Establishment of the Woody Grass *Arundinaria gigantea* for Riparian Restoration

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Abstract

Canebrakes are dense stands of *Arundinaria gigantea* (Walt.) Muhl. that covered large areas of the southeastern North America. With agricultural development, canebrakes were quickly converted to crop and pastureland and now occur only in small, isolated patches. There is growing interest in the use of *A. gigantea* and other temperate bamboo species in riparian and floodplain revegetation in North America, but lack of detailed information on propagation and management of woody perennial grasses hinders reestablishment activities. Our study assesses the influence of nutrient and woodchip mulch amendments on survival and growth of *A. gigantea* transplanted as part of a riparian restoration project in central Kentucky. After two growing seasons, culm number (aboveground stems) increased 4-fold and extent of transplanted clumps expanded 26-fold. The survival rate of transplanted cane clumps was 98%. Hardwood chip mulch significantly increased the emergence of new culms, culm height growth, and clump area. Composted manure, applied at a rate that contributed a similar mass of organic matter as the hardwood mulch, also significantly increased new culm number and clump area. Our findings demonstrate that addition of manure or hardwood mulch can significantly enhance aboveground production of *A. gigantea* transplants. However, survival and initial growth of untreated clumps were also adequate in this study. It appears that careful site selection, transplantation, and site maintenance may be sufficient to ensure *A. gigantea* establishment on many sites. Practitioners should assess soil drainage, water stress, and fertility along with herbaceous competition and incidence of overbank flooding before determining the necessity of organic amendments to supplement establishment of *A. gigantea* or other woody grasses for riparian restoration.

Key words: bamboo, buffer zone, canebrake, filter strip, floodplain forest, giant cane, organic and inorganic fertilizer, wood chip mulch.

Introduction

Restoration of degraded riparian forest improves terrestrial and aquatic wildlife habitats, enhances stream aesthetics, reduces streambank erosion, and protects water quality through stream corridor revegetation (Manci 1989; FISRWG 1998). Woody perennial grasses can help achieve these goals because of their rapid growth, compact stem and root morphology, and resprouting ability. Grasses belonging to the subfamily Bambusoideae and other perennial species (e.g., Vetiver grass [*Vetiveria zizanoides*; subfamily Andropogoneae]) are commonly used for soil erosion control and streambank stabilization throughout the wet, humid, and semiarid tropics (Rocheleau et al. 1988; Young 1989; National Research Council 1993). Recently, practitioners and researchers have begun to test the utility of temperate bamboos for riparian revegetation in eastern (Harker et al. 1999; Cirtain et al. 2004; Schoonover & Williard 2004) and northwestern (Miles 1998; Diver 2001) North America.

Arundinaria gigantea (Walt.) Muhl., commonly known as giant or river cane, is the only bamboo species native to the United States (Marsh 1977). *Arundinaria gigantea* occurs from Florida to eastern Texas, and to the north from southeastern Missouri to Virginia (Marsh 1977; Judziewicz et al. 1999). Canebrakes (dense stands of *A. gigantea*) covered vast areas of southeastern North America prior to European settlement (Campbell 1985; Platt & Brantley 1997). In central Kentucky, one canebrake was reported to be "15 miles [24 km] long and nearly half as wide" (Rodgers 1790 in Campbell 1985). Canebrakes were most common on floodplain terraces where they occurred beneath sparse forest canopies; they also occurred within canopy openings in upland forest and savannas (Farrelly 1984; Campbell 1985; Platt & Brantley 1997). Large canebrakes soon disappeared following introduction of European agriculture and the demise of Native Americans and their traditional burning patterns (Platt & Brantley 1997). Though cane still grows in small patches throughout its range, canebrakes approaching the size of those observed prior to European settlement are rare. Owing to extensive loss, *A. gigantea* canebrakes (85–98%) have been designated an endangered ecosystem (Noss et al. 1995) and are a priority for conservation and restoration (Platt et al. 2001).

