

Early Landscape Performance of 20 Field-Grown Birch Genotypes at Two Locations in Arkansas, U.S. and Response to Irrigation

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Abstract. Twenty birch genotypes were planted in the field in April 2002 to evaluate their survival and growth at Fayetteville and Hope, Arkansas, U.S., and to evaluate their response to two irrigation regimes at Fayetteville. After four growing seasons, the overall tree survival was 62% and 30% at Fayetteville and Hope, respectively. *Betula pendula* ‘Trost’s Dwarf’, *B. ermanii*, and *B. albosinensis* were among genotypes with the lowest survival at both locations. *Betula populifolia*, *B. nigra* ‘BNMTF’, *B. nigra* ‘Cully’, and *B. × ‘Royal Frost’* had greater survival after four growing seasons than the other birch genotypes investigated. *Betula nigra* ‘BNMTF’ and *B. nigra* ‘Cully’ were taller and had greater trunk diameter than the other surviving birch genotypes at both locations after four growing seasons. At the end of 2005, *B. utilis* var. *jacquemontii* was the shortest and had the smallest trunk diameter among the 18 surviving genotypes at Fayetteville, and *B. papyrifera* ‘Uenci’, *B. populifolia* ‘Whitespire’, *B. maximowicziana*, and *B. lenta* were the shortest and had the smallest trunk diameter among the 13 surviving genotypes at Hope. At Fayetteville, *B. nigra* and *B. davurica* had the greatest annual change in tree height in both 2004 and 2005, and *B. davurica* was among genotypes having the greatest annual change in trunk diameter in 2002, 2004, and 2005. At Hope, *B. papyrifera* had the greatest annual change in tree height in both 2004 and 2005, and *B. davurica* had the greatest annual change in trunk diameter in 2004. In 2005, annual change was not significant among birch genotypes at Hope. At Fayetteville, water-stress treatment reduced final tree height and trunk diameter in birch trees.

Key Words. Growth; irrigation regime; survival.

The birches (*Betula* L.), especially white-barked genotypes, are popular woody plants. Their ornamental characteristics include pendulous catkins, yellow fall foliage, and peeling bark featuring colors from reddish brown to white (Furlow 1990). The origins of most birch genotypes are the temperate, boreal, and arctic zones of North America, Europe, and Asia (Krussmann 1984; Furlow 1990; Atkinson 1992; Farrar 1995).

High air temperatures are often a limiting factor in a plant’s adaptability and productivity and there is considerable variation in high temperature tolerance among birch genotypes (Ranney and Peet 1994). Water deficit often limits tree growth in urban landscapes (Zwack and Graves 1998; Ladjal et al. 2000). Bronze birch borer, *Agrilus anxius* Gory, is a major problem causing birch dieback in urban landscapes (Santamour 1999). In many birch species under water stress, rhododendrol hydrolyzed from rhododendrin may act as a stimulant to its oviposition (Santamour et al. 1997). Water-deficit tolerance among birch genotypes was observed under controlled conditions (Ranney et al. 1991). Except for anecdotal observations, no research data are available on field

performance of birch genotypes or the effect of irrigation regimes on field-grown birch genotypes in the southern United States. Intensive landscape evaluation of birch genotypes in the southern United States would provide useful information for the ornamental industry and homeowners.

The objectives of this study were to evaluate survival and growth of 20 birch genotypes at two locations in Arkansas representing two USDA cold hardiness zones and two AHS heat zones, Fayetteville (USDA cold hardiness zone 7; AHS heat zone 7) and Hope (USDA cold hardiness zone 8; AHS heat zone 8), and to evaluate their response to two irrigation regimes at Fayetteville. The hypothesis was that the survival and growth of birch genotypes under higher temperature and nonirrigation conditions would not be as good as under cooler and irrigated conditions.

