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Comparative Growth of Giant Reed (*Arundo donax* L.) from Florida, Texas, and California

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ABSTRACT

Giant reed (*Arundo donax* L.) occurs throughout the U.S. from California to Maryland. It is considered an invasive plant in some parts of this range but not others. To test the hypothesis that plants from different regions have similar growth characteristics, we grew plants from stem cuttings collected at two sites in Florida, one site in Texas, and two sites in California in a common garden experiment in Davis, California. Plants were grown outdoors in topsoil or a 90:10 sand:topsoil mix, in large plastic containers. All plants survived winter conditions in Davis, California, during 2004, when the minimum air temperature was -3.3 C. Stem width, number of stems per plant, number of leaves per stem, total leaf area per plant, and RGR_{NSTEMS} did not differ among the provenances studied. Variegated plants had somewhat greater stem angles, indicating that the stems were more prostrate early in the growing season. Differences in stem height, number of internodes per stem, and mean internode distance were consistent with those expected from the inclusion of variegated plants in this study. Plant dry weight differed depending on plant origin and substrate type. Variegated plants weighed less regardless of the substrate. With the exception of a variegated form, plants from disparate geographic locations grew equally well under similar conditions, and no differences in growth characteristics were found that would suggest different invasive potential and impact on resident species.

Key words: Carrizo cane, common garden experiment, elephant grass, leaf nitrogen content, plant architecture, plant dry weight.

INTRODUCTION

Giant reed (*Arundo donax* L.), a rapidly growing invader of riparian habitat throughout the United States (Bell 1997), is a tall perennial reed frequently found growing in or near water and is thus classified as an emergent aquatic plant (Cook 1990). It is similar in appearance to *Phragmites australis* but is larger and more robust in appearance (DiTomaso and Healy 2003). It occurs in large dense clumps up to several meters across, containing stems (up to several hundred per clump) that may reach 8 m in height (DiTomaso and Healy 2003) and produces profuse quantities of biomass (Perdue 1958, Sharma et al. 1998, Spencer et al. 2006) that are quite flammable at the end of the growing season. It has changed control of ecosystem processes in some Californian riparian zones from flood-regulated to fire-regulated (Rieger and Kreager 1989); thus, it may be considered a transformer species in California (Richardson et al. 2000).

The usefulness of giant reed has also been long recognized, however. For example it is a source for high quality reeds for wood wind musical instruments and industrial cellulose (Perdue 1958) and has been considered as a fiber source for paper (Neto et al. 1997, Seca et al. 2000). Both the U.S. and Europe (Faix et al. 1989, Lewandowski et al. 2003) have evaluated the reed as an energy source, leading to interest in establishing farmed stands in several states and in at least one Canadian province. This in turn has raised interest in learning whether giant reed will be a problem invasive species should it escape cultivation where farming operations have been proposed.

Past performance is thought to be the best single predictor of a plant's invasive potential in new habitats (Rejmanek et al. 2005), but there is little information comparing growth responses of giant reed collected from different geographic regions of North America. Such information is important because plant ecotypes are well known in other species (Travis and Futuyma 1993), and existence of giant reed ecotypes would have important implications for evaluating potential invasiveness or alternative management approaches. For example, ecotypes based on differences in growth form and nutritional characteristics are known for other species (Begon et al. 1990), and these traits may affect plant-herbivore interactions. They may also affect the likelihood that plants from one area would be more or less invasive when transported to another for purposes of cultivation. Giant reed is included on the "noxious weed" lists of Texas (Office of the Secretary of State website, http://info.sos.state.tx.us/fids/200701978-1.html, August 13, 2007) and California (http://www.cdfa.ca.gov/phpps/ipc/encycloweedia/pdfs/noxiousweed_ratings.pdf, August 15, 2007), but not Florida (Center for Aquatic and Invasive Plants website, http://plants.ifas.ufl.edu/prohib.html, August 13, 2007). This raises the possibility that giant reed from different regions may not be equally invasive. The history of giant reed introduction into what is now the U.S. is not well known and also suggests the possibility of

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ecotypic differences. One source states that "giant reed was brought to North America quite early, as it was abundant by 1820 in the Los Angeles River" (Dudley 2000). Girant reed was present in southern Texas in the early 1900s (Weaver 1927). Perdue (1958) indicates that giant reed was brought from southern France and other unknown places in the periods in around World Wars I and II and planted in Texas, Georgia, Alabama, and California. Perdue (1958) also states that during the period preceding World War II, plants from existing U.S. plantings that were originally from Iran and Afghanistan were planted at Brownsville, Texas, by the U.S. Department of Agriculture. The fact that U.S. giant reed is from different sources, in conjunction with the fact that it seems to be invasive in some areas (Texas and California) and not others (Florida), is suggestive of different ecotypes.