Structural attributes of riparian canebrakes provide wildlife habitat and benefit water quality. The high stem

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density of *A. gigantea* canebrakes creates a habitat for a wide array of mammals, birds, reptiles, and insects (Meanley 1972; Eddleman et al. 1980; Kilgo et al. 1996; Thomas et al. 1996) including several cane-dependent species (Remsen 1986; Platt et al. 2001). This high culm density (16–26 culms/m^2) and rapid lateral spread and height growth (up to 6 m/year and 8 m/year, respectively; McClure 1973; Marsh 1977) also make *A. gigantea* a logical species of choice for streamside buffer zones. *Arundinaria gigantea*'s compact network of rhizomes benefits aquatic resources through streambank stabilization, sediment retention, and bioaccumulation of nutrients and toxins (Welsch 1991; Geyer et al. 2000; Lee et al. 2003). For example, plant nitrogen uptake and microbial denitrification reduce groundwater nitrate in *A. gigantea* plantings in riparian zones in southern Illinois (Schoonover & Williard 2003).

Though mature canebrakes are characterized by rapid culm growth, the survival of transplanted *A. gigantea* varies widely (Feeback & Luken 1992; Platt & Brantley 1993), and slow growth may continue for several years (Cusak 1999). Nutrient addition is recommended as a strategy to accelerate aboveground production following transplantation (Hughes 1951; Feeback & Luken 1992; Bell 2000), but field-level effectiveness of fertilization has not been demonstrated. The utility of *A. gigantea* for streambank stabilization and riparian corridor restoration is currently limited by the lack of transplantation methods that have been proven to minimize establishment failure.

This study provides a replicated field-scale test of the response of *A. gigantea* to hardwood mulch and to organic and inorganic fertilizer amendments applied at the time of transplantation. We quantify cane survival and growth over two growing seasons to assess how the response to mulch and fertilizer, singly or in combination, differs between treated and untreated transplants. This research contributes specific information regarding establishment techniques for woody, clonal grasses and complements efforts to formulate recommendations for regional stream corridor restoration.

Methods

Site Description

The riparian restoration study is located at the Bernheim Arboretum and Research Forest in the western Knobs of the Outer Bluegrass physiographic region (Braun 1950) in central Kentucky (37°51′N, 85°37′W). The study area is situated in the floodplain of Hart's Run, a tributary to the Rolling Fork River in the Salt River drainage. Row-crop agriculture represents 60% of the land area in the Rolling Fork watershed, and the Kentucky Division of Water (1998) reports that high fecal coliform levels and excessive nutrients impair the basin's water quality.

Forests at the study site were originally cleared for row cropping and then maintained as hay meadows dominated by tall fescue (*Festuca arundinacea*). The remnant forest is restricted to a 10- to 30-m-wide streamside zone (Dattilo 2003). These forests are dominated by American sycamore (*Platanus occidentalis*) and Black walnut (*Juglans nigra*), with Ohio buckeye (*Aesculus glabra*) and Eastern redbud (*Cercis canadensis*) in the midstory and Coralberry (*Symphoricarpos orbiculatus*), Spicebush (*Lindera benzoin*), and Pawpaw (*Asimina triloba*) in the shrub layer (Homoya 1999; Dattilo 2003). In addition to tall fescue, the non-native species multiflora rose (*Rosa multiflora*), Japanese honeysuckle (*Lonicera japonica*), and Japanese stilt grass (*Microstegium vimineum*) are abundant at the study site. *Arundinaria gigantea* grows in dense patches (<500 m^2) scattered in forested valley bottoms and slopes along Hart's Run.

The study was conducted within a hay meadow, 20–30 m away from a narrow streamside forest. Ordovician limestone and alluvium underlay the floodplain study site. Soils at the planting site have moderate water-holding capacity and soil fertility and are classified as fine-loamy, mixed, mesic, Dystric Fluventic Eutrochrepts (Whitaker & Waters 1986). Surface mineral soils (0–10 cm) contain 1–3% organic matter and 18–35% clay and have a mean pH of 6.0. Soils vary from poorly drained to well drained. Groundwater in poorly drained sites saturates rooting zones for prolonged periods during winter months; such sites are characterized by abundant crayfish burrows and wetland indicator plants.

