GREENHOUSE AND FIELD PERFORMANCE OF GIANT CANE PROPAGULES FROM NATURAL AND PLANTED STANDS

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Abstract.—The objective of this study was to determine whether giant cane (*Arundinaria gigantea*) vegetative macropropagules of nine stock types could generate surviving culms to be used in restoration plantings in southern Illinois. In spring 2006, studies were conducted to compare culm production and survival of giant cane stock types that had varying rhizome morphology, collection origin (putative genotypes), collection location (natural stands or restoration planting), propagule type (bare rhizome, culms with attached rhizomes, and culm only) or length of storage in greenhouse and subsequent field plantings. Greenhouse survival of culm-only and culms with attached rhizomes stock types was poor, averaging 3.4 percent and 31.7 percent, respectively, and were not subsequently field planted. Rhizome morphology differed among bare-rhizome stock types. Greenhouse development and survival of culms from rhizomes averaged 60.1 percent and varied among the seven bare-rhizome stock types from 80.0 percent for a source collected from a restoration planting to 20.0 percent for a source from a natural stand that had been stored for 1 year. Greenhouse survival of culms from rhizomes of a similar origin (putative genotype) did not vary when collected from natural stands or restoration plantings. For surviving greenhouse propagules planted in the field, survival after 10 months was 64.4 percent and was independent of stock type. Field height, but not number of culms per rhizome, varied by stock type. Survival of culms from bare rhizomes throughout greenhouse and subsequent field plantings was 38.7 percent overall and depended on stock type.

INTRODUCTION

Giant cane (*Arundinaria gigantea* [Walt. Muhl.]) is a native North American bamboo species and component of floodplain forests and riparian areas within the southernmost Central Hardwoods Region. Its distribution encompasses 22 states in the United States (Marsh 1977). Extensive assemblages of cane are called canebrakes. Historic records indicate that canebrake ecosystems serve as important habitat for a variety of mammalian, avian, and reptilian species because of the protective nature that the dense culms provide (Platt and Brantley 1997, Platt and others 2001). For example, giant cane is important to provide nest habitat for the rare Swainson's warbler (*Limnothlypis swainsonii*) (Eddleman and others 1980). Giant cane also can serve as an effective riparian zone buffer for the protection of water quality (Schoonover and Williard 2003, Schoonover and others 2005).

Currently, canebrakes have been reduced to less than 2 percent of former abundance primarily by agricultural conversion, altered disturbance regimes and hydrological modifications of the floodplain (Marsh 1977, Noss and others 1995, Platt and Brantley 1997, Gagnon 2006, Stewart 2007). Noss and others (1995) suggest that the development of conservation strategies and management initiatives will be needed to restore these critically endangered ecosystems.

Giant cane has proven to be more difficult to propagate than other members of the bamboo family (Feeback and Luken 1992, Platt and Brantley 1993). Natural flowering and subsequent seed production

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Table 1.—Stock type origin, source, and date of collection and planting in the greenhouse for seven rhizome-only stock types used in greenhouse and field plantings[1]

Stock type	Rhizome number	Origin (putative genotype)	Collection source location	Dates collected	Dates planted 2006
BR05	40	Bellrose(BR)	Natural stand BR	03/25/05	03/08
BR06	32	Bellrose(BR)	Natural stand BR	02/16/06	03/07
BW06	40	Bluewing(BW)	Natural stand BW	03/28/06	03/29,04/06
BulkRF06	40	BR and HB	Rose Farms (RF) planting	02/23/06	03/08,03/23
UCRF06	40	Upper Cache River(UC)	Rose Farms (RF) planting	02/23/06	03/23
BRRF06	39	Bellrose(BR)	Rose Farms (RF) planting	04/05/06	04/11
HBRF06	40	Hickory Bottoms(HB)	Rose Farms (RF) planting	04/05/06	04/11

[1] To summarize, stock type codes indicate the origin from its original natural stand (if known) with the first two letters, whether the stock had been previously established in a 2001 planting at Rose Farms (designated by RF, if applicable), and the year the stock was collected for planting in the current study (either 05 or 06).

