003. Association between plant canopies and the spatial patterns of infiltration in shrubland and grassland of the Chihuahuan Desert, New Mexico. Ecosystems 6, 185–196.

Biedenbender, S.H., Roundy, B.A., 1996. Establishment of native semidesert grasses into existing stands of Eragrostis lehmanniana in southeastern Arizona. Restor. Ecol. 4, 155–162.

Bleak, AT, Frischknecht, NC, Plummer, AP, Eckert, RE, 1965. Problems in artificial and natural revegetation of the arid shadscale vegetation zone of Utah and Nevada. J. Range Manag. 18, 59–65.

Bower, AD, Clair, JBS, Erikson, V, 2014. Generalized provisional seed zones for native plants. Ecol. Appl. 24, 913–919.

Boyd, CS, James, JJ, 2013. Variation in timing of planting influences bluebunch wheatgrass demography in an arid system. Rangel. Ecol. Manag. 66, 117–126.

Boyd, CS, Lemos, JA, 2013. Freezing stress influences emergence of germinated perennial grass seeds. Rangel. Ecol. Manag. 66, 136–142.

Boyd, CS, Lemos, JA, 2015. Evaluating winter/spring seeding of a native perennial bunchgrass in sagebrush steppe. Rangel. Ecol. Manag. 68, 494–500.

Boyd, CS, Obradovich, M, 2014. Is pile seeding Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) an effective alternative to broadcast seeding? Rangel. Ecol. Manag. 67, 292–297.

Bragg, TB, Stephens, LJ, 1979. Effects of agricultural terraces on the re-establishment of bluestem grasslands. J. Range Manag. 32, 437–441.

Brandt, CA, Rickard, WH, 1994. Alien taxa in the North American shrub-steppe 4 decades after cessation of livestock grazing and cultivation agriculture. Biol. Conserv. 68, 95–105.

Bremer, DJ, Ham, JM, 2010. Net carbon fluxes over burned and unburned native tallgrass prairie. Rangel. Ecol. Manag. 63, 72–81.

Bristow, KL, 1988. The role of mulch and its architecture in modifying soil temperature. Aust. J. Soil Res. 26, 269–280.

Brockway, DG, Gatewood, RG, Paris, RB, 2002. Restoring grassland savannas from degraded pinyon–juniper woodlands: effects of mechanical overstory reduction and slash treatment alternatives. J. Environ. Manag. 64, 179–197.

Brown, JC, Evans, RA, Young, JA, 1985. Effects of sagebrush control methods and seeding on runoff and erosion. J. Range Manag. 38, 195–199.

Brown, J, Angerer, J, Salley, SW, Blaisdell, R, Stuth, JW, 2010. Improving estimates of rangeland carbon sequestration potential in the US Southwest. Rangel. Ecol. Manag. 63, 147–154.

Bureau of Land Management, 2007. Burned area emergency stabilization and rehabilitation handbook. Washington, DC, USA: US Department of Interior, Bureau of Land Management Handbook H-1742 80 pp.

Cable, DR, 1980. Seasonal patterns of soil water recharge and extraction on semidesert ranges. J. Range Manag. 33, 9–15.

Call, CA, Roundy, BA, 1991. Perspectives and processes in revegetation of arid and semiarid rangelands. J. Range Manag. 44, 543–549.

Campbell, JL, Kennedy, RE, Cohen, WB, Miller, RF, 2012. Assessing the carbon consequences of western juniper *(Juniperus occidentalis)* encroachment across Oregon, USA. Rangel. Ecol. Manag. 65, 223–231.

Casler, MD, 1999. Repeated measures vs. repeated plantings in perennial forage grass trials: an empirical analysis of precision and accuracy. Euphytica 105, 33–42.

Chambers, JC, 1995. Relationships between seed fates and seedling establishment in an alpine ecosystem. Ecology 76, 2124–2133.

Chambers, JC, MacMahon, JA, 1994. A day in the life of a seed: movements and fates of seeds and their implications for natural and managed systems. Annu. Rev. Ecol. Syst. 25, 263–292.

Chivers, IH, Jones, TA, Broadhurst, LM, Larson, SR, Mott, IW, 2016. The merits of artificial selection for the development of restoration-ready plant materials of native perennial grasses. Restor. Ecol. 24 pp. 174–183.

Chung, SO, Horton, R, 1987. Soil heat and water flow with a partial surface mulch. Water Resour. Res. 23, 2175–2186.

Cione, NK, Padgett, PE, Allen, EB, 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. Restor. Ecol. 10, 376–384.

Cleary, MB, Pendall, E, Ewers, BE, 2010. Aboveground and belowground carbon pools after fire in mountain big sagebrush steppe. Rangel. Ecol. Manag. 63, 187–196.

Cline, JF, Uresk, DW, Rickard, WH, 1977. Comparison of soil water used by a sagebrush-bunchgrass and a cheatgrass community. J. Range Manag. 30, 199–201.

Cline, NL, Roundy, BA, Pierson, FB, Kormos, P, Williams, CJ, 2010. Hydrologic response to mechanical shredding in a juniper woodland. Rangel. Ecol. Manag. 63, 467–477.

Conant, RT, Paustain, K, Elliott, E, 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecol. Appl. 11, 343–355.

Cox, JR, Morton, HL, Johnson, TN, Jordan, GL, Martin, SC, Fierro, LC, 1984. Vegetation restoration in the Chihuahuan and Sonoran deserts of North America. Rangelands 6, 112–115.

Cox, RD, Anderson, VJ, 2004. Increasing native diversity of cheatgrass dominated rangeland through assisted succession. J. Range Manag. 57, 203–210.

Currie, PO, 1967. Seeding Sherman big bluegrass. J. Range Manag. 20, 133–136.

Davenport, DW, Breshears, DD, Wilcox, BP, Allen, CD, 1998. Viewpoint: sustainability of pinon–juniper ecosystems—a unifying perspective of soil erosion thresholds. J. Range Manag. 51, 231–240.

Davies, KW, 2010. Revegetation of medusahead-invaded sagebrush steppe. Rangel. Ecol. Manag. 63, 564–571.

Davies, KW, Boyd, CS, Johnson, DD, Nafus, AM, Madsen, MD, 2015. Success of seeding native compared with introduced perennial vegetation for revegetating medusahead-invaded sagebrush rangeland. Rangel. Ecol. Manag. 68, 224–230.

Davies, KW, Boyd, CS, Nafus, AM, 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. Rangel. Ecol. Manag. 66, 472–478.

Davison, JC, Smith, EG, 2007. Imazapic provides two-year control of weedy annuals in a seeded Great Basin fuelbreak. Native Plants J. 8, 91–95.

De Baets, S, Poesen, J, Gyssels, G, Knapen, A, 2006. Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology 76, 54–67.

Derner, JD, Schuman, GE, 2007. Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. J. Soil Water Conserv. 62, 77–85.

