SEEDING XERIC RIPARIAN SITES FOLLOWING REMOVAL OF INVASIVE PHREATOPHYTES

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Abstract

Following the eradication of invasive phreatophytes on floodplain areas in the Southwest, plant establishment by direct seeding is problematic on many sites because of deep water tables, fine-textured saline soils, aridity, and no flooding potential. Techniques to maximize success with direct seeding on these sites include appropriate species and ecotype selections, seeding depth control, and mulch application. An overview of seedbed ecology is presented to elucidate the factors that control germination and establishment in arid regions. The Los Lunas Plant Materials Center has developed a number of grass cultivars adapted to the soils and moisture regimes of these xeric riparian sites. Several new cultivars are being developed or are in the process of being released which could provide increased species diversity for seeding projects on these arid and often saline sites.

Introduction

The Los Lunas Plant Materials Center (LLPMC) has been involved with the development of plant materials and planting technologies for the revegetation of riparian areas in the southwestern U.S. for more than two decades. The establishment of herbaceous species through direct seeding is an issue gaining increased attention due to large areas requiring revegetation following control of invasive woody species such as saltcedar and Russian olive. Many of these sites have severe site limitations including extreme water table depths, fine-textured soils often with high salinity, and aridity. These factors make the establishment of herbaceous cover by seeding an extremely difficult endeavor. The primary factor controlling successful establishment by seeding in arid regions is the infrequent, variable, and highly unpredictable precipitation. The influence of this factor will be addressed in detail along with the selection of appropriate species and ecotypes and the influence of the seedbed ecology on eventual establishment. Grass releases developed by the LLPMC which might be used for seeding floodplain sites will be discussed.

Establishment of Herbaceous Species by Direct Seeding in Disturbed Riparian Areas

The revegetation of riparian sites disturbed by the eradication of invasive woody species and by wildfire has resulted in extensively using direct seeding as a conservation practice in riparian areas. In the arid Southwest, such plantings frequently fail to accomplish the intended conservation objectives. After saltcedar control, the deep water tables, saline fine-textured soils, and scarce precipitation make many of these sites especially difficult to establish herbaceous cover by seeding. The expense and effort expended on seeding provides motivation to thoroughly investigate all of the factors which may help to maximize the likelihood of successful establishment. Successful establishment requires:

- Coincidence of seed situated in favorable microenvironments
- Sufficient amount of precipitation to stimulate germination
- Subsequent precipitation pulses to allow seedling establishment
- Negligible competition from weeds
- Insignificant herbivory (Call and Roundy 1991).

Technical resources detailing the numerous aspects of revegetation by seeding have been developed in recent years and serve as excellent sources of background information and practical advice (e.g., Monsen et al. 2004, Colorado Natural Areas Program 1998).

Precipitation is the Controlling Factor

Many Southwestern floodplain forests are situated in arid regions that receive less than 10 inches (254 mm) of annual precipitation. Many of these riparian sites no longer undergo flooding and have deep water tables; thus, these sites are truly arid ecosystems relying on infrequent, variable, and highly unpredictable precipitation (Noy-Meir 1973). At the Jornada site in the northern Chihuahuan desert of New Mexico, long-term climatic data shows an average annual precipitation of 247 mm with 54% falling in the July-September period and 50 rainy days per year but one third of these days have rainfall amounts less than 1 mm (Reynolds et al. 2004). Storm pulses (rainfall events on successive days) of less than 5 mm occurred an average 17 times per year; whereas, pulses between 5-10 mm, 10-15 mm, and greater than 15 mm occurred an average of 6, 3, and 3 times per year, respectively (Reynolds et al. 2004). These data are long-term averages which overstate the number of significant pulses in drought years.

An estimate of how large of a pulse is required for a significant recruitment of seeded species is complicated by a myriad of weather and site variables. For grass seedings, near surface soil moisture content must be sufficient to allow seed imbibition and germination, seminal root extension, coleoptile emergence, and sufficient seminal and adventitious root development for the seedlings to survive the succeeding dry inter-pulse. Soil water in the top inch of soil is depleted from optimal to inadequate levels in 1 to 4 days after a rainstorm in hot desert areas (Winkel 1991a). For a number of desert grass species, if seeds imbibe for two or more days and then experience a dehydration event, substantial mortality of germinating seed results (Emmerich and Hardegree 1996). Seed of Arizona cottontop (*Digitaria californica*) exposed to three successive days of water applied in total amounts of 3 mm, 6 mm, 10 mm, and 15 mm had germination percentages of 0%, 15-20 %, 50-70%, and 90-95%, respectively during the subsequent dry inter-pulse (Smith et al. 2000). Adventitious root initiation in grasses requires 2 to 4 days of optimal soil water conditions (Winkel 1991b). Two scenarios favoring establishment can be postulated regarding wet-dry sequence effects on seed and seedling survival: 1) a wet period sufficiently short that the seed does not germinate during the wet or subsequent dry period or 2) a wet period sufficiently long to produce a seedling with vigor and root development to survive the following dry period (Frasier et al. 1985).