are irregular and unpredictable, and appear linked to age and site conditions, but specific details are not known (Gagnon 2006). Reproduction of giant cane and most bamboo is primarily vegetative, indicated by the spreading growth patterns of rhizomes and new culm shoots (Farrelly 1984, McClure 1993). Large-scale canebrake restoration is challenged by the lack of available planting stock and inadequate field establishment techniques (Feeback and Luken 1992, Sexton and others 2003, Hartleb and Zaczek 2007). Vegetative propagation using large clumps of rhizomes in soil with attached culms has shown to be a useful method (Dattilo and Rhoades 2005), but field-scale canebrake plantings with this method would be both expensive and resource limiting (Datillo and Rhoades 2005, Hartleb 2007). Propagation using smaller and more easily handled rhizome sections has shown promise in field-scale canebrake establishment (Hartleb 2007, Hartleb and Zaczek 2007).

Understanding factors that influence the propagation and field establishment of giant cane will help restore canebrake ecosystems to the landscape. Toward this goal, the objectives of this study were to determine if bare rhizomes from four origins of giant cane (putative genotypes), two collection sources (natural stands or plantings), and two storage times differ in their morphology, culm production ability, and survival and growth in greenhouse and subsequent field plantings after one growing season. Additionally, this study compared the survival and growth of culms without attached rhizomes and culms with attached rhizomes.

METHODS

There were seven stock types using bare rhizomes as propagules (Table 1). These rhizomes ultimately arose from four origins (putative genotypes because of giant cane's tendency to spread vegetatively) referred to as Upper Cache River (UC; Johnson County, IL), Hickory Bottoms (HB; Pulaski County, IL), Bluewing (BW), or Bellrose (BR). Rhizomes were dug from two collection sources (natural stands or restoration plantings). There were two different naturally established stands of giant cane (BW and BR, located about 1.5 km apart) and two adjacent 5-year-old giant cane plantings, a source collectively referred to as Rose Farms (RF). In all, seven bare-rhizome stock types were used (Table 1), that were various combinations of origin and collection source (indicated by letter codes) and collection year (indicated by either 05 or 06). Additionally, there were two other stock types using culm only and culm with attached rhizome pieces.

All collections were dug in early spring of 2006 except for Bellrose 2005(BRZ05), which was dug in early spring of 2005 from a natural giant cane stand on The Frank Bellrose Waterfowl Preserve in Pulaski County, IL, and stored under refrigeration until the spring of 2006. Three stock types came from this waterfowl preserve.

The other four stock types were dug from an experimental planting site established in 2001 at the Rose Farms, owned and managed by The Nature Conservancy. Giant cane rhizomes at RF had origins from BR, HB, and UC. The final RF stock type was a bulk collection of rhizomes from HB and BR in unknown proportions.

The bulk collection of stock type BulkRF06 rhizomes and stock type UCRF06 were dug with hand shovels (for dates see Table 1). A backhoe was used to dig the remaining stock types (Table 1). Rhizomes were shaken free of soil, cut to a range of 20 to 44 cm ($\bar{x}$ =28.9 cm) in length, and placed in white plastic bags to prevent drying. Attached culms, except for the culm only and culm with attached rhizome stock type described below, were removed before storage. Bags were then transported to the Tree Improvement Center (TIC) greenhouse at Southern Illinois University (SIU) where rhizomes were rinsed with tap water and any damaged sections were removed. Rhizomes were then placed in bags with peat-moss and stored at approximately 4 °C until measured and planted.

Before greenhouse planting, each rhizome was tagged with an identification number and data were collected on length (to the nearest cm), number of nodes and buds, and diameter (0.1 mm). Internode length (cm) was determined by dividing the length by the number of nodes. Rhizome diameters are the geometric mean of minimum and maximum diameters taken with a caliper at a mid-rhizome internode (Husch and others 1972). Rhizomes were trimmed to remove damaged sections, including damage from extended storage on BR05, resulting in a range of lengths (20 to 44 cm) in the rhizome only stock types.