MATERIALS AND METHODS

Of the 20 birch genotypes evaluated in the study, 10 are native North American species or their selections, nine are Euro-Asian origin species or their selections, and one hybrid

[*B.* × ‘Royal Frost’ = *B. populifolia* ‘Whitespire’ × *B.* × ‘Crimson Frost’; *B.* × ‘Crimson Frost’ = *B. platyphylla* var. *szechuanica* (Schneid.) Rehd × *B. pendula* ‘Purpurea’] has both North American and Euro-Asian heredity (Table 1). The 11 species typically grow in the range of USDA cold hardiness zone 2 to zone 6.

One-year-old rooted cuttings or bare-root plants obtained from commercial nurseries were potted in 3.8 L (1 gal) pots with SunGro SB300 Universal Mix (Pine Bluff, AR) in Winter 2001. Three of the genotypes were obtained from two different nursery sources (*B. nigra*—Evergreen N. and J. F. Schmidt & Son Co.; *B. nigra* ‘Cully’ Heritage®—Heritage Seedlings Inc. and Forest Hills N.; *B. pendula*—Meadow Lake N. and J.F. Schmidt & Son Co.). Container plants were grown in an outdoor lathe house until they were planted in the field plots.

Trees were planted on 12 and 5 April 2002 at the Arkansas Agriculture Research and Extension Center, Fayetteville

(latitude: 36.1N; longitude: 94.1W; altitude: 427 m/1400 ft; USDA cold hardiness zone 7; AHS heat zone 7) and Southwest Research and Extension Center, Hope (latitude: 33.7N; longitude: 93.6W; altitude: 106 m/350 ft; USDA cold hardiness zone 8; AHS heat zone 8), Arkansas, respectively. The soil type was Captina silt loam (pH = 6.2) at the Fayetteville site and Bowie fine sandy loam (pH = 5.5) at the Hope site. Trees were planted 2.5 m (8 ft) apart in a row and the distance between two rows of trees was 4.5 m (15 ft). After planting, rows were mulched with hardwood chips to a depth of 10 cm (4 in). Trees were fertilized with 10 g 15N–2P–8K fertilizer (Harrell’s Fertilizer, Lakeland, FL) with micronutrients after planting and with 10 g 45N–0P–0K (Oakley Fertilizer, North Little Rock, AR) annually from 2003 to 2005 as suggested by the soil analysis.

At Fayetteville, all trees were irrigated for 2 hours per day and 3 days per week from May to September using a drip system with Rainbird® EM-L20 SSP Lady Bug emitters

Table 1. Characteristics and origin of 20 birch genotypes evaluated at Fayetteville and Hope, Arkansas.

Genotypes	Common name ^z	Origin ^z	USDA cold		Nursery source
			hardiness zone ^z	Natural height (m) ^z	
<i>B. albosinensis</i> Burkill.	Chinese red birch	W. and SW. China	6	18–25	Heritage (OR)
<i>B. alleghaniensis</i> Britton	Yellow birch	Eastern N. America	2	20–30	Lawyer (MT)
<i>B. davurica</i> Pall.	Black birch	N. China, Korea	5	5–9	Forestfarm (OR)
<i>B. ermanii</i> Cham.	Erman’s birch	NE. Asia, Japan, Korea	6	20	Meadow Lake (OR)
<i>B. lenta</i> L.	Sweet birch	Eastern N. America	3	25	Lawyer (MT)
<i>B. maximowicziana</i> Regel.	Monarch birch	Japan	5	30	Lawyer (MT)
<i>B. nigra</i> L.	River birch	Eastern U.S.	5	12–20	Evergreen (WI); Schmidt (OR)
<i>B. nigra</i> ‘BNMTF’ Dura-Heat™	Dura-Heat birch	—	4	—	Moon (GA)
<i>B. nigra</i> ‘Cully’ Heritage®	Heritage birch	—	4	—	Heritage (OR); Forest Hill (SC)
<i>B. papyrifera</i> Marsh.	Paper birch	N. America	4	30	Schmidt (OR)
<i>B. papyrifera</i> ‘Renci’ Renaissance Reflection™	Renaissance Reflection paper birch	—	—	—	Evergreen (WI)
<i>B. papyrifera</i> ‘Uenci’ Renaissance Upright™	Renaissance Upright paper birch	—	—	—	Evergreen (WI)
<i>B. pendula</i> Roth. Schmidt (OR)	European white birch	Europe, Asian Minor	2	20	Meadow Lake (OR);
<i>B. pendula</i> ‘Trost’s Dwarf’	Trost’s Dwarf birch	—	—	1	Briggs (WA)
<i>B. pendula</i> ‘Laciniata’	Laciniata birch	—	—	12	Briggs (WA)
<i>B. platyphylla</i> Sukatchev. ‘Fargo’ Dakota Pinnacle™	Dakota Pinnacle Manchurian birch	—	5	10–20	Meadow Lake (OR)
<i>B. populifolia</i> Marsh.	Gray birch	Eastern N. America	3	10–20	Forestfarm (OR)
<i>B. populifolia</i> ‘Whitespire’	Whitespire birch	—	—	—	Briggs (WA)
<i>B.</i> × ‘Royal Frost’	Royal Frost birch	—	—	—	Evergreen (WI)
<i>B. utilis</i> D. Don var. <i>jacquemontii</i> (Spach.) Winkl.	White-barked Himalayan birch	W. Himalaya	6	—	Briggs (WA)

