TECHNICAL NOTE

USDA-Natural Resources Conservation Service

Boise, Idaho

TN PLANT MATERIALS NO. 72 **April 2018**

A REVIEW OF TECHNIQUES AND TECHNOLOGIES FOR IMPROVING SEEDLING ESTABLISHMENT

Derek Tilley, PMC Manager, Aberdeen, Idaho
Adam Fund, Oregon State University, Corvallis, Oregon
Terron Pickett, PMC Agronomist, Aberdeen, Idaho

This Technical Note provides a brief review of several techniques and products that have been used, or are currently under investigation, for improving seedling establishment in rangeland seedings. Mention of a specific product in this technical note does not constitute an endorsement nor does it guarantee the reliability or quality of products.

Introduction

There is an ever-growing demand by the general public, conservation organizations, private landowners, and public land managers to increase the biodiversity of rangeland restoration seedings and to restore rangelands with native plant species, especially native forbs (Richards and others 1998; Shaw and others 2005). Despite progress in developing new technologies and techniques for using native plants to restore disturbed ecosystems, low rates of forb establishment continues to limit the use of expensive forb seed in restoration projects in the Great Basin (Bushman and others 2015). High seed costs, limited commercial seed availability, and low establishment rates are routinely cited as some of the major limitations to the incorporation of native forbs in restoration projects (Rawlins and others 2009; Bushman and others 2015).

Often, seeding failure is the result of highly variable environmental conditions, limited precipitation and soil water availability, and soil fungal pathogens (Crist and Friese 1993; James and others 2011; Gornish and others 2015; Hardegree and others 2016, 2017). Successful restoration in semiarid ecosystems is typically dependent on soil water availability during early plant life stages (Roundy 1985; David 2013; Hardegree and others 2017) with seed germination and seedling growth often cited as the critical stages of plant development leading to the establishment of new individuals in plant communities (Frasier 1989). These early stages of seedling growth are highly susceptible to environmental variability, and require favorable abiotic and biotic soil conditions.

Soil water is paramount for seedling establishment, with higher levels of water alleviating competitive pressures on seeds and seedlings from existing vegetation with more developed root systems (Roundy 1985; Minnick and Alward 2012; Gornish and others 2015). In semiarid ecosystems, precipitation and soil water availability vary widely between and within years, leading to short periods of favorable conditions for plant development (Abbot and Roundy 2003). This is especially important within the semiarid Great Basin where mean annual precipitation ranges from 6 to 16 inches. The seasonality of precipitation also varies, with annual precipitation typically occurring from October through May, in the form of winter and spring precipitation, with little summer precipitation (Bailey 1995).

As precipitation becomes infrequent in the Great Basin with the onset of summer, soil water availability quickly decreases and becomes unavailable for plants to utilize (Roundy 1985). Thus, plant survival during early life stages is dependent upon precipitation frequency and intensity, soil water availability, and the ability of seeds to germinate and physiologically develop as precipitation and soil water decrease. If soil water is available in adequate quantities during early life stages, seedlings often have a much higher rate of establishment and survival. Therefore, restoration techniques that increase or sustain soil water availability during forb life stages in the spring and summer may lead to better restoration outcomes.

Site Preparation

The most important steps in establishing a range seeding are site preparation and proper seeding technique. Site preparation techniques, including chemical and mechanical treatments to control weeds and other plants that might compete for available moisture, are the first step in preparing a site for planting. Failure to adequately reduce weed pressure and competition will nearly always result in stand failure of new seedings.

Seedbed preparation to ensure adequate seed to soil contact is also critical. Seeds that have good contact with soil are less likely to experience widely fluctuating wet-dry cycles because the soil transfers water efficiently to the germinating seed allowing it to grow roots into the deeper soil moisture. Good seedbed preparation provides for seed to soil contact by creating the ideal soil "firmness". When soil is too loose, air in the soil increases the amount of wetting and drying cycles in the soil. In contrast, when a seedbed is too firm, it is difficult to get the seed into the soil. A seed lying on the surface is very likely to experience widely fluctuating wet-dry cycles.