Rhizomes were planted vertically with the distal end up in D40 Deepot containers (Stuewe & Sons, Inc., Corvallis, OR) measuring 25.0 cm in length and 6.4 cm in diameter and filled with Promix BX potting medium (Premier Horticulture Inc., Quakertown, PA). For rhizomes shorter than 27 cm, rhizomes were planted not extending to the container bottom and were left to protrude from the surface of the potting medium ~2 cm. Longer rhizomes were planted touching the bottom and any remaining portion was left exposed above the potting medium. On the date of planting (Table 1), potted rhizomes were watered and placed on greenhouse benches under intermittent mist at a frequency of 12 seconds every 6 minutes during daylight hours. After at least 1 month in the greenhouse and prior to field planting, data were collected on survival (those rhizomes that produced a surviving culm), number of culms, and height (cm) of tallest culm.

Stock types for culms alone (C) and culms with rhizome (C+R) were collected with shovels on April 5, 2006 at Rose Farms. Fifty-six C propagules were separated from their attached rhizome at a rhizome node while maintaining their associated roots were maintained (Fig. 1). Fifty-eight C+R propagules with rhizomes ~10 cm long with at least one live bud were collected. In both cases, original height of the culms (40 to 60 cm) was maintained and the propagules were placed into white trash bags to prevent drying and

Figure 1.-Image of culm and rhizome (C+R) indicating the location where culms were detached from rhizomes (green dashed line) for culm-only (C) propagules.

taken to the TIC greenhouse at SIU. The C and C+R propagules were planted (April 11-13, 2006) in CL-300 pots 17 cm wide by 18 cm deep (Nursery Supplies, Inc. Chambersburg, PA), watered, and maintained under mist as described previously.

After 6 to 11 weeks in the greenhouse, rhizomes that had maintained surviving culms (N=163) were field planted (May 24, 2006) on the Cypress Creek National Wildlife Refuge. The field site was an abandoned agricultural field located within 1 km of an existing natural giant cane stand (HB). Propagules were machine planted in a completely random design using a Whitfield (Mableton, GA) tree planter towed behind a tractor. Newly grown plants were removed from the D40 pots and planted with the top of the potting media approximately 1 cm below the surface of the ground at 1.5-m distances within a row (seven rows total). Rows were spaced 3.0-m intervals apart. The soil is in the Petrolia series with taxonomic class being described as fine-silty, mixed, superactive, nonacid, mesic Fluvaquentic Endoaquepts (Natural Resource Conservation Service 2007).

Chi-square analysis was used to test for survival differences among treatments (Preacher chi-square online software 2001). One-way analysis of variance was used to test for differences among treatments for continuous variables and correlation analyses were used to test for significant relationships among variables (SPSS 15.0.0., SPSS Inc., Chicago, IL). The significance level was set at α=0.05 for all tests.

RESULTS

Rhizome Characterization

Comparisons of preplanting rhizome morphology among the seven stock types showed that rhizomes differed in diameter ($p<0.001$), number of nodes ($p<0.001$), length of internodes ($p<0.001$), number of buds ($p<0.001$), but not ($p=0.089$) length (Table 2). The range of diameters and internode lengths varied by approximately twofold across stock types and in many cases were distinct when comparing stock types that arose from natural stands versus plantings. Comparing sources grouped as being collected from natural stands vs. plantings (Table 3), rhizomes from plantings were smaller in diameter ($p<0.001$) and were shorter ($p=0.039$), but had more nodes ($p<0.001$) and buds ($p<0.001$), and shorter internode length ($p<0.001$) than those arising from natural giant cane stands.

