

SOUTHWEST RIPARIAN RESTORATION: NEW STOCK TYPES AND RELEASES, PLANTING CONCERNS, AND SEEDING CONSIDERATIONS

David R. Dreesen, Gregory A. Fenchel, Danny G. Goodson, and Keith White

USDA-NRCS Plant Materials Center, 1036 Miller St. SW, Los Lunas, NM 87031

ABSTRACT

A broad overview of riparian restoration experience was presented by the Los Lunas Plant Materials Center at the Sixteenth High Altitude Revegetation Workshop in 2004. Since that time, new planting methodologies and plant material stock types have been tested to improve establishment and reduce restoration costs. In particular, longstem transplants of riparian understory shrubs have shown promising results in plantings on cottonwood floodplain sites. New releases of important riparian grasses are being developed or are in the process of being released. Recent revegetation experiences have highlighted a number of concerns that can hinder restoration activities including the proliferation of annual weeds following saltcedar control and the effects of inundation on new plantings. Following saltcedar control, many riparian sites in the Southwest have deep water tables and no flooding potential and present serious challenges to establishment by direct seeding. An overview of seedbed ecology is presented to elucidate the factors that control germination and establishment in arid regions. Techniques to maximize success with direct seeding on these sites include appropriate species and ecotype selections, seeding depth control, and mulch application.

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 over two decades. Although some of these activities have addressed restoration of montane riparian areas, the vast majority of our efforts have involved the cottonwood floodplain forests of the major rivers in the Southwest (Dreesen et al. 2002). During the development of riparian restoration techniques, the LLPMC has conducted numerous large-scale demonstration plantings to test plant materials and planting methods and has monitored the success of these plantings to determine how to improve survival percentages and reduce costs. New planting techniques to establish riparian vegetation with minimal or no irrigation have been developed, some of which can be recommended for broad application in the Southwest.

The 2004 Proceedings of the High Altitude Revegetation Workshop contains a paper by the LLPMC which addresses a broad overview of topics related to restoration of southwestern U.S. riparian ecosystems (Dreesen et al. 2004). The previous paper discussed the mechanisms of riparian disturbance, the selection of revegetation species based on site characteristics, riparian plant material stock types and their production, planting procedures for the various stock types, and case studies of several large plantings in the Middle Rio Grande Valley. The current paper will serve as an update on plant material development and new planting methods as well as address site limitations which have impeded revegetation efforts or have reduced the establishment of desirable vegetation. In addition, 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. The factors that make the establishment of herbaceous cover so difficult in arid regions will be reviewed as well as techniques to improve the success rate of direct seeding.

DEEP PLANTING OF LONGSTEM TRANSPLANTS

Many riparian sites requiring revegetation in the Southwest have relatively deep water tables because of altered hydrology of large rivers due to flood control structures and flow management. The cottonwood floodplain forests can no longer regenerate due to the lack of flooding. The establishment of phreatophytic woody plants (overstory and understory) requires either lengthy irrigation until the transplant's root system can extend into the permanent soil moisture (capillary fringe) above the water table, or planting techniques that allow immediate or rapid root extension into this water source by utilizing deep planting methods.

The LLPMC began investigating deep planting methods over two decades ago with studies to improve pole planting methods by determining the influence of ground water depth relative to pole placement, salinity, and stock attributes (Dreesen et al. 2002). Large-scale plantings based on these results have shown high success rates when site characteristics are not limiting. In the last decade, two other techniques have been tested on large scales: (1) the use of non-rooted dormant poles or large whips of understory species not in the Salicaceae (cottonwoods and willows) family and (2) the planting of rooted stock with very long root balls.

Plantings of non-rooted poles of understory species such as New Mexico olive (*Forestiera pubescens*), false indigo (*Amorpha fruticosa*), false willow (*Baccharis salicina*) have been problematic. The best success rates achieved have approached 50 % for certain species under particular circumstances, but poorer survival rates are more common as well as some complete failures. Factors that may influence establishment of these "understory poles" include the amount of time the pole is hydrated after cutting, the age of the cutting, and planting site characteristics. Although no comprehensive study has been made to ascertain the cause of failures, a number of factors may be important: hydration times after harvest should not be longer than a few days, cuttings from old stems are less likely to root, and planting in fine-textured sediments with poor aeration may retard rooting. Because these species are considerably slower growing than cottonwoods and willows, pole length materials (>6 feet) are by necessity older stems. Although the understory pole technique can work to a limited degree, we do not recommend this technique except when it is the only remaining planting option.

