NINE-YEAR RESULTS FROM A *PAULOWNIA* FIELD TRIAL OF THREE SPECIES IN THE SOUTHERN APPALACHIANS

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Abstract—Three species of *Paulownia (P. elongata, P. fortune,* and *P. tomentosa)* were evaluated for attained survival and diameter breast height (d.b.h.) after 9 years in the Southern Appalachian Mountains of western North Carolina. Because species of *Paulownia* vary in their cold-hardiness and moisture requirements, the primary purpose of this study was to compare their survival and diameter growth under the temperature and precipitation conditions of a region where they had not been previously evaluated. Particularly important was comparison of the documented invasive species, *P. tomentosa*, with the other two species that have not been reported as invasive. Mean survival differed little among species and averaged about 28 percent overall. Mean d.b.h. of *P. fortunei* was 4.5 inches, which was smaller than that for either *P. elongata* (6.7 inches) or *P. tomentosa* (6.8 inches). Preliminary results from this field trial suggest little difference in performance among the species.

INTRODUCTION

The genus *Paulownia* includes seven species native to the temperate region of eastern Asia, primarily China. One species, *P. tomentosa*, has been naturalized throughout the Eastern United States following its introduction in the 1840s as an ornamental (Snow 2015). Certain silvical characteristics of *P. tomentosa,* including prolific production of wind-disseminated seeds, rapid juvenile height growth, abundant basal sprouts following top kill, and the ability to colonize xeric sites, have led to its classification as an invasive species in the United States (Hemmerly 1989, Kuppinger 2008, Miller and others 2010, Snow 2015) and Austria (Franz 2007). However, these same characteristics, when combined with its desirable wood properties, have resulted in increasing attention to *P. tomentosa* as an important species for short rotation, high-quality saw log production (Clatterbuck and Hodges 2004, Henning 1989, Kays and others 1997), coppice biomass production (Beckjord and McIntosh 1983, Rad 2015), agroforestry (Mueller and others 2001), antibacterial drugs (Smejkal 2008), phytoremediation (Doumett and others 2008), flavanones (Asai and others 2008), pulp (Olsen 1985), and bioenergy (Yadav and others 2013).

Other species of *Paulownia* have not been reported as invasive, and some have potential productivity exceeding *P. tomentosa* (Kuppinger 2008). Although much is known about the temperature- and moisture-stress tolerance and the rapid growth rate of the deep-rooted *P. tomentosa*, relatively little has been reported for other species, particularly in response to extreme levels of temperature and precipitation. Beyond considerable study in their native range in China, two species of *Paulownia*, *P. elongata* and *P. fortunei*, have received trial evaluations of performance in Spain (Zuazo and others 2013), Iran (Rad 2015), Brazil (Zeni and Simberloff 2013), South Africa (Donald 1990), Turkey (Ayan and others 2006) and Australia (Sun and Dickerson 1997). In many of those studies, performance of *P. elongata* and *P. fortunei* were superior to *P. tomentosa*. In several trials in the Coastal Plain and Piedmont of the Southern United States, short-term evaluations of *Paulownia* species other than *P. tomentosa* have reported similar or better survival and growth (Bergman 2003, Dong and Buijtenen 1994). The primary purpose of our study was long-term evaluation of *P. elongata* and *P. fortunei* survival and growth in comparison to *P. tomentosa* in the cool climate of the southern Appalachian Mountains. The scope of our study was limited to a single site and did not encompass the range of sites and soils present in the southern Appalachian Mountains. Also, our study did not include cultural treatments, such as coppicing, fertilization, irrigation, weed control, and stem pruning, which are typically part of intensive management in commercial plantings. Presented in this report are final results of attained survival and diameter breast height (d.b.h.) at 9 years of age.

STUDY SITE AND METHODS

The study was established in the Bent Creek Experimental Forest, within the Pisgah National

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Forest, which is located in the southern Appalachian Mountains physiographic province (35.5 ºN, 82.6 ºW). This area has a warm, humid continental climate. Annual temperature averages 55.8 ºF and varies from 41.2 ºF in winter to 70.5 ºF in summer. Annual precipitation averages 47.8 inches and is evenly distributed among seasons, with occasional soil moisture deficits of several weeks duration during late summer. Growing season length averages 157 days, extending from late April to middle October.

The study site was a low elevation, southwest-facing slope that had been cleared of upland hardwood vegetation (primarily *Quercus* spp. and *Carya* spp.) two years earlier to allow disposal of sediments removed from nearby Lake Powhatan. The 13-acre lake receives sediments from the third-order stream, Bent Creek, which drains a forested watershed of about 6 square miles. Sediments are derived primarily from soils formed from gneiss and schist formations that have eroded from roads and occasionally from debris avalanches (Neary and others 1986). Surface soils in the Lake Powhatan watershed are classified as fine to coarse textured loams and sandy loams with < 33 percent clay content. The saturated sediments were allowed to drain for a year and were then leveled to form a uniform layer of soil material approximately 2 feet thick with a slope gradient of about 15 percent. The soil material was characterized from samples systematically collected to a depth of 6 inches throughout the study area for determination of pH, carbon, organic matter, nitrogen, and texture. The Bouyoucos hydrometer method was used for particle size analysis of oven-dried, 2-mm sieved samples. Air temperature and precipitation were recorded daily at a standard weather station located 2 miles northeast of the study area, at about the same elevation.