Table 2.—Mean length, diameter, internode length, and number of nodes and buds for the seven rhizome-only stock types prior to planting in the greenhouse

Stock types	Number of rhizomes	Rhizome diameter (mm)	Rhizome length (cm)	Internode length (cm)	Nodes per rhizome	Buds per rhizome
BR05	40	11.42 a[1]	29.9	4.2 a[1]	7.6 c[1]	3.7 c[1]
BR06	32	10.63 a	29.8	3.1 b	10.3 b	8.0 b
BW06	40	8.26 b	29.4	2.7 bc	11.9 ab	7.2 b
BulkRF06	40	6.55 c	30.0	2.3 cd	14.0 a	9.6 ab
UCRF06	40	6.53 c	28.1	2.1 d	14.0 a	9.8 ab
BRRF06	39	5.46 d	27.0	2.2 cd	13.4 a	9.1 ab
HBRF06	40	5.11 d	28.3	2.2 cd	14.2 a	10.9 a

[1]Means with the same letter within a column are not significantly different according to Tukey's HSD at p=0.05

Table 3.—Mean length, diameter, and the number of nodes and buds combining rhizomes from sources collected from three natural stands or from four field plantings prior to potting rhizomes in the greenhouse

Collection source	Rhizome length (cm)	Nodes per rhizome	Buds per rhizome	Rhizome diameter (mm)
Plantings	28.4 b[1]	13.9 a[1]	9.9 a[1]	5.91 b[1]
Natural stands	29.7 a	9.9 b	6.1 b	10.07 a

[1]Means with the same letter within a column are not significantly different according to Tukey's HSD at p=0.05.

Table 4.-Pearson correlation coefficients and p-values (2-tailed) for morphological traits of bare rhizomes for all sources (N=271)

		Internode length	Rhizome Diameter	Nodes per rhizome	Buds per rhizome
Rhizome length	Pearson r	0.156	0.137	0.037	0.197
	P=	0.010	0.024	<0.001	0.001
Internode length	Pearson r	1	0.621	-0.776	-0.686
	P=		<0.001	<0.001	<0.001
Rhizome Diameter	Pearson r		1	-0.463	-0.428
	P=			<0.001	<0.001
Nodes per rhizome	Pearson r			1	0.784
	P=				<0.001

Correlation analysis showed significant relationships among all rhizome morphological characteristics (Table 4). There were strong positive relationships between internode length and rhizome diameter, and between the number of nodes and buds. Conversely, numbers of buds were negatively correlated with rhizome diameter and internode length.

Propagule Planting

Greenhouse Phase

The C stock type had only 3.7 percent survival. None of the originally existing planted culms from the C+R stock survived. However, 30 percent of the C+R stock formed new culms from buds on the attached rhizomes. Consequently, neither of these stock types was field planted because of low numbers of surviving plants for comparisons.

For bare rhizome stock types, greenhouse survival (or rhizomes that produced surviving culms at the end of the greenhouse growing period) was dependent on treatment and varied greatly when all seven stock types (chi-square; p=<0.001) were compared (Table 5). For other specific comparisons, survival depended on year of collection (storage duration) for those rhizomes collected from a common location in 2005 vs. 2006 (BR05 vs. BR06, p=0.007), stock type for those collected only in 2006 (chi-square; p=0.038), and putative genotype for those of known single origins collected from plantings only (chi-square; p=0.04). Survival was independent of origin for those collected from natural stands (BR06 vs. BW06, p=0.08). Concerning rhizomes from similar origins, survival was also independent of being collected from planted vs. natural stands (BRRF06 vs. BR06, p=0.747).

Table 5.—Greenhouse survival, number of culms per rhizome, and height of tallest culm of the seven bare-rhizome stock types after the greenhouse growing period and prior to field planting

Stock types	Survival (%)	Number of culms	Height of tallest culm (cm)
BR05	20.0	1.3 b[1]	35.8 a[1]
BR06	50.0	1.7 ab	34.5 a
BW06	70.0	2.1 ab	22.0 bc
BulkRF06	75.0	2.0 ab	21.1 bc
UCRF06	70.0	2.4 a	27.2 ab
BRRF06	53.8	2.0 ab	8.4 d
HBRF06	80.0	2.8 a	12.5 cd

[1]Means with the same letter within a column are not significantly different according to Tukey's HSD at p=0.05.