Here we report results of a common garden experiment conducted in northern California that compared growth and architectural characteristics of giant reed collected from five U.S. locations to test the hypothesis that giant reed from these collections were similar in this regard. We compared these characteristics because growth rate and form are factors in competitiveness of a species (Myers and Bazeley 2003, Westoby and Wright 2006), and high relative physiological performance (Rejmanek 2000) and physiological robustness (Myers and Bazeley 2003) have been related to increased invasiveness.

MATERIALS AND METHODS

We planted giant reed stem cuttings (15 cm long with at least one node present) from five U.S. locations (Figure 1), hereafter referred to as provenances, at a depth of 2.5 cm in individual 76-L rectangular plastic containers (0.44 m length by 0.43 m width by 0.45 m depth) filled with either topsoil or a 90:10 mixture of sand and topsoil. We used two soil types because giant reed has been reported to grow well in all types of soils from heavy clays to gravelly soils and to grow better in soils with higher nitrogen (N) content (Perdue 1958, Quinn and Holt 2007). Topsoil nitrate-N was 5.5 mg kg^{-1}, Olsen extractable P was 14.0 mg kg^{-1}, and exchangeable K was 60 mg kg^{-1} (University of California ANR Analytical Laboratory, http://danranlab.ucdavis.edu, February 15, 2007). Thus, we expected nutrient levels in the 90:10 mixture of sand and topsoil to be approximately 10% of those in the topsoil alone. The topsoil values are similar to those reported for Cache Creek, California, giant reed sites (Spencer et al. 2005).

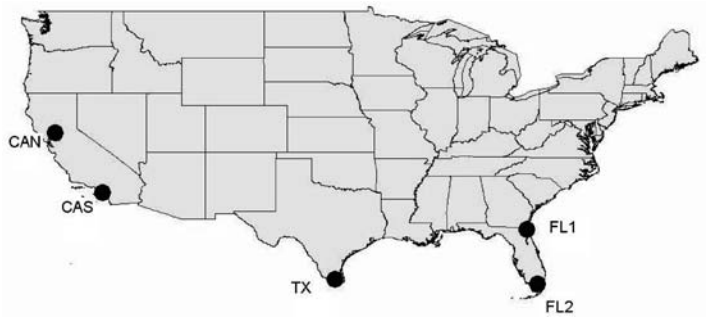

Figure 1. Locations of giant reed sources used in this experiment. Latitude and longitude were California North (CAN), 38°38.294 N, 121°51.496 W; California South (CAS), 33°33.718'N, 117°43.107'W; Florida 1 (FL1), 30°25.417'N, 81°36.996'W; Florida 2 (FL2), 25°45.041'N, 80°36.996'W; Texas (TX), 26°12'52"N, 97°59'53"W.

Initial plantings of stem cuttings were made on May 24, 2004. Due to poor sprouting, Florida 1 (FL1) was replanted on July 15, 2004, and Florida 2 (FL2) was replanted on July 19, 2004. The cuttings designated as FL2 were from variegated plants. (Variegated plants have patches of tissue that lack pigments that may in turn lead to reduced growth.) Because we had to replant the Florida plants, we only present data from 2005. Aboveground plant material was harvested on September 23, 2005; the belowground plant material was harvested on October 12, 2005. All plant material was washed to remove soil particles, separated in shoots, rhizomes, and roots, dried at 80 C for 48 h, and weighed. The belowground:aboveground biomass ratio was calculated by dividing the sum of root and rhizome weights by the sum of shoot weights.

At weekly intervals between February and September 2005, leaves from each container were measured with a Minolta SPAD 502 Chlorophyll Meter (Konica Minolta Photo Imaging (HK) Ltd., Hong Kong). Leaf nitrogen content (N, % dry weight) was estimated from SPAD readings using equations derived from field collected plants (Spencer et al. 2007).

At bi-weekly intervals during this period the number of stems per plant was counted. These data were used to calculate the rate of stem production (RGR_{NSTEMS}) by linear regression of the log (number of stems) versus sample date. The resulting regression coefficients (i.e., slopes) were used as RGR_{NSTEMS}.