We have been producing riparian understory transplants in 30-inch deep pots (tallpots) for about 10 years. Success rates of 90% or more have been achieved in many situations when the bottom of the root balls have been placed in contact with the capillary fringe or when embedded watering tubes have been placed in the planting hole. Depending on the depth to the capillary fringe and soil moisture conditions, up to three irrigations per year using the watering tubes are applied for the first year or two which provides deep soil moisture which allows root extension through the soil above the capillary fringe.

In the last few years, we have encountered riparian planting sites with fairly deep water tables where the bottom of 30-inch root ball is still quite distant from the capillary fringe. Some initial trials with deep burial of tallpot stock in holes up to 6 feet deep have shown positive results using transplants with stem heights up to 6 feet (i.e., total plant height 8.5 ft.). This approach violates several basic horticultural tenets including the deep burial of the root crown and the use of transplants with high shoot-to-root ratios. After one or two growing seasons, samples of each of the species planted using this technique, New Mexico olive (*Forestiera pubescens*), false indigo (*Amorpha fruticosa*), false willow (*Baccharis salicina*), were excavated to ascertain the development of adventitious roots above the root ball. Impressive shoot growth and root observations indicate that extension of roots into the capillary fringe has occurred as well as the development of adventitious roots in shallow soil horizons. The main cause of mortality of longstem plantings has resulted from some sites undergoing prolonged (i.e., 6 week) inundation due to an extreme runoff event in the Middle Rio Grande Valley during the spring of 2005.

As soon as it became apparent that deep burial of longstem planting stock might hold promise for planting in sites with deeper water tables, we decided to test the same procedure with one gallon treepot (4" x 4" x 14") longstem stock. The expense and inconvenience of producing 30-inch tallpots makes treepots an attractive alternative stock type. Longstem treepot stock of the same three species previously mentioned was installed in later comparison plantings along with deep planted tallpot stock. Similar results with survival, growth, and adventitious root development were observed. Although the growing time to produce longstem one-gallon treepot stock may only be slightly less than tallpot stock, treepot production offers the advantages of an inexpensive container, the ease of transplanting seedlings into the container, the ease of watering and moving plants, and the simplicity of supporting and insulating treepots. These efficiencies result in a production cost of a one-gallon longstem treepot being only one-third to one-half of a tallpot. One approach to reduce production time is to plant large bareroot seedlings into treepots, if a source for these native riparian species can be identified. Other species of the cottonwood floodplain forests that might be amenable to longstem deep plantings include golden currant (*Ribes aureum*) and skunkbush sumac (*Rhus trilobata*). We have not yet tried this technique with tree species such as netleaf hackberry (*Celtis reticulata*) or boxelder (*Acer negundo*), but we may have an opportunity to test these species in the near future. Some understory riparian species are not amenable to this technique because of the difficulty in growing longstem material in containers; wolfberry (*Lycium torreyi*) is a prime example.

After the initial longstem deep burial trials were installed, we came across some restoration work from Australia that has taken a similar approach, which they call "longstem tubestock" (Hicks 2003a, Hicks 2003b, Hakewell and Hicks 2004). Their work acknowledges the longstem approach runs counter to conventional horticultural recommendations regarding deep burial and establishment of plants with long stems in small containers. Their approach uses smaller container sizes, 2" x 5" forestry tubes, and attempts to produce stock with stem heights of 3 to 4 feet. Much of their deep planting has been in riparian environments, but they have also used this stock type for arid region plantings in areas with high salinity in surface soils as well sand dune restoration.

New deep plantings are planned which will be monitored for the long-term survival and growth response. Additional riparian species of longstem stock will also be included in new trials to determine their response to deep planting. Shorter and less expensive longstem stock may also be grown in smaller containers for testing on sites where water table depths are not excessive.

PLANT MATERIALS PROGRAM CULTIVARS FOR RIPARIAN SITES

A number of native grass cultivars have been released by the LLPMC which are appropriate for revegetation of 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 Los Lunas Plant Materials Center that are suitable for revegetation of southwestern U.S. riparian areas. Most of these species are adapted to xeric sites no longer undergoing periodic flooding.