After 6 to 11 weeks in the greenhouse, height of the tallest culm and culm number differed (p<0.001; p=0.004, respectively) among stock types (Table 5). However, when stock types were grouped by collection source (natural stand vs. plantings), rhizomes from natural stands produced fewer (p=0.021) culms ($\bar{x}$=1.9) than those collected from plantings ($\bar{x}$=2.3), but were taller (27.9 cm vs. 17.7 cm respectively, p<0.001).

Since there were differences in morphology among stock types, analyses were completed for each source (Table 6) to identify whether original rhizome characteristics differed between rhizomes that produced live culms versus those that did not (no culm). For a limited number of comparisons by stock type, surviving propagules arose from rhizomes that tended to be larger in diameter, had more buds, and were shorter in length than those that did not produce a living culm (Table 6).

Field Phase

For those rhizomes that produced culms in the greenhouse trial and were planted outdoors (n=105), field survival after one growing season (Table 7) was independent of stock type (chi-square; p=0.674) and year

Table 6.—Rhizome length, diameter, and number of buds for rhizomes with live culms (culms) and without live culms (no culms) of seven stock types after growing 6 to 11 weeks in the greenhouse

Stock type	Rhizome Length(cm)		Buds per Rhizome		Rhizome Diameter(mm)	
	Culm	No culm	Culm	No culm	Culm	No culm
BR05	29.0	30.1	6.0 *[1]	3.1 *	11.21	11.47
BR06	29.2	30.3	9.1	6.9	11.23	10.03
BW06	29.1	30.2	8.3 *	4.7 *	8.40	7.95
BulkRF06	30.5	28.5	10.0	8.5	6.34 *[1]	7.17 *
UCRRF06	27.7	28.9	10.4	8.4	6.24 *	7.19 *
BRRF06	25.3 *[1]	28.9 *	9.6	8.6	5.47	5.44
HBRF06	26.6 *	35.4 *	10.9	10.8	5.06	5.30

[1]Means along a row between culm and no culm producing rhizomes within a characteristic with an (*) are significantly different at p=0.05.

Table 7.—Percentage survival, number of culms, height of the tallest culm for greenhouse-grown, field-planted propagules; and overall survival percentage (a product of greenhouse survival and field survival) of initial rhizomes surviving both greenhouse and field planting with live culms from seven stock types 10 months after field planting

Stock types	Number field planted	Field survival (%)	Number of culms	Height of tallest culm (cm)	Overall survival (%)
BR05	8	75.0	2.3	19.0 a	15.0
BR06	16	75.0	2.5	15.9 ab[1]	37.5
BW06	28	64.3	2.6	13.0 bc	45.0
BulkRF06	30	66.7	2.9	9.7 cde	50.0
UCRF06	28	67.9	3.2	10.7 cd	47.5
BRRF06	21	47.6	2.4	6.2 e	25.6
HBRF06	32	56.3	2.9	7.2 de	50.0

[1]Means with the same letter within a column are not significantly different according to Tukey's HSD at p=0.05.

of collection (BR05 vs. BR06) (chi-square; p=0.617). For those rhizomes collected only in 2006, survival was independent of stock type (chi-square; p=0.207). The percentage of rhizomes that produced culms that survived both greenhouse and field planting (Table 7) was dependent on stock type (chi-square; p=0.005) when the seven stock types were considered. However, survival of culms was independent of collection source (chi-square; p=0.061) when natural stands were compared with plantings.

Height of the tallest culm differed among stock types after one growing season (p<0.001). Rhizomes collected from natural stands tended to be taller (p<0.001), but had similar numbers of culms (p=0.195) in comparison to those collected from plantings (Table 8).

Table 8.—Number of culms and height of tallest culm 10 months after field planting combined across rhizomes collected from three natural stands and four field plantings (n=105)

Collection Source	n	Number of culms[1]	Height, tallest culm[1] (cm)
Natural stands	36	2.5	15.0 a
Plantings	69	2.9	8.7 b

[1]Means with the same letter within a column are not significantly different according to Tukey's HSD at p=0.05.

