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Nutrient and Physical Soil Characteristics of River Cane Stands, Western North Carolina

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ABSTRACT *Arundinaria gigantea* (Walt.) Muhl., commonly called river cane, is a member of the grass family (*Poaceae*). The primary purpose of this research is to characterize the physical and chemical properties of the soils of existing stands of *A. gigantea* in western North Carolina and to provide guidance for the restoration of river cane to the stream valleys of the Southern Appalachian Mountains. We analyzed soils at 20 sites in Cherokee, Jackson, and Macon Counties in North Carolina and collected data on soil characterization, nutrient levels, bulk density, particle size, pH, and hydraulic conductivity. River cane soils varied significantly for carbon, nitrogen, phosphorus, and sand levels, even within the same watershed (ANOVA, $p < 0.05$). Typical soils are very sandy, mineral soils with low carbon levels and low nutrient levels. Soils are well drained, have very low bulk densities, and low pH. Despite low nutrient conditions, the plant does not appear to be nutrient limited. Restoration potential for the species is high, but more research is required to determine specific limitations on growth.

INTRODUCTION *Arundinaria gigantea* (Walt.) Muhl., river cane, is a species of the grass family (Poaceae) and one of three North American members of the subfamily *Bambuseae* (Clark and Triplett 2007). From an environmental perspective, river cane has potential as a riparian buffer reducing agricultural runoff and stream nutrient loading and may stabilize eroding river banks (Schoonover and Williard 2003; Schoonover et al. 2005, 2006). In this study, we characterized the soil, nutrient and drainage conditions of river cane stands in western North Carolina to provide guidance for the restoration of river cane to the stream valleys of the Southern Appalachian Mountains.

Arundinaria gigantea grows from Maryland to Florida and west to Ohio, Missouri and Texas (Ohrnberger 1999, Weakley 2008). Soils in which it grows range from 90% silt and clay (Schoonover et al. 2005) to primarily sand (Farrelly 1984). In western North Carolina, river cane grows abundantly on floodplains of rivers and streams in sandy soils (Griffith et al. 2007). *Arundinaria gigantea* is prominent on cleared pastureland and occurs locally as an understory plant in mixed hardwood forests. *Arundinaria gigantea* grows on well-drained sites (Cirtain et al. 2004) more frequently than its congener, *A. tecta*, which has rhizomatous air canals (Weakley 2008) and grows mainly in saturated soils. The current geographic distribution of river cane is similar to the historically observed distribution (Platt and Brantley 1997), but the area of canebrakes has been reduced by 98% (Noss et al. 1995).

Locally, river cane is now only found on narrow strips on floodplains of rivers and streams. Interest for restoration of this species is high, but ideal habitat parameters are unknown, making the critical task of site selection more difficult. In order to identify the ideal habitat parameters for river cane, it was necessary to determine whether or not there were significant differences among canebrake soils. If there is not, then the parameters we describe will be considered the ideal growth habitat. If significant statistical variation is found, then other factors

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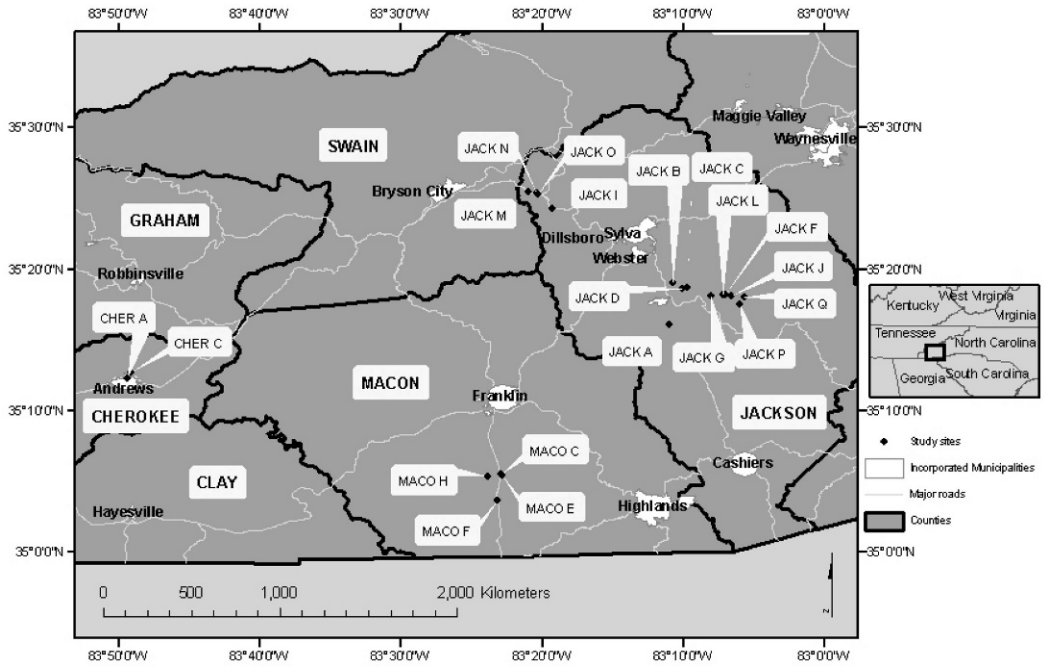

Figure 1. River cane soil study sites in Cherokee, Jackson, and Macon Counties in western North Carolina.

besides chemical and physical properties may be controlling the distribution of *A. gigantea*. These may include competition, anthropogenic influence or other factors.