We determined plant architecture characteristics on June 30 and September 22, 2005, by digitizing each plant using a Fastrak three-dimensional magnetic impulse digitizer (Polhemus, Colchester, Vermont) in conjunction with Floradig software (Hanan and Room 2000). Using data transmitted by Fastrak, the Floradig software calculated mean stem angle, internode length, basal stem width, and leaf area. We calculated stem height by summing the internode lengths. For these two dates we also derived the number of stems for each plant, the number of leaves on each stem, and the number of internodes in each stem from the Floradig calculated data.

Data were checked for homogeneity of variances and normality of error distributions prior to further analysis. When necessary to remove heterogeneity of variance, an appropriate transformation was applied before performing analysis. A mixed model analysis was fitted using SAS software, PROC MIXED (Litell et al. 2006), considering provenance, substrate, and date as fixed effects and plant and stem as random effects. Significance testing was performed for all fixed effects and all possible interactions among them. Measurements taken on a whole plant basis utilized "between" and "within plants" variance measures. When multiple stems were measured, an additional variance of stem within plant was needed. Count variables (number of stems per plant, number of internodes per stem, and number of leaves per stem), which could not meet the normal distribution assumption, required a Generalized Linear Mixed Model and were fitted with SAS PROC GLIMMIX. Tests were considered significant at a probability level below 0.05; however, exact probability levels for fixed effect tests are shown in the results. For the biomass data and RGR_{STEMS}, which were only de-

termined at the end of the experiment, an analysis of variance was calculated using PROC GLM in SAS (SAS Institute, Inc. 2004), with provenance and substrate type as the treatments. When Provenance or Provenance × Date or Provenance × Substrate was significant below P = 0.05, mean comparisons were computed using Sidek's adjusted t-tests for the means as estimated by least squares.

RESULTS AND DISCUSSION

All plants survived outdoor conditions during winter 2004-2005 in Davis, California. Air temperature data (UC IPM Online, Statewide Integrated Pest Management Program, http://ipm.ucdavis.edu, February 15, 2007) indicate that the mean daily temperature was less than 9 C on 25% of the days between September 1, 2004, and May 1, 2005. The lowest daily minimum temperature during this period was -3.3 C.

Stem widths were within the reported range (10-40 mm) for giant reed (DiTomaso and Healy 2003) and were not significantly affected by either substrate type or provenance (Tables 1 and 2). Mean stem angles (measured from the vertical) were affected by both sampling date and provenance. Greater stem angles were produced by FL1 and FL2 plants, indicating that the stems were slightly more prostrate initially (Tables 1, 2, and 5). Mean stem angles decreased with time as the stem produced internodes that were more upright. The number of stems per plant was affected by substrate early in the growing season but not later. Provenance did not significantly affect this characteristic (Tables 1 and 2).

The number of leaves per stem increased over time. The significant two-way interaction term for date and provenance indicates that plants from FL1 and FL2 changed more over time than plants from other provenances (Tables 1 and 2). The significant two-way interaction term between date and substrate indicates that plants grown on sand changed more over time than plants grown on soil (Tables 1 and 2). Stem length for plants grown in soil was greater than for those grown in the sand mixture, and there were significant differences due to provenance and sampling date as well (Tables 1, 3, and 5) with shorter stems for the FL2 provenance. Mean internode length was significantly shorter for FL1 and FL2 compared to mean internode lengths from other provenances, which overlapped (Tables 1, 3, and 5). Mean internode length was significantly greater for plants grown in soil (Tables 1, 3, and 5). The number of internodes per stem was significantly reduced for FL2 compared to Texas (TX) and California North (CAN) plants (Tables 1, 3, and 5). However, this difference was no longer significant on the second sampling date. Total leaf area per plant was affected by substrate early in the growing season but not later, as indicated by the significant interaction term between substrate and date (Tables 1 and 3).

The RGR_{NSTEMS} varied from 0.0006 to 0.005 stems stem^{-1} day^{-1}; RGR_{NSTEMS} did not differ significantly among substrate types or provenance (Figure 2; Table 4). The production of new stems is one of three methods (the other two being layering and re-growth from fragments) by which giant reed occupies new areas and thus spreads (Boose and Holt 1999, Decruyenaere and Holt 2001, Boland 2006, Spencer and Ksander 2006). Giant stems are closely packed and maintain their interconnection for long periods. In the parlance of Lovett Doust and Lovett Doust (1982), giant reed is a phalanx invader. Thus, the fact that RGR_{NSTEMS} did not differ among the provenances examined implies that they would spread by

TABLE 1. SUMMARY STATISTICS FOR GIANT REED MORPHOMETRIC CHARACTERISTICS FOR PLANTS COLLECTED FROM FIVE SOURCES (SEE FIGURE 1) AND GROWN IN TWO SUBSTRATES DURING 2005. THE FL2 PLANTS WERE VARIEGATED. STEM ANGLE IS A MEASURE OF DEPARTURE FROM VERTICAL. "SAND" WAS A 90:10 MIXTURE OF SAND AND TOPSOIL.