For more information on seedbed preparation, refer to Idaho Plant Materials Technical Note 13.

Timing

The timing of dryland seedings can be very important. Restorationists in the Intermountain West commonly employ dormant-fall seedings where seed is applied after temperatures have dropped enough that there is little chance of accidental germination (Figure 1). With the dormant fall seeding, the seed is in place to take advantage of the accumulated moisture from snow melt and from spring rains. Studies have indicated that high percentages of seed can be lost due to early germination (James and others 2011; Jones and others 2016). Delaying the seeding as long as possible into the late fall and winter can prevent early germination and ice damage. Spring seedings can also be effective, but they come with a different risk. In the spring, soil moisture levels are often at the saturation point due to the winter snow load. As temperatures warm the soils turn to mud, making it very difficult to use seeding equipment. Often by the time the soil has sufficiently dried enough to allow seeding, the wet period has passed and there may not be enough rainfall to facilitate establishment until the fall.

Figure 1. Late fall dormant seedings are recommended in the Intermountain West to allow seed to take advantage of early spring moisture.

Topography

Correctly interpreting the lay of the land can also be a useful tool for providing adequate moisture for germination and establishment. Recently researchers and restorationists have begun viewing the landscape in a manner similar to precision agriculture. Changes in topography such as slope and aspect of hills, mounds, depressions and swales will hold different levels of moisture due to shading and ponding. Using site characteristics to determine site-specific seed mixes rather than planting large, varied landscapes to a uniform seed mix will help ensure adequate moisture availability.

Figure 2. Imprinters (above) and aerators (left) create depressions and microsites that can aid in trapping moisture for seedling emergence. Photos by Kimseed, Australia and Derek Tilley, NRCS respectively.

Similarly, using heavy equipment can be an option for physically manipulating the topography to create micro- and macro-level variations for enhancing plant moisture availability. For example, terraces and berms, typically created for erosion control on slopes, will hold water from snow melt and rain events and may also provide some degree of shading to further retain moisture. Range imprinters and aerators (Figure 2) create small depressions or microsites which have also been shown to facilitate moisture accumulation and retention (Winkel and others 1991).

Natural Moisture Traps

In the U.S. Intermountain West, where much of the annual precipitation falls in the form of snow (West 1983; Bailey 1995), rigid structures like trees, shrubs and snow fences have been effectively used as moisture traps. Capturing moisture with the aid of downed trees, layered bushes, or standing stubble can be very beneficial and enhance seedling establishment. Downed juniper and pinyon trees following chaining are very effective at trapping drifting snow (Monsen and others 2004). No-till seeding while maintaining surface mulch and standing crop residue also works to trap snow, provide shade and effectively reduce loss of soil moisture.

Snow Fences

Snow fences, while commonly used to prevent snow from creating hazardous road conditions, are being evaluated for their potential to improve seedling establishment. Snow fences are placed perpendicular to the prevailing winter wind and this allows the capture of wind-blown snow in uniform, dense drifts. Snow fences create zones of increased snow accumulation immediately downwind of the snow fence and an area of reduced snow accumulation farther downwind (Figure 3). Depending on the depth of the snow drift created by the fence, snow accumulation can significantly influence soil properties; particularly soil water availability (David 2013). The legacy effect of increased snowpack can lead to increases in soil water availability in the spring and summer (Blumenthal and others 2008; David 2013; Gornish and others 2015), which can increase restoration success (David 2013; Fund 2018).

Figure 3. Snow fences, like the Hollow Frame Fencing System shown, accumulate snow drifts for slow moisture release as temperatures rise. Photos by Adam Fund, OSU.

Snow fences have been shown to improve restoration outcomes by increasing soil water availability during the periods of seed germination and seedling emergence (David 2013), leading to an increase in seedling emergence and establishment of Wyoming big sagebrush and other native species in sage-steppe restoration (David 2013). Their use for restoration of native forbs, however, has been limited.