The primary purpose of this research is to establish characteristics and properties of soils where *A. gigantea* grows in western North Carolina with the overarching objective of identifying ideal restoration sites. Specific project goals are to characterize cane brake soils and to quantify micro and macronutrients, particle size, bulk density, and *in situ* hydraulic conductivity. Other goals are to assess differences between and among sites and elucidate the relationship, if any, between fine sediment and nitrogen, phosphorus, and carbon. Lastly, this project sought to describe sites in a geomorphic context, both qualitatively and quantitatively, and using GIS software.

Twenty sites were chosen using a database that we developed of river cane sites in western North Carolina, from three river basins: the Tuckasegee, Little Tennessee, and Hiawassee Rivers. The study sites are in Jackson, Macon, and Cherokee Counties (Figure 1).

MATERIALS AND METHODS We removed a 1 m soil core from within 10 m of the GPS position for each site for characterization using an Eijkelkamp Dutch Auger with a 2 cm diam core barrel. Soil characterization included Munsell soil colors, texture using the ''feel'' method (Brady and Weil 2002), mottles, and any other distinguishing characteristics. Soil characterization is a general term for describing soil properties such as color, texture, stickiness, consistency, and structure and is useful when comparing soils. Characterization results may be impacted by the type and number of soil mineral and organic constituents and degree of soil formation. Soil characterization data for non-cane sites were obtained from Soil Survey Staff (2008a).

To quantify particle size and nutrient levels, including C:N ratios, we collected four 30 cm soil cores using a 10.2 cm diam mud/clay auger at each site along a 10 m transect within each canebrake. We used the Mehlich III extraction method to remove the nutrients from soil that might be readily available to plants (Mehlich 1984). In addition to the Mehlich III method, we used a sequential acid extraction technique for P because it was below detection limits using the Mehlich III method at some sites. We analyzed, in triplicate, 1 g sub-samples of calcium (Ca), phosphorus (P), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and zinc

(Zn) using inductively coupled plasma optical emission spectroscopy (ICP-OES) for detection. The ICP-OES detection method was used for all analyses with the exception of K. Flame atomic absorption was used for K analyses.

We used an Elementar Vario EL III Elemental Analyzer running Vario EL software to analyze bulk C, N, and S. Sediment samples were first dried at 60°C in an oven for two days and were then ground using a mortar and pestle. Four, 1 g sub-samples of each soil sample were analyzed for total organic carbon, total nitrogen, and total sulfur. We analyzed sub-samples from each site in duplicate (standard deviations for duplicate samples were all <5%) and also calculated C:N ratios. C:N ratios are useful indicators of site suitability for vegetation types (Yamakura and Sahunalu 1990) and N is often limiting for plants.

The Environmental Geology Laboratory (EGL) at Bates College analyzed a sample of *Arundinaria gigantea* for C isotope values. The $\delta^{13}C$ value for *A. gigantea* is reported relative to the Pee Dee Belemnite (PDB) standard. We measured soil pH at seven sites using a YSI 556 Multi-probe system and methodology from the Soil and Plant Analysis Council (1992).

To quantify bulk density, we collected four cores at each site within a 10 m radius of the GPS coordinate for each study site using a coring device following methodology outlined by Blake and Hartage (1986). Bulk density, the mass of soil solids per unit volume of soil, is the inverse of soil porosity and is useful when comparing soils for vegetation analyses. Low values of bulk density (<1 g/cm^3) are associated with organic-rich and wetland soils; soils with large mineral fractions typically have high bulk densities. Bulk density generally increases with depth from the surface because roots and associated fauna decrease with depth. The Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado at Boulder analyzed our soil sub-samples for particle size using a Malvern, long bed Mastersizer. Particle size can serve as proxy for nutrient availability and other abiotic factors such as moisture retention.

A compact constant head permeameter (CCHP)(Amoozegar 1989a) was used for K_{sat} measurements in river cane soil boreholes. Conceptually, K_{sat} expresses how easily water flows through the soil, so a high value of K_{sat} indicates that water moves rapidly. Large, interconnected pores, typical of sandy soils, are associated with high values of K_{sat} and clay soils with small disconnected pores have K_{sat} values that are orders of magnitude lower than sandy soils (Freeze and Cherry 1979). Standard procedures outlined in Amoozegar (1989b) guided measurements at all 20 study sites. Values of saturated hydraulic conductivity (K_{sat}) provide a quantitative description of the drainage status of the soil (e.g., well-drained, poorly-drained, etc.).