DISCUSSION

We found less than 4 percent of culm-only (C) propagules still had live culms after 6 weeks in the greenhouse; C propagules did not produce any new culms. Platt and Brantley (1993) reported 40 percent of trimmed culm-only segments had produced new culms, but the new culms were smaller and were produced later than their trimmed culm segments with attached rhizomes. In the current study, the C+R propagules had the original culms die back, but 30 percent did produce newly sprouted culms. Since the original culm of the C+R treatment died back, we do not recommend using intact culms or intact culms with untrimmed attached rhizomes for macropropagules.

Although we did not determine whether new rhizomes were formed from culm-only segments, we observed more than 3,000 pieces (approximately 20 to 50 cm in length) of excavated rhizomes with attached culm segments and saw that new rhizomes did not emanate from bases of culms, but rather from existing rhizomes. This observation suggests that, although culm-only segments may stay alive and even produce new culm shoots, they may not produce the new rhizomes that are important in field establishment and the spread of canebrake communities. Platt and Brantley (1993) did obtain delayed production of shorter than average culms from culm-only stock, but it was unclear from their report whether or not these new culms arose from newly formed rhizomes or from remnant culms without new rhizome formation. Others have concluded that vegetative propagation of temperate bamboo species by culm segments is ineffective (Farrelly 1984, McClure 1993). Our experience with culm-only segments was similar and suggests that if culm segments are to be used, a portion of rhizome should remain attached.

Before attempting to understand giant cane's greenhouse- and field-growth performance, we need to recognize the preliminary "traits" each of the sources have, and how those compare with one another. For the most part, rhizomes from planted stands were smaller in diameter, and had more nodes and buds than those from natural stands. This result may in part reflect the fairly recent establishment of these (approximately 5 years previously), which are still developing compared to the natural stands. Although of unknown age, the natural stands were older (>5 years), more well developed, and had larger aboveground culms. Our results showed that the culm heights were greater when generated from rhizomes collected from relatively undisturbed and established natural stands versus more recently planted stands.

Size potentials of giant cane appear linked to age and site conditions, but specific details are not known (Gagnon 2006). Repeated reduction of culms and leaves by disturbance depletes rhizome stores (Hughes 1966, Marsh 1977). Hughes (1951) noted that appreciable changes in rhizome development from seedlings precede any substantial changes in height. Although the phenotype of the rhizomes in the current study may be related to their growing environment and the age of the stand, phenotype is also influenced by origin (genotype) and ontogeny of the stand. We can see this influence (Table 2) when comparing BRRF06 and BR06. Both stocks originated from Bellrose, but planted BRRF06 was smaller in diameter, with more nodes, and buds compared to the more established natural stand BR06.

The other natural stand source with Bellrose origin (BR05) had differing morphology even compared to BR06. The BR05 source tended to be most morphologically distinct among all sources with fewer nodes and buds, and longer internodes. It also had a larger diameter than all but the BR06 source, which had common origins from the same natural stand. The disturbance of digging rhizomes in 2005 at Bellrose may have stimulated formation of more newly formed rhizomes with differing morphology which were collected in 2006 when digging in the same general area.

Stock type influenced the number of culms generated from rhizomes in the greenhouse. But once those rhizomes with living culms were outplanted, the stock types did not differ in survival in response to field conditions. Considering rhizomes collected only from plantings, origin (putative genotype) influenced production and survival of culms. Differences in culm shoot production among origins have been previously reported (Sexton and others 2003). However, in the current study, survival was not significantly affected—although nearly so ($p=0.08$)—by origin for those collected from natural stands.

If macropropagation techniques are to be employed for large-scale restoration initiatives, knowledge about giant cane's handling and storage constraints would help managers decide on size and scope of plantings. In the current study, year-long refrigerated storage negatively affected survival. It has been recommended that bamboo be collected in the early spring (McClure 1993, Bell 2000) and be planted as soon as possible after digging (Farrelly 1984). Production of any surviving giant cane propagules from rhizomes subjected to year-long storage had not been previously reported although shorter-term storage of 1 month under refrigeration was shown not to be detrimental to survival or production of living shoots (Hartleb 2007). A flexible window of time for collection coupled with extended storage of giant cane could be beneficial to meet management constraints that are affected by available labor, and favorable soil moisture conditions for digging and field planting.

