CHAPTER

4

Assessment of Range Planting as a Conservation Practice

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INTRODUCTION

The Range Planting Conservation Practice Standard is used to inform development of Natural Resource Conservation Service (NRCS) management recommendations for improving vegetation composition and productivity of grazed plant communities. Range planting recommendations are generally implemented within an integrated conservation management system in conjunction with related conservation practices such as brush management, prescribed burning, prescribed grazing, herbaceous weed control, and upland wildlife habitat management. The Range Planting Standard is defined as "establishment of adapted perennial or self-sustaining vegetation such as grasses, forbs, legumes, shrubs and trees." The six specific purposes of this standard are to:

- Restore a plant community similar to the Ecological Site Description reference state for the site or the desired plant community.
- Provide or improve forages for livestock.
- Provide or improve forage, browse, or cover for wildlife.
- Reduce erosion by wind and/or water.
- Improve water quality and quantity.
- Increase carbon sequestration

Additional conservation effects associated with related conservation practices include reduction of negative weed impacts and reduction of wildfire hazard. Range planting conservation practices apply where desirable vegetation is below the acceptable level for natural reseeding to occur, or where the potential for vegetation enhancement by grazing management is not satisfactory.

Range planting was implemented on 517 000 ha of grazing land in the 17 conterminous western states in the 5-yr period, 2004–2008. This is a relatively small area compared to implementation of some other conservation practices within the region over the same period: prescribed grazing, 31 360 000 ha; upland wildlife habitat management, 19 166 000 ha; herbaceous weed control, 7 603 000 ha; brush management, 1 457 000 ha; and prescribed burning, 371 000 ha. Conservation cover, a closely related conservation practice for reducing erosion on retired cropland as part of the Conservation Reserve Program (Young and Osborn 1990), was implemented on over 1 600 000 ha during the same period.

Rangeland drill used for site preparation and seed placement. (Photo: USFS, 2006)

Site-specific conservation management plans are developed for areas where existing plant community attributes are insufficient to meet management goals for productivity or species composition, and where natural recovery toward a more desirable state is not expected. The goal of a conservation management plan is to transition an existing undesirable plant community to a more desirable state. It is assumed that successful implementation of this change in state will be associated with specific conservation effects.

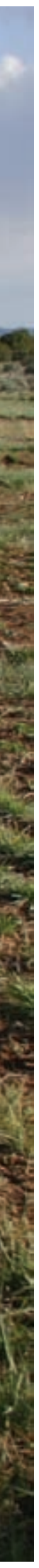
The National Standard for range planting is usually modified at the state level with specific recommendations of regional or local relevance. State standards, however, retain the same general guidance, and usually vary only in the degree to which they include more detailed recommendations extracted from region-specific NRCS technical notes and seeding guides. Recommendations for the following management elements are common to both the national and state range planting standards: selection of appropriate plant materials,

USDA-ARS Plant material selection trials, Beaver, UT (Photo: Craig Rigby, 2009)

seed-bed preparation, planting methods, seeding depth, seeding rate, time of seeding, postplanting management, and weed control.

The spatial domain of interest in this evidence-based assessment includes rangeland systems in the Great Plains, Intermountain West, southwestern desert, and interior-California hydroclimatic zones (Barbour and Billings 2000). These areas are characterized by different vegetation types, management priorities, and climatic syndromes that also vary internally along both latitudinal and elevational gradients (Natural Resources Conservation Service 2006). Range planting issues common to all areas are a generally arid or semiarid climatology, and high annual and seasonal variability in weather and climate. These areas are also commonly under pressure from highly competitive annual and perennial weeds or expanding populations of native woody plants.

The success of specific conservation practice recommendations and the potential ecological outcomes realized are both highly dependent upon 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. An important implication of this high variability, in both initial establishment and later-seral processes, is that virtually no direct experimental evidence exists to link specific range planting conservation practices to conservation effects *per se*. The linkage is instead derived indirectly through evidence of



the degree to which specific planting techniques have been shown to produce successful plant establishment, and evidence supporting the positive conservation effects of alternative vegetation states. We have, therefore, separated our assessment of the conservation effects of rangeland planting practices into two components: assessment of the direct benefits of specific planting techniques recommended in the range planting standard, and assessment of specific conservation effects of alternative vegetation states. The assessment of rangeland planting techniques involved a survey of 189 range planting studies from the refereed journal literature. These studies were classified as to bioclimatic zone, initial plant community and type of disturbance, plant materials and seed-mix characteristics, seeding rate, site preparation and weed control methodology, planting depth, planting season, experimental design, weather, and relative success criteria. Summary statistics cited in this synthesis were derived from the survey.