Descheemaeker, K, Nyssen, J, Poesen, J, Raes, D, Haile, M, Muys, B, Deckers, S, 2006. Runoff on slopes with restoring vegetation: a case study from the Tigray Highlands, Ethiopia. J. Hydrol. 331, 219–241.

Doblas-Reyes, FJ, Hagedorn, R, Palmer, TN, 2006. Developments in dynamical seasonal forecasting relevant to agricultural management. Clim. Res. 33, 19–26.

Douglas, DS, Hafenrichter, AL, Klages, KH, 1960. Cultural methods and their relation to establishment of native and exotic grasses in range seedings. J. Range Manag. 13, 53–57.

Dunkerley, D, 2002. Systematic variation of soil infiltration rates within and between the components of the vegetation mosaic in an Australian desert landscape. Hydrol. Process. 16, 119–131.

Durlak, JA, Lipsay, MW, 1991. A practitioner's guide to meta-analysis. Am. J. Community Psychol. 19, 291–332.

Eck, HV, Sims, PL, 1984. Grass species adaptability in the southern high plains—a 36 year assessment. J. Range Manag. 37, 211–217.

Eckert, RE, Evans, RA, 1967. A chemical-fallow technique for control of downy brome and establishment of perennial grasses on rangeland. J. Range Manag. 20, 35–41.

Eckert, RE, Peterson, FF, Meurisse, MS, Stephens, JL, 1986. Effects of soil-surface morphology on emergence and survival of seedlings in big sagebrush communities. J. Range Manag. 39, 414–420.

Ehrenfeld, JG, 2000. Defining the limits of restoration: the need for realistic goals. Restor. Ecol. 8, 2–9.

Eiswerth, ME, Shonkwiler, JS, 2006. Examining post-wildfire reseeding on arid rangeland: a multivariate tobit modelling approach. Ecol. Model. 192, 286–298.

Eiswerth, ME, Krauter, K, Swanson, SR, Zielinski, M, 2009. Post-fire seeding on Wyoming big sagebrush ecological sites: regression analyses of seeded nonnative and native species densities. J. Environ. Manag. 90, 1320–1325.

Elseroad, AC, Rudd, NT, 2011. Can Imazapic increase native species abundance in cheatgrass *(Bromus tectorum)* invaded native plant communities? Rangel. Ecol. Manag. 64, 641–648.

Ethridge, DE, Sherwood, RD, Sosebee, RE, Herbel, CH, 1997. Economic feasibility of rangeland seeding in the arid Southwest. J. Range Manag. 50, 185–190.

Evans, RA, Young, JA, 1978. Effectiveness of rehabilitation practices following wildfire in a degraded big sagebrush–downy brome community. J. Range Manag. 31, 185–188.

Evans, RA, Holbo, HR, Eckert, RE, Young, JA, 1970. Functional environment of downy brome communities in relation to weed control and revegetation. Weed Sci. 18, 154–162.

Flanagan, LB, Wever, LA, Carlson, PJ, 2002. Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. Glob. Chang. Biol. 8, 599–615.

Follett, RF, Reed, DA, 2010. Soil carbon sequestration in grazing lands: societal benefits and policy implications. Rangel. Ecol. Manag. 63, 4–15.

Follett, RF, Schuman, GE, 2005. Grazing land contributions to carbon sequestration. In: McGilloway, D.A. (Ed.), Grassland: a global resource. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 265–277.

Francis, MG, Pyke, DA, 1996. Crested wheatgrass cheatgrass seedling competition in a mixed-density design. J. Range Manag. 49, 432–438.

Frank, KW, Gaussion, RE, Riordan, TP, Miltner, ED, 1998. Date of planting effects on seeded turf-type buffalograss. Crop Sci. 38, 1210–1213.

Frasier, GW, Cox, JR, Woolhiser, DA, 1987. Wet–dry cycle effects on warm-season grass seedling establishment. J. Range Manag. 40, 2–6.

Fulbright, TE, Ortega-Santos, JA, Lozano-Cavazos, A, Ramirez-Yanez, LE, 2006. Establishing vegetation on migrating inland sand dunes in Texas. Rangel. Ecol. Manag. 59, 549–556.

Funk, JL, Cleland, EE, Suding, KN, Zavaleta, ES, 2008. Restoration through reassembly: plant traits and invasion resistance. Trends Ecol. Evol. 23, 695–703.

Garbrecht, JD, Schneider, JM, 2007. Climate forecast and prediction product dissemination for agriculture in the United States. Aust. J. Agric. Res. 58, 966–974.

Garza, NE, Blackburn, WH, 1985. The effect of early winter and spring burning on runoff, sediment, and vegetation in the post oak savannah of Texas. J. Range Manag. 38, 283–287.

Gates, DH, 1962. Revegetation of a high-altitude, barren slope in northern Idaho. J. Range Manag. 15, 314–318.

Ghersa, CM, Benech Arnold, RL, Martinez-Ghersa, MA, 1992. The role of fluctuating temperatures in germination and establishment of *Sorghum halepense*—regulation of germination at increasing depths. Funct. Ecol. 6, 460–468.

Gifford, GF, 1970. Some water movement patterns over and through pinyon-juniper litter. J. Range Manag. 23, 365–366.

Gifford, GF, 1972. Infiltration rate and sediment production trends on a plowed big sagebrush site. J. Range Manag. 25, 53–55.

Gifford, GF, 1973. Runoff and sediment yields from runoff plots on chained pinyon–juniper sites in Utah. J. Range Manag. 26, 440–443.

Gifford, GF, 1975. Approximate annual water budgets of two chained pinyon–juniper sites. J. Range Manag. 28, 73–74.

Gilmanov, TG, Aires, L, Barcza, Z, Baron, VS, Belelli, L, Beringer, J, Billesbach, D, Bonal, D, Bradford, J, Ceschia, E, Cook, D, Corradi, C, Frank, A, Gianelle, D, Gimeno, C, Gruenwald, T, Guo, H, Hanan, N, Haszpra, L, Heilman, J, Jacobs, A, Jones, MB, Johnson, DA, Kiely, G, Li, S, Magliulo, V, Moors, E, Nagy, Z, Nasyrov, M, Owensby, C, Pinter, K, Pio, C, Reichstein, M, Sanz, MJ, Scott, R, Soussana, JF, Stoy, PC, Svejcar, T, Tuba, Z, Zhou, G, 2010. Productivity, respiration, and light-response parameters of world grassland and agroecosystems derived from flux-tower measurements. Rangel. Ecol. Manag. 63, 16–39.

Gimeno-Garcia, E, Andreu, V, Rubio, JL, 2007. Influence of vegetation recovery on water erosion at short and medium-term after experimental fires in a Mediterranean shrubland. Catena 69, 150–160.

Giordanengo, JH, Frasier, GW, Trlica, MJ, 2003. Hydrologic and sediment responses to vegetation and soil disturbances. J. Range Manag. 56, 152–158.