			Stem width (mm)		Stem angle		Number of stems		Number of leaves per stem		Stem length (mm)		Internode length (mm)		Number of internodes	
Substrate	Date	Provenance	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Sand	06/30	CAN	25.4	2.9	25.4	2.9	7.8	0.5	7.7	0.6	570.3	29.3	35.0	1.2	16.2	0.7
Sand	06/30	CAS	19.4	2.0	19.4	2.0	10.0	1.7	6.8	0.6	462.2	38.4	31.8	2.0	13.8	0.8
Sand	06/30	FL1	19.0	2.0	19.0	2.0	7.5	0.6	7.5	0.7	332.9	31.6	22.3	1.0	14.2	1.0
Sand	06/30	FL2	16.0	0.7	16.0	0.7	7.7	0.5	7.5	0.4	262.3	13.4	19.9	0.5	12.8	0.5
Sand	06/30	TX	17.8	1.0	17.8	1.0	7.6	0.8	7.6	0.6	661.5	44.8	40.8	2.0	15.7	1.0
Sand	09/22	CAN	15.9	1.3	15.9	1.3	10.0	0.8	9.7	0.9	616.3	44.0	32.0	1.8	17.2	1.0
Sand	09/22	CAS	17.5	1.4	17.5	1.4	11.8	2.1	9.6	1.0	594.0	54.2	31.5	2.4	16.8	1.1
Sand	09/22	FL1	15.5	1.0	15.5	1.0	10.0	0.8	10.2	0.9	422.4	32.1	22.4	1.3	16.8	1.0
Sand	09/22	FL2	16.1	0.9	16.1	0.9	10.6	0.6	11.7	0.7	365.2	22.5	19.7	0.9	16.3	0.8
Sand	09/22	TX	16.4	1.2	16.4	1.2	9.4	1.0	9.0	0.9	751.0	54.5	37.4	2.1	17.8	1.1
Soil	06/30	CAN	18.9	1.2	18.9	1.2	8.4	0.7	8.3	0.5	688.5	36.4	39.5	1.3	17.4	0.9
Soil	06/30	CAS	18.7	2.1	18.7	2.1	9.0	1.0	7.6	0.9	560.5	52.2	34.4	2.5	15.1	1.1
Soil	06/30	FL1	19.3	1.1	19.3	1.1	8.4	0.5	8.1	0.6	388.0	30.3	26.3	1.2	14.1	0.8
Soil	06/30	FL2	20.5	1.4	20.5	1.4	10.6	1.1	7.6	0.4	392.3	21.7	25.5	0.8	14.7	0.6
Soil	06/30	TX	19.0	1.0	19.0	1.0	10.5	1.0	7.5	0.6	769.0	50.3	44.1	1.9	16.9	1.1
Soil	09/22	CAN	17.2	1.6	17.2	1.6	10.0	1.0	9.1	0.7	683.4	41.7	33.6	1.7	18.4	1.1
Soil	09/22	CAS	15.6	1.3	15.6	1.3	10.7	1.2	8.2	1.1	641.7	60.9	33.1	2.5	16.9	1.4
Soil	09/22	FL1	17.2	1.0	17.2	1.0	10.2	0.8	10.1	0.9	492.1	38.3	25.8	1.4	17.1	1.1
Soil	09/22	FL2	18.4	1.2	18.4	1.2	12.3	1.3	9.1	0.7	459.5	25.8	23.2	1.0	17.7	0.9
Soil	09/22	TX	21.4	1.9	21.4	1.9	11.6	1.7	8.3	0.7	898.9	69.5	43.7	2.4	18.7	1.1

TABLE 2. RESULTS OF ANALYSIS OF VARIANCE USING PROC MIXED AND PROC GLMMIX FOR MORPHOMETRIC CHARACTERISTICS FOR GIANT REED FROM FIVE LOCATIONS GROWN IN TWO SUBSTRATE TYPES.