ASSESSMENT OF THE DIRECT BENEFITS OF RANGE PLANTING PRACTICES

The range planting standard specifically requires 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, but also the suitability of introduced plant materials (Shown et al. 1969; Shiflet 1994; Vogel et al. 2005; Natural Resources Conservation Service 2006). 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 (Roundy and Call 1988; Call and Roundy 1991; Sheley et al. 1996; Krueger-Mangold et al. 2006; Sheley et al. 2006).

A major problem with synthesizing range planting research results is the high variability in metrics used to evaluate success. Relatively few authors have directly evaluated alternative criteria for quantification of success (Ries and Svejcar 1991). The majority of range planting studies use arbitrary, relative criteria for judging success, and only consider planting-year or first-year effects. Typical criteria for evaluating success generally involve measurements or ocular estimates of density, frequency, cover, and/or biomass.

SELECTION OF PLANT MATERIALS

Climatic Considerations

Weather and climate patterns in western North America are highly variable in space and time (Rajagopalan and Lall 1998). The relationship between climate and both vegetation distribution and production on western rangelands is well documented (Barbour and Billings 2000; Natural Resources Conservation Service 2006). 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). Seeding guides may also cite climatic thresholds below which active seeding practices are not recommended (Anderson et al. 1957; Jordan, 1981). Unfortunately, the microclimatic requirements for germination, emergence, and seedling establishment are much more restrictive than the longer-term climatic requirements for maintenance of mature plant communities (Call and Roundy 1991; Peters 2000; Hardegree et al. 2003). Current state-and-transition models acknowledge that there are perhaps a limited set of potential trajectories for moving between undesirable and desirable vegetation states (Westoby et al. 1989; Batabyal and Godfrey 2002; Bestelmeyer et al. 2003; Briske et al. 2003, 2005, 2006, 2008; Bashari et al. 2008). Westoby et al. (1989) noted that many transition pathways between alternative states require the occurrence of a specific and perhaps infrequent series of climatic events.

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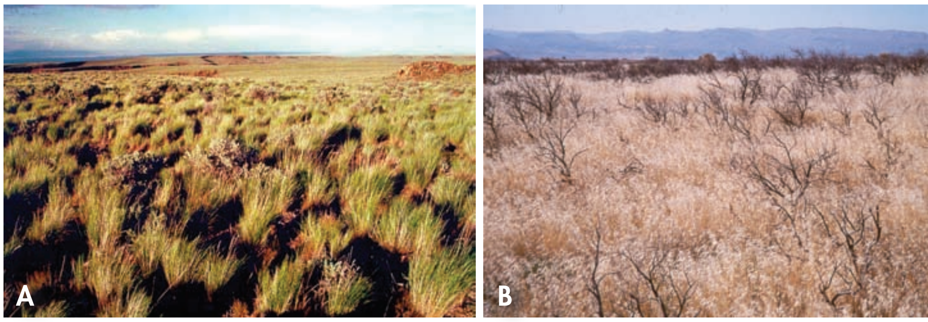

A Native sagebrush/bunchgrass plant community at Jacks Creek in southwestern Idaho (Photo: USFS) **B** Cheatgrass dominated site in southern Idaho after wildfire (Photo: USFS)

“…successful establishment was frequently associated with average or above-average precipitation for either the entire year, or during the season of establishment.”

The range planting literature is somewhat biased relative to inferences that can be drawn from plant-material/climate interactions. Less than 60% of the studies reviewed for this synthesis reported weather conditions during the study, and less than half of these studies were replicated for year effects. In studies that reported weather conditions, successful establishment was almost always associated with average or above-average precipitation for either the entire year, or during the season of establishment. This implies that climatic thresholds exist below which management actions have little effect on establishment success. These thresholds may vary for species with different establishment requirements, but previous studies have not been designed to test this hypothesis specifically.

The strongest evidence for plant-material suitability for a given climatic region is derived from observation of historical relationships between species and climate, experience-based observation, and long-term assessment of persistence of planted species (Harris and Dobrowolski 1986; Shiflet 1994; Barbour and Billings 2000; Natural Resources Conservation Service 2006).