Fund (2018) evaluated the efficacy of snow fences to improve forb establishment at three sites in Idaho and Utah. They found that the establishment response was very site specific, as sites with limited snow fall saw increased soil moisture and retention likely related to the snow fences which resulted in increased establishment, but other sites with above average winter snow fall did not see similar increases in establishment. They also found that while at some sites, the snow fences resulted in increased seedling emergence and establishment, the gains did not result in better long-term establishment than the control.

Fabrics

Plant protection fabric or landscape cloth, while less commonly used in semiarid or arid restoration, also has the potential to provide favorable abiotic conditions for forb restoration in the Great Basin. Plant protection fabric was originally developed to control insect pests and protect plants in horticultural and agricultural production settings. In forest and wetland ecosystems, fabrics have been used to enhance seed germination and seedling development due to the insulation it provides for seeds and seedlings (Tilley and others 2009; West and others 2012). By acting as an insulating barrier against soil freezing and evaporation, it can enhance soil water availability and thus create favorable abiotic conditions for rangeland restoration (Figure 4).

Although plant protection fabric has been shown to have positive effects on plant establishment in temperate ecosystems, the use of plant protection fabric to alter abiotic conditions for restoration within semiarid ecosystems has remained relatively unexplored. Fund (2018) evaluated the efficacy of plant protection fabric to improve forb establishment at three sites in Idaho and Utah. They found that the establishment response was very site specific. Sites with relatively warm and dry spring and summer months had poor emergence and establishment rates with the fabric while sites with relatively cool and wet spring and summer months saw increased seedling emergence with the fabric.

Figure 4. Plant protection fabric is under investigation for restoration plantings to improve native forb establishment. The fabric prevents water loss and protects seedlings from hard frost events.

Hydroseeding

Hydroseeding with a mulch additive has been successfully used for rangeland restoration seedings on arid sites, but climactic conditions in the Intermountain West may pose difficulties. A case study in south Texas showed hydroseeding establishment rates did not differ significantly from drill or broadcast seeding (Pawelek and others 2015). However, seeding in sites where monsoonal summer rains are common would likely have an advantage over Intermountain sites where summer rain is rare. Shock and others (2016) compared a simulated hydroseeding and 6 other direct surface seeding strategies with 15 native Great Basin forbs under controlled conditions in eastern Oregon. Hydroseeding did not produce any better establishment, while other types of mulch coverings (sawdust, sand, and fabric) showed varying levels of improvement.

Water-manipulating Seed Coatings

In addition to altering the surrounding abiotic conditions, land managers can potentially increase native forb restoration success by manipulating the area immediately surrounding the seeds. Seed coating is increasingly being examined as a restoration tool in the Great Basin (Madsen and others 2016; Williams and others 2016; Davies and others 2018). Seed coating is frequently used within the seed and agricultural industry for applying materials to the surface or external portions of the seed (Figure 5). Seed coating technologies allow for the direct application of various materials to a seed that can influence seed germination and seedling emergence (Madsen and others 2016). These applications may include substances to retain moisture, absorb water, repel water, or inhibit fungal infection.

Various superabsorbent polymers (SAP) seed coatings and soil amendments are available to capture and hold moisture from intermittent moisture events. These materials can quickly absorb hundreds of times its own weight of pure water (Li-qiang and others 2017). Coating seeds with water absorbent materials can improve their survival, especially in drought or barren areas. In agriculture, the SAPs' amendment effectively increases the water storage capacity of soil (Johnson 1984), leading to improvement of seed germination and survival rate of crop plants. Application of this hydrogel has been shown to improve soil moisture content, increase the number of germinated seeds, and improve the yield of rice (Rehman and others 2011). Results investigating polymer coated turfgrass seed being established showed that seed coating has the potential to improve establishment and can compensate for less favorable conditions (Leinauer and others 2010). In a study conducted using peashrub seed in Inner Mongolia, seedling establishment increased by 200% when coated with SAPs compared to a non-treated control (Li-qiang and others 2017). However differing results have also been seen. In one study, establishment and forage yield decreased with increasing rates of dried polyacrylamide gel on alfalfa and Russian wildrye in Saskatchewan (Waddington 1997).