The storage of moisture in the top 100 mm of soil is critical for germination and establishment (Noy-Meir 1973). The volumetric water storage capacity (i.e., the difference between soil at field capacity and dry soil) of sands varies from 3 to 6 %, and for clays from 15 to 25 % (Noy-Meir 1973). For a sandy soil, a rainfall pulse of 5 mm totally infiltrating the soil surface might wet approximately the top 100 mm of soil and could result in significant germination and root elongation. In a heavy soil, an infiltration pulse of 5 mm might only wet approximately the top 25 mm; this surface soil moisture would be depleted rapidly by evaporation. Based on storm pulse data, recruitment events for sandy soils during the growing season would be infrequent in average years but rare in drought years and very rare for heavy soils.

The preceding precipitation data indicates the low likelihood of precipitation pulses adequate for recruitment events. The unpredictability of precipitation pulses within decades, years, and seasons, makes it paramount to maximize the use of the precipitation that occurs by selecting the appropriate species and ecotypes, by burying the seed at optimal depths for establishment, and by manipulating the seedbed to conserve near-surface soil moisture.

Species and Ecotype Selection

Appropriate native species should be given top priority when specifying seed mixes. Unique situations may require the use of introduced species, for instance, to better compete with invasive weed competition. Introduced species are often used when:

1. Appropriate native species are not available
2. Adapted, introduced species can be identified and will not have an adverse effect on the surrounding ecosystem

Often seed cost is used as the primary reason to justify the seeding of introduced species. This economic rationalization must be balanced against long-term ecological consequences.

The surrounding plant community can be used as indicator of suitable species, especially if nearby sites with minimal disturbance can be identified. Descriptions of range cover types (e.g., Shiflet 1994), ecological sites (e.g., USDA-NRCS New Mexico 2006), and other plant community lists (e.g., Dick-Peddie 1993) can be useful in determining common or dominant species for various plant community types.

By selecting species that are well-suited to the soil texture and chemistry, the chances of successful establishment are greatly enhanced. Certain species perform best on well aerated (well drained) coarse (sandy) soils whereas others perform better on fine-textured (clay) soils. The salinity and sodicity of the soil will have profound effects on which species will become established. If the planting site contains a variety of soil textures, a seed mix could include species suitable for the range of textures and salinity. Conversely, separate mixes could be used if the site can be delineated into separate soil types and seeded accordingly.

Cultivars resulting from selection or breeding as well as source-identified germplasm have been developed by various Plant Materials Centers in the western U.S. and have been extensively tested in seeding trials. Many of these native plant materials are appropriate for riparian restoration seedings depending on the eco-region in question and other site characteristics. Use of cultivars or germplasm from the applicable eco-region is generally preferred. If such plant materials are not available, testing has shown that some cultivars have broad areas of adaptation.

Other seed characteristics of particular species to be considered include the dormancy of the seed. In agronomic settings, seed dormancy is undesirable due to reduced germination rates or percentages. However, in wildland restoration, particularly in areas where seedbed conditions conducive for a recruitment event are rare, it is very desirable to have seed of some species persist in the seedbank. Non-dormant seed can imbibe water and initiate germination as a result of precipitation events insufficient to allow the establishment of the seedling. By initiating germination with inadequate soil moisture, this seed is lost from the seedbank for future adequate soil moisture events which could result in regeneration. Some grass species have seed coat-induced dormancy and/or embryo dormancy. These types of dormancy may be desirable attributes in order to retain viable seed in the soil seedbank for several years. Seed coats can be barriers to water or oxygen uptake, impediments to embryo expansion, or sources of germination inhibitors (Adkins et al. 2002). After-ripening is often referred to as the development of a mature embryo after seed harvest by storage under warm, dry conditions; moist chilling or stratification has also been classified as after-ripening during which the dormant seed is transitioning to a germinable state (Foley 2001).

