Deep-planting techniques to establish riparian vegetation in arid and semiarid regions

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ABSTRACT

Invasion by exotic woody species and disruption of natural hydrologic conditions require the restoration of native riparian plant communities along rivers and streams in the Southwest. Successful establishment of phreatophytic riparian plant species has been accomplished using deep planting techniques that involve the immediate exploitation of capillary fringe moisture by the existing root system of nursery stock or the adventitious root system of a cutting. These techniques, which require minimal or no post-planting irrigation in arid and semiarid regions, include the planting of dormant pole cuttings, dormant whip cuttings, tallpots with long root systems, as well as long-stem nursery stock whose root crowns are deeply buried.

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NOMENCLATURE
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A diverse riparian community established by natural regeneration along the Rio Grande near Socorro, New Mexico, comprising Rio Grande cottonwood, New Mexico olive, Emory's baccharis, and giant sacaton (*Sporobolus wrightii* Munro ex Scribn. [Poaceae]). Photo by

Many of the common overstory trees and understory shrubs in riparian areas are phreatophytes and also obligate riparian species. *Phreatophytes* have been described as plants whose "roots are in the water table or its capillary fringe during all or most of the growing season" (Dick-Peddie 1993) or as plants that "habitually send their roots to the capillary fringe and feed on ground water" as stated by Meinzer (1923) who coined the word "phreatophyte." The capillary fringe has been described as "the zone immediately above the water table" where the water is held "by interfacial forces (surface tension)" and "is typically saturated to some distance above its base at the water table; upward from the saturated part only progressively smaller pores are filled and the upper limit is indistinct" (Lohman and others 1972). Thus, the capillary fringe serves as a constant water supply with sufficient aeration for roots of phreatophytic species to flourish. In dry climates, the natural regeneration of riparian species is dependent on overbank flooding, but the persistence of this vegetation is dependent on the appropriate groundwater level (Hupp and Oster-kamp 1996) and the associated capillary fringe.

On lower elevation floodplain sites in the Southwest, cottonwood species of the Salicaceae family (Rio Grande [*Populus deltoides* Bartram ex Marsh. ssp. *wislizeni* (S. Watson) Eckenwalder], plains [*Populus deltoides* Bartram ex Marsh. ssp. *monilifera* (Aiton) Eckenwalder], Fremont [*Populus fremontii* S. Watson], and Goodding's willow [*Salix gooddingii* C.R. Ball]) are common obligate riparian overstory species and phreatophytes. An assortment of common understory shrubs on these sites in New Mexico are obligate riparian species including desert false indigo (*Amorpha fruticosa* L. [Fabaceae]), screwbean mesquite (*Prosopis pubescens* Benth. [Fabaceae]), *Baccharis* L. species (Asteraceae), New Mexico olive (*Forestiera pubescens* Nutt. var. *pubescens* [Oleaceae]), Torrey wolfberry (*Lycium torreyi* A. Gray [Solanaceae]), and coyote willow (*Salix exigua* Nutt. [Salicaceae]) (Dick-Peddie 1993). Restoration with appropriate native species is being attempted where natural regeneration can no longer be relied on because overbank flooding has been perturbed or where exotic saltcedar (*Tamarix ramosissima* Ledeb. [Tamaricaceae]) and Russian olive (*Elaeagnus angustifolia* L. [Elaeagnaceae]) have been removed.

Figure 1. Plains cottonwood pole planting along the Arkansas River near Pueblo, Colorado, at the end of the third growing season after installation. Note 1.5 m (5 ft) tall poultry wire tree guards for beaver protection. Photo by

Any plantings of nursery stock must exploit the capillary fringe as rapidly as possible. If conventional nursery stock with a short root system is planted with its root crown at the soil surface, substantial precipitation or flood events must occur to provide a sufficient amount of deep soil moisture for the roots to extend to the capillary fringe. Although this strategy is effective in mesic environments with high annual precipitation and frequent high water events, it is doomed to failure in arid and semiarid regions where low annual precipitation and infrequent overbank flood events prevent roots from reaching the capillary fringe. One option is frequent irrigation but this is rarely practical for the following reasons:

- Surface application of water in basins often encourages competitive annual weed growth, and it is difficult to apply sufficient water to moisten the deeper soil layers. Installation of weed barrier fabric can alleviate the weed problem.
- Restrictive soil layers can prevent roots from reaching the unsaturated zone above the water table.
- Small nursery plants are difficult to locate in an expansive outplanting area in order to apply water.
- Frequent watering of numerous and widely dispersed plants requires a major long-term commitment of labor and equipment.