Effect	Num DF	Den DF	F Value	Pr > F
Basal Stem Width (reciprocal square root transformation)				
Provenance	4	45.8	0.53	0.72
Substrate	1	45.8	2.36	0.13
Provenance × Substrate	4	45.8	0.80	0.53
Date	1	528.0	0.64	0.42
Provenance × Date	4	528.0	1.14	0.34
Substrate × Date	1	528.0	1.74	0.19
Provenance × Substrate × Date	4	528.0	1.34	0.26
Stem Angle				
Provenance	4	42.8	11.98	<0.0001
Substrate	1	42.9	0.74	0.39
Provenance × Substrate	4	42.8	0.23	0.92
Date	1	409.0	31.20	<0.0001
Provenance × Date	4	409.0	0.42	0.79
Substrate × Date	1	409.0	0.28	0.60
Provenance × Substrate × Date	4	409.0	0.51	0.73
Stems per plant				
Provenance	4	42.8	0.58	0.68
Substrate	1	42.8	1.63	0.21
Provenance × Substrate	4	42.8	0.71	0.59
Date	1	40.8	294.72	<0.0001
Provenance × Date	4	40.8	0.99	0.42
Substrate × Date	1	40.8	5.52	0.02
Provenance × Substrate × Date	4	40.8	2.38	0.07
Leaves per stem				
Provenance	4	413.9	0.75	0.56
Substrate	1	414.6	0.15	0.70
Provenance × Substrate	4	413.6	0.52	0.72
Date	1	989.0	76.85	<0.0001
Provenance × Date	4	989.0	3.39	0.009
Substrate × Date	1	989.0	12.96	0.0003
Provenance × Substrate × Date	4	989.0	0.89	0.47

this method at similar rates. We did not observe layering in this study, but the growth conditions we used may not have been suitable for its occurrence.

Stem width, number of stems per plant, number of leaves per stem, total leaf area per plant, and RGR_{NSTEMS} did not differ significantly among the provenances studied. Differences in stem height, number of internodes per stem, and mean internode distance were consistent with those expected from the inclusion of variegated plants (FL2) in this study (i.e., variegated plants were smaller than the other plants). A comparative study of variegated and completely green forms of *Agonis flexuosa* and *Nerium oleander* indicated that the variegated forms weighed less and had less leaf area per plant than did the completely green forms (Downton and Grant 1994). Similar results (i.e., variegated plants weighed less, produced less leaf area per plant, and were shorter than fully green forms) were reported for variegated and fully green forms of *Hedera helix* grown under identical conditions (Li et al. 2000). The minor differences in plant architecture characteristics noted in this study for the other giant reed provenances (i.e., nonvariegated) imply that invasive potential and impact on resident species would be similar.

Total dry weight was affected by provenance and substrate (Figure 3; Table 4). Differences due to provenance are related to the lower dry weights for variegated plants (Figure 3; Table 5). These results differ somewhat from those of Cosentino et al. (2006) who evaluated biomass and morphological characteristics for 39 giant clones collected from locations in Sicily and Calabria, Italy. They reported that plant biomass, stem weight, stem density, and stem height varied significantly among clones; however, they evaluated a greater number of clones than the present study. It is also possible that plants introduced to the U.S. from Europe in the early part of the 20th century (Perdue 1958) represented a reduced set of clonal diversity compared to that available throughout Europe.

On average the proportion of giant reed underground biomass is equal to shoot biomass (belowground:aboveground ratio of 1.01 for all plants combined), but the range from 0.43 to 1.71 indicated considerable variation. The belowground:aboveground ratio was influenced by provenance and substrate type (Figure 3; Table 4 and 5) due to the significantly lower values for plants from Texas that allocated more biomass to shoots than plants from the other provenances in this experiment. The belowground:aboveground ratios were

TABLE 3. RESULTS OF ANALYSIS OF VARIANCE USING PROC MIXED AND PROC GLMMIX FOR MORPHOMETRIC CHARACTERISTICS FOR GIANT REED FROM FIVE LOCATIONS GROWN IN TWO SUBSTRATE TYPES.