Gokbulak, F, Call, CA, 2004. Grass seedling recruitment in cattle dungpats. J. Range Manag. 57, 649–655.

Gonzalez, CL, Dodd, JD, 1979. Production response of native and introduced grasses to mechanical brush manipulation, seeding, and fertilization. J. Range Manag. 32, 305–309.

Gornish, ES, Aanderud, ZT, Sheley, RL, Rinella, MJ, Svejcar, T, Englund, SD, James, JJ, 2015. Altered snowfall and soil disturbance influence the early life stage transitions and recruitment of a native and invasive grass in a cold desert. Oecologia 177, 595–606.

Gray, EC, Muir, PS, 2013. Does *Kochia prostrata* spread from seeded sites? An evaluation from Southwestern Idaho, USA. Rangel. Ecol. Manag. 66, 191–203.

Grismer, ME, 2007. Soil restoration and erosion control: quantitative assessment and direction. Trans. ASABE 50, 1619–1626.

Groen, AH, Woods, SW, 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, northwestern Montana, USA. Int. J. Wildland Fire 17, 559–571.

Grotkopp, E, Rejmanek, M, 2007. High seedling relative growth rate and specific leaf area are traits of invasive species: phylogenetically independent contrasts of woody angiosperms. Am. J. Bot. 94, 526–532.

Grotkopp, E, Rejmanek, M, Rost, TL, 2002. Toward a causal explanation of plant invasiveness: seedling growth and life-history strategies of 29 pine (*Pinus*) species. Am. Nat. 159, 396–419.

Guo, LB, Gifford, RM, 2002. Soil carbon stocks and land use change: a meta analysis. Glob. Chang. Biol. 8, 345–360.

Gurevitch, J, Hedges, LV, 1999. Statistical issues in ecological meta-analyses. Ecology 80, 1142–1149.

Gurevitch, J, Curtis, PS, Jones, MH, 2001. Meta-analysis in ecology. Adv. Ecol. Res. 32, 199–247.

Gurevitch, J, Morrow, LL, Wallace, A, Walsh, JS, 1992. A meta-analysis of competition in field experiments. Am. Nat. 140, 539–572.

Gurney, CM, Prugh, LR, Brashares, JS, 2015. Restoration of native plants is reduced by rodent-caused soil disturbance and seed removal. Rangel. Ecol. Manag. 68, 359–366.

Gyssels, G, Poesen, J, Bochet, E, Li, Y, 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog. Phys. Geogr. 29, 189–217.

Haferkamp, MR, Ganskopp, DC, Miller, RF, Sneva, FA, 1987. Drilling versus imprinting for establishing crested wheatgrass in the sagebrush-bunchgrass steppe. J. Range Manag. 40, 524–530.

Hardegree, SP, Van Vactor, SS, 2004. Microclimatic constraints and revegetation planning in a variable environment. Weed Technol. 18, 1213–1215.

Hardegree, SP, Cho, J, Schneider, JM, 2012a. Weather variability, ecological processes, and optimization of soil micro-environment for rangeland restoration. In: Monaco, T.A., Sheley, R.L. (Eds.), Invasive plant ecology and management: linking processes to practice. CAB International, Wallingford, Oxfordshire, England, pp. 107–121.

Hardegree, SP, Flerchinger, GN, Van Vactor, SS, 2003. Hydrothermal germination response and the development of probabilistic germination profiles. Ecol. Model. 167, 305–322.

Hardegree, SP, Moffet, CA, Flerchinger, GN, Cho, J, Roundy, BA, Jones, TA, James, JJ, Clark, PE, Pierson, FB, 2013. Hydrothermal assessment of temporal variability in seedbed microclimate. Rangel. Ecol. Manag. 66, 127–135.

Hardegree, SP, Schneider, JM, Moffet, CA, 2012b. Weather variability and adaptive management for rangeland restoration. Rangelands 34, 53–56.

Hardegree, SP, Sheley, RL, Duke, SE, James, JJ, Boehm, AR, Flerchinger, GN, 2016. Temporal variability in microclimatic conditions for grass germination and emergence in the sagebrush steppe. Rangel. Ecol. Manag. 69, 123–128.

Harper, JL, Williams, JT, Sagar, GR, 1965. The behavior of seeds in soil I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. J. Ecol. 53, 273–286.

Harris, GA, Dobrowolski, JP, 1986. Population dynamics of seeded species on northeast Washington semiarid sites 1948–1983. J. Range Manag. 39, 46–51.

Hart, RH, Dean, JG, 1986. Forage establishment: weather effects on stubble vs. fallow and fall vs. spring seeding. J. Range Manag. 39, 228–230.

Hastings, SJ, Oechel, WC, Muhlia-Melo, A, 2005. Diurnal, seasonal and annual variation in the net ecosystem CO_2 exchange of a desert shrub community *(sarcocaulescent)* in Baja California, Mexico. Glob. Chang. Biol. 11, 927–939.

Hatfield, JL, 1990. Agroclimatology of semiarid lands. Adv. Soil Sci. 13, 9–26.

Hauser, VL, 1982. Punch planting to establish grass. J. Range Manag. 35, 294–297.

Hendrickson, JR, Lund, C, 2010. Plant community and target species affect responses to restoration strategies. Rangel. Ecol. Manag. 63, 435–442.

Hereford, R, Webb, RH, Longpre, CI, 2006. Precipitation history and ecosystem response to multidecadal precipitation variability in the Mojave Desert region, 1893–2001. J. Arid Environ. 67, 13–34.

Hibbert, AR, 1983. Water yield improvement potential by vegetation management on western rangelands. Water Resour. Bull. 19, 375–381.

Hill, LW, Rice, RM, 1963. Converting from brush to grass increases water yield in southern California. J. Range Manag. 16, 300–305.

Hirsch, MC, Monaco, TA, Call, CA, Ransom, CV, 2012. Comparison of herbicides for reducing annual grass emergence in two Great Basin soils. Rangel. Ecol. Manag. 65, 66–75.

Hobbs, RJ, Norton, DA, 1996. Towards a conceptual framework for restoration ecology. Restor. Ecol. 4, 93–110.

Holmgren, M, Scheffer, M, 2001. El Nino as a window of opportunity for the restoration of degraded arid ecosystems. Ecosystems 4, 151–159.

Huang, Y, Wilcox, BP, Stern, L, Perotto-Baldivieso, H, 2006. Springs on rangelands: runoff dynamics and influence of woody plant cover. Hydrol. Process. 20, 3277–3288.

Hubbard, WA, Smoliak, S, 1953. Effect of contour dykes and furrows on short-grass prairie. J. Range Manag. 6, 55–62.

Hull, AC, 1948. Depth, season and row spacing for planting grasses on southern Idaho range lands. J. Am. Soc. Agronomy 40, 960–969.