Therefore, we have developed specialized nursery stocktypes and outplanting methods that require little if any irrigation and that help achieve the goal of large-scale revegetation of disturbed or decadent riparian areas. The approach the Los Lunas Plant Materials Center (LLPMC) has been investigating for more than 2 decades involves what we term "deep-planting." This denotes an attempt to place the existing root system of a nursery plant or the potential root system of a cutting into the capillary fringe. Instead of using "tall pots" with long root systems, we developed a new long-stemmed nursery stocktype that can be deep-planted so that its roots are in contact with the capillary fringe. Similarly, if a long-stem cutting is placed with its cut end into groundwater, then adventitious roots could develop in the capillary fringe. The latter technique has been employed for decades and is termed dormant pole planting or live stake planting.

For deep-planting of rooted nursery stock to be successful, the plants must tolerate burial of the root crown. Naturally regenerated riparian plant communities are adapted to burial by sediments. The long-term burial and survival of obligate riparian species is shown by plains cottonwoods that are more than 100 years old with root crowns buried by at least 1 m (3.3 ft) of alluvium and adventitious roots growing out of these buried trunks (Gonzalez 2001).

The deep-planting methods em-ployed by the LLPMC include the following types of plant materials:

- long, large-diameter, dormant pole cuttings,
  shorter, small-diameter, dormant whip cuttings, and
- containers with long root balls or long-stem stock whose
- root crowns will be deeply buried.

Publications summarizing the refinement of these deep-planting techniques can be found at the website of the Los Lunas Plant Materials Center, New Mexico, USDA NRCS (2008b).

DEEP-PLANTING DORMANT POLE CUTTINGS

The following important planting considerations and intrinsic characteristics of dormant pole cuttings will enhance riparian revegetation. Pole cuttings are generally 3.7 to 4.9 m (12 to 16 ft) long and are harvested and planted while dormant (during early winter to early spring). Branches, except a few at the top of the cutting, are removed from the pole at harvest. Vigorous young poles (3 to 4 y old) with larger stump diameters establish more readily and successfully than older or small diameter poles. The stump ends of poles should be placed in water tanks, streams, or ditches to keep them hydrated between the time of harvesting and planting. Pole cuttings can tolerate being out of water for less than a day during transport, but this should be minimized. The traditional pole cuttings are cottonwoods (Salicaceae: for example, Rio Grande, plains, Fremont, lanceleaf [*Populus* ×*acuminata* Rydb. (pro sp.) [*angustifolia* × *deltoids*]], or narrowleaf [*Populus angustifolia* James] and tree type willows such as Goodding's or peachleaf [*Salix amygdaloides* Andersson]), which readily produce adventitious roots and provide the dominant overstory structure of Southwest riparian forests. Establishing pole production areas using seedlings will assist in maintaining genetic diversity and an appropriate mix of male and female cuttings (Landis and others 2003).