Figure 5. Seed coatings can include water absorbing polymers, hydrophobic coatings, fungicides, or a combination of features. Photo by Matt Madsen, BYU.

Alternatively, hydrophobic materials can also be applied to a seed coat (Turner and others 2006; Madsen and others 2016), which can help mitigate highly variable abiotic conditions by preventing seed imbibition and germination until optimal soil water conditions in the spring and prevent mortality from soil fungal pathogens. Often fall seedings are followed by a warm, wet period which can prematurely initiate seed germination (Jones and others 2016). If the seedlings fail to develop sufficiently they can be killed by cold temperatures or by frost heaving of the roots. Hydrophobic coatings are being designed to withstand multiple freeze-thaw cycles, effectively preventing the seed from imbibing water and beginning the germination process until spring (Madsen and others 2016).


Figure 6. Fungal pathogens can infect and kill seeds or seedlings. Various chemicals and application treatments are available to reduce fungal induced losses. Photo by Derek Tilley, NRCS.

Fungicides

Biotic factors are yet another barrier towards successful restoration of native forb species in rangeland restoration. In many ecosystems, fungal pathogens are ubiquitous in soil and can have multiple, negative effects on seeds, resulting directly in seed and seedling mortality or indirectly through altered seedling survivorship following germination (Figure 6). In sage-steppe rangelands, soil fungal pathogens can lead to the death or decomposition of seeds or germinated seeds (Crist and Friese 1993; James and others 2011; Gornish and others 2015). As seeds germinate and protective seed structures are lost, seedlings are also vulnerable to soil fungal pathogens (James and others 2011) through damping-off, seedling blight, and root rot (Madsen and others 2016).

While many pathogen-plant relationship studies in the Great Basin have focused on native grasses and shrubs, relatively little is known regarding the effects of soil fungal pathogens on forb species native to the Great Basin. Given the extended amount of time between germination and seedling emergence, soil fungal pathogens may be a biotic factor that significantly influences native forb restoration (James and others 2011). Thus, restoration treatments that reduce mortality from soil fungal pathogens may greatly improve native forb restoration.

In Fund (2018), they tested the efficacy of different fungicide and hydrophobic seed coatings on basalt milkvetch at three sites in Utah and Idaho. They found that both fungicide and hydrophobic seed coatings increased seedling emergence at all sites, but combining fungicide and hydrophobic coatings led to the greatest increases in seedling emergence. Other studies have examined how soil amendments such as biochar (Lehmann and others 2011) and activated carbon (Kulmatiski 2011) can affect restoration outcomes by altering soil pathogen loads.

Figure 7. Some rangeland drills are configured to lay alternating rows for drill seeded and broadcast seeded species (above, photo by Derek Tilley, NRCS). Perpendicular drill passes can also help alleviate competition between forbs and grasses (below, photo by Joe Scianna, NRCS).

Alternative Seeding Configurations

In typical seeding mixtures, all of the seeds are blended together leading to a uniform distribution of the different species throughout the planting. In some instances, however, it may be beneficial to separate certain components of the mixture, for example, separating seed which will be planted at different depths. Many planters are equipped with a large seed or grass seed box, an alfalfa seed box, and a “fluffy” seed box. These boxes can be directed to separate drop tubes, allowing for some (typically the grasses) to be planted in the drill rows to a specific depth, while others (typically forbs or rangeland shrubs) are planted shallow or on the soil surface. Another example may be planting alternate rows of grasses and forbs in order to reduce competition between species. Grasses are often much more competitive than range- and pasture-land forbs, and separating the forb seed into alternate rows reduces the effects of shading and water usage from neighboring grasses.