Effect	Num DF	Den DF	F Value	Pr > F
Stem length (log transformation)				
Provenance	4	44.7	20.64	<0.0001
Substrate	1	44.7	5.40	0.02
Provenance × Substrate	4	44.7	0.12	0.97
Date	1	424.0	84.47	<0.0001
Provenance × Date	4	424.0	0.90	0.46
Substrate × Date	1	424.0	0.32	0.57
Provenance × Substrate × Date	4	424.0	0.10	0.98
Mean internode length (log transformation)				
Provenance	4	44.8	45.43	<0.0001
Substrate	1	44.8	9.24	0.004
Provenance × Substrate	4	44.8	0.19	0.94
Date	1	427.0	2.65	0.10
Provenance × Date	4	427.0	1.04	0.39
Substrate × Date	1	427.0	0.01	0.93
Provenance × Substrate × Date	4	427.0	0.28	0.89
Number of internode per stem				
Provenance	4	421.9	3.51	0.008
Substrate	1	421.4	2.87	0.09
Provenance × Substrate	4	421.9	0.30	0.88
Date	1	989.0	276.41	<0.0001
Provenance × Date	4	989.0	2.79	0.03
Substrate × Date	1	989.0	1.37	0.24
Provenance × Substrate × Date	4	989.0	0.40	0.81
Total leaf area per plant (reciprocal square root transformation)				
Provenance	4	42.8	1.78	0.15
Substrate	1	42.8	11.49	0.002
Provenance × Substrate	4	42.8	0.79	0.54
Date	1	42.3	72.92	<0.0001
Provenance × Date	4	42.3	1.97	0.12
Substrate × Date	1	42.3	17.93	0.0001
Provenance × Substrate × Date	4	42.3	0.26	0.90

greater for plants on sand than on soil. The present data have a larger range than those of Sharma et al. (1998), who reported giant reed above- and belowground dry weights for plants from two sites near Jaipur, India. The ratios of belowground:aboveground biomass calculated from their data ranged from 0.23 to 1.33 with an average value of 0.70, n = 4. But, Sharma et al. (1998) only excavated belowground biomass to 0.5 m depth, which may underestimate belowground biomass because giant reed roots reportedly penetrate to 1 m depth (Lewandowski et al. 2003).

Leaf nutrient concentrations determine to some degree a plant species' functioning within a habitat (Aerts and Chapin 2000) and therefore are an indicator of the suitability of a particular habitat for giant reed growth. Giant reed leaf N differed significantly over time and among provenances. Leaf N values reached a peak in March and April except for variegated plants (Figure 4; Table 4). Values after April fluctuated around 2%. Leaf N for the variegated plant varied less and was always between 1 and 2%. The values for plants grown in topsoil were similar to those grown in the 90:10 sand:toposil mix. In all cases, peak spring values in this experiment were less than the 3 to 4% range reported from giant reed plants growing in a natural setting at Cache Creek, California (Spencer et al. 2005). Giant reed from the provenances we examined seem to tolerate a wide range of nutrient levels in the substrate. The variability in leaf N among provenances implies that insect herbivores that feed on giant reed leaves may exhibit different development times and

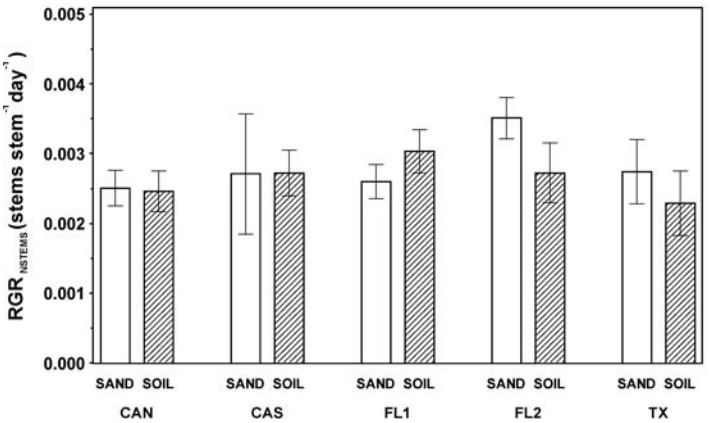

Figure 2. Mean (±95% confidence interval) RGR_{NSTEMS} for giant reed from five locations on two dates. The FL2 plants were variegated.

TABLE 4. RESULTS OF ANALYSIS OF VARIANCE USING PROC MIXED AND PROC GLM FOR LEAF N CONTENT, BIOMASS, AND GROWTH RATE VALUES FOR GIANT REED FROM FIVE LOCATIONS GROWN IN TWO SUBSTRATE TYPES. NOTE THE VALUES FOR RGR_{NSTEMS} WERE MULTIPLIED BY 1000 TO AVOID LOSS OF ACCURACY DUE TO ROUNDING ERRORS, AND THE VALUES FOR SUM OF SQUARES AND MEAN SQUARES LISTED BELOW FOR THOSE VARIABLES REFLECT THIS FACT.