We used software (SAS 2003) to analyze differences in bulk P, percent C, percent N, and percent sand at 19 of the 20 sites. Site CHER C was excluded because one soil core from this site was lost. SAS software transformed the percent data using an arcsine transformation, performed a MANOVA, and calculated Pearson's correlation coefficients for sediment size versus P, N, and C. We performed subsequent ANOVAs for the same variables at a significance level of $p = 0.05$ also using SAS software. One way ANOVAs were also performed on sites from one sub-watershed, Caney Fork, for the same four parameters at the same significance level.

GPS software (GPS Pathfinder Office 2002) used site longitude and latitudes to determine site elevations. Horizontal and vertical accuracies are less than 2 m. We determined river sinuosity (the actual length divided by the straight line-length) and watershed area of the river channel adjacent to study sites using software (RiverTools 2008) on a 1/3 arcsecond scale United States Geological Survey (USGS) digital elevation model (DEM). Reported areas of sites are from Bugden et al. (2006) and are based on 2006 study site perimeters. Reported soil types are from Soil Survey Staff (2008a) and general soil properties from Soil Survey Staff (2008b).

RESULTS The typical 1 m soil core from a Dutch auger consisted of four similar layers of sand and sandy loam with Munsell values of approximately 10 YR 3/3. Munsell values quantify soil color with regard to hue, value, and chroma. In this case, 10 YR refers to the hue of the soil, three refers to the value, and the second three refers to the chroma. A conceptual, vertical model for the soil includes an extensive litter layer, and a rhizome-rich, porous A horizon which extends

Table 1. Mean nitrogen, carbon, and sulfur values for each study site. Values represent total elemental values, not specific chemical components (e.g., ammonium). Means are from duplicate runs from four soil cores at each site

Site	% N	% C	% S	C:N Ratio
CHER A	0.1452	2.0170	0	13.72
CHER C	0.3474	5.1121	0	14.83
JACK A	0.2427	3.3583	0	13.88
JACK B	0.0865	1.1703	0	13.38
JACK C	0.2201	3.2151	0	14.79
JACK D	0.1255	1.4607	0	11.63
JACK F	0.1487	1.9105	0	12.76
JACK G	0.1437	1.7317	0	12.05
JACK I	0.0945	1.1368	0	11.81
JACK J	0.1073	1.2251	0	11.28
JACK L	0.1758	2.4506	0	13.82
JACK M	0.1897	2.5718	0	13.49
JACK N	0.1656	1.9216	0	11.55
JACK O	0.1994	2.5028	0	12.55
JACK P	0.1895	2.6324	0	13.72
JACK Q	0.1351	1.8295	0	13.65
MACO C	0.2225	2.9251	0.0490	13.15
MACO E	0.1752	2.3914	0	13.66
MACO F	0.1917	2.7207	0	14.19
MACO H	0.2727	3.6416	0.0491	13.37
AVERAGE	0.1749	2.3280	0.0250	13.07

down to ~30 cm that is underlain by largely rhizome-free sand. Roots from tree species, when present, appear lower in the profile, but at a lower density than river cane rhizomes. Soil development is low at these sites, as the soils are largely Entisols (Soil Survey Staff 2008a) and at only one site did we identify a buried A horizon. Average core length was 81 cm because we hit refusal above 1 m at some sites.

Carbon levels ranged from 1.14% at site JACK I to 5.11% at site CHER C (Table 1). Nitrogen levels ranged from 0.09% at site JACK B to 0.35% at site CHER C (Table 1). The mean C:N ratio was 13.07. Sulfur levels were below the detection limit of 0.005 mg (absolute) at all sites with the exception of sites MACO H and MACO C.

Nutrient levels shown here (Table 2 and Table 3) represent mean nutrient levels from each site. Nutrient levels were below detection limits at nine of the sites for Zn, two of the sites for Cu, and one site for P (Table 3). Low nutrient levels close to detection limits account for the higher coefficients of variation for Cu and Zn (Table 2). Calcium levels were the highest overall, followed by Mg, Fe, and K. The *A. gigantea* tissue sample yielded a nitrogen level of 2.5%, a carbon level of 42.0%, and a C:N ratio of 19.9. The *A. gigantea* tissue also yielded a $\delta^{13}C$ value of −30.3‰. Soil pH measured at seven sites had a mean of 5.7 and a range from 5.0 to 6.6.

Grain size analyses showed that the soils were 57% sand, 30% silt, and 13% clay (Table 4). Average bulk density of the surface of canebrake soils was 0.661 g/cm^3 and ranged from 0.48 to 0.82 g/cm^3 (Table 4). At one site, the vertical distribution of bulk density increased with depth below the root zone (0.51 to 1.1 cm^3)(Figure 2).

The mean K_{sat} value measured at 13 sites with the CCHP was 6.8×10^{-4} cm/sec. Seven of the sites exceeded the maximum value of K measurable with the CCHP (calculated as 7.7×10^{-3} cm/sec). Two vertical profiles indicate that despite vertical variability in the bulk density and the dense rhizome network, K_{sat} only varies slightly (~1 order of magnitude) from the rhizome zone to the lower soil profile.