Plant-Material Development

NRCS has developed relatively specific and detailed recommendations for suitability of plant materials for different site conditions, climatic zones, and management objectives (Ogle et al. 2008a, 2008b). 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 (Hafenrichter 1948; Stewart 1950; Harlan 1951; Schwendiman 1956; Anderson et al. 1957; Schwendiman 1958; Harlan 1960; Roundy and Call 1988; Alderson and Sharp 1994; Asay et al. 2003; Erickson et al. 2004). Selected or bred plant materials deemed to have superior productivity, vigor, establishment, disease resistance and/or seed-production characteristics are then cultivated and released for development as commercial varieties (Schwendiman 1958; Johnson and Asay 1995; Asay et al. 2003). The more recent efforts in plant-material development and evaluation focus on selection for, or comparison of, specific ecological and physiological traits (Aguirre and Johnson 1991b; Johnson and Asay 1995; Arredondo et al. 1998; Jensen et al. 2005). These efforts incorporate and report more detailed experimental design information, but are often based on relatively controlled experimental conditions in the laboratory, greenhouse, or an agricultural field environment (Arredondo et al. 1998; Jones et al. 2003). The majority of current plant-material recommendations are based on evaluations of field performance that are not accessible through refereed journal publications (Stewart 1950; Schwendiman 1956; Great Plains Council 1966; Jensen et al. 2001; Lambert 2005; Ogle et al. 2008a, 2008b).

The literature documenting management-scale range planting is dominated by studies in which few inferences can be made about relative performance of different species and seed sources (Casler 1999). Very few studies are replicated in such a way that within- or between-species variability can be assessed (Kneebone and Cremer 1956; Pitman and Jaymes 1980; Asay and Johnson 1983b; Rumbaugh and Johnson 1986; Burner et al. 1988; Asay and Johnson 1990; Kitchen and Monsen 1994; Asay et al. 1996; Casler 1999; Asay et al. 2001; Vogel and Jensen 2001; Jones et al. 2003; Robins et al. 2007). About 60% of the rangeland planting studies surveyed for this synthesis evaluated performance of either a single seed lot, or a unique seed mix. In studies that evaluated more than one seed lot of a given species, only 6% were replicated at the seed-lot level.

Seed Quality

Seed-quality recommendations for range planting conservation practices are generally limited to those concerning germination testing, and the calculation of seeding rates based on estimates of pure live seed (PLS). Seed quality, however, has been evaluated in a number of studies that have correlated seed size and other morphological attributes to seedling emergence, growth rate, nutrient utilization, and seedling morphology and yield (Trupp and Carlson 1971; Carren et al. 1987a, 1987b; Limbach and Call 1995a, 1996; Smith et al. 2003).

Recurrent selection for increased seed size, deep-seeding emergence, or rapid seedling growth can result in plant materials with improved stand establishment. McKell (1972) and Kneebone (1972) recommended selection for seed mass to improve seedling vigor and establishment. McKell (1972) also emphasized the importance of rapid germination and pointed out that this is often a characteristic of weedy opportunistic grasses. Kneebone (1972) asserted that seed mass is highly heritable, and thus is a trait that will often be responsive to selection.

For cross-pollinated species, genetic manipulation through artificial selection or hybridization may be used to develop plant materials that increase the likelihood of seeding success. Kneebone (1972) suggested selection for high seed mass with hand screens, air columns, or gravity tables. This may be combined with selection for rapid germination under stress conditions, coleoptile length, and deep-seeding emergence. Large numbers of seeds and seedlings can be easily screened, a feature that lends itself to genetic improvement. This type of genetic manipulation is unsuitable for self-pollinated species where natural outcrossing and within-population genetic diversity is limited.

Seedbed Preparation and Planting Methods

The following conservation practice recommendations are directly or indirectly related to microclimatic management of the seed bed: surface soil modification, microsite improvement, seeding depth, seeding rate, timing of seeding, and weed control. Seedbed microsite improvement can consist of operations designed to reduce water loss and/or adverse thermal conditions in the seed zone by improving infiltration into the soil, improving water availability to the seed, reducing water loss to the atmosphere or reducing plant competition for water. This is accomplished through initial mechanical disturbance, soil firming and surface modification, control of seeding depth, application of soil surface amendments, and weed control (Roundy and Call 1988; Sheley et al. 1996).

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 by creating specific microsites that either receive or retain water more effectively (McGinnies 1959; Roundy et al. 1992). In some situations, cultivation without surface firming can increase the

A Seedbed disturbance caused by a rangeland drill (USFS, 2008) **B** Seedbed disturbance caused by a low-till drill (USFS, 2008) **C** Seedbed disturbance caused by a brillion cultipacker (Photo: Alex Boehm, 2009)

“Specific seedbed treatments to conserve water may not have much effect on establishment success in very wet or very dry years”

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). 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 range planting literature does not separate out treatment effects of soil-firming procedures, which are usually performed in conjunction with specific cultivation and planting procedures (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). 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 (Hyder et al. 1955; Hyder and Sneva 1956; McGinnies 1959, 1962; Houston 1965; Haferkamp et al. 1987; Roundy et al. 1990; Winkel and Roundy 1991; Winkel et al. 1991a; Roundy et al. 1992; Ethridge et al. 1997). 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; Ocumpaugh et al. 1996; Auman et al. 1998; Traba et al. 2003; Gokbulak and Call 2004). Differential establishment success relative to position of soil surface features has been reported, and is generally attributed to differences in 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 have also been noted 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 beyond establishment depth (Hyder and Sneva 1956; Kincaid and Williams 1966; McGinnies 1972; Slayback and Renney 1972; Winkel et al. 1991a). Positive effects of these surface features 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 seed-bed preparation technique (McGinnies 1968; Stuth and Dahl 1974; Wood et al. 1982; Eckert et al. 1986; Roundy et al. 1990; Winkel and Roundy 1991; Roundy et al. 1992; Romo and Grilz 2002).