Experimental Treatment

Inorganic or organic fertilizer, with or without hardwood mulch, was applied to cane transplants to evaluate the influence of nutrients and moisture on initial *A. gigantea* survival and growth. We transplanted cane in March 2002 (see details below) and applied amendments later that year, during the first growing season. Inorganic fertilizer (196 kg N/ha, 66 kg P/ha, and 168 kg K/ha) was applied to the base of each clump on three occasions (May, June, and September 2002). The fertilizer rate was based on graminoid forage recommendations following evaluation of total soil nitrogen and exchangeable phosphorus and potassium (University of Kentucky Regulatory Services Soil Testing Lab, Lexington, KY, U.S.A.). We compared two applied rates of composted cow manure: (1) equivalent to the nutrient input of inorganic fertilizer and (2) 15 times the inorganic fertilizer amendment. Manure additions were 0.2 and 2.9 kg dry manure/clump for the low and high rates, respectively. The lower rate of manure application contributed 200 kg N/ha, 53 kg P/ha, and 176 kg K/ha; the higher rate added 2,900 kg N/ha, 770 kg P/ha, and 2,550 kg K/ha. The lower application rate did not produce a measurable manure layer, but the higher rate formed a 5-cm-thick layer at the base of each clump (0.25 m^2 area).

We applied hardwood chip mulch (uncomposted) at a rate of 5 kg dry matter/clump; this addition covered a similar area to the same depth as the high rate of manure application. The mulch added 453 kg N/ha, 49 kg P/ha, and 204 kg K/ha. Relative to composted manure and inorganic fertilizer, the high ratios of carbon to nitrogen (107:1) and carbon to phosphorus (1,000:1) in the woodchip mulch were expected to slow its decomposition and the release of nutrients into the soil.

Cane Transplantation

We transplanted cane using clump division, a technique commonly employed for vegetative propagation of rhizomatous grasses such as *A. gigantea* (Farrelly 1984; McClure 1993; Bell 2000). The operation transferred intact culms, rhizomes, and roots directly from a donor canebrake to the planting site. Root balls (approximately 45 cm in diameter) were hand-dug in March 2002, prior to initiation of seasonal culm growth. Culms were pruned above the third branching node (Bell 2000) to an average height of 61 cm. We wrapped root balls in burlap, watered, and planted within 1 hr of digging to reduce desiccation during transplantation. Transplant sites were about 500 m from the donor canebrakes. We watered clumps every other day for 1 week after transplantation. Fescue sod was removed by hand from 0.25-m^2 patches at each planting site. Potentially competitive fescue regrowth surrounding transplanted cane was treated periodically with a 3% glyphosate solution (RoundUp Pro®; Monsanto Co., St. Louis, MO, U.S.A.) throughout the study.

Data Collection

We recorded culm number and clump area for each clump and the height and measured basal diameter of each individual culm at the time of transplantation. On average, clumps contained four culms (range three to eight) with a mean height of 86 cm (range = 5–235 cm) and basal diameter of 6 mm (range = 0.5–12 mm) (n = 480). Total culm number (original plus new culms), height of the three tallest new culms per clump, and clump area were measured following the first and second growing seasons (November 2002 and December 2003). Clump area was calculated as the product of the greatest distance between the bases of any two culms and the span between two culms oriented perpendicular to the long axis. The fate of individual culms (live or dead) was determined at the end of the first growing season and related to initial individual culm dimensions. Gravimetric soil moisture was sampled 15 cm from the center of each clump in the top 10 cm of mineral soil. Soil moisture sampling was performed during a prolonged summer dry period (August 2002) and again following several weeks of high rainfall (September 2002). Moisture content was calculated from the mass lost from a subsample of field moist soil after drying for 24 hr at 105°C.

Statistical Analysis

The study compared mulch and nutrient amendments in a 2 × 4 factorial treatment arrangement; mulching (no mulch and mulched) and fertilization (unamended, inorganic fertilizer, low manure application rate, and high manure application rate) were evaluated in a completely randomized design. The eight treatment combinations were replicated in six planting sites. Each experimental unit ("treatment plot") consisted of 10 individually transplanted clumps that were averaged to evaluate treatment effects. Individual clumps (n = 480) were planted at 1 × 1–m spacing within treatment plots. Two-meter buffers separated treatment plots. Planting sites were distributed along a 1,000-m section of hay meadow in the Hart's Run floodplain.