^zFrom Krussmann (1984) and Dirr (1998).

(nominal flow rate = 2.0 L/hour⁻¹; Rain Bird Corp., Glendora, CA) in 2002. There was one emitter for each tree and emitters were placed close to the tree trunk. Water was collected from randomly selected emitters and the average flow rate was 1.4 L/hour⁻¹. In April 2003, mulch was removed and all rows were covered with 1.2 m (4 ft) wide plastic film (4 mil) to limit precipitation infiltration to the soil before being remulched with hardwood chips to a depth of 10 cm (4 in). In May 2003, soil tensiometers (Irrometer Company, Inc., Riverside, CA) were installed at 30 cm (12 in) depth close to the trunk of two randomly selected birch trees within each row at Fayetteville. Tensiometers were removed after each growing season. In April 2004, tensiometers were installed at 30 cm (12 in) depth at a distance of 30 cm (12 in) from the trunks of three randomly selected birch trees within each row. In April 2005, tensiometers were installed at 30 cm (12 in) depth at a distance of 50 cm (20 in) from the trunks of four randomly selected birch trees within each row. Tensiometer readings were recorded daily.

Two irrigation regimes were applied to the Fayetteville field plot from 2003 to 2005: (1) watered (WW): four rows of trees were watered to keep the average tensiometer readings

between 0 and 10 KPa (10 cb); and (2) water-stressed (WS); the other four rows of trees were watered after the average tensiometer readings exceeded 40 KPa (40 cb).

At Hope, tree rows were not covered with plastic film but mulched and fertilized in a manner similar to Fayetteville. From 2002 to 2005, all trees were irrigated for 2 hours per day and 3 days per week from May to September, which was similar to the irrigation treatment for WW trees at Fayetteville.

Weather data were obtained from both Fayetteville and Hope locations from 2002 to 2005 (Tables 2 and 3). The average annual high and low temperatures during the 4 years were 20°C (68°F) and 9°C (48°F) at Fayetteville, which were 3°C (37°F) and 1°C (34°F) lower than those at Hope, respectively. The average annual precipitation during that period was 97.9 cm (39.2 in) at Fayetteville and 112.3 cm (44.9 in) at Hope. At Fayetteville, the number of frost-free days from 2002 to 2005 was 192, 225, 247, and 209, respectively. At Hope, the number of growing days from 2002 to 2005 was 239, 226, 298, and 222, respectively.

Tree height and trunk diameter were measured after planting in April 2002 at both locations and after the trees shed all

Table 2. Monthly average high temperature and monthly average low temperature at Fayetteville and Hope, Arkansas, from 2002 to 2005.