Mulch Application

Application of mulch to improve range seeding success 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). Relatively expensive soil surface amendments such as mulch are generally applied only after high-impact disturbance such as mine reclamation, or for mitigation of erosion after wildfire on topographically complex terrain (Jacoby 1969; Meyer et al. 1970; Lavin et al. 1981; Pinchak et al. 1985; Schuman et al. 1985; McGinnies 1987; Schuman et al. 1998; Whisenant 1999; Kruse et al. 2004; Groen and Woods 2008). An exception may be mulch production as a byproduct of mechanical shredding for control of juniper and other woody species (Brockway et al. 2002). 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 on rangelands is derived from greenhouse, laboratory, and modeling studies, all of which confirm general benefits of water conservation and mitigation of high temperature near the soil surface as a function of relative coverage (Hopkins 1954; Bond and Willis 1970; Chung and Horton 1987; Bristow and Abrecht 1989; Jalota 1993; Brar and Unger 1994; Bussiere and Cellier 1994; Gill and Jalota 1996; Novak et al. 2000a, 2000b, 2000c; Giminez and Govers 2008), and field studies, most of which have been conducted after tillage or on severely disturbed, or otherwise extreme, sites (Dudeck et al. 1970; Meyer et al. 1970; Stubbendieck et al. 1973; Schuman et al. 1985; Hart and Dean 1986; Ethridge et al. 1997; Ji and Unger 2001; Dahiya et al. 2007; Groen and Woods 2008). Water conservation associated with mulch application on range seeding success 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). For the 21 studies surveyed for this review that specifically evaluated mulch treatments, 62% concluded that mulch application improved establishment success. Regardless of the variable effects of mulch on seeding success, application of mulch for effective erosion control and soil stabilization is well documented (Meyer et al. 1970; Bautista et al. 1996; Fulbright et al. 2006; Groen and Woods 2008).

Seeding Depth

Successful germination and establishment is dependent upon placement of seeds in favorable soil microsites (Hyder et al. 1955; Harper et al. 1965; Young et al. 1990; Call and Roundy 1991; Winkel and Roundy 1991, Winkel et al. 1991b; Roundy et al. 1992; Chambers and MacMahon 1994; Sheley et al. 1996; Ott et al. 2003). A major assumption of many site-preparation treatments is that they increase the number of potential safe sites for germination and establishment either by covering the seed, by reducing soil water loss from around the seed, or by redistributing and concentrating resources (Anderson and Swanson 1949; Hubbard and Smoliak 1953).

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 are based on rules of thumb regarding seeding depth as a function of seed size (Hull and Holmgren 1964; Plummer et al. 1968; Jordan 1981; Roundy and Call 1988; Jensen et al. 2001; Monsen and Stevens 2004; Lambert 2005; Ogle et al. 2008a, 2008b). 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 (Roundy and Call 1988; Call and Roundy 1991). 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).

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). A major exception is for studies comparing the relative establishment of broadcast versus planted seeds. Of the 23 field studies surveyed for this review that specifically compared broadcast versus drill seeding, 73% concluded that drill seeding outperformed broadcast seeding. These studies, however, did not generally include quantification of


Brillion wheel for pressing broadcast seeds into the soil (Photo: USFS, 2006)

Standard 1X seeding rate of 247 seeds/m^2 or 23 seeds/ft^2 in a 0.25-m^2 frame (left). Middle frame shows a 2X seed rate and right frame shows a 5X seed rate (Photo: Alex Boehm, 2011)

the specific depth distribution after planting (Stewart 1950; Hyder et al. 1955; Douglas et al. 1960; Gomm 1964; Bement et al. 1965; Statler 1967; Shown et al. 1969; Nelson et al. 1970; McGinnies 1972; Drawe et al. 1975; Wood et al. 1982; Haferkamp et al. 1987; Ott et al. 2003). Relative seeding depth in field studies is often reported 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 postplanting (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). 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. Broadcast seeding rates are generally recommended at two to three times the rates for seed that can be incorporated into the soil (Stewart 1950; Hyder et al. 1955; Douglas et al. 1960; Gomm 1964; Bement et al. 1965; Statler 1967; Shown et al. 1969; Nelson et al. 1970; McGinnies 1972; Drawe et al. 1975; Wood et al. 1982; Haferkamp et al. 1987; Ott et al. 2003).