After two growing seasons, mulch, amendment, and planting site effects were analyzed at the treatment plot level (n = 6) using a mixed model analysis of variance (Proc Mixed, SAS version 8.2, SAS Institute, Cary, NC, U.S.A.). Data were checked for homogeneity of variance with Levene's test and normality using the Shapiro–Wilks

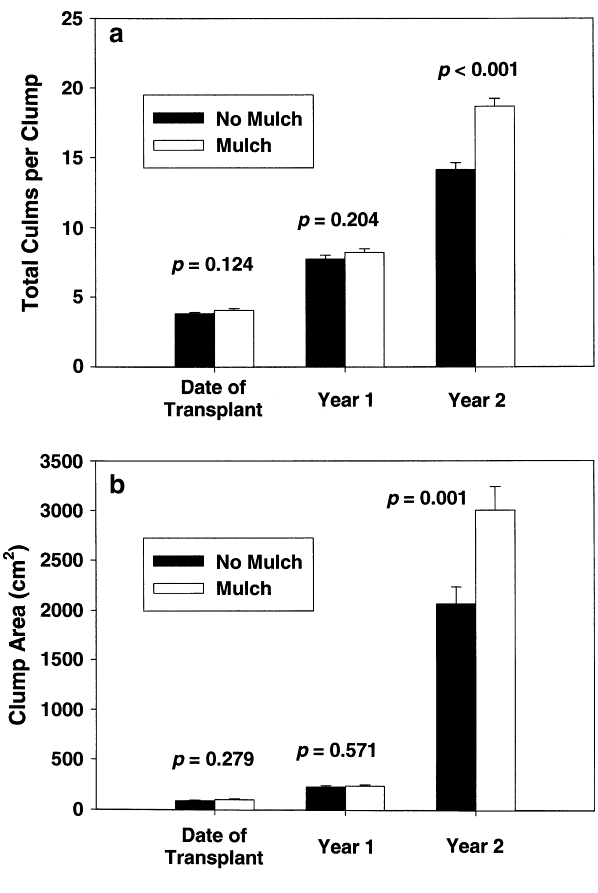

Figure 1. Effect of hardwood mulch on (a) total culms per clump and (b) total clump area at the time of planting and following one and two growing seasons in *Arundinaria gigantea* transplanted in riparian corridors. Bars show means of mulched and unmulched treatments with SE; p values report the significance of mulch effects at the three sampling periods.

statistic prior to analysis. Where significant differences ($p = 0.05$) occurred, the least significant difference (LSD) procedure was used to compare specific means (PROC LSMEANS SAS version 8.2, SAS Institute, Cary, NC, U.S.A.).

Results

Overall, there was 98% clump survival during the 2-year study, with relatively uniform mortality between the two growing seasons (4 in year 1; 6 in year 2). The number of culms per clump doubled during the first growing season and quadrupled by the end of the 2-year study (Fig. 1a). New culms averaged 60.1 cm in height after 2 years. Clump area expanded from 95 cm^2 at the time of transplantation to 2,525 cm^2 by the end of the study (Fig. 1b), and new culms emerged as much as 1.5 m away from the clump centers. During the first growing season, clump area increased for 93% of the transplanted clumps.

First season emergence, growth, and fate of individual culms was related to the diameter, height, and number of culms in transplanted clumps. New culm emergence increased 1.3-fold for each culm in individual transplanted clumps ($r^2 = 0.81$; $p = 0.014$). Individual culm death decreased with initial culm diameter ($r^2 = 0.96$; $p = 0.001$) and height ($r^2 = 0.93$; $p = 0.002$).

The hardwood chip mulch significantly increased new culm emergence, new culm height, and clump area (Table 1) during the 2-year study, but these responses did not appear until the second growing season (Fig. 1a & 1b). After two growing seasons, clumps in mulched plots had added 14.6 new culms compared to 10.3 culms in unmulched plots. Mulched culms were 10% taller, and clump area was 31% larger than unmulched clumps.

Nutrient amendment (i.e., manure and inorganic fertilizer) significantly increased new culm number but had marginal effect on culm height or clump area (Table 1). The overall amendment effect was largely attributable to the high-rate manure treatment applied to unmulched clumps. For the high-rate manure treatment, new culm emergence (Fig. 2a) and clump area (Fig. 2b) both increased significantly relative to the unamended control or the other nutrient applications. In contrast, mulched cane clumps did not respond to either manure application rate. Similar to the mulch effect, the influence of the high-rate manure treatment emerged during the second growing season.

Mean culm height differed significantly among the six planting sites after 2 years (Table 1), most likely due to differences in soil drainage. Across the six planting sites, mean culm height declined by half with increasing wet-season soil moisture (Fig. 3). New culm emergence also decreased significantly with wet-season soil moisture (new culms = 58–1.6X; $r^2 = 0.61$; $p < 0.1$).