Month	2002 (°C)		2003 (°C)		2004 (°C)		2005 (°C)		Average ^z (°C)	
	High	Low	High	Low	High	Low	High	Low	High	Low
Fayetteville										
Jan.	10	-2	6	-6	7	-4	10	0	8	-3
Feb.	10	-2	8	-3	8	-4	13	3	10	-2
Mar.	12	0	15	2	17	7	14	3	15	3
Apr.	22	10	22	8	21	10	20	9	21	9
May	23	13	24	13	25	16	24	12	24	14
June	29	19	27	16	27	18	30	19	28	18
July	31	22	31	20	28	19	32	20	31	20
Aug.	32	21	32	19	28	18	33	21	31	19
Sept.	29	16	24	12	29	15	31	18	28	15
Oct.	18	10	21	8	22	12	23	10	20	10
Nov.	13	2	13	3	16	7	18	5	14	4
Dec.	9	-1	6	1	9	-1	9	-2	8	-1
Hope										
Jan.	13	1	11	-2	12	1	14	3	13	1
Feb.	13	-2	11	-1	11	-1	15	4	12	0
Mar.	16	3	18	4	21	8	18	5	18	5
Apr.	24	12	24	9	21	4	24	9	23	8
May	25	14	27	16	21	18	28	12	28	15
June	31	18	28	18	31	21	32	18	30	19
July	33	22	32	22	32	21	34	21	33	21
Aug.	33	21	33	22	32	19	37	21	34	21
Sept.	31	18	28	16	31	16	33	18	31	17
Oct.	21	12	25	11	26	14	25	9	24	12
Nov.	16	2	19	7	18	9	21	7	18	6
Dec.	12	1	13	-1	13	-1	14	-2	13	0

^zThe average is calculated based on the weather data from 2002 to 2005.

Table 3. Monthly precipitation at Fayetteville and Hope, Arkansas, from 2002 to 2005.

Month	Precipitation (cm)				Avg. ^z
	2002	2003	2004	2005	
Fayetteville					
Jan.	4.8	0.6	3.6	14.5	5.9
Feb.	4.5	6.9	2.1	5.3	4.7
Mar.	24.4	6.7	6.8	3.3	10.3
Apr.	17.3	6.3	18.6	10.4	13.2
May	13.2	15.0	2.7	9.4	10.1
June	10.2	10.3	14.1	11.4	11.5
July	2.2	8.9	21.2	4.6	9.2
Aug.	15.8	4.2	2.1	4.8	6.7
Sept.	1.5	8.4	1.5	7.4	4.7
Oct.	5.6	11.7	8.7	0.8	6.7
Nov.	2.6	10.7	18.1	6.0	8.3
Dec.	12.7	4.8	3.9	1.0	5.6
Total	114.8	94.4	103.4	79.0	97.9
Hope					
Jan.	7.4	1.2	9.7	13.5	7.9
Feb.	4.6	21.5	11.6	7.4	11.3
Mar.	20.9	4.3	12.5	7.4	11.3
Apr.	5.1	6.3	17.2	8.4	9.2
May	17.3	12.9	21.0	4.4	13.9
June	1.0	17.6	9.8	4.7	8.3
July	9.3	10.2	8.4	6.2	8.5
Aug.	3.7	2.7	4.0	7.5	4.5
Sept.	5.1	6.8	3.9	13.2	7.3
Oct.	24.7	6.4	17.3	0	12.1
Nov.	5.3	6.4	20.6	7.6	10.0
Dec.	19.4	7.2	4.1	1.4	8.0
Total	123.7	103.5	140.2	81.6	112.3

^zThe average is calculated based on the weather data from 2002 to 2005.

leaves each fall (except 2005). Tree height was measured as the distance between the tallest bud on the tree and the soil surface. Trunk diameter was measured at 15 cm (6 in) above the soil surface using a caliper. Year-end measurements were taken at Fayetteville and Hope on 29 and 17 October 2002, on 4 December and 13 November 2003, on 16 and 28 November 2004, and on 13 and 4 October 2005, respectively. Annual change, presented as a percentage, is defined as the change in tree height or trunk diameter between the fall of the previous year and the fall of the current year divided by the same growth parameter at the end of the previous growing season. For 2002 data, the change in growth is divided by the initial value at planting. Survival of each birch genotype was recorded annually.