Hull, AC, 1964. Emergence of cheatgrass and three wheatgrasses from four seeding depths. J. Range Manag. 17, 32–35.

Hull, AC, 1966. Emergence and survival of intermediate wheatgrass and smooth brome seeded on a mountain range. J. Range Manag. 19, 279–283.

Hull, AC, 1970. Grass seedling emergence and survival from furrows. J. Range Manag. 23, 421–424.

Hull, AC, 1971. Grass mixtures for seeding sagebrush lands. J. Range Manag. 24, 150–152.

Hull, AC, 1972. Seeding rates and row spacings for rangelands in southeastern Idaho and northern Utah. J. Range Manag. 25, 50–53.

Hull, AC, 1973. Duration of seeded stands on terraced mountain lands, Davis County, Utah. J. Range Manag. 26, 133–136.

Hull, AC, 1974. Seedling emergence and survival from different seasons and rates of seeding mountain rangelands. J. Range Manag. 27, 302–304.

Humphrey, LD, Schupp, EW, 2002. Seedling survival from locally and commercially obtained seeds on two semiarid sites. Restor. Ecol. 10, 88–95.

Huxman, TE, Wilcox, BP, Breshears, DD, Scott, RL, Snyder, KA, Small, EE, Hultine, K, Pockman, WT, Jackson, RB, 2005. Ecohydrological implications of woody plant encroachment. Ecology 86, 308–319.

Hyder, DN, Sneva, FA, 1956. Seed and plant-soil relations as affected by seedbed firmness on a sandy loam rangeland soil. Soil Sci. Soc. Am. Proc. 20, 416–419.

Hyder, DN, Everson, AC, Bement, RE, 1971. Seedling morphology and seeding failures with blue grama. J. Range Manag. 24, 287–292.

Hyder, DN, Sneva, FA, Sawyer, WA, 1955. Soil firming may improve range seeding operations. J. Range Manag. 8, 159–163.

Imeson, AC, Prinsen, HAM, 2004. Vegetation patterns as biological indicators for identifying runoff and sediment source and sink areas for semi-arid landscapes in Spain. Agric. Ecosyst. Environ. 104, 333–342.

James, JJ, Drenovsky, RE, 2007. A basis for relative growth rate differences between native and invasive forb seedlings. Rangel. Ecol. Manag. 60, 395–400.

James, JJ, Gornish, ES, DiTomaso, JM, Davy, J, Doran, MP, Bechetti, T, Lile, D, Brownsey, P, Laca, EA, 2015. Managing medusahead *(Taeniatherum caput-medusae)* on rangeland: a meta-analysis of control effects and assessment of stakeholder needs. Rangel. Ecol. Manag. 68, 215–223.

James, JJ, Rinella, MJ, Svejcar, T, 2012. Grass seedling demography and sagebrush steppe restoration. Rangel. Ecol. Manag. 65, 409–417.

James, JJ, Svejcar, TJ, Rinella, MJ, 2011. Demographic processes limiting seedling recruitment in arid grassland restoration. J. Appl. Ecol. 48, 961–969.

Jensen, KB, Horton, WH, Reed, R, Whitesides, RE, 2001. Intermountain planting guide. Logan, UT, USA: Utah State University Extension Publication AG510 104 pp.

Jensen, KB, Peel, MD, Waldron, BL, Horton, WH, Asay, KH, 2005. Persistence after three cycles of selection in NewHy RS wheatgrass (*Elymus hoffmannii* K.B. Jensen & Asay) at increased salinity levels. Crop Sci. 45, 1717–1720.

Johansen, MP, Hakonson, TE, Breshears, DD, 2001. Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. Hydrol. Process. 15, 2953–2965.

Johnson, DA, Asay, KH, 1995. Breeding and selection of grasses for improved drought response: a review. Ann. Arid Zone 34, 163–178.

Johnson, DH, 2006. The many faces of replication. Crop Sci. 46, 2486–2491.

Jones, MB, Donnelly, A, 2004. Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO_2. New Phytol. 164, 423–439.

Jones, TA, 1990. A viewpoint on Indian ricegrass research. Its present status and future prospects. J. Range Manag. 43, 416–420.

Jones, TA, 2003. The restoration gene pool concept: beyond the native versus non-native debate. Restor. Ecol. 11, 281–290.

Jones, TA, 2010. Notice of release of Rattlesnake Germplasm bottlebrush squirreltail. Native Plants J. 11, 45–50.

Jones, TA, 2013. Ecologically appropriate plant materials for restoration applications. Bioscience 63, 211–219.

Jones, TA, Monaco, TA, 2009. A role for assisted evolution in designing native plant materials for domesticated landscapes. Front. Ecol. Environ. 7, 541–547.

Jones, TA, Monaco, TA, James, JJ, 2010. Launching the counterattack: Interdisciplinary deployment of native-plant functional traits for repair of rangelands dominated by invasive annual grasses. Rangelands 32, 38–42.

Jones, TA, Monaco, TA, Rigby, CW, 2015. The potential of novel native plant materials for the restoration of novel ecosystems. Elementa 3, 000047.

Jones, TA, Nielson, DC, Larson, SR, Johnson, DA, Monaco, TA, Caicco, SL, Ogle, DG, Young, SA, 2004a. Registration of Fish Creek bottlebrush squirreltail germplasm. Crop Sci. 44, 1879–1880.

Jones, TA, Nielson, DC, Larson, SR, Johnson, DA, Monaco, TA, Caicco, SL, Ogle, DG, Young, SA, Carlson, JR, 2004b. Registration of Toe Jam Creek bottlebrush squirreltail germplasm. Crop Sci. 44, 1880–1881.

Jordan, GL, 1981. Range seeding and brush management on Arizona rangelands. Tucson, AZ, USA: Agricultural Experiment Station University of Arizona College of Agriculture Bulletin T81121.

Kincaid, DR, Williams, G, 1966. Rainfall effects on soil surface characteristics following range improvement treatments. J. Range Manag. 19, 346–351.

Kinsinger, FE, 1962. The relationship between depth of planting and maximum foliage height of seedlings of Indian ricegrass. J. Range Manag. 15, 10–13.

Klomp, GJ, Hull, AC, 1972. Methods for seeding three perennial wheatgrasses on cheatgrass ranges in southern Idaho. J. Range Manag. 25, 266–268.

Knapp, PA, 1996. Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin Desert—history, persistence, and influences to human activities. Glob. Environ. Chang. 6, 37–52.

Knutson, KC, Pyke, DA, Wirth, TA, Arkle, RS, Pilliod, DS, Brooks, ML, Chambers, JC, Grace, JB, 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. J. Appl. Ecol. 51, 1414–1424.

Kronberg, SL, 2015. Improving cattle nutrition on the Great Plains with shrubs and fecal seeding of fourwing saltbush. Rangel. Ecol. Manag. 68, 285–289.