Discussion

Factors Contributing to Mulch and Manure Effects

Cane responded similarly to the hardwood mulch and the high–manure application treatment. The positive effect of the hardwood mulch addition probably resulted from more consistently moist soil and reduced herbaceous competition. Soil moisture was 30% greater at the base of

Table 1. Responses of *Arundinaria gigantea* to mulch and nutrient amendments measured 2 years after establishment.

	New Culm Number		*Culm Height (cm)*		*Clump Area (cm^2)*	
Planting Treatment	*Mean (SE)*	*Maximum*	*Mean (SE)*	*Maximum*	*Mean (SE)*	*Maximum*
Unamended						
Unmulched	8.19 (0.8)	30	51.73 (3.3)	103	1,719.0 (410.3)	19,602
Mulched	12.8 (1.0)	39	57.88 (3.0)	109	3,005.8 (711.5)	40,586
Inorganic fertilizer						
Unmulched	10.52 (0.9)	37	56.61 (3.6)	124	1,820.1 (256.2)	9,072
Mulched	16.75 (1.1)	45	71.68 (3.5)	147	3,636.6 (453.9)	17,034
Manure—low rate						
Unmulched	9.39 (0.9)	26	60.70 (3.4)	135	1,658.0 (230.8)	8,400
Mulched	15.22 (1.0)	46	61.89 (2.9)	124	2,662.1 (250.6)	8,470
Manure—high rate						
Unmulched	13.21 (0.9)	37	59.05 (2.6)	106	3,083.3 (387.7)	15,000
Mulched	14.29 (1.3)	68	60.66 (2.7)	113	2,694.9 (362.9)	15,120
Analysis of variance						
Main effects	*F*	*p*	*F*	*p*	*F*	*p*
Amendment	3.76	0.034	1.76	0.198	0.99	0.423
Mulch	23.55	<0.001	4.38	0.054	7.42	0.016
Planting site	1.98	0.140	15.94	<0.001	2.71	0.061
Amendment × mulch	1.76	0.199	0.96	0.438	1.83	0.186

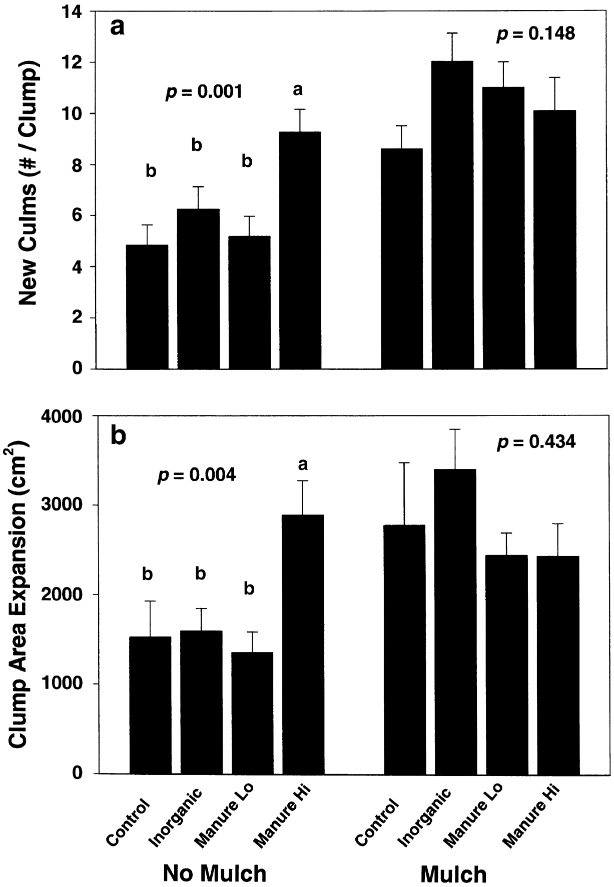

Figure 2. Effect of fertility amendments on (a) new culm emergence and (b) expansion of *Arundinaria gigantea* clumps during the second growing season following transplantation. Bars show means for amendment treatments with SE; p values report the significance of amendments for mulched or unmulched transplants. Where significant amendment effects occur, letters indicate that means differ at $\alpha = 0.05$.