Two trial locations were treated as two separate experiments. The experimental design was a completely randomized design consisting of a two-factor factorial of 16 genotypes (*B. albosinensis* and *B. pendula* 'Trostr's Dwarf' did not survive through 2005, and *B. ermanii* and *B. lenta* were not included in statistical analysis as a result of excessive mor-

tality) × two irrigation regimes with seven to 15 replications at Fayetteville and a completely randomized design consisting of one factor of 13 genotypes with four to 12 replications at Hope (seven of 20 genotypes did not survive through 2005). Data were subjected to analysis of variance (ANOVA) in a General Linear Model using SAS software (version 9.1, 2004; SAS Institute Inc., Cary, NC). Means were considered significantly different if *P* value was less than 0.05 or 0.1 as determined by ANOVA.

RESULTS

Fayetteville

The overall tree survival was 62% (Table 4). The average survival for WW trees and WS trees was 64% and 59%, respectively. Survival after four growing seasons ranged from 100% (*B. × 'Royal Frost'*) to 0% (*B. albosinensis* and *B. pendula* 'Trostr's Dwarf'). Genotypes, which had greater than 90% survival, also included *B. nigra* 'BNMTF' Dura-Heat™ (93%), *B. nigra* 'Cully' (94%), *B. pendula* 'Laciniata' (93%), and *B. populifolia* (93%).

There was an interaction between genotype and irrigation on the tree height in 2005 (Table 5). Main effects of genotype and irrigation treatment were significant. The WS treatment

Table 4. Survival of 20 birch genotypes evaluated at Fayetteville^z and Hope^y, Arkansas, in 2005.

Genotype	Fayetteville		Hope	
	No. of trees	Survival (%)	No. of trees	Survival (%)
<i>B. albosinensis</i>	14	0	6	0
<i>B. pendula</i> 'Trostr's Dwarf'	14	0	6	0
<i>B. ermanii</i>	14	7	6	0
<i>B. lenta</i>	14	14	6	50
<i>B. maximowicziana</i>	14	29	6	17
<i>B. alleghaniensis</i>	14	36	6	0
<i>B. utilis</i> var. <i>jacquemontii</i>	14	36	6	0
<i>B. platyphylla</i> 'Fargo'	18	44	6	17
<i>B. papyrifera</i>	19	68	6	17
<i>B. davurica</i>	14	71	6	17
<i>B. nigra</i>	28	75	12	17
<i>B. papyrifera</i> 'Renci'	14	79	4	0
<i>B. papyrifera</i> 'Uenci'	14	79	4	50
<i>B. populifolia</i> 'Whitespire'	14	79	6	33
<i>B. pendula</i>	29	83	12	17
<i>B. nigra</i> 'BNMTF'	14	93	6	100
<i>B. pendula</i> 'Laciniata'	14	93	6	0
<i>B. populifolia</i>	14	93	6	83
<i>B. nigra</i> 'Cully'	30	94	12	92
<i>B. × 'Royal Frost'</i>	14	100	4	75
Average	–	62	–	30

^zTrees were exposed to two irrigation regimes at Fayetteville since 2003.

^yAll trees were irrigated at Hope.

Table 5. Statistical significance from analysis of variance of genotype and irrigation treatment on the initial and final tree height and trunk diameter of birch trees planted in Spring 2002 at Fayetteville and Hope, Arkansas.^z

Source	Statistical significance (<i>P</i> value)			
	Fayetteville			Hope
	Genotype × irrigation	Genotype	Irrigation	Genotype
Initial tree height	0.4381	0.0001	0.5030	0.0030
Initial trunk diameter	0.4348	0.0001	0.0608	0.0014
Final tree height	0.0236	0.0001	0.0001	0.0001
Final trunk diameter	0.3838	0.0001	0.0005	0.0001
AC ₂₀₀₂ in tree height	0.2849	0.0001	0.2334	0.0939
AC ₂₀₀₂ in trunk diameter	0.4733	0.0001	0.3059	0.0001
AC ₂₀₀₃ in tree height	0.9972	0.0001	0.3682	0.0001
AC ₂₀₀₃ in trunk diameter	0.3816	0.0001	0.6797	0.0020
AC ₂₀₀₄ in tree height	0.1815	0.0008	0.4559	0.0034
AC ₂₀₀₄ in trunk diameter	0.2585	0.0001	0.1177	0.0001
AC ₂₀₀₅ in tree height	0.1290	0.0001	0.0009	0.0681
AC ₂₀₀₅ in trunk diameter	0.2119	0.0001	0.0001	0.5204