Krueger-Mangold, JM, Sheley, RL, Svejcar, TJ, 2006. Toward ecologically-based invasive plant management on rangeland. Weed Sci. 54, 597–605.

Krzysztofowicz, R, 2001. The case for probabilistic forecasting in hydrology. J. Hydrol. 249, 2–9.

Kulmatiski, A, Beard, KH, Stark, JM, 2006. Exotic plant communities shift water-use timing in a shrub–steppe ecosystem. Plant Soil 288, 271–284.

Kyle, GP, Beard, KH, Kulmatiski, A, 2007. Reduced soil compaction enhances establishment of non-native plant species. Plant Ecol. 193, 223–232.

Kyser, GB, Peterson, VF, Davy, JS, DiTomaso, JM, 2012. Preemergent control of medusahead on California annual rangelands with aminopyralid. Rangel. Ecol. Manag. 65, 418–425.

Kyser, GB, Wilson, RG, Zhang, J, Di Tomaso, JM, 2013. Herbicide-assisted restoration of Great Basin sagebrush steppe infested with medusahead and downy brome. Rangel. Ecol. Manag. 66, 588–596.

Lambert, S, 2005. Guidebook to the seeds of native and non-native grasses, forbs and shrubs of the Great Basin. Boise, ID, USA: Idaho BLM Technical Bulletin 2005-04 134 pp.

Larson, JE, Sheley, RL, Hardegree, SP, Doescher, PS, James, JJ, 2016. Do key dimensions of seed and seedling functional trait variation capture variation in recruitment probability? Oecologia 181, 39–53. http://dx.doi.org/10.1007/s00442-015-3430.3.

Larson, JE, Sheley, RL, Hardegree, SP, Doescher, PS, James, JJ, 2015. Seed and seedling traits affecting critical life stage transitions and recruitment outcomes in dryland grasses. J. Appl. Ecol. 52, 199–209.

Lavin, F, Johnson, TN, 1977. Species adapted for planting Arizona pinyon–juniper woodland. J. Range Manag. 30, 410–415.

Lavin, F, Gomm, FB, Johnson, TN, 1973. Cultural, seasonal, and site effects on pinyon–juniper rangeland plantings. J. Range Manag. 26, 279–285.

Lavin, F, Johnson, TN, Gomm, B, 1981. Mulching, furrowing, and fallowing of forage plantings on Arizona pinyon–juniper ranges. J. Range Manag. 34, 171–177.

Leger, EA, Baughman, OW, 2015. What seeds to plant in the Great Basin? Comparing traits prioritized in native plant cultivars and releases with those that promote survival in the field. Natural Areas J. 35, 54–68.

Leger, EA, Espeland, EK, 2010. The shifting balance of facilitation and competition affects the outcome of intra- and interspecific interactions over the life history of California grassland annuals. Plant Ecol. 208, 333–345.

Leger, EA, Goergen, EM, Forbis De Queiroz, T, 2014. Can native annual forbs reduce *Bromus tectorum* biomass and indirectly facilitate establishment of a native perennial grass? J. Arid Environ. 102, 9–16.

Longland, WS, Ostoja, SM, 2013. Ecosystem services from keystone species: diversionary seeding and seed-caching desert rodents can enhance Indian ricegrass seedling establishment. Restor. Ecol. 21, 285–291.

Ludwig, JR, McGinnies, WJ, 1978. Revegetation trials on a saltgrass meadow. J. Range Manag. 31, 308–311.

Madsen, MD, Zvirzdin, DL, Petersen, SL, Hopkins, BG, Roundy, BA, 2015. Anchor chaining's influence on soil hydrology and seeding success in burned pinyon-juniper woodlands. Rangel. Ecol. Manag. 68, 231–240.

Mangla, S, Sheley, RL, James, JJ, Radosevich, SR, 2011. Role of competition in restoring resource poor arid systems dominated by invasive grasses. J. Arid Environ. 75, 487–493.

Mangold, JM, Poulsen, CL, Carpinelli, MF, 2007. Revegetating Russian knapweed *(Acroptilon repens)* infestations using morphologically diverse species and seedbed preparation. Rangel. Ecol. Manag. 60, 378–385.

Masters, RA, 1997. Influence of seeding rate on big bluestem establishment with herbicides. Agron. J. 89, 947–951.

McGinnies, WJ, 1959. The relationship of furrow depth to moisture content of soil and to seedling establishment on range soil. Agron. J. 51, 13–14.

McGinnies, WJ, 1962. Effect of seedbed firming on the establishment of crested wheatgrass seedlings. J. Range Manag. 15, 230–234.

McGinnies, WJ, 1968. Effect of post-emergence weed control on grass establishment in north-central Colorado. J. Range Manag. 21, 126–128.

McGinnies, WJ, 1972. An alternate-furrow system for seeding northern Colorado rangeland. J. Range Manag. 25, 450–452.

McGinnies, WJ, 1973. Effects of date and depth of planting on the establishment of three range grasses. Agron. J. 65, 120–123.

McGinnies, WJ, 1987. Effects of hay and straw mulches on the establishment of seeded grasses and legumes on rangeland and a coal strip mine. J. Range Manag. 40, 119–121.

McMurray, MH, Jenkins, SH, Longland, WS, 1997. Effects of seed density on germination and establishment of a native and an introduced grass species dispersed by granivorous rodents. Am. Midl. Nat. 138, 322–330.

Meeuwig, RO, 1965. Effects of seeding and grazing on infiltration capacity and soil stability of a subalpine range in central Utah. J. Range Manag. 18, 173–180.

Mergen, DE, Trlica, MJ, Smith, JL, Blackburn, WH, 2001. Stratification of variability in runoff and sediment yield based on vegetation characteristics. J. Am. Water Resour. Assoc. 37, 617–628.

Meyer, LD, Wischmeier, WH, Foster, GR, 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Am. Proc. 34, 928–931.

Michener, WK, 1997. Quantitatively evaluating restoration experiments: research design, statistical analysis, and data management considerations. Restor. Ecol. 5, 324–337.

Miller, ME, Bowker, MA, Reynolds, RL, Goldstein, HL, 2012. Post-fire land treatments and wind erosion—lessons from the Milford Flat Fire, UT, USA. Aeolian Res. 7, 29–44.

Monsen, SB, Stevens, R, 2004. Seedbed preparation and seeding practices. Restoring Western Ranges and Wildlands 1. USDA, Washington, DC, USA, pp. 121–154 USFS General Technical Report RMRS-GTR-136.

Moore, G.W., Barre, D.A., Owens, M.K., 2012. Does shrub removal increase groundwater recharge in southwestern Texas semiarid rangelands? Rangel. Ecol. Manag. 65, 1–10.

Nafus, AM, Davies, KW, 2014. Medusahead ecology and management: California annual grasslands to the Intermountain West. Invasive Plant Sci. Manag. 7, 210–221.

Natural Resources Conservation Service, 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. NRCS Agricultural Handbook 296. USDA, Washington, DC, USA 669 pp.