Bell (2000) recommends that for vegetative propagation, cuttings should come from rhizomes no more than 2 years old. In the current study, although rhizome age was undetermined, those from the 5-year-old plantings were more likely to have been younger and ontogenetically more juvenile than those from natural stands of unknown age. As evidence, rhizomes from the plantings tended to be smaller in diameter with shorter, more slender culms. Rhizomes from younger planted stands did have higher survival in the greenhouse; having a higher number of buds may lead to a higher probability of a bud to produce a culm.

It has been recommended that for monopodial bamboo, rhizome propagules be yellowish, 38 to 102 cm long, with at least 10 good buds (Farrelly 1984). In the current study using containers, we used rhizomes that were generally smaller (20 to 44 cm). In our study, surviving rhizomes also tended to be shorter, which differed from a previous experiment using more widely contrasting sizes without containers (Sexton and others 2003), but was similar to that found by Hartleb (2007), who used rhizomes of more similar length using the same type of containers. This difference may be attributed to longer rhizomes having a larger portion of exposed giant cane protruding from the containers which may desiccate the rhizomes when the mist system was off during nighttime hours (Hartleb 2007). Consequently, in containers, long rhizomes are not desirable, but characteristics such as larger diameter and more buds are important for culm production.

We used D40 Deepot containers to meet planting constraints when using machine tree planters. Tree planters cut an approximate 10 cm wide slit in which to plant stock. Within these constraints, using large potted rhizomes is not feasible. Hartleb (2007) showed greenhouse rearing using D40 Deepots prior to field outplanting produced no survival advantage to direct field planting of rhizomes. We also found no significant advantage of growing propagules in the greenhouse with these methods. Planting rhizomes directly in the field required less effort, time, and resources than initial growing in the greenhouse.

Potential culm size (height and diameter) is a reflection of available food reserves in the rhizomes (Bell 2000). Li and others (1998) noted a conspicuous decrease of carbohydrate concentration in the rhizomatous *Phyllostachys pubescens* with development of new shoots. While using longer rhizomes provides more available non-structural carbohydrates, this advantage is lost with container-grown propagules because the exposed section of the rhizomes dries out, perhaps making these carbohydrates unavailable for culm growth. If greenhouse planting utilizing D40 Deepots is to be used for rhizomes, we recommend that the length of the rhizome exposed be limited to a maximum of 7 to 12 cm above the surface of the potting medium and that any exposed roots be removed to reduce surface area.

SUMMARY

This study demonstrated that bare rhizomes can be used to generate greenhouse-grown giant cane plants for use in subsequent field plantings. Intact rooted culms and culms with rhizomes are not recommended for use, nor are bare rhizomes stored 1 year. Our trials stress the importance of stock type to survival and growth of planted giant cane. Both origin (putative genotype) and stand development (collection source) influence survival and growth of culms generated from rhizomes. Obtaining stock directly from natural stands tends to produce taller culms although overall survival was similar to rhizomes collected from plantings. Although it was shown that rhizomes could produce surviving culms even after 1 year in storage, this extended storage period greatly reduced the rhizome viability and is not recommended.

While natural stand rhizomes are larger in diameter and provide taller initial culms, they do not provide the same number of buds per unit length as a plantation source. Having buds that form both new culms and new rhizomes is desirable and choosing propagules with fewer buds lowers any chances of that happening. Macropropagation success in containers can increase with rhizomes that have more buds per unit length and greater diameter.

Developing field-expedient, operationally feasible giant cane restoration techniques would help promote the species' return to sites it once occupied. Propagation by rhizomes has shown to be a viable option, but inadequate knowledge as to the physiological ecology of the species and limited availability of planting material remain a challenge. Continued development of regeneration techniques for this valuable species will provide the knowledge needed for managers and ecologists to restore canebrake ecosystems to the landscape.

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