A number of site factors can significantly influence the survival and growth of pole cuttings planted in riparian areas. The depth of the planting hole must be sufficient for the stump end of the pole to be in groundwater throughout the growing season even if the water table drops. The depth of the hole and the desired aboveground height of the planted pole will determine the length of pole needed. Shallow monitoring wells are recommended to confirm the depth and seasonal fluctuation of the water table. These groundwater depth measurements can help in the selection of appropriate species for revegetation. Pole cuttings of cottonwood species will usually not thrive when planted in alluvium with less than 1 m (3.3 ft) of aerated soil above the water table, while shrub willow species are tolerant of these shallower groundwater conditions. Soil salinity levels (for instance, electroconductivity [EC] measurements) greater than 3 to 4 dS/m indicate excessive salts that preclude adventitious root development on both cottonwood and willow pole cuttings. Alluvium with high percentages of cobble is impossible to auger. Augered holes in dry sands and gravels will often collapse before the pole can be inserted. Fine-textured soils with high percentages of silt and (or) clay (> 50% silt plus clay) will inhibit aeration in deeper soil layers, which will diminish root development and growth. Pole plantings are not appreciably affected by weed competition because the poles are usually tall enough so as not to be shaded by the canopy of annual weeds, and the poles are exploiting groundwater rather than shallow soil moisture. Planting dormant pole cuttings into cold soils of high elevation sites can be problematic because rooting will not occur until soil temperatures moderate in midsummer. On these high elevation sites, the buried portion of the pole can degrade in the time between the planting of dormant cuttings and the onset of warm subsoils. Wet meadows with shallow depth to groundwater, organic or anaerobic fine-textured soils, and low stream gradients are not appropriate for deep-planting of woody species. Figure 1 shows the rapid growth of dormant cottonwood pole cuttings after 3 growing seasons when high-quality poles are planted on an appropriate site. Cottonwoods in arid regions generally establish where the water table depth is 1 to 2 m (3 to 6 ft) but can be found at sites with water table depths of less than 3.5 m (11.5 ft) if the water table declined after establishment (Scott and others 1999). When the water table declines to 2 to 3 m (7 to 10 ft), cottonwoods suffer moisture stress (Scott and others 2000). Even on suitable sites, pole plantings must be protected from beaver damage with 1.5 m (5 ft) tall poultry wire tree guards and from defoliation (such as happens from the cottonwood leaf beetle) by spraying newly planted poles.

DEEP-PLANTING WHIP CUTTINGS

Streambanks prone to erosion during high-flow events may be stabilized by establishing a dense, woody cover to armor the banks and a prolific root system to stabilize the streambank soils. At lower elevations in the Southwest, the several native species frequently serve this role: coyote willow, seepwillow (*Baccharis salicifolia* (Ruiz & Pav.) Pers. [Asteraceae]), desert false indigo, and occasionally arrowweed (*Pluchea sericea* (Nutt.) Coville [Asteraceae]). At higher elevations, a variety of shrub willows (*Salix* L. sp. [Salicaceae]), redosier dogwood (*Cornus sericea* L. ssp. *sericea* [Cornaceae]), thinleaf alder (*Alnus incana* (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung [Betulaceae]), and occasionally water birch (*Betula occidentalis* Hook. [Betulaceae]) serve the same purpose. Species that root readily from dormant cuttings, including most willows and redosier dogwood, are good candidates for streambank stabilization. The key to successful establishment is to place the base of the dormant cutting into the water table to assure the cutting is well hydrated while it forms adventitious roots. Another crucial factor is to plant dormant cuttings deep enough so that they resist being washed out by floods.

Ideal specifications for shrub willow and redosier dogwood whip cuttings are a small base diameter (less than 2.5-cm [1-in] caliper) and relatively short length (1.5 to 2.4 m [5 to 8 ft]). Not only is this the natural growth form of young vigorous shoots of these species but also they are the most likely to root readily. Our method of augering the holes to plant dormant whip cuttings is to use a spline-drive rotary hammer with a 2.5 cm (1 in) diameter bit that is 91 cm (36 in) long (Figure 2A). The 76-cm (30-in)-plus deep holes have a sufficient diameter to accept most whip cuttings. A portable generator can provide sufficient power for several rotary hammers by way of extension cords outfitted with ground fault circuit interrupters for safety (Figure 2B). Two people, one augering and one planting, can install up to 800 whip cuttings per day provided the soil is cohesive sand with only small amounts of gravel or cobble. Rotary hammers can penetrate the 5 to 10 cm (2 to 4 in) of frozen surface soil that is frequently encountered during the winter or early spring planting window for dormant cuttings. In soils containing some cobble, deep holes can be augered by trial and error if care is taken not to exert excessive lateral force on the bit, which may fracture it. A better planting option in cobble or riprap is to use a backhoe or excavator arm equipped with a pointed planting bar (a "stinger") (Hoag and Ogle 1994). For fine-textured soils, you can use a water jet stinger, which uses high-pressure water to excavate a hole; this method requires a pump and an easily accessible water source because appreciable water is consumed to jet each hole (Hoag and others 2001). Another method for planting whip cuttings is to use a large diameter auger to reach the water table and to place several whips in each hole, which produce a clump of plants that appears more natural.