Nearing, MA, Jetten, V, Baffaut, C, Cerdan, O, Couturier, A, Hernandez, M, Le Bissonnais, Y, Nichols, MH, Nunes, JP, Renschler, CS, Souchere, V, van Oost, K, 2005. Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena 61, 131–154.

Nelson, JR, Wilson, AM, Goebel, CJ, 1970. Factors influencing broadcast seeding in bunchgrass range. J. Range Manag. 23, 163–170.

Nichols, MH, 2006. Measured sediment yield rates from semiarid rangeland watersheds. Rangel. Ecol. Manag. 59, 55–62.

Nord, EC, Hartless, PF, Nettleton, WD, 1971. Effects of several factors on saltbush establishment in California. J. Range Manag. 24, 216–223.

Novak, MD, Chen, WJ, Hares, MA, 2000. Simulating the radiation distribution within a barley–straw mulch. Agric. For. Meteorol. 102, 173–186.

O'Dea, ME, Guertin, DP, 2003. Prescribed fire effects on erosion parameters in a perennial grassland. J. Range Manag. 56, 27–32.

O'Lenic, EA, Unger, DA, Halpert, MS, Pelman, KS, 2008. Developments in operational long-range climate prediction at CPC. Weather Forecast. 23, 496–515.

Ocumpaugh, WR, Archer, S, Stuth, JW, 1996. Switchgrass recruitment from broadcast seed vs seed fed to cattle. J. Range Manag. 49, 368–371.

Ogle, D, John, LS, Cornwell, J, Stannard, M, Holzworth, L, 2008a. Pasture and range seedings: planning-installation-evaluation-management. Washington, DC, USA: USDA-NRCS Technical Note PM-TN-10 36 pp.

Ogle, D, John, LS, Stannard, M, Holzworth, L, 2008b. Grass, grass-like, forb, legume, and woody species for the intermountain west. Washington, DC, USA: USDA-NRCS Technical Note, TN Plant Materials No. 24 43 pp.

Osborn, HB, Simanton, JR, 1990. Hydrologic modeling of a treated rangeland watershed. J. Range Manag. 43, 474–481.

Osenberg, CW, Sarnelle, O, Goldberg, DE, 1999a. Meta-analysis in ecology: concepts, statistics, and applications. Ecology 80, 1103–1104.

Osenberg, CW, Sarnelle, O, Cooper, SD, Holt, RD, 1999b. Resolving ecological questions through meta-analysis: goals, metrics, and models. Ecology 80, 1105–1117.

Ott, JE, McArthur, ED, Roundy, BA, 2003. Vegetation of chained and non-chained seedings after wildfire in Utah. J. Range Manag. 56, 81–91.

Parsons, MC, Jones, TA, Larson, SR, Mott, IW, Monaco, TA, 2011. Ecotypic variation in *Elymus elymoides* subsp. *brevifolius* in the northern Intermountain West. Rangel. Ecol. Manag. 64, 649–658.

Pastorok, RA, MacDonald, A, Sampson, JR, Wilber, P, Yozzo, DJ, Titre, JP, 1997. An ecological decision framework for environmental restoration projects. Ecol. Eng. 9, 89–107.

Peters, DPC, 2000. Climatic variation and simulated patterns in seedling establishment of two dominant grasses at a semi-arid–arid grassland ecotone. J. Veg. Sci. 11, 493–504.

Petersen, SL, Stringham, TK, 2008. Infiltration, runoff, and sediment yield in response to western juniper encroachment in southeast Oregon. Rangel. Ecol. Manag. 61, 74–81.

Pierson, FB, Bates, JD, Svejcar, TJ, Hardegree, SP, 2007a. Runoff and erosion after cutting western juniper. Rangel. Ecol. Manag. 60, 285–292.

Pierson, FB, Blackburn, WH, Van Vactor, SS, 2007b. Hydrologic impacts of mechanical seeding treatments on sagebrush rangelands. Rangel. Ecol. Manag. 60, 666–674.

Pierson, FB, Spaeth, KE, Weltz, MA, Carlson, DH, 2002. Hydrologic response of diverse western rangelands. J. Range Manag. 55, 558–570.

Pierson, FB, Williams, CJ, Hardegree, SP, Weltz, MA, Stone, JJ, Clark, PE, 2011. Fire, plant invasions, and erosion events on western rangelands. Rangel. Ecol. Manag. 64, 439–449.

Pierson, FB, Williams, CJ, Kormos, PR, Al-Hamdan, OZ, 2014. Short-term effects of tree removal on infiltration, runoff, and erosion in woodland-encroached sagebrush steppe. Rangel. Ecol. Manag. 67, 522–538.

Pierson, FB, Williams, CJ, Kormos, PR, Hardegree, SP, Clark, PE, Rau, BM, 2010. Hydrologic vulnerability of sagebrush steppe following pinyon and juniper encroachment. Rangel. Ecol. Manag. 63, 614–629.

Pimentel, D, Kounang, N, 1998. Ecology of soil erosion in ecosystems. Ecosystems 1, 416–426.

Pinchak, BA, Schuman, GE, Depuit, EJ, 1985. Topsoil and mulch effects on plant species and community responses of revegetated mined land. J. Range Manag. 38, 262–265.

Plummer, PA, Christensen, DR, Monsen, SB, 1968. Restoring big-game range in Utah. Ephraim, UT, USA: Utah Division of Fish and Game Publication No. 68-3 183 pp.

Pokorny, ML, Sheley, RL, Zabinski, CA, Engel, RE, Svejcar, TJ, Borkowski, JJ, 2005. Plant functional group diversity as a mechanism for invasion resistance. Restor. Ecol. 13, 448–459.

Prater, MR, DeLucia, EH, 2006. Nonnative grasses alter evapotranspiration and energy balance in Great Basin sagebrush communities. Agric. For. Meteorol. 139, 154–163.

Puigdefabregas, J, 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. Earth Surf. Process. Landf. 30, 133–147.

Pyke, DA, Archer, S, 1991. Plant–plant interactions affecting plant establishment and persistence on revegetated rangeland. J. Range Manag. 44, 550–555.

Quinton, JN, Edwards, GM, Morgan, RPC, 1997. The influence of vegetation species and plant properties on runoff and soil erosion: results from a rainfall simulation study in south east Spain. Soil Use Manag. 13, 143–148.

Rayner, S, Lach, D, Ingram, H, 2005. Weather forecasts are for wimps: why water resource managers do not use climate forecasts. Clim. Chang. 69, 197–227.

Rees, RM, Bingham, IJ, Baddeley, JA, Watson, CA, 2005. The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems. Geoderma 128, 130–154.

Richards, RT, Chambers, JC, Ross, C, 1998. Use of native plants on federal lands: policy and practice. J. Range Manag. 51, 625–632.