The MANOVA results show that at least one site differs in at least one dependent variable (Wilks' Lambda = 0.032 and F = 5.29 (60, 224.7)). Subsequent ANOVA results reinforce the MANOVA results. Differences in P levels were significant for study sites (F = 6.65, p = 1.7×10^{-8}). Differences in C levels at study sites were also significant (F = 7.92, p = 8.1×10^{-10}). Differences in N levels and percent sand were also significant at 19 study sites (F = 7.4, p = 2.7×10^{-9} and F = 31.83,

Table 2. Nutrient concentration (μg nutrient/g soil) data for canebrake soils for all study sites together. Standard deviation (SD) is the mean SD of all 20 site SD's. The coefficient of variation (CV) is the mean CV of all 20 sites. The coefficient of variation is calculated as the SD divided by the mean multiplied by 100

	Ca	Cu	Fe	Mg	Mn	Zn	K	P
Min	154.96	0	40.33	36.64	17.24	0	21.65	0
Max	988.15	7.62	137.97	274.50	53.74	2.38	138.73	22.50
Mean	538.55	2.42	90.34	102.74	36.26	0.67	84.39	7.58
SD	246.29	6.59	35.49	55.83	13.31	5.96	35.63	10.25
CV (%)	21.36	100.83	18.93	17.74	21.01	159.88	24.87	66.09

Table 3. Mean nutrient levels (μg nutrient/g soil) at individual rivercane study sites

Site	Ca	K	P	Cu	Fe	Mg	Mn	Zn
CHER A	660.38	21.65	17.75	1.39	118.40	99.83	43.98	1.34
CHER C	988.15	112.31	6.31	2.31	57.45	121.20	23.51	1.21
JACK A	748.86	86.61	1.66	3.48	101.84	123.17	48.61	0.99
JACK B	225.55	30.89	10.96	1.16	40.33	38.56	37.11	1.22
JACK C	689.95	106.80	10.73	1.53	131.10	133.84	42.53	0.40
JACK D	325.38	69.25	7.60	7.62	61.26	72.18	19.49	2.22
JACK F	541.98	107.11	4.14	6.57	90.91	103.02	30.49	2.38
JACK G	550.11	134.48	1.29	0.00	82.12	110.35	31.89	0.00
JACK I	321.59	77.95	17.79	0.58	58.15	58.04	35.72	0.00
JACK J	887.13	79.54	0.58	0.00	119.41	274.50	53.74	0.00
JACK L	868.25	112.00	4.80	5.46	137.96	155.88	47.70	0.00
JACK M	612.01	138.73	5.41	2.84	124.52	156.62	47.15	0.00
JACK N	402.68	64.60	2.22	0.76	53.03	96.36	41.83	0.00
JACK O	487.92	104.26	6.85	0.80	107.68	103.75	49.72	0.00
JACK P	537.38	72.48	0.00	2.20	45.24	92.89	17.24	0.84
JACK Q	450.62	93.70	16.74	1.88	134.97	71.66	45.79	0.78
MACO C	479.27	57.99	4.59	5.98	95.58	72.13	28.08	1.55
MACO E	513.73	60.51	6.72	1.68	74.13	72.82	24.61	0.00
MACO F	154.96	59.26	22.50	1.85	99.55	36.64	24.39	0.00
MACO H	325.17	97.77	2.98	0.37	73.12	61.42	31.60	0.46

$p = 3.0 \times 10^{-23}$, respectively). ANOVA results from the Caney Fork sites also were all significantly different for all four dependent variables.

The correlation coefficient between percent N and percent sand was −0.68. Site JACK B had the lowest carbon levels (1.17%) and the highest sand content (88.5%). The correlation coefficient between percent C and percent sand was −0.59. Site JACK B also had the lowest percent N levels (0.09%). The correlation coefficient between percent P and percent sand was 0.59.

Table 4. Mean soil bulk density and mean sand, silt, and clay percentages from river cane study sites

Site	Bulk Density (g/cm^3)	% Sand	% Silt	% Clay
CHER A	0.60	55.2	33.8	11.0
CHER C	0.65	16.6	49.4	34.0
JACK A	0.70	44.5	38.3	17.1
JACK B	0.82	88.5	8.7	2.8
JACK C	0.58	71.8	21.0	7.2
JACK D	0.76	74.6	18.8	6.5
JACK F	0.53	69.8	21.3	8.9
JACK G	0.48	71.7	20.1	8.2
JACK I	0.72	71.6	21.3	7.1
JACK J	0.67	62.0	28.3	9.7
JACK L	0.65	67.0	23.2	9.8
JACK M	0.74	40.1	41.2	18.7
JACK N	0.79	36.8	41.1	22.1
JACK O	0.65	34.7	43.6	21.7
JACK P	0.57	67.0	24.0	9.0
JACK Q	0.55	72.6	19.1	8.3
MACO C	0.70	45.0	35.4	19.5
MACO E	0.72	60.5	27.0	12.5
MACO F	0.70	43.4	36.9	19.7
MACO H	0.59	34.8	44.0	21.2

Site characteristics, including elevation, soil type and stream characteristics such as drainage area, slope, and sinuosity are reported in Table 5 with a key to primary soil descriptions in Table 6 and additional physical soil characteristics in Table 7. Stream channels with river cane tended to meander with a mean sinuosity of 1.16. Tables 6 and 7 show NRCS data for the soils where river cane grows and are provided for comparative purposes only.