^zFinal measurements were taken in Fall 2005.

reduced tree height (data not shown). Of those genotypes that survived, *B. nigra* ‘Cully’, *B. nigra* ‘BNMTF’, *B.* × ‘Royal Frost’, *B. nigra*, and *B. pendula* ‘Laciniata’ were among the tallest trees in the plot (Figure 1). Only *B. nigra* was among the genotypes with the greatest annual change in tree height during every growing season from 2002 to 2005 (data not shown). In both 2004 and 2005, *B. davurica* was also among the genotypes with the greatest annual change in tree height. *Betula utilis* var. *jacquemontii* was the shortest tree and had the lowest annual change in tree height in both 2004 and 2005. The overall average annual change in height was 169%, 117%, 59%, and 23% from 2002 to 2005.

No interaction between birch genotypes and irrigation regimes was observed for the final trunk diameter (Table 5).

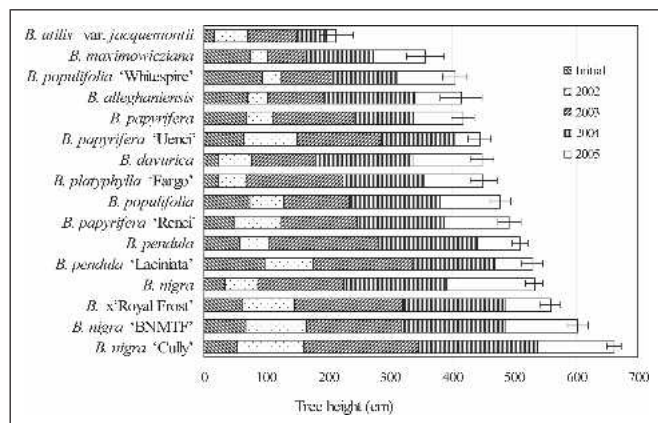


Figure 1. Tree height of birch trees at Fayetteville, Arkansas, from 2002 to 2005. Bars represent standard error of genotype on the final tree height (Tukey’s adjusted test; *P* ≤ 0.05).

Main effects of genotype and irrigation treatment were significant for final trunk diameter. The WS treatment reduced trunk diameter in birch trees (data not shown). Of the surviving birch genotypes, *B. nigra* and its two selections, ‘BNMTF’ and ‘Cully’, had greater final trunk diameter than *B. utilis* var. *jacquemontii*, *B. populifolia* ‘Whitespire’, *B. papyrifera* ‘Uenci’ Renaissance Upright™, *B. papyrifera*, *B. platyphylla* ‘Fargo’ Dakota Pinnacle™, *B. alleghaniensis*, and *B. maximowicziana* (Figure 2). In 2005, *B. nigra*, *B. nigra* ‘BNMTF’, *B. davurica*, and *B. platyphylla* ‘Fargo’ had the greatest annual change in trunk diameter, and *B. papyrifera* ‘Uenci’, *B. pendula* ‘Laciniata’, and *B.* × ‘Royal Frost’ had the lowest annual change in trunk diameter (data not shown). The overall average annual change in trunk diameter

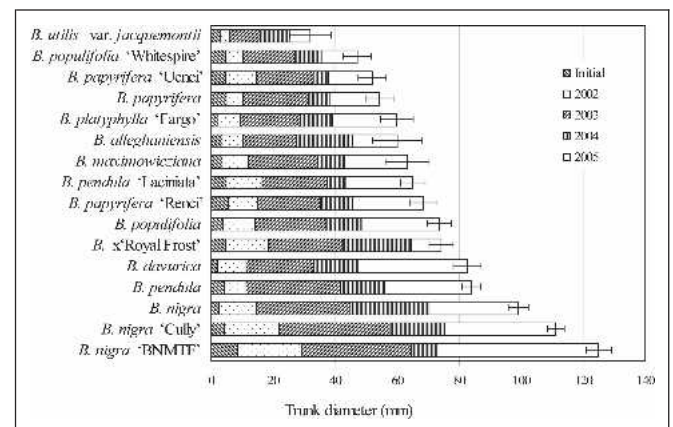


Figure 2. Trunk diameter of birch trees at Fayetteville, Arkansas, from 2002 to 2005. Bars represent standard error of genotype on the final trunk diameter (Tukey’s adjusted test; *P* ≤ 0.05).