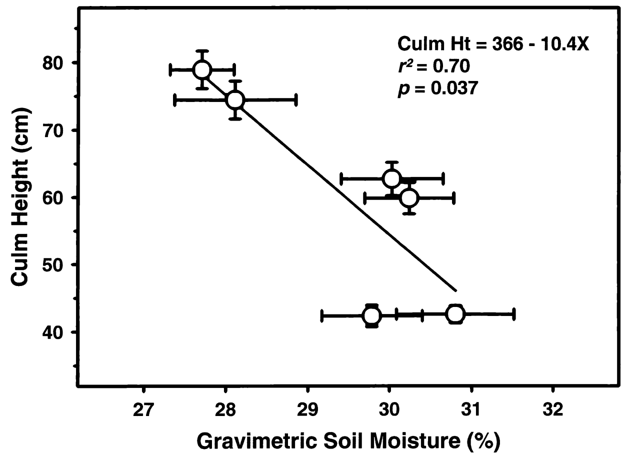

Figure 3. Relation between culm height and gravimetric soil moisture during wet conditions for cane clumps at six riparian planting sites in central Kentucky (all treatments combined). Data are means and SE ($n = 8$).

mulched clumps under dry-season conditions ($p < 0.000$); mulch had no effect on wet-season soil moisture. The 5-cm-thick layer of wood chips reduced evaporation and formed a barrier to herbaceous growth near the base of the cane clumps, though in our study, belowground competition was also limited by periodic herbicide application.

Cane treated with composted manure also benefited from increased moisture when soils were dry but may have responded to greater nutrient availability as well. Soil moisture was significantly higher at the base of manure-treated clumps (high rate) compared to non–manure-treated clumps ($p < 0.05$), though the difference was less than that between mulched and unmulched treatments. The high rate of manure application added 6, 16, and 12 times more N, P, and K than the hardwood mulch with a similar mass of organic matter. When applied alone, inorganic fertilizer did not accelerate cane growth, but the combination of inorganic fertilizer and hardwood mulch resulted in a 40% increase in new culms compared to clumps treated with mulch alone (Fig. 2a). This suggests that cane production was limited by both nutrients and soil moisture. The very high carbon to nutrient (N or P) ratio of wood chips may cause a net reduction of soil nutrients beneath the hardwood mulch; in contrast, by simultaneously enhancing soil moisture and nutrient availability, transplants treated with composted manure may overcome both limitations.

Considerations for Riparian Canebrake Establishment

Arundinaria gigantea survival and initial growth were high in this study, even for unamended clumps. We believe that our establishment success was due in large part to careful clump transplanting and maintenance combined with favorable post establishment conditions. Frequent precipitation in the weeks following transplantation reduced drought stress and probably contributed to high clump survival. Chemical control of grass competition may have also increased soil water available to transplants, enhancing initial cane performance.

Excavating, transporting, and planting cane clumps with attached roots and soil is time consuming, but less-painstaking techniques have not proven effective. Transfer of unrooted culms of temperate bamboos, like *A. gigantea*, is typically unsuccessful (Farrelly 1984; McClure 1993). Under favorable site conditions, transplanted culms bearing multiple basal buds may take root, but initiation of lateral growth is inconsistent and slow (Platt & Brantley 1993).

In our study, one person transplanted approximately 50 clumps per 8-hr day using hand tools. The use of mechanized forest nursery equipment to undercut roots of donor canebrakes might reduce physical effort required to dig and separate cane clumps. However, the process would probably inflict heavy damage to donor canebrakes.

Chemical site preparation to eliminate competing grass would shorten both the planting process and the time invested in post establishment maintenance. Tillage should be avoided in riparian areas where frequent flooding can scour unstable soils and dislodge transplanted clumps.

Composted manure and hardwood mulch each doubled new culm emergence after 2 years, at this flood plain site where plant water stress was seasonally brief and soil fertility was moderate. At low-fertility sites, the additional nutrient benefits of the manure might favor that treatment over the hardwood mulch. At sites with more prolonged dry spells, mulch in conjunction with supplemental irrigation may be required to ensure adequate transplant survival. Near sensitive aquatic habitats, where herbicide use is not possible, mulch may represent the only competition control option. The effectiveness of a one-time organic matter addition probably declines substantially within 4 years of transplantation, so the effort may not be justified at sites where frequent overbank flooding threatens to remove the amendments. Prior to selecting treatments aimed at ensuring transplant success of *A. gigantea* or other woody grasses, restoration practitioners must evaluate soil drainage, seasonal plant water stress, and soil fertility, as well as the relative availability and cost of various mulch or nutrient amendment sources.

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