DISCUSSION

Physical characteristics of river cane soils

In general, the river cane rhizome network appears to have very little impact on the overall permeability of the system. Saturated hydraulic conductivity values at river cane sites with a rhizome-rich layer are consistent with values in Freeze and Cherry (1979) for silty sand and clean sand. Silty sand has a range from 1.0×10^{-5} to 1×10^{-1} cm/s and clean sand has a range from about 1.0×10^{-4} to 1 cm/s (Freeze and Cherry 1979). River cane soils range from 9.40×10^{-5} to $>7.7 \times 10^{-3}$ cm/s. The vertical distribution of K_{sat} at one site shows some decrease with depth, but not the pronounced decrease seen in other environments, like the root-rich surface of tropical soils (Elsenbeer 2001). In two profile measurements, K_{sat} varied from 2.5×10^{-3}

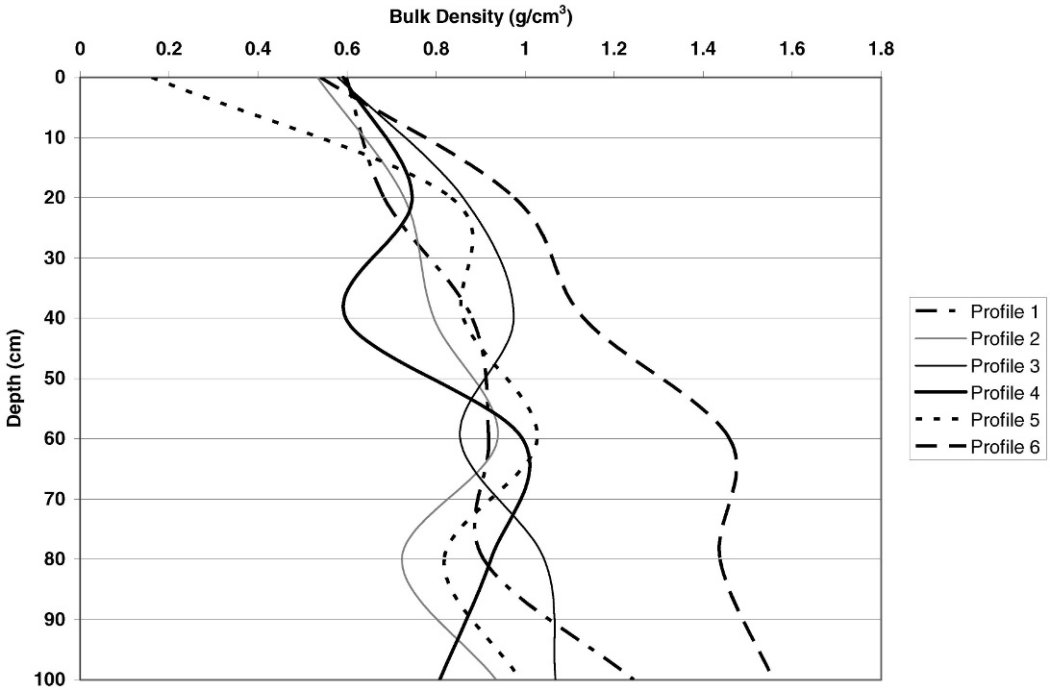

Figure 2. Bulk density of canebrake soils versus depth from six excavated pits at one study site. Bulk density was measured every 20 cm between 0 and 100 cm including 0 and 100 cm.

Table 5. Study site soil, watershed, and stream characteristics from RiverTools in ArcMap 9.2. Sinuosity is stream channel length divided by stream channel straight line distance and is dimensionless. Slope is rise over run and is also dimensionless. Primary soil types are described in Table 6

Site*	Associated Stream	Elev. (m)	Watershed Area (km^2)	Elev. (m)	Stream Channel Sinuosity	Stream Channel Slope	Primary Soil Type**
CHER A	Valley River	538.1	108.67	538.1	1.0952	0.0050	Not avail.
CHER C	Valley River	536.5	108.07	536.5	1.0795	0.0079	Not avail.
JACK A	Caney Fork	677.7	26.11	677.7	1.0912	0.0037	CwA
JACK B	Tuckasegee	628.7	60.87	628.7	1.1200	0.0027	BaA
JACK C	Tuckasegee	633.7	518.82	633.7	1.1724	0.0000	BaA
JACK D	Tuckasegee	627.3	535.32	627.3	1.0197	0.0030	BaA
JACK F	Caney Fork	686.1	103.33	686.1	1.0422	0.0000	RdA
JACK G	Caney Fork	680.7	0.09	680.7	0.9967	0.0074	NkA
JACK I	Tuckasegee	563.5	968.46	563.5	1.0363	0.0000	Ufb
JACK J	Caney Fork	689.1	101.34	689.1	1.2307	0.0119	SbD
JACK L	Caney Fork	681.2	103.67	681.2	1.0832	0.0000	RdA
JACK M	Tuckasegee	566.1	996.74	566.1	1.0732	0.0000	Ud
JACK N	Tuckasegee	569.0	994.95	569.0	1.0821	0.0000	Ufb
JACK O	Tuckasegee	564.3	980.00	564.3	1.0815	0.0000	Ufb
JACK P	Caney Fork	712.0	87.22	712.0	1.1833	0.0001	NkA
JACK Q	Caney Fork	711.4	85.69	711.4	1.0603	0.0139	RdA
MACO C	Little TN	617.7	311.52	617.7	1.4697	0.0000	RsA
MACO E	Little TN	623.8	311.52	623.8	1.4697	0.0000	BeA
MACO F	Little TN	629.6	213.63	629.6	1.1802	0.0000	RsA
MACO H	Little TN	618.9	301.37	618.9	1.6411	0.0023	ScB
Mean		627.8	345.87	627.8	1.1604	0.0029	