Study treatments consisted of measuring the survival and growth response of three species of *Paulownia—P. elongata, P. fortunei,* and *P. tomentosa*—to the prevailing edaphic and climatic conditions of the planting site. In March 1995, we hand planted 150, 1-year-old containerized seedlings of each species from a commercial nursery on a spacing of 11 feet between rows and 7 feet between seedlings within each row. Vegetation on the planting site consisted primarily of a sparse cover of native grasses and herbs originating from wind-blown seeds from the surrounding (< 50 feet distance) forested area. A corrugated plastic collar (4 inches diameter x 6 inches tall) was placed around each seedling at planting for water conservation, weed control, protection from rodent girdling, and support of the relatively weak succulent stem and root system from breakage by strong winds during thunderstorms. Seedlings received no fertilization, cultivation, or weed control during the study. Attained survival and d.b.h. were summarized by species after 9 years of growth, when the study ended in December 2003.

RESULTS AND DISCUSSION

Climate and Soil Environments

Winter temperature and summer precipitation during the 9 years of the study were near the 30-year normal (table 1); however, several extreme events occurred that provided environmental stresses desirable for our species trials. The 9-year minimum temperature of -5 ºF

Table 1—Mean, minimum, and maximum climatic and edaphic properties of the study site in the Bent Creek Experimental Forest, near Asheville, NC

Variable	N[d]	Mean (SD)	Minimum	Maximum
Climatic variables (1995-2003)				
Winter temperature (ºF) [a]	9	39.2 (1.83)	35.70	42.65
Summer precipitation (inches) [b]	9	14.3 (5.42)	5.2	23.70
Edaphic properties [c]				
Acidity (pH)	9	4.27 (0.029)	4.25	4.32
Carbon (%)	9	0.026 (0.004)	0.021	0.032
Organic matter (%)	9	0.005 (0.0006)	0.004	0.006
Nitrogen (ppm)	9	369.44 (81.962)	256.00	478.00

[a] Winter season includes January-March. The 30-year normal winter season temperature during the 9 years of the study was 40.7 ºF. The minimum daily temperature recorded during the study was -5 ºF;

[b] Summer season includes July-September. The 30-year normal summer season precipitation during the 9 years of the study was 12.36 inches. The minimum monthly precipitation recorded during the study was 0.25 inch.

[c] To depth of 6 inches.

[d] N; 9 years for climatic variables or 9 samples for edaphic variables.

SD = standard deviation.

occurred in February 1996, after the second year of growth for the seedlings. Variation of cold-temperature hardiness of species in their native China is not well known; however, because species have been widely planted, Donald (1990) reported that *P. tomentosa* has greatest cold tolerance (-4 °F) and *P. elongata* is least tolerant (14 °F). Minimum temperatures occurring during our study were near or exceeded values reported as critical for each of the three species. Except for late frosts during the early growing season (Mitchem and others 2002), results of *Paulownia* trials seldom specify temperature as a factor affecting survival and growth, which suggests other characteristics of sites are of greater importance, such as soil fertility and moisture availability. Summer precipitation during the study averaged 14.3 inches, which was 2 inches above normal. Drought, however, occurred during the third growing season, 1998, resulting in a summer season precipitation of 5.2 inches, including one month in which only 0.25 inch was recorded. Mature *P. tomentosa* and other species are relatively drought tolerant as a result of their deep root systems (Donald 1990, Reynolds and others 2009), which are well suited when combined with shallow-rooted, inter-planted agricultural crops in agroforestry systems (Mueller and others 2001). Compared with other species of *Paulownia*, *P. elongata* has been reported as most drought tolerant (Llino-Sotelo and others 2010).

The soil material of our planting site is classified as a loam with mean coarse material >2 mm of 7.0 (SD = 3.2) percent. The loam soil consisted of 49 (3.5) percent sand, 21 (1.2) percent clay and 30 (2.6) percent silt. Mean soil pH was 4.3, which is characterized as extremely acidic; N content was low, and organic matter was nearly zero (table 1). Soil quality of our planting site is classified as low using criteria of organic matter and nitrogen (Schoenholtz and others 2000) and in comparison with other *Paulownia* studies in the Virginia Piedmont (Mitchem and others 2002). Fertility requirements are minimal for survival and growth of *Paulownia* as indicated by successful establishment of several species for restoration of mine spoils (Jiang and others 2012, Tang and others 1994). Although low in fertility, the dredged sediments at our planting site were also low in clay content and well drained, which is suitable for *Paulownia* survivorship and growth (Kay and others 1998). Darmody and others (2004) found that dredged lake sediments can be highly productive for agricultural crops when properly fertilized.