Costs and Conclusions

Many of the treatments discussed here are relatively expensive and may only be feasible on a small scale or in specifically targeted areas within a larger planting. Targeting certain areas such as north facing slopes, natural depressions, or exceptionally weed-free areas for forb and shrub planting within a broader grass seeding, may improve overall establishment and species richness. The cost of traditionally low success rates and seeding establishment failure must, however, also be accounted for when comparing the value of treatments. Repeated seedings due to establishment failure, soil loss from erosion, encroachment from invasive weeds and low species richness as a result of poor planning or reliance on grass monocultures, bear additional inherent costs.

References

Abbott, L.B., Roundy, B.A., 2003. Available water influences field germination and recruitment of seeded grasses. Journal of Range Management 56, 56–64.

Bailey, R.G., 1995. Description of the ecoregions of the United States. USDA Forest Service Misc. Publ No. 1391, Washington, D.C.

Blumenthal, D., Chimner, R.A., Welker, J.M., Morgan, J.A., 2008. Increased snow facilitates plant invasion in mixedgrass prairie. New Phytologist 179, 440–448.

Bushman, B.S., Johnson, D.A., Connors, K.J., Jones, T.A., 2015. Germination and seedling emergence of three semiarid western North American legumes. Rangeland Ecology & Management 68, 501–506.

Crist, T.O., Friese, C.F., 1993. The impact of fungi on soil seeds: implications for plants and granivores in a semiarid shrub-steppe. Ecology 74, 2231–2239.

David, E., 2013. Innovative snow harvesting technology increases vegetation establishment success in native sagebrush ecosystem restoration. Plant and Soil 373, 843–856.

Frasier, G.W., 1989. Characterization of seed germination and seedling survival during the initial wet-dry periods following planting. Journal of Range Management 42, 299–303.

Fund A.J. 2018. Novel treatments for native forb restoration in the Great Basin [MSc thesis]. Logan (UT): Utah State University. 125 p.

Gornish, E.S., Aanderud, Z.T., Sheley, R.L., Rinella, M.J., Svejcar, T., Englund, S.D., James, J.J., 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.

Hardegree, S.P., Abatzoglou, J.T., Brunson, M.W., Germino, M.J., Hegewisch, K.C., Moffet, C.A., Pilliod, D.S., Roundy, B.A., Boehm, A.R., Meredith, G.R., 2017. Weather-centric rangeland revegetation planning. Rangeland Ecology & Management. In Press.

Hardegree, S.P., Sheley, R.L., Duke, S.E., James, J.J., Boehm, A.R., Flerchinger, G.N., 2016. Temporal variability in microclimatic conditions for grass germination and emergence in the sagebrush steppe. Rangeland Ecology & Management 69, 123–128.

James, J.J., Svejcar, T.J., Rinella, M.J., 2011. Demographic processes limiting seedling recruitment in arid grassland restoration: Seedling recruitment and aridland restoration. Journal of Applied Ecology 48, 961–969.

Johnson MS. The effects of gel-forming polyacrylamides on moisture storage in sandy soils. J Sci Food Agric. 1984; 35(11):1196–1200.

Jones, T.A., Johnson, D.A., Bushman, B.S., Connors, K.J., Smith, R.C., 2016. Seed dormancy mechanisms in basalt milkvetch and western prairie clover. Rangeland Ecology and Management 69, 117–122.

Kulmatiski, A., 2011. Changing soils to manage plant communities: activated carbon as a restoration tool in ex-arable fields. Restoration Ecology 19, 102–110.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., Crowley, D., 2011. Biochar effects on soil biota – A review. Soil Biology and Biochemistry 43, 1812–1836.

Leinauer, B., Serena, M. and D. Singh. 2010. Seed coating and seeding rate effects on turfgrass germination and establishment. HortTechnology. 20 (1): 179-185.

Li-qiang Su, Jia-guo Li, Hua Xue and Xiao-feng Wang. 2017. Super absorbent polymer seed coatings promote seed germination and seedling growth of *Caragana korshinskii* in drought. Journal of Zhejiang University Science. 18(8): 696-706.