*Site names include County: CHER = Cherokee County, JACK = Jackson County and MACO = Macon County.
**From Soil Survey Staff (2008a). See Table 6 for descriptions of these soils.

Table 6. Key to primary soil types from Soil Survey Staff (2008a)

Soil	Description	Flooded	Slope (%)
BaA	Biltmore sand	Frequently	0–3
BeA	Biltmore sandy loam	Frequently	0–3
CwA	Cullowhee fine sandy loam	Occasionally	0–2
NkA	Nikwasi fine sandy loam	Frequently	0–3
RdA	Reddies fine sandy loam	Occasionally	0–3
RsA	Rosman fine sandy loam	Frequently	0–2
SbD	Saunook gravelly loam	No data	15–30
ScB	Saunook loam	No data	2–8
Ud	Udorthents, loamy	No data	0–15
Ufb	Udorthents urban land complex	Rarely	0–5

(borehole 1) and 7.5×10^{-4} (borehole 2) at 20 cm depth to 3.7×10^{-4} cm/sec (borehole 1) and 3.75×10^{-5} cm/sec (borehole 2) at 60 cm depth. Thus in both profiles, K_{sat} decreased marginally with depth. Hydraulic conductivity, therefore, appears to be fairly high throughout the profile and seems to be controlled largely by the soil texture rather than the large network of rhizomes near the surface.

Brady and Weil (2002) give a range for bulk density of uncultivated grassland soil of 0.8–1.2 g/cm^3. Bulk density of soil series where river cane grows reported by the NRCS is 1.25–1.65 g/cm^3 (Table 7), and river cane soils have an average surface bulk density of 0.661 g/cm^3. The values measured in river cane soils are among the lowest measured in this kind of environment. The reduced bulk density of river cane soils is likely a result of the plant's growth habit and associated conditions. The relatively impenetrable nature of remaining river cane sites allows them to be relatively undisturbed by humans; thus, canebrakes are likely a rich, and undocumented, habitat for arthropods, annelids, and small mammals. The activities of these animals may reduce the bulk density drastically by increasing the number of macropores; pores >2 mm in diam (Beven and Germann 1982). Moles and voles may be abundant in canebrakes as evidenced by their tunnels left in the soil. These large macropores often collapsed from the weight of the coring hammer when it was resting on the ground. Another factor that may reduce soil bulk density is the leptomorphic character of the rhizomes. The entire genet may not die, but individual culms die from time to time and rhizomes probably suffer the same fate. When rhizomes die, the decaying underground stem leaves a cavity in the soil. The thick litter layer may also act to protect the collapse of the macropores created by animals and dead rhizomes.

In general, the soils were sandy and silty sand textures (Table 4). Coarse soils do not retain moisture after rain and instead drain readily (Lu and Likos 2004). Additionally, specific surface area is less, meaning that there are fewer sites for cation adsorption and nutrient storage. An inter-site comparison

Table 7. Details of river cane soil types from Soil Survey Staff (2008b). A restrictive layer, or aquitard, affects water table depth. K_{sat} is the hydraulic conductivity in a saturated state of a given medium

Soil	Minimum Depth To Restrictive Layer (cm)	Minimum Depth To Water Table (cm)	K_{sat} Range (cm/s)	Depth (cm)	Clay (%)	Bulk Density (g/cm^3)
BaA	203.2	106.7	1.397×10^{-3}–4.198×10^{-3}	0–30	2–12	1.45–1.65
BeA	203.2	106.7	1.397×10^{-3}–4.198×10^{-3}	0–30	2–12	1.45–1.65
CwA	50.8	45.7	1.397×10^{-3}–4.198×10^{-3}	0–33	5–18	1.3–1.5
NkA	50.8	0	1.397×10^{-3}–4.198×10^{-3}	0–66	5–18	1.3–1.5
RdA	50.8	60.9	1.397×10^{-3}–4.198×10^{-3}	0–36	5–19	1.3–1.5
RsA	203.2	106.7	1.397×10^{-3}–4.198×10^{-3}	0–41	8–18	1.25–1.45
SbD	203.2	203.2	1.397×10^{-3}–4.198×10^{-3}	0–23	7–20	1.3–1.6
ScB	203.2	203.2	1.397×10^{-3}–4.198×10^{-3}	0–23	7–20	1.35–1.6
Ud	203.2	203.2	0–1.397×10^{-3}	0–203	10–50	1.3–1.65
Ufb	203.2	203.2	0–1.397×10^{-3}	0–203	10–50	1.3–1.65
Mean	157.5	123.9				

between texture and nutrient content did not identify a relationship between the two variables.