Survival

Mean survival at age 9 averaged 28.7 percent overall and was similar among species (table 2). The lower level of survival for *P. tomentosa* in our study was similar to that for a 6-year species trial in Texas by Dong and Builigi (1994), who cited late spring frosts as the likely cause. Unlike our findings of low survival for *P. fortunei*, however, Dong and Builigi (1994) reported high survival (60 percent) after 6 years. Bergmann (2003) reported relatively high mean survival (>70 percent) after 5 years for *P. elongata* and *P. fortunei* in the Piedmont of North Carolina and also found superior survival of rooted stem cuttings compared to seedlings (Bergmann 1998). In the Virginia Piedmont, Mitchem and others (1999) suggested soil moisture stress was likely the primary factor for low survival of *Paulownia* seedlings. Low moisture was probably not the reason for the high mortality that occurred during the first growing season after planting in our study because precipitation was above the 9-year average, and weed competition was not severe.

The plastic collars installed at planting had been firmly imbedded in soil; this action eliminated the possibility of "chimney" drying and mortality of seedlings which can occur when gaps are left at collar bases. Further, we did not observe rodent damage to seedlings. However, some species of *Paulownia* have been reported as susceptible to fatal bacterial and fungal diseases, spores of which could have been present in the lake sediments on the planting site (Mehrotra 1997). Also, *Paulownia* is sensitive to late spring frosts (Personal communication, W.C. Clatterbuck. 2017. Professor, Ellington Plant Sciences Building, University of Tennessee, Knoxville, TN 37996) that can cause top dieback of young seedlings and result in increased levels of mortality (Dong and Builigi 1994). During the study period, a low temperature of 29 °F was recorded in early May 1996, which could have been a factor that reduced survival when the seedlings were beginning their second growing season. We have no satisfactory explanation for the low survival of all species in our study.

Table 2—Mean survival (SE) and d.b.h. (SE) attained by three species of *Paulownia* 9 years after planting in the Bent Creek Experimental Forest, near Asheville, NC

Species	Survival (%)	D.b.h. (*inches*)
P. elongata	34.3 (4.03)	6.7 (0.42)
P. fortunei	30.2 (4.06)	4.5 (0.46)
P. tomentosa	21.9 (3.44)	6.8 (0.51)
All	28.7 (2.22)	6.0 (0.46)

Diameter

Mean d.b.h. attained at age 9 averaged 6.0 inches overall and was similar among species (table 2). *P. fortunei* averaged 4.5 inches compared to *P. elongata* (6.7 inches) or *P. tomentosa* (6.8 inches). Variation of mean tree d.b.h. was also similar among species (0.46 inches). Our study was not designed to associate precipitation or soil moisture with tree size. However, because diameter growth of some species varies directly with fertility (Rad and Mirkala 2015), the diameter attained by trees in our study was likely affected by the relatively infertile lake sediments.

Overall mean d.b.h. of *Paulownia* in our study averaged 6.0 inches at 9 years, or a mean annual increment (MAI) of 0.67 inch. For other studies in the South, Mitchem and others (2002) and Bergmann (1998) reported MAI of approximately 1.3 inches for 5-year-old *P. elongata* in the Piedmont of Virginia. In the Piedmont of North Carolina, Bergmann (2003) found MAI of 1.7 inches for *P. elongata* at 4 years. Beckjord and McIntosh (1993) and Bergman (2003) reported that diameter of all *Paulownia* species responded to fertilization, particularly increased nitrogen. In our study, the primary factor affecting d.b.h. was probably low fertility of the lake sediments of our site, which was about half that of a typical upland hardwood site (Mitchem and others 2002). Another explanation for the smaller tree sizes in our study could be a shorter growing season resulting from the cooler climate of the southern Appalachians compared to the Piedmont of North Carolina (Bergmann 2003) or east Texas (Dong and Buijten 1994).

CONCLUSIONS

Results of our study revealed low survival at age 9 among all species, but we were unable to determine if it was associated with temperature, soil moisture, or fertility. Our study was not designed to determine critical levels of minimum temperature or moisture that are important for survival of the three species of *Paulownia*. However, the levels of temperature and precipitation encountered are near the extremes likely for this part of the southern Appalachians and therefore provide useful information on species selection. Most surprising was the satisfactory performance of *P. elongata*, which has been reported as less tolerant of low temperatures compared to *P. tomentosa*. The relatively good performance of *P. elongata* was also noteworthy because it has not been reported as invasive. Although *P. tomentosa* has many desirable qualities, this species is not recommended for planting because of its reported invasive characteristics on certain sites. The lake sediment soils of our planting site were not typical of the southern Appalachians; however, the purpose of our study was an initial assessment of species performance and not to determine potential growth. Overall, our preliminary assessment indicated similar attained survival and diameter among the three species at 9 years of age.

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