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

SITE LIMITATIONS IMPEDING RESTORATION EFFORTS

The experience of implementing numerous riparian restoration demonstrations for the last two decades has yielded a list of concerns which have often hampered the installation or success of projects (Los Lunas Plant Materials Center 2005a, 2005b). In the past few years, problems with inundation of planting sites from extreme water releases and dense herbaceous weed stands following exotic woody species control have been large impediments to recent projects. Other site limitations that have often affected revegetation ease or success are described as well as some potential responses or solutions to these hindrances.

Flooding Resulting in Prolonged Inundation

A site consideration which has not received adequate attention in recent years is the impact of significant flood events and prolonged inundation. This inattention is reasonable considering the drought the Southwest has been experiencing for many years. In the late spring and early summer of 2005, a controlled release of massive quantities of snowmelt water stored in reservoirs was released in the Rio Grande. Within the confines of the levee system, many low lying areas were flooded, and many of these areas remained inundated from six to eight weeks. Several sites that had been planted in the spring of 2004 and 2005 were inundated. High mortality rates of pole and containerized stock (tallpot and longstem treepot) were observed for plants that had been planted several months prior to the flooding. A majority of the pole plantings that had been installed in 2004 survived the inundation while those planted in 2005 succumbed. If extreme snowmelt flood events are forecast, it would be advisable to delay plantings in low areas until later in the year or into the next year or make sure the inundation potential for the site is known in advance.

Effect of Weed Competition on Revegetation

Proliferation of annual weeds can drastically influence reseeding efforts to re-establish native grasses and forbs. After the control of invasive exotic woody species, it is paramount that land managers consider the herbaceous weeds that frequently invade such areas after clearing and the accompanying disturbances. For severe weed infestations on disturbed sites, herbicidal control of weeds for two or more years may be necessary to reduce the weed seedbank before direct seeding and to maximize revegetation potential. The survival and growth of small containerized stock will be severely diminished by competition with large dense weed stands which shade transplants and deplete soil moisture. In some extreme situations, the installation of weed barrier fabrics in V-ditches or basins can be used for planting woody species to reduce weed competition, to harvest runoff, and to reduce evaporation.

Extreme Depth to Ground Water and Severe Water Table Fluctuation

Measurement of depth to ground water using shallow monitoring wells will confirm the depth and seasonal fluctuation of the water table to help determine appropriate species and the most effective stock type (container depth or pole length) for revegetation. Extreme depths to groundwater may indicate the only practical restoration goal is revegetation with xeric shrubs and grasses rather than riparian species.

Revegetation Limitations Due to Soil Salinity and/or Soil Texture Extremes

Fine-textured soils or soils with restrictive layers can limit the selection of species and stock types for revegetation. Soils with high percentages of cobble can make augering impossible; whereas, augered holes in dry sands and gravels will often collapse before planting. Visual observation of soil samples from augered holes should be sufficient to determine if soil texture or restrictive soil layers will be limiting. Extreme salinity and sodicity of floodplain soils can profoundly influence species suitable for revegetation. Salinity problems (i.e., electroconductivity greater than 3 dS/m) can be especially persistent in clay soils where natural leaching of salts is limited. Augered soil samples can be analyzed for electroconductivity (EC) to determine if surface or subsurface salinity is a problem. Electromagnetic induction field instrumentation can also be used to rapidly estimate soil salinity for large acreages.

Loss of Planting Stock from the Scouring Action of Flood Flows

Dormant pole and whip cuttings planted to substantial depths can resist the extractive forces of flood flows compared with shallow planted containerized and cutting stock. Willow whips with their inherent flexibility are more appropriate for higher flow regimes and less stable channel systems. In lower elevation situations where scouring is severe, it is advantageous to plant containerized stock with deep root balls during the fall to provide some root development prior to spring runoff. Some riparian species in small containers but with long stems (i.e., longstem stock) can be buried in deep planting holes for anchorage. Many riparian species should be adapted to this planting method which is comparable to natural burial by sediment deposits.

Eradication of Woody Invasive Species and Removal of Resulting Biomass

A long-term commitment for spot spraying of sprouts must be part of any control program. The dead biomass resulting from herbicide treatment can be burned in slash piles for interspersed noxious woody plants or by crown fires in monoculture stands. The removal of large diameter biomass as firewood and burning of slash is another alternative. The mulching of dead biomass is expensive, but the benefits of mulch include limiting wind and water erosion, reducing soil moisture loss, and enhancing salt leaching

by decreasing evaporation and increasing infiltration. A mulch layer will also retard the growth of weeds that commonly occurs after clearing operations.