Ries, RE, Hofmann, L, 1996. Perennial grass establishment in relationship to seeding dates in the northern Great Plains. J. Range Manag. 49, 504–508.

Ries, RE, Svejcar, TJ, 1991. The grass seedling: when is it established? J. Range Manag. 44, 574–576.

Robertson, TE, Box, TW, 1969. Interseeding sideoats grama on the Texas High Plains. J. Range Manag. 22, 243–245.

Robins, JG, Jensen, KB, Jones, TA, Waldron, BL, Peel, MD, Rigby, CW, Vogel, KP, Mitchell, RB, Palazzo, AJ, Cary, TJ, 2013. Stand establishment and persistence of perennial cool-season grasses in the Intermountain West and the central and northern Great Plains. Rangel. Ecol. Manag. 66, 181–190.

Robocker, WC, Gates, DH, Kerr, HD, 1965. Effects of herbicides, burning, and seeding date in reseeding an arid range. J. Range Manag. 18, 114–118.

Romo, JT, Grilz, RW, 2002. Establishment of silver sagebrush in the northern mixed prairie. J. Range Manag. 55, 217–221.

Roundy, B.A., Abbot, L.B., Livingston, M., 1997. Surface soil water loss after summer rainfall in a semidesert grassland. Arid Soil Res. Rehab. 11, 49–62.

Roundy, BA, Call, CA, 1988. Revegetation of arid and semiarid rangelands. In: Tueller, P.T. (Ed.), Vegetation science applications for rangeland analysis and management. Kluwer Academic, Dordrecht, The Netherlands, pp. 607–635.

Roundy, BA, Keys, RN, Winkel, VK, 1990. Soil response to cattle trampling and mechanical seedbed preparation. Arid Soil Res. Rehabil. 4, 233–242.

Roundy, B.A., Winkel, V.K., Cox, J.R., Dobrenz, A.K., Tewolde, H., 1993. Sowing depth and soil water effects on seedling emergence and root morphology of three warm-season grasses. Agron. J. 85, 975–982.

Roundy, BA, Winkel, VK, Khalifa, H, Matthias, AD, 1992. Soil water availability and temperature dynamics after one-time heavy cattle trampling and land imprinting. Arid Soil Res. Rehabil. 6, 53–69.

Roundy, BA, Young, K, Cline, N, Hulet, A, Miller, RF, Tausch, RJ, Chambers, JC, Rau, B, 2014. Pinon-juniper reduction increases soil water availability in the resource growth pool. Rangel. Ecol. Manag. 67, 495–505.

Royer, PD, Breshears, DD, Zou, CB, Villegas, JC, Cobb, NS, Kurc, SA, 2012. Density-dependent ecohydrological effects of pinon-juniper woody canopy cover on soil microclimate and potential soil evaporation. Rangel. Ecol. Manag. 65, 11–20.

Sankey, JB, Wallace, CSA, Ravi, S, 2013. Phenology-based remote sensing of post-burn disturbance windows in rangelands. Ecol. Indic. 30, 35–44.

Schantz, MC, Sheley, RL, James, JJ, 2015. Role of propagule pressure and priority effects on seedlings during invasion and restoration of shrub-steppe. Biol. Invasions 17, 73–85.

Schneider, JM, Garbrecht, JD, 2003. A measure of the usefulness of seasonal precipitation forecasts for agricultural applications. Trans. ASAE 46, 257–267.

Schneider, JM, Garbrecht, JD, 2006. Dependability and effectiveness of seasonal forecasts for agricultural applications. Trans. ASABE 49, 1737–1753.

Schuman, GE, Taylor, EM, Rauzi, F, Pinchak, BA, 1985. Revegetation of mined land: influence of topsoil depth and mulching method. J. Soil Water Conserv. 40, 249–252.

Schwendiman, JL, 1958. Testing new range forage plants. J. Range Manag. 11, 71–76.

Scurlock, JMO, Hall, DO, 1998. The global carbon sink: a grassland perspective. Glob. Chang. Biol. 4, 229–233.

Seyfried, MS, Wilcox, BP, 2006. Soil water storage and rooting depth: key factors controlling recharge on rangelands. Hydrol. Process. 20, 3261–3275.

Shaner, DL, O'Conner, SL, 1991. The imidazolinone herbicides. CRC Press, Boca Raton, FL, USA.

Sheley, RL, Half, ML, 2006. Enhancing native forb establishment and persistence using a rich seed mixture. Restor. Ecol. 14, 627–635.

Sheley, RL, Bingham, BS, Davies, KW, 2012. Rehabilitating medusahead *(Taeniatherum caput-medusae)* infested rangeland using a single-entry approach. Weed Sci. 60, 612–617.

Sheley, RL, Jacobs, JS, Velagala, RP, 1999. Enhancing intermediate wheatgrass establishment in spotted knapweed infested rangeland. J. Range Manag. 52, 68–74.

Sheley, RL, Mangold, JM, Anderson, JL, 2006. Potential for successional theory to guide restoration of invasive-plant dominated rangeland. Ecol. Monogr. 76, 365–379.

Sheley, RL, Svejcar, TJ, Maxwell, BD, 1996. A theoretical framework for developing successional weed management strategies on rangeland. Weed Technol. 10, 766–773.

Shiflet, TN, 1994. Rangeland cover types of the United States. Society for Range Management, Denver, CO, USA 152 pp.

Shown, LM, Miller, RF, Branson, FA, 1969. Sagebrush conversion to grassland as affected by precipitation, soil, and cultural practices. J. Range Manag. 22, 303–311.

Singh, T, 1969. Infiltration and soil stability of a summer range. J. Range Manag. 22, 123–128.

Slayback, RD, Renney, CW, 1972. Intermediate pits reduce gamble in range seeding in the Southwest. J. Range Manag. 25, 224–227.

Sperow, M, Eve, M, Paustian, K, 2003. Potential soil C sequestration on US agricultural soils. Clim. Chang. 57, 319–339.

Steers, RJ, Funk, JL, Allen, EB, 2011. Can resource-use traits predict native vs. exotic plant success in carbon amended soils? Ecol. Appl. 21, 1211–1224.

Stewart, G, 1950. Reseeding research in the Intermountain Region. J. Range Manag. 3, 52–59.

Stoddard, MT, Huffman, DW, Alcoze, TM, Fule, PZ, 2008. Effects of slash on herbaceous communities in pinyon-juniper woodlands of northern Arizona. Rangel. Ecol. Manag. 61, 485–495.

Stoddart, LA, Smith, AD, 1955. Range management. McGraw-Hill, New York, NY, USA 433 pp.

Stroh, JR, Sundberg, VP, 1971. Emergence of grass seedlings under crop residue culture. J. Range Manag. 24, 226–230.

Stubbendieck, J, Koshi, PT, McCully, WG, 1973. Establishment and growth of selected grasses. J. Range Manag. 26, 39–41.