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 two–five 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). 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 (Harper et al. 1965; Call and Roundy 1991; Roundy et al. 1992; Chambers 1995). 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 (Schultz and Biswell 1952; Mueggler and Blaisdell 1955; Hull and Holmgren 1964; Launchbaugh and Owensby 1970; Hull 1972a, 1974b; Papanastasis and Biswell 1975; Vogel 1987; Masters 1997; McMurray et al. 1997; Williams et al. 2002). 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). Seeding-rate impacts remain highly dependent upon threshold requirements for water availability in the early stages of establishment, and individual seedling growth can be negatively impacted by both inter- and intraspecific competition later in development. The majority of the literature pertaining to seeding-rate effects is derived either from 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). Eisworth 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 nonnative 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.

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 require getting the seed planted in time to take advantage of the most favorable season for plant establishment (Hull 1948; Stoddart and Smith 1955; Plummer et al. 1968; McGinnies 1972; Vallentine 1979; Jordan, 1981; Roundy and Call 1988; Ries and Hofmann 1996; Monsen and Stevens 2004; Stevens 2004). In some cases, dormant-fall seeding is recommended well in advance of the optimal growing season to take advantage of all opportunities for potential establishment in a highly variable, and often arid or semiarid environment (Hull 1948; Stewart 1950; Douglas et al. 1960; Plummer et al. 1968; Young et al. 1969b; Nelson et al. 1970; Klomp and Hull 1972; Hart and Dean 1986; Young et al. 1994; Monsen and Stevens 2004). Dormant-fall seeding is also recommended when there are logistical concerns for use of mechanical equipment during wet-spring planting conditions, or to mitigate effects of unpredictable spring weather (Stewart 1950; Douglas et al. 1960; McGinnies 1973; Hart and Dean 1986). 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 1972a; Klomp and Hull 1972). 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 1972a; 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; Currie 1967; Lavin et al. 1973; Hull 1974a, 1974b). Postplanting microclimate must be favorable for growth, but 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

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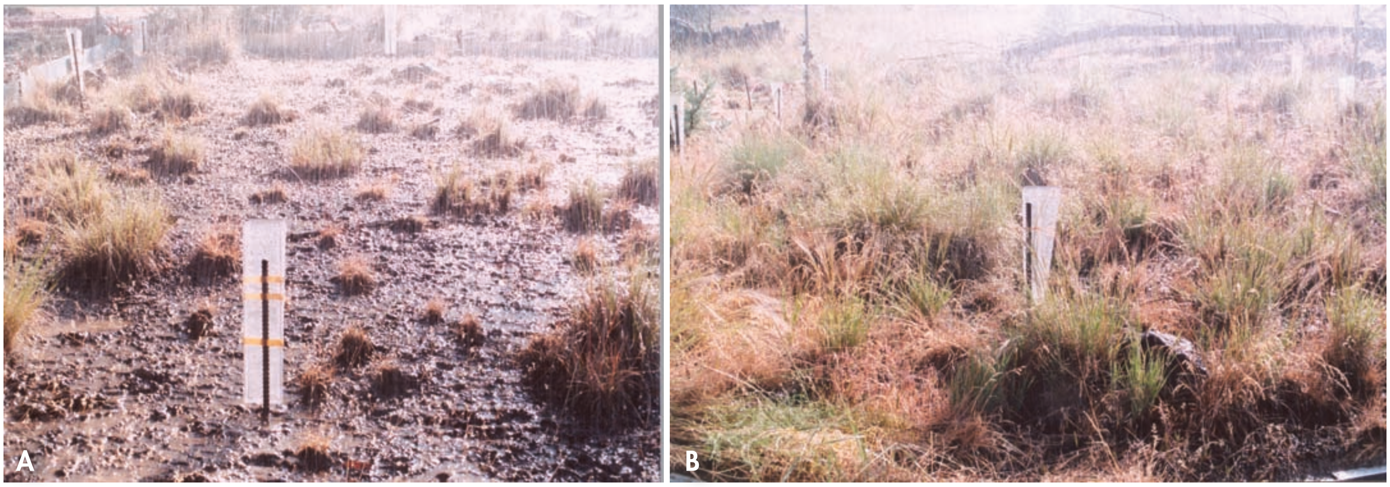
benefits of fall/winter-dormant seeding on intermountain rangelands in Nevada with the use of meta-analysis of long-term Bureau of Land Management fire-rehabilitation monitoring data. Very few experimental studies of seeding-season effects are replicated in more than 1 or 2 yr (Hull 1948; Douglas et al. 1960; Robocker et al. 1965; Hull 1974b; Ries and Hofmann 1996). Fall-dormant planting, however, was found to be superior to spring planting in 73% of Great Basin studies where planting season was evaluated.