Woody Riparian Plant Communities versus Wet Meadow Communities

Planting sites should be evaluated to determine whether they are a wet meadow environment and not appropriate for woody vegetation. Shallow depth to ground water and fine-textured organic-rich or anaerobic soils are some of the factors consistent with wet meadow environments. On low elevation floodplains, saltgrass (*Distichlis spicata*) meadows are inappropriate for revegetation with woody species because of shallow groundwater as well as generally high levels of soil salinity.

Planting Equipment Access

Large equipment requires site access which can be restricted by ditches, arroyos, levees, soft sand, or steep slopes. One unanticipated problem with equipment access, which has been identified with the recent upsurge in saltcedar clearing, is the ubiquitous presence of cut stumps which can easily puncture heavy duty truck and tractor tires.

Protection and Maintenance of Revegetated Sites

The continued spot spraying of sprouts of noxious woody species and any other invasive weeds will be required for an indefinite period. Protection from cattle will require adequate fencing and periodic monitoring of fence integrity. The presence of beaver necessitates poultry wire tree guards around individual pole plants as well as protection of unplanted poles and whips placed in streams or canals for hydration. Controlling defoliating insects is crucial for pole plantings during the initial growing seasons; cottonwood leaf beetle will occasionally require control.

ESTABLISHMENT OF HERBACEOUS SPECIES BY DIRECT SEEDING IN DISTURBED RIPARIAN AREAS

The revegetation of riparian sites disturbed during the eradication of invasive woody species and by wildfire has resulted in direct seeding being extensively used 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 for establishing herbaceous cover by seeding. The expense and effort expended on seeding provides motivation to thoroughly investigate all the factors which may help to maximize the likelihood of successful establishment. Successful establishment requires the coincidence of seed situated in favorable microenvironments, precipitation sufficient to stimulate germination, subsequent precipitation pulses to allow seedling establishment, and negligible competition from weeds and 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 with 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 seedlings, 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 Hardegee 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 (Smith et al. 2000). Adventitious root initiation in grasses requires 2 to 4 days of optimal soil water conditions (Winkel 1991b). Two scenarios 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 range 3 to 6 %, and for clays from 15 to 25 % (Noy-Meir 1973). For a sandy soil, a rainfall pulse of 5 mm infiltrating the soil surface would 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 would only wet approximately the top 25 mm; this surface soil moisture could 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, 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 and (2) adapted introduced species can be identified which will not adversely affect 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 repercussions.

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 to determine common or dominant species for various plant community types.

By selecting species 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 may be 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 which should 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 control of annual weed competition, conservation or concentration of soil moisture, depth of seed burial, and 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.

As previously described, 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 such as made by heavy equipment traffic, extraction of root crowns, and skidding fallen trees often result 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 provided 4 to 5 days longer favorable soil moisture than bare soil under situations of intermittent water pulses (Winkel 1991b). These mulches provided 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 proper selection of species and ecotypes, seeding methodology, and manipulation of the seedbed environment, the chances of 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.