Stuth, JW, Dahl, BE, 1974. Evaluation of rangeland seedings following mechanical brush control in Texas. J. Range Manag. 27, 146–149.

Suyker, AE, Verma, SB, 2001. Year-round observations of the net ecosystem exchange of carbon dioxide in a native tallgrass prairie. Glob. Chang. Biol. 7, 279–289.

Svejcar, T, Angell, R, Bradford, JA, Dugas, W, Emmerich, W, Frank, AB, Gilmanov, T, Haferkamp, M, Johnson, DA, Mayeux, H, Mielnick, P, Morgan, J, Saliendra, NZ, Schuman, GE, Sims, PL, Snyder, K, 2008. Carbon fluxes on North American rangelands. Rangel. Ecol. Manag. 61, 465–474.

Takar, AA, Dobrowolski, JP, Thurow, TL, 1990. Influence of grazing, vegetation life-form, and soil type on infiltration rates and interrill erosion on a Somalian rangeland. J. Range Manag. 43, 486–490.

Thompson, TW, Roundy, BA, McArthur, ED, Jessop, BD, Waldron, B, Davis, JN, 2006. Fire rehabilitation using native and introduced species: a landscape trial. Rangel. Ecol. Manag. 59, 237–248.

Thurow, TL, Blackburn, WH, Warren, SD, Taylor, CA, 1987. Rainfall interception by midgrass, shortgrass, and live oak mottes. J. Range Manag. 40, 455–460.

Traba, J, Azcarate, FM, Peco, B, 2004. From what depth do seeds emerge? A soil seed bank experiment with Mediterranean grassland species. Seed Sci. Res. 14, 297–303.

Traba, J, Levassor, C, Peco, B, 2003. Restoration of species richness in abandoned Mediterranean grasslands: seeds in cattle dung. Restor. Ecol. 11, 378–384.

Tranel, PJ, Wright, TR, 2002. Resistance of weeds to ALS-inhibiting herbicides: what have we learned? Weed Sci. 50, 700–712.

Tromble, JM, Renard, KG, Thatcher, AP, 1974. Infiltration for three rangeland soil-vegetation complexes. J. Range Manag. 27, 318–321.

Vallentine, JF, 1979. Range development and improvements. second ed. Brigham Young University Press, Provo, UT, USA 545 pp.

Vargas, M, Crossa, J, Van Eeuwijk, F, Sayre, KD, Reynolds, MP, 2001. Interpreting treatment X environment interaction in agronomy trials. Agron. J. 93, 949–960.

Vogel, KP, 1987. Seeding rates for establishing big bluestem and switchgrass with preemergence atrazine applications. Agron. J. 79, 509–512.

Vogel, KP, Schmer, MR, Mitchell, RB, 2005. Plant adaptation regions: ecological and climatic classification of plant materials. Rangel. Ecol. Manag. 58, 315–319.

Vogel, WG, 1963. Planting depth and seed size influence emergence of beardless wheatgrass seedlings. J. Range Manag. 16, 273–275.

Weltz, MA, Blackburn, WH, 1995. Water budget for south Texas rangelands. J. Range Manag. 48, 45–52.

Westoby, M, Walker, B, Noy-Meir, I, 1989. Opportunistic management for rangelands not at equilibrium. J. Range Manag. 42, 266–274.

Whisenant, SG, 1999. Repairing damaged wildlands: a process-oriented, landscape-scale approach. Cambridge University Press, Cambridge, UK 312 pp.

Wiedemann, HT, Cross, BT, 2000. Disk chain effects on seeded grass establishment. J. Range Manag. 53, 62–67.

Wilcox, BP, 2002. Shrub control and streamflow on rangelands: a process based viewpoint. J. Range Manag. 55, 318–326.

Wilcox, BP, Thurow, TL, 2006. Emerging issues in rangeland ecohydrology: vegetation change and the water cycle. Rangel. Ecol. Manag. 59, 220–224.

Wilcox, BP, Breshears, DD, Allen, CD, 2003. Ecohydrology of a resource-conserving semiarid woodland: effects of scale and disturbance. Ecol. Monogr. 73, 223–239.

Williams, MI, Schuman, GE, Hild, AL, Vicklund, LE, 2002. Wyoming big sagebrush density: effects of seeding rates and grass competition. Restor. Ecol. 10, 385–391.

Winkel, VK, Roundy, BA, 1991. Effects of cattle trampling and mechanical seedbed preparation on grass seedling emergence. J. Range Manag. 44, 176–180.

Winkel, VK, Roundy, BA, Blough, DK, 1991a. Effects of seedbed preparation and cattle trampling on burial of grass seeds. J. Range Manag. 44, 171–175.

Winkel, VK, Roundy, BA, Cox, JR, 1991b. Influence of seedbed microsite characteristics on grass seedling emergence. J. Range Manag. 44, 210–214.

Wood, MK, Eckert, RE, Blackburn, WH, Peterson, FF, 1982. Influence of crusting soil surfaces on emergence and establishment of crested wheatgrass, squirreltail, Thurber needlegrass and fourwing saltbush. J. Range Manag. 35, 282–287.

Workman, JP, Tanaka, JA, 1991. Economic feasibility and management considerations in range revegetation. J. Range Manag. 44, 566–573.

Wright, HA, Churchill, FM, Stevens, WC, 1982. Soil loss, runoff, and water quality of seeded and unseeded steep watersheds following prescribed burning. J. Range Manag. 35, 382–385.

Xu, LK, Baldocchi, DD, 2004. Seasonal variation in carbon dioxide exchange over a Mediterranean annual grassland in California. Agric. For. Meteorol. 123, 79–96.

Yoder, CK, Boutton, TW, Thurow, TL, Midwood, AJ, 1998. Differences in soil water use by annual broomweed and grasses. J. Range Manag. 51, 200–206.

Young, JA, Longland, WS, 1996. Impact of alien plants on Grant Basin rangelands. Weed Technol. 10, 384–391.

Young, JA, Blank, RR, Longland, WS, Palmquist, DE, 1994. Seeding Indian ricegrass in an arid environment in the Great Basin. J. Range Manag. 47, 2–7.

Young, JA, Evans, RA, Palmquist, D, 1990. Soil surface characteristics and emergence of big sagebrush seedlings. J. Range Manag. 43, 358–367.

Young, KR, Roundy, BA, Eggett, DL, 2013. Plant establishment in masticated Utah juniper woodlands. Rangel. Ecol. Manag. 56, 597–607.

Zhang, L, Wylie, BK, Ji, L, Gilmanov, TG, Tieszen, LL, 2010. Climate-driven interannual variability in net ecosystem exchange in the northern Great Plains grasslands. Rangel. Ecol. Manag. 63, 40–50.

Ziegler, AD, Giambelluca, TW, 1998. Influence of revegetation efforts on hydrologic response and erosion, Kaho'olawe Island, Hawai'i. Land Degrad. Dev. 9, 189–206.