The success of a whip cutting planting depends on several factors that are similar to pole planting requirements. As with all dormant cuttings, it is important to keep the whips hydrated by storing newly harvested cuttings in water and minimizing desiccation during transport. Willow whip cuttings can be damaged by beavers. Even though the


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Figure 2. (A) Planting coyote willow whips along the Rio Chama near Espanola, New Mexico, using spline-drive rotary hammer drills. (B) Spline-drive hammer drill equipped with a 2.5 cm (1 in) diameter x 91 cm (36 in) long bit. This generator can run 2 drills simultaneously. Note ground fault circuit interrupter plugged into generator. Photo by

entire aboveground portion of a newly planted whip might be removed, the belowground stem often has sufficient reserves to sprout and form new shoots. In situations where the groundwater depth fluctuates significantly, planting on a streambank at different elevations above the water level may be advisable as long as the base of the cutting is in saturated alluvium. Those cuttings close to the water's edge and inserted into very shallow groundwater may endure if the water level recedes drastically. If water levels are elevated for a long period, however, the cuttings at the higher elevations may be the only ones to survive.

The density of a planting depends on the following factors:

- the urgency of stabilizing the streambank,
- the spreading potential of the species planted, and
- the cost per unit area.

Coyote willow can form dense stands from root sprouts. Because low density plantings can fill in rapidly, coyote willow can be very useful for streambank stabilization. On higher elevation sites, most willow species, other than coyote willow, are multistem shrubs that can resprout from root crowns but do not root sprout to form thickets. For this reason, higher density plantings of these willow species may be necessary to rapidly stabilize eroding streambanks in montane environments. One montane species, redosier dogwood, does propagate by stem layering, which may allow rapid spread on streambanks.

DEEP-PLANTING OF LONG-STEMMED CONTAINER NURSERY STOCK

The establishment of other important woody riparian species, particularly understory shrubs, has not been generally successful using pole cuttings. As a result about 10 y ago, we began producing riparian understory transplants in 76 cm (30 in) long and 10 cm (4 in) diameter "tallpots" constructed from PVC drain pipe (USDA NRCS 2008c) as a means to allow rapid root access to the capillary fringe and to minimize irrigation requirements. If the top of the capillary fringe was just below the tallpot root system, a few irrigations using an embedded 2.5 cm (1 in) diameter perforated PVC watering tube placed in the planting hole (a method similar to the deep pipe irrigation of Bainbridge [2006]) provided deep soil moisture for rapid root extension into the capillary fringe (see Figure 5). If extreme conditions such as drought or a declining water table were encountered, a maximum of 3 irrigations per year were applied for the first 2 y using the watering tubes. Success rates of 90% or more were achieved in many such situations.

Some especially challenging riparian sites, however, had low or declining water tables where the bottom of a 71-cm (28-in) root ball was far above the capillary fringe. On these sites, we tried long-stem plants with stem heights of up to 2 m (6 ft) and total plant heights of up to 2.8 m (9 ft). When these long-stem plants were planted deeply in holes up to 2 m (6 ft) deep, we had good success. Note that this approach violates several basic horticultural tenets that consider deep burial of the root crown and transplants that have large shoot-to-root ratios as detrimental practices.

Our first trials with deep-planting of long-stemmed nursery stock included New Mexico olive, desert false indigo, and Emory's baccharis (*Baccharis emoryi* A. Gray [Asteraceae]). When these plants were excavated after one or 2 growing seasons, adventitious roots were found to have developed along the stem in shallow soil horizons (Figure 3), and impressive shoot growth indicated the extension of roots into the capillary fringe.

As soon as it became apparent that deep-planting of long-stem stock might hold promise for improved establishment on sites with deeper water tables, the LLPMC tested the same procedure with long-stem stock grown in 10 cm x 10 cm x 36 cm (4 in x 4 in x 14 in) one-gallon treepots (Tall One Treepot™, Stuewe and Sons, Tangent, Oregon). One-gallon treepots (left, Figure 4) are an advantageous alternative stocktype because of the time, expense, and inconvenience of producing 76 cm (30 in) tallpots (right, Figure 4). Long-stem treepots of the 3 species mentioned above were installed in comparison plantings along with deep-planted, tallpot stock; similar survival rates, growth rates, and adventitious root development were observed for the 2 stocktypes. Planting scenarios for both treepot and tallpot stock in relation to the capillary fringe are illustrated in Figure 5. Advantages of producing one-gallon, long-stem treepot stock include ease of transplanting seedlings into the container, ease of watering and moving plants, and the simplicity of supporting and insulating treepots in the nursery. These efficiencies result in reducing the production cost of long-stem treepots by at least 50% relative to tallpot stock.