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, prior to the early stages of establishment, are generally required for establishment success of both native and nonnative 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). Of 52 studies surveyed for this review that included mechanical or chemical weed control, all but two concluded that weed control was either necessary, or at least beneficial to successful establishment. Efficacy of alternative mechanical and chemical weed control treatments is more extensively discussed elsewhere in this volume (Sheley et al., this volume).

NRCS TECHNICAL RECOMMENDATIONS AND THE RANGE PLANTING LITERATURE

General management recommendations, and associated NRCS technical references (e.g., Ogle et al. 2008a, 2008b), are consistent with current rangeland planting technical guidance and authorities (Vallentine 1979; Jordan 1981; Sours 1983; Redente and DePuit 1988; Roundy and Call 1988; Roundy 1996; Sheley et al. 1996; Whisenant 1999; Jensen et al. 2001; Monsen and Stevens 2004; Stevens 2004; Sheley et al. 2006). These recommendations and guidelines do not fundamentally differ from earlier-cited works that predate current standards for hypothesis testing, statistical inference, and experimental design norms (Stoddart and Smith 1943; Stewart 1950; Stoddart and Smith 1955; Anderson et al. 1957; Plummer et al. 1968; Vallentine 1979). Many of the historical references used to justify range planting practices, however, come from Agricultural Experiment Station reports, internal agency documents, and syntheses of unpublished field trials, as opposed to the refereed literature (McGinnies et al. 1963; Great Plains Council 1966; Plummer et al. 1968; Gomm, 1974; Cox et al. 1984; Call and Roundy 1991). With the exception of some specific plant-material selection and development programs, the underlying principles of these earlier recommendations were primarily based on previously established agricultural concepts, and a probabilistic assessment of best management practices derived from the practical experience and



A High erosion potential for soil surface with low plant cover caused by competition with western juniper. **B** Low erosion potential for soil surface with high plant cover after removal of woody-plant competition (Photo: Fred Pierson, 2003) personal observations of land management professionals. The scientific literature from the more recent 40–50 yr has attempted to refine and to validate these commonly recommended practices experimentally. The more recent literature, however, is dominated by empirical studies that provide examples of field success for specific planting techniques, but, individually, are insufficiently replicated for general inferences (Call and Roundy 1991). We therefore surveyed 189 range planting field studies to draw the following general inferences regarding assumptions inherent to current seeding technical references, and range planting conservation practice documents:

- General recommendations supported by the aggregate literature must be prefaced by an acknowledgement that climatic conditions during the establishment year must be favorable. Ninety percent of the range planting papers surveyed report at least one successful treatment. Of the 57% that reported climatic conditions during the study, however, 89% claimed average or above-average precipitation in the year of establishment for the successful treatments. Over half of the studies that report successful establishment in a below-average precipitation year note that the seasonal distribution of precipitation was favorable during early seedling development.
- Few inferences can be made from the range planting literature about the relative establishment characteristics of alternative plant materials. Very few studies are designed and replicated in such a way that within- or between-species variability can be assessed. Over 35% of studies evaluated used only one seed lot or a unique seed mix, and 24% compared relative establishment among unique seed mixes. Of the 86 studies in which more than one seed lot of the same species were evaluated, only 6% were fully replicated, and 19% were partially replicated at the species level. Almost half of the studies used at least some named varieties, but only four specifically evaluated within-species variability. The strongest evidence for plant materials suitability is derived from observation of historical relationships between species and climate, experience-based observation, long-term assessment of persistence of planted species, and field trials conducted during the process of plant-materials selection and development.
- General conservation practice recommendations regarding site preparation and seeding methodology are generally supported from the aggregate literature. Drill-seeding treatments outperformed broadcast-seeding treatments in 73% of the studies that included a direct comparison. Application of mulch improved establishment success in 62% of the studies where there was a direct comparison. Increasing seeding rate was found to improve establishment success in 79% of the 24 studies where this was directly tested. Of the 52 studies that included mechanical or chemical weed control treatments, all but 2 concluded that weed control was either necessary or at least beneficial to successful establishment. Fall-dormant planting was determined to be superior to spring planting in 73% of the Great Basin studies where planting season was evaluated. Seedbed preparation, seeding depth, planting season, and seeding-rate recommendations may be irrelevant in very dry and perhaps very wet years.
- The majority of range planting field studies are unreplicated in either space or time. Only 47% replicate planting years and 41% replicate site locations. The predominant form of treatment replication was within site, with 69% of studies having at least two, and 61% having at least three, within-site treatment replicates. Meta-analysis of studies that are individually underreplicated for general inferences is hampered by the fact that negative results are usually not published, and plant-materials selection is often based on *a priori* assumptions about their suitability for a given location.