Carbon and nitrogen

Organic carbon levels are used to determine if a soil is organic or mineral, among other things. Mineral soils have less than 5% organic carbon by mass if there is no clay present, but can have increasing clay levels if carbon increases accordingly (Richardson and Vepraskas 2001). Mean carbon level among river cane sites is 2.3% with 19 sites below 3.75% (Table 1), so all soils are mineral soils. Site CHER C had the highest carbon levels of 5.1% but has 34% clay (Table 4), making it a mineral soil. Carbon levels for other river cane sites are apparently absent in the literature.

C:N ratios are connected to decomposition of organic matter by microbes which immobilize and mineralize nitrogen (Swift et al. 1979). Decomposition decreases C:N ratios (Swift et al. 1979) and decomposition is fastest with moderate pHs, mean temperatures between 25 and 35°C, moist soil, and adequate aeration within the soil (Brady and Weil 2002), all conditions met at river cane sites. C:N ratios generally decrease with sediment size due to an abundance of adsorption sites for ammonia (Meyers 1997). Based on this, C:N ratios at sandy river cane sites should be higher than sites with more silt and clay, but this was not the case ($R^2 = 0.047$ for sand versus C:N ratio, $p < 0.05$). Larger organic debris also has higher ratios due to less advanced stages of decomposition (Meyers 1997).

Lower C:N ratios indicate less competition for nitrogen between plants and microorganisms in the soil. If ratios are high, above 25:1, plants may be limited by nitrogen. Generally, similar soils have common C:N ratios because inputs into the soil are alike (Brady and Weil 2002). River cane soils in this study show remarkably similar C:N ratios, ranging from 11.28 to 14.83. This is a fairly narrow range and at the low range compared to forests, which tend to range from 30–50 (Brady and Weil 2002). This suggests that decomposition is rapidly occurring, possibly because of the low density, well-aerated soils, and inputs into the soil are homogenous from site to site. Also, the low C:N ratio of 19.9 for *A. gigantea* leaves logically leads to low soil C:N ratios. The litter layer at study sites consists primarily of culm sheath leaves and foliage leaves from *A. gigantea*, not other species. In some stands, virtually all the litter has this composition. The dense canopy of foliage leaves also may block high C:N ratio inputs into the soil, such as leaves from deciduous trees, which would raise the C:N ratio. Both the canopy and littler layer in mature stands of *A. gigantea* serve as an effective barrier between the soil and the environment.

Nitrogen inputs into the system can also decrease C:N ratios and this may be an issue in the southeastern United States due to climatic and anthropogenic factors. Many of the study sites are contiguous with or border current or former agricultural fields. Historically, liberal N addition probably occurred at these types of sites, which would result in C:N ratio reduction. Another possible nitrogen input into soils is atmospheric ammonium ions. National Atmospheric Deposition Program (2006) data show ammonium deposition between 2.3 and 4.6 kg/ha, much higher than other areas of the country. The N detection method used here was a bulk method, so all forms of nitrogen were detected.

The $\delta^{13}C$ value, to our knowledge, represents the first report of a carbon isotope value for *Arundinaria gigantea* and suggests that the plant uses the C_3 photosynthetic pathway. If *A. gigantea* had been a C_4 plant, as most grasses are, it would have been somewhat unique in its setting. This could have allowed for use as a proxy for past abundance of the plant using sediment deposits.

Importance of nutrients and floodplain nutrient dynamics

Nutrients may limit river cane at some sites to some degree, but it seems unlikely for several reasons. During the course of site visits over two full years, plants at all sites appeared healthy and free of any of typical signs of low nutrient levels: chlorosis (yellowing of leaves), necrosis (tissue death), misshapen leaves, stunted growth, weak plants, brittle or stiff leaves, and short internodal regions (Mengel and Kirkby 1987). New growth occurred at nearly all sites despite record drought and new culms were free of signs of low nutrient levels. While we report values for all analyzed macro and micronutrients (Table 1 and Table 3), several of these nutrients warrant further discussion due to their low abundance

at our sites and therefore potentially limiting nature (S and P) or high variability at our sites (Ca).

Sulfur levels were too low to be detected at nearly all the sites (Table 1). Freney (1961) found that many soils have C:N:S ratios of 125:10:1.2. Values reported here follow this trend for C:N ratios, but the two S levels that were within detection limits (sites MACO C and MACO H) deviate from this ratio. N levels are very close to those expected by the 12.5:1 C:N ratio suggested, but N:S ratios are about 6.5, indicating possible low S levels instead of elevated N levels.