Other species of the cottonwood floodplain forests that have been found to thrive when deep-planted as long-stem stock include golden currant (*Ribes aureum* Pursh [Grossulariaceae]), screwbean mesquite, skunk-bush sumac (*Rhus trilobata* Nutt. [Ana-cardiaceae]), netleaf hackberry (*Celtis laevigata* Willd. var. *reticulata* (Torr.) L.D. Benson [Ulmaceae]), silver buffaloberry (*Shepherdia argentea* (Pursh) Nutt. [Elaeagnaceae]), and boxelder (*Acer negundo* L. [Aceraceae]). Some understory riparian species are not amenable to this technique because of the difficulty in growing stock with long-stems in containers; Torrey's wolfberry is a prime example.

After our initial long-stem deep burial trials were installed, we became aware of revegetation projects in Australia that utilized a similar planting method; the originator calls the approach "long-stem tubestock" and acknowledges that this methodology runs counter to conventional horticultural recommendations regarding deep burial of root crowns and use of plants with long-stems in small containers (Hicks 2006). This technique employs small size (5 cm x 10 cm [2 in x 5 in]) forestry tubes and attempts to produce stock with stem heights of 0.9 to 1.2 m (3 to 4 ft). Much of his long-stem tubestock planting has been in riparian environments, but he has used this stocktype also for arid region plantings in areas with high salinity in surface soils as well as sand dune revegetation.

The deep-planting of long-stem stock can preclude or drastically reduce the need to apply irrigation water to establish riparian shrubs and trees. The cost savings of minimal or no watering and high percentages of transplant success will, in most situations, far outweigh the added expense of the planting stock and deep-planting.

CONCLUSION

The concept of deep-planting long-stemmed nursery plants is based on the phreatophytic nature of most riparian plant species. Given the phreatophytic requirement for root proliferation in the capillary fringe, any means feasible to expedite this root development should be a worthwhile expenditure of resources. By deep-planting, we are making an immediate hydrologic connection between the transplant and this unsaturated zone containing readily available water and air that will support rapid establishment and growth. To accomplish this connection, we are defying horticultural rules about burying root crowns and using planting stock with large shoot-to-root ratios. The adaptation of riparian species to burial by sediment in fluvial systems makes these techniques a viable method of minimizing irrigation requirements for establishment. We expect 90%-plus survival with minimal post-planting care if high-quality stock is deep-planted on appropriate sites.

Figure 3. Desert false indigo adventitious root development on the buried stem of a long-stem treepot transplant after 2 growing seasons. This planting reintroduced native understory shrubs following saltcedar removal along the Rio Grande near Belen, New Mexico. Photo by

Figure 4. Dormant long-stem New Mexico olive in a one-gallon treepot (left) and a 76 cm (30 in) long x 10 cm (4 in) diameter tallpot (right). Note yardstick for scale. Photo by

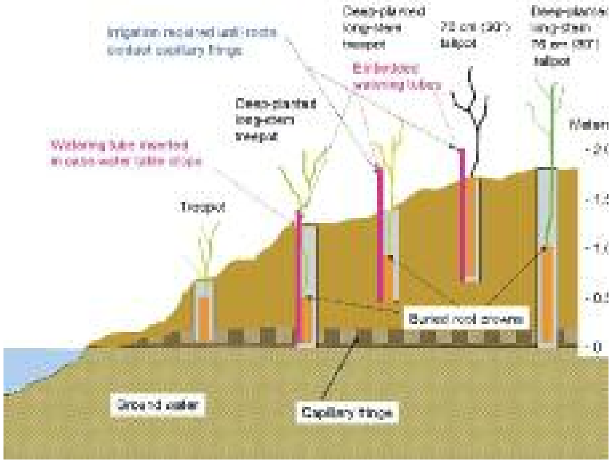

Figure 5. Planting scenarios for treepot and tallpot stock depending on the depth to the capillary fringe. If the root balls are not in contact with the capillary fringe, irrigation through the embedded watering tubes will be required until the roots can access groundwater. If the water table declines during severe droughts, several applications of water into watering tubes will enhance survival. Illustration by

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