> “There is virtually no experimental evidence directly linking rangeland seeding to conservation effects.”

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 Conservation Practices section of this

> Application of mulch to improve range planting success is probably not cost effective for most rangeland applications ”

chapter. The literature supports the concept that seeding, if successful, results in positive conservation effects. There is virtually no literature, 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, because these conservation effects are not specifically addressed in the other chapters in this volume. Conservation effects related to livestock and wildlife needs, weed proliferation, and fire are left to the chapters in this volume concerning prescribed grazing, upland wildlife habitat management, herbaceous weed control, and prescribed burning.

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). 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). 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). 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 (Williams et al. 1969; Gifford 1972, 1973; Tromble 1976; Roundy et al. 1978; Tromble 1980; Brown et al. 1985; Benavides-Solorio and Macdonald 2001; Gimeno-Garcia et al. 2007; Grismer 2007; Pierson et al. 2007). In most cases, the nature of this cover is less relevant than the issue of soil surface protection above some threshold level (Mergen et al. 2001; Aguilera et al. 2003; Descheemaeker et al. 2006). Some studies, however, have shown differential hydrologic effects under adjacent plant communities due to differences in growth and litter production, interception, water-use efficiency, or rooting depth and spread (Dunkerley 2002; Bhark and Small 2003; Kulmatiski et al. 2006). 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). 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. 2007; 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; Wilcox and Thurow 2006; Pierson et al. 2007). 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). Indeed, the primary objective of most fire-rehabilitation seeding practices is to improve soil stability and reduce erosion (Richards et al. 1998; Bureau of Land Management 1999; Beyers 2004; 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 (Meyer et al. 1970; Gifford 1975; Knight et al. 1983; Bautista et al. 1996; Brockway et al. 2002; Benik et al. 2003; Grismer and Hogan 2004, 2005; Fulbright et al. 2006; Groen and Woods 2008).

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 available water in the soil profile in most years (Wright and Dobrenz 1973; Cable 1980; Trlica and Biondini 1990; Dugas and Mayeux 1991; Weltz and Blackburn 1995; Hester et al. 1997; Wilcox 2002; Huxman et al. 2005; Wilcox and Thurow 2006). 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 the woody plant material has access to groundwater (Hill and Rice 1963; Hibbert 1983; Wilcox 2002; Huxman et al. 2005; 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. 2007).

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; Follet and Schuman 2005; Hastings et al. 2005; Derner and Schuman 2007; Svejcar et al. 2008). 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). 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. 2003). Restoration of severely disturbed rangeland, and activities such as mine reclamation, can significantly improve carbon-sequestration rates (Follet 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), 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 been invaded by introduced annual weeds such as cheatgrass (*Bromus tectorum* L.). Cheatgrass-dominated systems are characterized by frequent recurrence of wildfire and are resistant to management actions that are designed to return them to a more desirable ecological state (Brandt and Rickard 1994; Knapp 1996; Young and Longland 1996). Carbon-sequestration rates can be nullified when vegetation is periodically removed by prescribed fire or wildfire (Suyker

> "Current conservation practice standards should include references to more ecologically based technical literature and specific guidance for both monitoring and adaptive management."

“The most useful potential technology for enhancing establishment success lies in development and utilization of relatively long-range weather-forecast technology”

and Verma 2001). Management activities, such as rangeland planting, that result in an increase in forage production can be expected to increase carbon-sequestration rates (Ma et al. 2000; Conant et al. 2001).

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 should include references to more ecologically based technical literature and specific guidance for both monitoring and adaptive management. Additional research needs to be conducted to test the ecological underpinnings of existing and new ecological models for plant community dynamics explicitly, and to develop new tools to take advantage of existing and emerging knowledge of weather variability and anticipated shifts in regional climate. Individual seeding studies are seldom replicated sufficiently to make valid inferences in such a variable field environment. Therefore, monitoring protocols that can facilitate meta-analysis in support of more general inferences need to be developed.