Effect	Num DF	Den DF	F Value	Pr > F
Leaf N content				
Provenance	4	43.2	21.42	<0.0001
Substrate	1	43.2	0.10	0.76
Provenance × Substrate	4	43.2	1.00	0.42
Date	23	901.0	14.25	<0.0001
Provenance × Date	92	917.0	2.33	<0.0001
Substrate × Date	23	901.0	0.77	0.77
Provenance × Substrate × Date	92	917.0	0.87	0.81

Effect	DF	Sum of squares	Mean square	F Value	Pr > F
RGR_{NSTEMS}					
Provenance	4	0.06	0.006	1.57	0.20
Substrate	1	0.009	0.009	2.31	0.14
Provenance × Substrate	4	0.03	0.07	1.74	0.16
Error	43	0.17	0.04		
Corrected Total	52	0.23			
Total dry weight (log transformation)					
Provenance	4	0.93	0.23	4.22	0.007
Substrate	1	0.34	0.34	5.95	0.018
Provenance × Substrate	4	0.39	0.10	1.68	0.170
Error	43	2.48	0.06		
Corrected Total	52	4.38			
Belowground:Aboveground biomass ratio					
Provenance	4	1.45	0.36	7.72	<0.0001
Substrate	1	0.26	0.26	5.61	0.02
Provenance × Substrate	4	0.23	0.06	1.22	0.31
Error	43	2.01	0.05		
Corrected Total	52	4.00			

adult weights, especially if feeding upon variegated forms (Wheeler 2001). This could be an important factor in future biological control efforts.

Rejmanek et al. (2005) conclude that knowing whether a particular species is invasive elsewhere can help managers decide the likelihood that it will be invasive in new areas; spe-

TABLE 5. RESULTS OF SIDEK'S ADJUSTED T-TEST, MEANS COMPARISON PROCEDURE USING THE LEAST SQUARE MEANS FOR VARIABLES THAT HAD A SIGNIFICANT MAIN EFFECT DUE TO "PROVENANCE" OR WITH A SIGNIFICANT INTERACTION TERM THAT INCLUDED "PROVENANCE." SIGNIFICANT DIFFERENCES AMONG PROVENANCES ($P < 0.05$) ARE INDICATED BY THE PRESENCE OF DIFFERENT UPPERCASE LETTERS. COMPARISONS WERE FOR MEANS POOLED ACROSS DATES EXCEPT FOR TWO VARIABLES THAT HAD SIGNIFICANT INTERACTION TERMS FOR DATE AND PROVENANCE. IN THOSE CASES, MEAN COMPARISONS WERE MADE WITHIN EACH DATE AND THE RESULTS FOR EACH DATE ARE INDICATED BELOW.

		Provenance				
Variable		CAN	CAS	TX	FL1	FL2
Stem Angle		B	AB	B	A	A
Stem Length		AB	BC	A	CD	D
Internode Length		AB	B	A	C	C
Number of internodes per stem[1]	6/30/05	A	AB	A	AB	B
	9/22/05	A	A	A	A	A
Leaves per stem[2]	6/30/05	A	A	A	A	A
	9/22/05	A	A	A	A	A
Total Dry Weight		AB	A	A	AB	B
Belowground:aboveground Ratio		A	A	B	A	A

[1]For this variable the interaction between Provenance and Date was due to differences among provenances on the first date but not the second.
[2]For this variable there were no significant differences among provenances on either sampling date. The significant interaction was due to the fact that the differences between dates were of different magnitudes.