LITERATURE CITED

- Adkins, S.W., S.M. Bellairs, and D.S. Loch. 2002. Seed dormancy mechanisms in warm season grass species. *Euphytica* 126:13-20.
- Branson, F.A., R.F. Miller, and I.S. McQueen. 1966. Contour furrowing, pitting, and ripping on rangelands of the western United States. *Journal of Range Management* 19:182-190.
- Call, C.A. and B.A. Roundy. 1991. Perspectives and processes in revegetation of arid and semiarid rangelands. *Journal of Range Management* 44(6):543-549.
- Colorado Natural Areas Program. 1998. Native plant revegetation guide for Colorado. Caring for the Land Series, Volume III, October 1998. In collaboration with Colorado State Parks and Colorado Department of Natural Resources. 258 p.
- Dick-Peddie, W.A. 1993. New Mexico vegetation: past, present, and future. University of New Mexico Press, Albuquerque, NM. 244 p.
- Dreesen, D., J. Harrington, T. Subirge, P. Stewart, and G. Fenchel. 2002. Riparian restoration in the Southwest: species selection, propagation, planting methods, and case studies. p. 253-272. In: Dumroese, R.K., L.E. Riley, and T.D. Landis, technical coordinators. National Proceedings Forest and Conservation Nursery Associations – 1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden UT, USDA Forest Service, Rocky Mountain Research Station.
- Dreesen, D., G. Fenchel, D. Goodson, and J. Lee. 2004. Plant materials and planting methods for riparian restoration in the Southwest. p. 201-209. In: Keammerer W. and J. Todd, editors. Proceedings: High Altitude Revegetation Workshop No. 16. Information Series 99, Colorado Water Resources Research Institute, Colorado State Univ., Fort Collins, CO.
- Emmerich, W.E. and S.P. Hardegree. 1996. Partial and full dehydration impact on germination of 4 warm season grasses. *Journal of Range Management* 49(4):355-360.
- Foley, M.E. 2001. Seed dormancy: an update on terminology, physiological genetics, and quantitative trait loci regulating germinability. *Weed Science* 49:305-317.
- Frasier, G.W., J.R. Cox, and D.A. Woolhiser. 1985. Emergence and survival responses of seven grasses for six wet-dry sequences. *Journal of Range Management* 38(4):372-377.
- Hakewell, G. and B. Hicks. 2004. Trails of longstem tube stock at Katandra Reserve, Gosford NSW. <http://farrer.csu.edu.au/ASGAP/APOL33/mar04-3.html>. Accessed 2/7/06.
- Hicks, B. 2003a. Longstem planting. Australian Plants Society Central Coast Group. <http://www.austalianplants.org/longstem.htm>. Accessed 3/8/2005.
- Hicks, B. 2003b. Longstem native tubestock – the solution to the willow problem. <http://farrer.csu.edu.au/ASGAP/APOL29/mar03-6.html>. Accessed 2/7/06.
- Hyder, D.N., A.C. Everson, and R.E. Bement. 1971. Seedling morphology and seeding failures with blue grama. *Journal of Range Management* 24:287-292.

Los Lunas Plant Materials Center. 2005a. Guidelines for planning riparian restoration in the Southwest. USDA-NRCS Plant Materials Center, Los Lunas, NM. 4p.
www.nm.nrcs.usda.gov/news/publications/planning-riparian-restoration.pdf

Los Lunas Plant Materials Center. 2005b. The pole cutting solution: guidelines for planting dormant pole cuttings in riparian areas of the Southwest. USDA-NRCS Plant Materials Center, Los Lunas, NM. 4p.
www.nm.nrcs.usda.gov/news/publications/pole-cutting-solution.pdf

Monsen, S.B., R. Stevens, and N.L. Shaw (comps.). 2004. Restoring western ranges and wildlands. Gen. Tech. Report RMRS-GTR-1365-Vols. 1-3. Fort Collins, CO, USDA, Forest Service, Rocky Mountain Research Station. 884 p.

Noy-Meir, I. 1973. Desert ecosystems: environment and producers. *Annual Review of Ecology and Systematics* 4:25-51.

Reever Morghan, K., R.L. Sheley, M.K. Denny, and M.L. Pokorny. 2005. Seed islands may promote establishment and expansion of native species in reclaimed mine sites (Montana). *Ecological Restoration* 23(3):214-215. Summary and abstract accessed from
www.ars.usda.gov/research/publications/publications.htm?seq_no_115=181998&pf=1.

Reynolds, J.F., P.R. Kemp, K. Ogle, and R.J. Fernandez. 2004. Modifying the 'pulse-reserve' paradigm for deserts of North America: precipitation pulses, soil water, and plant responses. *Oecologia* 141:194-210.

Shiflet, T.N. (ed.). 1994. Rangeland cover types of the United States. Society for Range Management, 1839 York St., Denver, CO 80206. 152 p.

Smith, S.E., E. Riley, J.L. Tiss, and D.M. Fendenheim. 2000. Geographical variation in predictive seedling emergence in a perennial desert grass. *Journal of Ecology* 88:139-149.

Tischler, C.R. and P.W. Voight. 1993. Characterization of crown node elevation in Panicoid grasses. *Journal of Range Management* 46:436-439.

USDA-NRCS New Mexico. 2006. Field office technical guide. Section II Soil and site information. F. Ecological site descriptions. www.nm.usda.gov/technical/fotg/section-2/esd.html.

Wein, R.W. and N.E. West. 1971. Seedling survival on erosion control treatments in a salt desert area. *Journal of Range Management* 24:352-357.

Winkel, V.K., B.A. Roundy, and D.K. Blough. 1991a. Effects of seedbed preparation and cattle trampling on burial of grass seeds. *Journal of Range Management* 44(2):171-175.

Winkel, V.K., B.A. Roundy, and J.R. Cox. 1991b. Influence of seedbed microsite characteristics on grass seedling emergence. *Journal of Range Management* 44(3):210-214.