KNOWLEDGE GAPS

Explicit Testing of New Conceptual Models for Dynamic Rangeland Systems

Call and Roundy (1991) recommended changes to the prevailing research approach to address problems inherent in highly variable rangeland systems more directly. A more general scientific understanding of vegetation change may now be achievable with the use of more recently developed conceptual models for understanding dynamic rangeland systems (Westoby et al. 1989; Bestelmeyer et al. 2003; Sheley et al. 2006). NRCS has already adopted some of these paradigms by utilizing state-and-transition-model concepts in the development of Ecological Site Descriptions, but these models do not currently form the basis for 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 and utilized in order to use weather information to inform rangeland planting management decisions (Workman and Tanaka 1991; Peters 2000; Rayner et al. 2005; Andales et al. 2006).

The most useful potential technology for enhancing establishment success lies in development and utilization of relatively long-range weather-forecast technology specific to rangeland planting applications (Barnston et al. 1994, 2005; Garbrecht and Schneider 2007). Long-term 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). Similar technology is in relatively common use for more traditional agricultural applications and for some rangeland applications (Schneider and Garbrecht 2003; Doblas-Reyes et al. 2006; Schneider and Garbrecht 2006; Baigorria et al. 2008; O’Lenic et al. 2008).

Monitoring native planting at the site of the Scooby fire in northern Utah (Photo: USFS, 2010)

Even low-resolution 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 (Bakker et al. 2003; Westoby et al. 1989). 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 nonnative 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 nonnative species. In some years, and on some sites, it may be prudent to plant more easily established nonnative 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

> “Adoption of minimum experimental design standards would facilitate meta-analysis of future range planting studies.”

and Scheffer 2001; Bakker et al. 2003; Hardegree et al. 2003; Cox and Anderson 2004; Hardegree and Van Vactor 2004).

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). 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).

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. 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 prior to release.

For many years, the NRCS and Agricultural Research Service have routinely evaluated released and experimental materials as part of their ongoing plant-material research and development programs. For the rangelands

Wildfire disturbance at the site of the Crowbar fire in south-western Idaho (Photo: USFS, 2010) of the semiarid west, these trials are typically dormant planted in late fall for spring emergence. 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. The single most important trait of these trials is seedling establishment. These trials are typically replicated complete block design experiments subject to statistical analysis, but are usually analyzed as individual experiments rather than as a collective whole. Because these trials are conducted every year, a large volume of data have been collected. More robust comparisons of species and plant materials could be made if these data were compiled and subjected to meta-analysis. A Web-accessible program to update and combine data sets for analysis would greatly increase the statistical power of plant-material evaluations and improve decision making. With the use of additive main and multiplicative interaction (AMMI) statistical models, NRCS PRISM climatic data could be included in the data set to facilitate recommendations that take into consideration environmental parameters.

Direct Conservation Effects of Plant Materials on Nutrient Cycling

Ecosystem disruption commonly results in a shift in nutrient-cycling dynamics from systems where nutrients, such as carbon (C) and nitrogen (N), are quickly sequestered by plants and microorganisms to systems that contain relatively greater amounts of available nutrients (Norton et al. 2007). These systems are more susceptible to weed dominance, leach more mineral N, and sequester less carbon than effectively functioning systems. Although these systems have higher N mineralization rates, soil N concentration is lower (Kulmatiski and Beard 2006). Nutrient-cycling conservation effects could be cited as an additional positive purpose for this conservation practice standard.

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).


Bluebunch wheatgrass seedlings (Photo: Lori Ziegenhagen, 2007)

Success metrics are highly variable and often consist of relative ranking of treatment effects, and there has been very 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 postplanting (Bleak et al. 1965; Hull 1971a, 1973; Lavin and

Standard rangeland drill conducting a native seeding following the East Humboldt fire, Elko Co., NV. (Photo: USFS, 2008)

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, and 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; Adams et al. 1997; Michener 1997; Gurevitch and Hedges 1999; Osenberg et al. 1999a, 1999b; Gurevitch et al. 2001; Johnson 2006). Much of this information may only be suitable for low-level meta-analysis similar to the summary statistics used here 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 Bureau of Land Management data set to evaluate postfire management treatment effects on seeded nonnative 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. Effective utilization of these types of 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.

CONCLUSIONS

There is virtually no refereed journal literature directly linking NRCS rangeland seeding conservation practices to specific conservation effects. The aggregate literature, however, generally supports general conservation practice recommendations for rangeland seeding, and the potential conservation benefits should these practices result in successful establishment of a more desirable plant community. A major limitation to current conservation practice recommendations is that they do not explicitly acknowledge or provide management guidance to deal with the high variability in soil microclimate during germination, emergence, and early seedling development. Additional guidance is warranted to provide recommendations for monitoring and adaptive management in these arid and semiarid rangelands. Future research efforts would also benefit from experimental designs that were amenable to meta-analysis, as inferences from individual rangeland planting trials are generally limited to specific site conditions and plant materials.

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