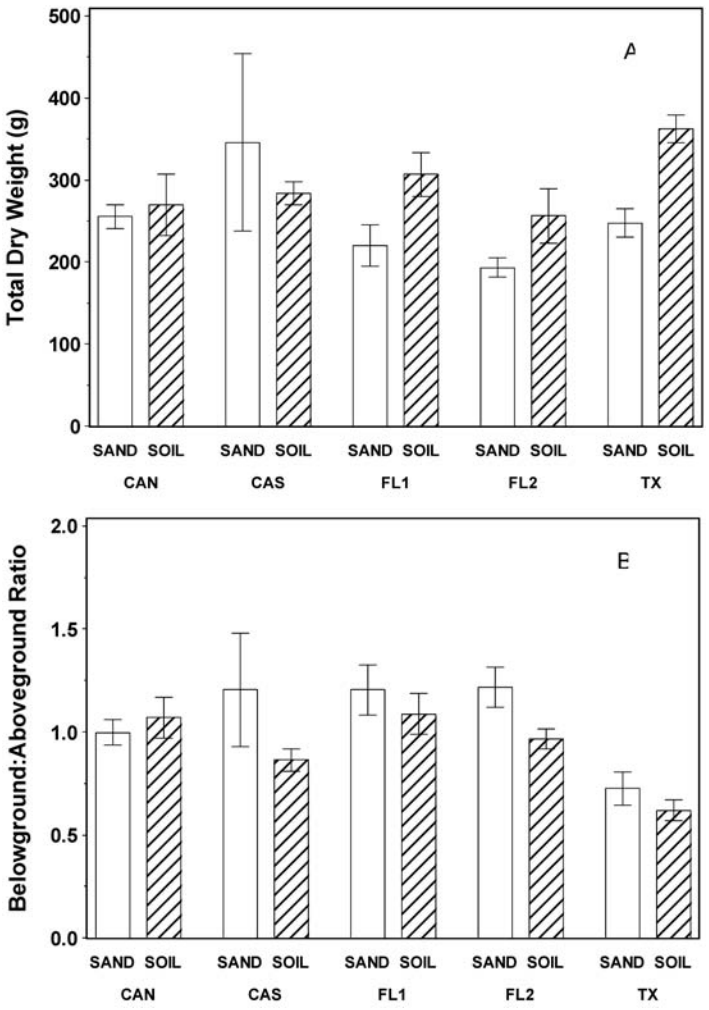

Figure 3. Mean (±95% confidence interval) plant weight (A) and belowground:aboveground biomass ratio (B) for giant reed from five locations on two dates. The FL2 plants were variegated.

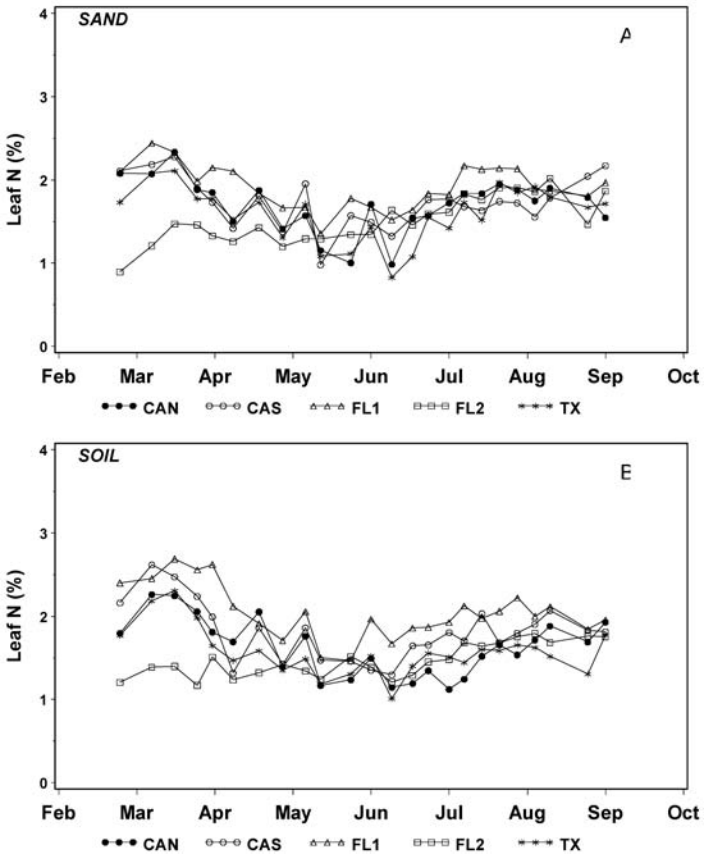

Figure 4. Estimated mean nitrogen content (%, dry weight) for giant reed leaves for plants from five locations grown in 90:10 sand:topsoil mixture (A) and 100% topsoil (B). Error bars have not been included to improve clarity. The FL2 plants were variegated.

cies that invade in one area have a high likelihood of being invasive in other habitats. With the possible exception of the variegated form from Florida and the lower belowground:aboveground ratio of plants from Texas, this comparative study did not detect large differences in growth or architectural characteristics among giant reed from widely disparate geographic locations grown under similar conditions, and thus provides little evidence suggesting the giant reed provenances examined would express differences in invasive potential or impact on resident plant communities. Nonvariegated plants from more southerly latitudes performed as well as more northerly collections in this common garden experiment conducted at a latitude that may be near the northern extent of this species' distribution in the U.S.

Results of this experiment may be limited by ambient conditions in Davis, California, during the experimental duration. Environmental factors that differ between this site and those found in more southerly latitudes may limit the invasiveness of this species, but there is little evidence that intrinsic growth capabilities distinguish nonvariegated plants from the geographic locations examined here. Although these results agree with the low degree of clonal diversity among North American specimens recently observed by Ahmad et al. (unpublished data), they may not apply to all horticultural varieties of giant reed. Given this information, it may be prudent to monitor areas adjacent to those where giant reed is cultivated to minimize impacts from escaped plants.

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