was 276%, 181%, 52%, and 29%, respectively, from 2002 to 2005.

Hope

The tree survival by the end of 2005 was 30% (Table 4). Seven of 20 birch genotypes (*B. albosinensis*, *B. alleghaniensis*, *B. ermanii*, *B. papyrifera* ‘Renci’ Renaissance Reflection™, *B. pendula* ‘Trost’s Dwarf’, *B. pendula* ‘Laciniata’, and *B. utilis* var. *jacquemontii*) did not survive through four growing seasons. Six of 13 surviving birch genotypes died back in 2002 (Figure 3). Survival of the 13 genotypes ranged from 17% (*B. davurica*, *B. maximowicziana*, *B. nigra*, *B. pendula*, and *B. platyphylla* ‘Fargo’) to 100% (*B. nigra* ‘BNMTF’). *Betula nigra* ‘Cully’ (94%) was the only other genotype, which had greater than 90% survival.

There were significant differences for final tree height, final trunk caliper, and annual annual change among genotypes (Table 5). Of the 13 surviving genotypes, *B. nigra* ‘Cully’, *B. nigra* ‘BNMTF’, *B. ×* ‘Royal Frost’, *B. pendula*, and *B. papyrifera* were significantly taller than *B. papyrifera* ‘Uenci’, *B. populifolia* ‘Whitespire’, *B. maximowicziana*, and *B. lenta* after four growing seasons (Figure 3). In both 2004 and 2005, *B. papyrifera* was among trees with the highest annual change in tree height, and one of its selections, ‘Uenci’, had the lowest annual change in tree height (data not shown). The overall average annual change in height was 56%, 151%, 40%, and 26% from 2002 to 2005.

Betula nigra ‘Cully’, *B. nigra* ‘BNMTF’, and *B. pendula* had greater final trunk diameter than *B. papyrifera* ‘Uenci’, *B. populifolia* ‘Whitespire’, *B. nigra*, *B. maximowicziana*, and *B. lenta* (Figure 4). In 2004, *B. davurica* and *B. papyrifera* had the highest annual change in trunk diameter and *B. papyrifera* ‘Uenci’ had the lowest annual change (data not shown). In 2005, annual change in trunk diameter was not significant among the birch genotypes (Table 5). The overall

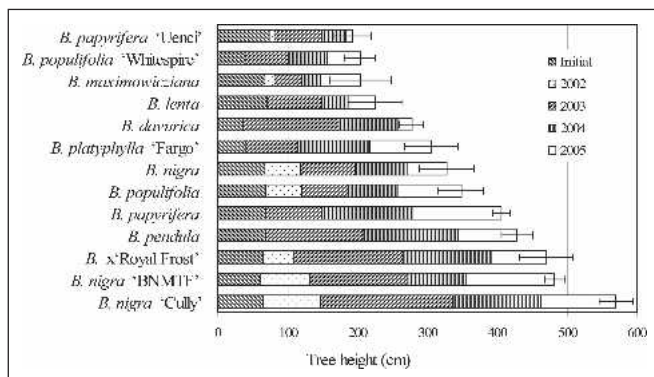


Figure 3. Tree height of birch trees at Hope, Arkansas, from 2002 to 2005. Bars represent standard error of genotype on the final tree height (Tukey’s adjusted test; $P \leq 0.05$).