Seedbed Ecology

Some of the dominant issues regarding the manipulation of the seedbed to improve the likelihood of establishment include:

- Controlling annual weed competition
- Conservation or concentration of soil moisture
- Depth of seed burial
- Optimizing seedbed environmental conditions.

The rarity of optimum precipitation pulses for recruitment is justification to manipulate those factors which could maximize establishment with scarcely adequate soil moisture events.

Proliferation of annual weeds (e.g., *Kochia scoparia*) following the removal of invasive exotic woody species often occurs during the restoration of floodplain cottonwood forests. Soil disturbance from heavy equipment traffic, extraction of root crowns, and skidding fallen trees often results in flushes of annual weed growth. Thick mulch layers resulting from shredding or chipping this biomass can suppress this weed growth. If this mulch layer is disrupted during seeding to achieve seed contact with mineral soil, annual weeds could proliferate. If annual weeds invade right after invasive species removal, it is of paramount importance to control these stands before they can release additional weed seed into the soil seedbank. To reduce the weed seedbank, herbicidal control may be required for several years. Alternatively, controlled burns of herbicide-killed annual weed stands might produce sufficient soil temperatures to reduce the weed seedbank. The ability of many of the common annual weeds to establish with minimal moisture inputs portends little or no survival of seeded species having to compete with such weed stands.

The depth of seed burial is a crucial factor in establishment of grasses and forbs. A number of factors influence optimum depths including intrinsic seed characteristics of the species as well as soil and site factors. The depth of seeding of grasses is influenced to a great degree by the length of coleoptile (the structure that forces through the soil while protecting the plumule bud). Some grasses (panicoid type) have an internode (sub-coleoptile) structure which allows the reach of the coleoptile to be the total length of the coleoptile plus the internode (Hyder et al. 1971). The presence of the internode in panicoid grasses results in adventitious roots developing well above the seed position (Hyder et al. 1971). Establishment of grass seedlings is dependent on the development of adventitious roots from the crown node (between the coleoptile and sub-coleoptile internode); elevation of the crown node by the elongation of the internode results in root development occurring in the moisture limited near-surface soil (Tischler and Vogt 1993). The other grass type, festucoid, does not have an elongated sub-coleoptile internode resulting in the lowermost adventitious roots developing near the seed planting depth (Hyder et al 1971). Under sub-optimal soil moisture conditions, adequate emergence of seedlings from shallow seed burial depths must be balanced against the more favorable moisture environment at greater depths.

An ideal seedbed assures that the seed is surrounded by soil particles firmly packed around the seed to ensure conductivity of water from the soil to the seed (Winkel et al. 1991b). Very small seeded species can be sown on the soil surface where this intimate contact with soil particles is provided without any disturbance beyond rain drop impact (Winkel et al. 1991b). For broadcast or drilled seed, firming of the seedbed is recommended to assure adequate seed to soil contact. In areas where equipment traffic has compacted surface soils, ripping or other tillage methods may be required to provide seedbed tilth sufficient to allow optimal root elongation and resulting drought resilience.

Seedling recruitment depends on the number of seeds in favorable micro-sites (Call and Roundy 1991). The micro-topography of the seedbed surface can greatly influence seedbed temperature and moisture: cracks, depressions, rocks and gravel, and plant litter can all play a significant role in eventual germination and establishment (Call and Roundy 1991). Depressions retain surface moisture longer and have more favorable temperature regimes than smooth soil surfaces; these imprints also aid seed burial by trapping wind-blown particles and by soil sloughing off the sides of the depression (Call and Roundy 1991). Deep-furrow rangeland drills, rangeland imprinters, and contour furrowers have improved seedling recruitment under certain soil and site conditions (Call and Roundy 1991). Contour furrows improved recruitment by increasing moisture storage and leaching salts from the surface soil; furrow treatments were most effective for medium to fine-textured soils (Branson et al. 1966). Contour furrowing provided favorable microenvironments in the bottom of the furrow for seedling recruitment in salt desert habitats (Wein and West 1971). Soil cracks can also provide beneficial micro-environments for seedling establishment (Winkel et al. 1991b).