Madsen, M.D., Davies, K.W., Boyd, C.S., Kerby, J.D., Svejcar, T.J., 2016. Emerging seed enhancement technologies for overcoming barriers to restoration: Emerging seed enhancement technologies. Restoration Ecology 24, S77–S84.

Minnick, T.J., Alward, R.D., 2012. Soil moisture enhancement techniques aid shrub transplant success in an arid shrubland restoration. Rangeland Ecology & Management 65, 232–240.

Monsen, S.B., Stevens, R. and N. Shaw. 2004. Restoring Western Ranges and Wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-2. Fort Collins, CO: US Department of Agricultur, Forest Service, Rocky Mountain Research Station. 1-294.

Pawelek, K.A., Smith, F.S., Falk, A.D., Clayton, M.K., Haby, K.W.and D.W. Rankin. 2015. Comparing three common seeding techniques for pipeline vegetation restoration: a case study in South Texas. Rangelands 37(3): 99-105.

Rehman A, Ahmad R, Safdar M. Effect of hydrogel on the performance of aerobic rice sown under different techniques. Plant Soil Environ. 2011. 57(7):321–325.

Richards, R.T., Chambers, J.C., Ross, C., 1998. Use of native plants on federal lands: policy and practice. Journal of Range Management 51, 625.

Roundy, B.A., 1985. Emergence and establishment of basin wildrye and tall wheatgrass in relation to moisture and salinity. Journal of Range Management 38, 126.

Shaw, N.L., Lambert, S.M., DeBolt, A.M., Pellant, M., 2005. Increasing native forb seed supplies for the Great Basin. In: Dumroese, R.K., Riley, L.E., Landis, T.D. (Eds.), National proceedings: Forest and Conservation Nursery Associations—2004; 12–15 July 2004; Charleston, NC, USA; and 26–29 July, 2004; Medford, OR, USA. Proceedings RMRS-P-35. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 94–102 (technical coordinators).

Shock, C.C., Feibert, E.B.G., Rivera, A., Saunders, L.D., Shaw, N.L. and F. Kilkenny. 2017. Direct surface seeding systems for the establishment of native plants in 2016. Oregon State University Agricultural Experiment Station, MES Annual Report 2016, Departmetn of Crop and Soil Science. Ext/CrS 157. Pp. 123-130.

Tilley, D.J., Frommelt, D., Meyer, D., Smith, C., Young-Matthews, A., 2009. Floating row cover improves in-field germination of broadcast seeded clustered field sedge (*Carex praegracilis* W. Boott) (Final Report). USDA-NRCS Lockeford Plant Materials Center, Lockeford, CA.

Turner, S.R., Pearce, B., Rokich, D.P., Dunn, R.R., Merritt, D.J., Majer, J.D., Dixon, K.W., 2006. Influence of polymer seed coatings, soil raking, and time of sowing on seedling performance in post-mining restoration. Restoration Ecology 14, 267–277.

[USDA NRCS] USDA natural Resources Conservation Service. 2018. The PLANTS database. URL: http://plants.usda.gov (accessed 13 Apr 2018). Greensboro (NC): National Plant Data Team.

Waddington, J. 1997. Effects of including dry polyacrylamide gel with seed on establishment of alfalfa and Russian wildrye. Canadian Journal of Plant Science. 381-384.

West, N.E., 1983. Great Basin-Colorado Plateau Sagebrush Semi-Desert, in: Goodall, D. (Ed.), Ecosystems of the World: Temperate Deserts and Semi-Deserts. Elsevier, New York, pp. 331–349.

Williams, J.R., Morris, L.R., Gunnell, K.L., Johanson, J.K., Monaco, T.A., 2017. Variation in sagebrush communities historically seeded with crested wheatgrass in the eastern Great Basin. Rangeland Ecology & Management 70, 683–690.

Winkel, V.K., Roundy, B.A., Cox, J.R., 1991. Influence of seedbed microsite characteristics on grass seedling emergence. Journal of Range Management 210–214.