It does not appear that P levels are low enough to limit the plant despite levels below the detection limit at two sites based on river cane stand health assessments detailed above. Mean river cane soil P levels were 7.58 μg/g with a range from 0 to 22.5 μg/g (Table 3). Detailed P levels from floodplain soils in seven large river systems from Spink et al. (1998) are comparable to river cane P levels. Total P in river cane soils average 7.3 μg/g and the Spink et al. (1998) values range from 0.63 μg/g on the Loire River, France, to 11.57 μg/g on the Mississippi River. Spink et al. (1998) identified flooding as the major P input into floodplain soils. This could also be the case with river cane soils.

Calcium levels in plants vary greatly from species to species and are genetically determined and calcium levels in soils also vary greatly compared to other nutrient levels, especially in uncultivated areas (Mengel and Kirkby 1987). This variability is evident in river cane soil calcium levels. The standard deviation of 246 μg/g for calcium between sites was the highest of all nutrients (Table 2) and levels within each core were generally close, but calcium levels of another core one or two meters away sometimes varied by a factor of 2. High Ca levels in soils make conditions favorable for increased microbial activity (Brady and Weil 2002), thereby reducing the available N.

Simple nutrient presence in soils does not necessarily constitute availability to the plant. Nutrients exist in solid, liquid, and gaseous forms in soils and those in the solid form serve as the supply while the liquid nutrients are the medium for transport to the roots (Mengel and Kirkby 1987). The use of the Mehlich III method in this study sought to identify plant available nutrients, rather than simply total nutrient concentrations. Clay particles serve as binding sites for cations such as K, Ca, Mg, and Mn (Brady and Weil 2002). A study has shown positive correlations between grain size and levels of Mg, Ca, K, N, and P at a single river cane site (McDowell et al. 2007).

Fine-textured river cane soils have higher N contents, evidenced by an R^2 value between N and the silt + clay fraction of 0.458. Linear regressions between the clay fraction and other nutrients show no relationship ($R^2 < 0.05$). Steiger and Gurnell (2002) showed a strong relationship ($R^2 = 0.85$) between nitrogen and silt and clay percentage on the Garonne River in France. In a separate study, Pinay et al. (1995) found soil texture to influence N retention and cycling on the Garonne River. A floodplain site with finer grain sizes retained more nitrogen as particulate organic material during flooding and also retained the nitrogen through higher rates of vegetative uptake than a sandy riparian site.

River systems are capable of transporting large quantities of nutrients via sediments and depositing them during flood events. Spink et al. (1998) show that large rivers in North America and Europe carry more nutrients than smaller ones and those nutrients do not limit floodplain species. Agricultural fertilization is also an important consideration due to the number of small farms on floodplains near our research sites. A similar situation was described in detail in Poland and The Netherlands, where researchers concluded that nutrients were no longer limiting floodplain plant species due to decades of heavy fertilization (Antheunisse et al. 2006). This situation may apply here, but more research is required to make this determination.

Another concept critical to plant nutrition is that direct nutrient interception by root hairs does not account for the majority of nutrient transport for uptake by the plant (Mengel and Kirkby 1987). The vast majority of nutrient transport occurs via mass flow and simple diffusion, but both need adequate soil moisture to occur. Mass flow is when dissolved nutrients are moved to root hairs via a convective flow of water. Sites in closer proximity to the water table may be in position to receive more nutrients from fluctuating groundwater levels. This may aid river cane in acquiring nutrients since many of the sites, particularly the Caney Fork sites, are in close proximity to the water table.

Summary and recommendations for restoration projects

River cane grows abundantly on floodplains in western North Carolina on low density, sandy soils that are very well drained ($K_{sat} < 1.4 \times 10^{-3}$ cm/s). These soils exhibit distinctively low C:N ratios for three reasons: 1) *A. gigantea* plant tissue exhibits a low C:N ratio; 2) high C:N ratio inputs into the soils are blocked by river cane canopy and river cane leaf litter cover; and 3) atmospheric and agricultural N inputs into the soils are probably high. While there is a relationship between total nitrogen and fine-grained sediment at river cane sites, we found no significant relationship between grain size and N, P, or C. Nutrients appear not to limit *A. gigantea* at study sites, but more research needs to be carried out in other areas. The chemical and physical characteristics of river cane soils in the study area were highly variable. This leads to the rejection of our null hypothesis that site characteristics would show statistical similarity and that there would be identifiable controls on river cane distribution. The plant appears not to be growing at sites based on any of the abiotic variables quantified here and further study is needed to determine specific controls on *A. gigantea* site selection for restoration purposes.

Arundinaria gigantea appears to be enough of a generalist to succeed on many potential restoration sites. Yet, river cane in the study area is found in a very restricted geomorphic position. Ideal restoration sites are on flood plains of rivers and streams where the rooting zone of the plant is out of the zone saturation of the adjacent stream. The soils at these sites should be highest in sand compared to silt and clay and drain water very efficiently ($K_{sat} < 1.4 \times 10^{-3}$ cm/s). Hydric soils should not be present.

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