Surface mulches can provide substantially enhanced micro-site environments. Gravel and plant litter mulches provide 4 to 5 more days of favorable soil moisture than bare soil does under situations of intermittent water pulses (Winkel 1991b). These mulches provide increased emergence under all watering scenarios (daily, intermittent, and single pulse) for surface-sown seed (Winkel 1991b). Thick mulch applications can be detrimental to seedling survival if the mulch layer hinders coleoptile emergence or causes increased elevation of coleoptile node in grasses and results in adventitious root development in more droughty surface soils. Thin straw mulch applications with gaps exposing the soil surface should provide some micro-site enhancement but not alter seedling root development (Hyder et al. 1971). Litter and by implication thin mulch layers modify seasonal and diurnal temperature patterns, moderate the diurnal range of relative humidity, and delay water depletion in the soil surface (Call and Roundy 1991). Mulch or litter layers need to be anchored to prevent redistribution by wind forces. Vertical crimping of straw is one of the most frequently employed methods of anchoring mulch.

In the arid Southwest, revegetation of xeric riparian sites by direct seeding always will be problematic, especially in times of drought. By selecting the proper species and ecotypes, the proper seeding methodology, and the proper manipulation of the seedbed environment, the chances of a successful establishment can be maximized. An alternative approach to the restoration of diverse plant communities involves the use of seed source islands or seed islands to provide a natural source for seed dispersal and eventual seedling recruitment (Reever Morghan et al. 2005). In arid regions, intensive cultural practices (e.g., irrigation, herbivore exclusion, mulch application) could be employed to establish these small islands of diverse plant communities. The continued dispersal of seed should provide soil seedbanks which over time will establish an expanding community around the periphery of the seed source islands. This approach would involve an alternative expenditure of resources compared with conventional seeding methods. Direct seeding represents a large-scale, non-intensive, immediate, high-risk venture compared with seed source islands which involve small-scale, intensive, enduring, low risk endeavors. However, the patience required for plant community expansion from the seed source islands is not an attribute of most restoration projects.

Plant Materials Program Cultivars for Riparian Sites

A number of native grass cultivars have been released by the LLPMC are appropriate for revegetating cottonwood floodplain riparian sites in the Southwest. Many of these releases are adapted to xeric sites no longer under the influence of periodic flooding. These species are listed in Table 1.

The LLPMC is in the process of releasing alkali muhly (*Muhlenbergia asperfolia*) Westwater Germplasm from San Juan Co., New Mexico. This species is an aggressive rhizomatous species principally adapted to moist soils along streambanks and ditches, but it is also found on dryer floodplain sites. A release of vine mesquite (*Panicum obtusum*) is also being planned and will contain a composite of Southwestern accessions which produce high seed yields; this species is a stoloniferous/rhizomatous grass of heavy soils in swales, playas, and low spots. The LLPMC has been working for a decade on a release of giant or big sacaton (*Sporobolus wrightii*) which has been selected for its large (8-10 feet tall) upright stature for use as an herbaceous windbreak. It also should be suitable for revegetation of xeric floodplain sites; sacaton meadows still exist on some undisturbed floodplains along secondary drainages in central and southern New Mexico. A release of sandhill muhly (*Muhlenbergia pungens*) is also contemplated from germplasm collected from xeric sandy areas in northwest New Mexico.

Table 1. Native grass cultivars released by the LLPMC suitable for revegetation of southwestern U.S. riparian areas. Many of these species are adapted to xeric sites no longer undergoing periodic flooding.

Scientific Name	Common Name	Cultivar	Origin
Achnatherum hymenoides	indian ricegrass	Paloma	Pueblo, CO
Andropogon hallii	sand bluestem	Elida	Elida, NM
Bothriochloa barbinodis	cane bluestem	Grant Germplasm	composite from AZ and NM
Bouteloua curtipendula	sideoats grama	Niner	Socorro Co., NM
Bouteloua curtipendula	sideoats grama	Vaughn	Guadalupe Co., NM
Bouteloua eriopoda	black grama	Nogal	Socorro Co., NM
Bouteloua gracilis	blue grama	Alma	composite
Bouteloua gracilis	blue grama	Hachita	Hachita Mtn., NM
Bouteloua gracilis	blue grama	Lovington	Lea Co., NM
Elymus elymoides	bottlebrush squirreltail	Tusas Germplasm	composite from NM
Pascopyrum smithii	western wheatgrass	Arriba	Kit Carson Co., CO
Pleuraphis jamesii	galleta grass	Viva	Newkirk, NM
Schizachyrium scoparium	little bluestem	Pastura	Pecos, NM
Sorghastrum nutans	indiangrass	Llano	Elida, NM
Sporobolus airoides	alkali sacaton	Salado	Socorro Co., NM

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