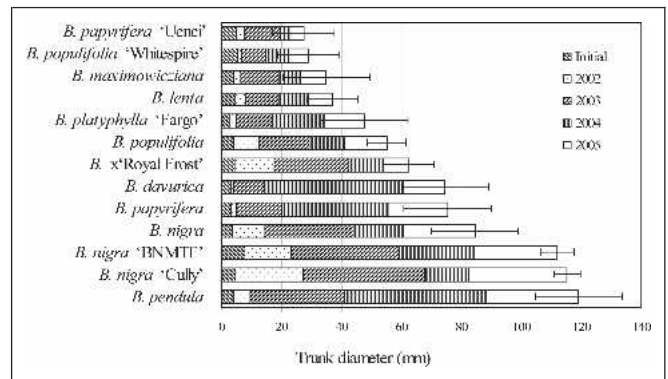


Figure 4. Trunk diameter of birch trees at Hope, Arkansas, from 2002 to 2005. Bars represent standard error of genotype on the final trunk diameter (Tukey’s adjusted test; $P \leq 0.05$).

average annual change in trunk diameter was 169%, 196%, 79%, and 31% from 2002 to 2005.

DISCUSSION

Hope is located at a lower latitude and lower elevation than Fayetteville and in a different USDA cold hardiness zone and AHS heat zone. Both monthly average high temperatures and monthly average low temperatures were higher at Hope than Fayetteville from 2002 to 2005 (Table 1). The warmer temperature at Hope may account for the lower overall survival compared with Fayetteville (Table 4). Only 41% of birch trees survived through the first growing season at Hope compared with 86% at Fayetteville. The warmer temperature may also increase transpiration, which exceeded water uptake capacity from the establishing root system and led to shoot dieback in six birch genotypes at Hope in 2002. The survival changed slightly after 2003, which could be attributed by initial screening in the first 2 years and the established root systems in survived trees.

In 2003 and 2004, most birch trees had greater growth in both height and trunk caliper at two locations than in 2002 (Figures 1–4), which could be attributed to more established roots. Although there was more rainfall in 2004, the relatively cool summer in Fayetteville could result in less growth in trunk diameter (Figure 2).

Betula pendula ‘Trost’s Dwarf’, *B. ermanii*, and *B. albosinensis* had the lowest survival at both locations in Arkansas after four growing seasons (Table 4). Dirr (1998) found that *Betula pendula* ‘Trost’s Dwarf’ did not perform as well in the landscapes as indicated by articles, and *B. ermanii* was rarely seen in the eastern United States as a result of high temperature. *Betula populifolia*, *B. nigra* ‘BNMTF’, *B. nigra* ‘Cully’, and *B. ×* ‘Royal Frost’ had greater survival than the other birch genotypes investigated at both locations. One unexpected results was the low survival of *B. nigra* at both

locations. One possible explanation is the provenance sources for the seed-grown *B. nigra* seedlings.

Experiments under controlled conditions indicated that water-deficit stress reduced tree height of birch genotypes (Fort et al. 1998; Pääkkönen et al. 1998; Wang et al. 1998). Similar reductions were observed for most birch trees investigated under the field conditions at Fayetteville (data not shown). *Betula populifolia* 'Whitespire' was reported to be better adapted to dry sites than *B. nigra*, *B. maximowicziana*, *B. papyrifera*, *B. pendula*, and *B. populifolia* in a study under controlled conditions (Ranney et al. 1991). However, its growth was among the lowest at Fayetteville (Figures 1 and 2), and the difference between the growth of WW plants and WS plants was not significant (data not shown). Dirr's (1998) observation at a nursery indicated that 'Cully' was superior in every aspect when compared with 'Whitespire'.

CONCLUSION

Based on the tree survival, growth, and annual change of the 20 birch genotypes, *B. nigra* 'Cully', *B. ×* 'Royal Frost', *B. pendula*, *B. nigra* 'BNMTF', *B. davurica*, and *B. papyrifera* could survive and be used for landscape use in the southern United States. *Betula pendula* 'Trost's Dwarf', *B. ermanii*, *B. albosinensis*, *B. populifolia* 'Whitespire', *B. papyrifera* 'Uenci', *B. lenta*, *B. maximowicziana*, *B. utilis* var. *jacquemontii*, and *B. alleghaniensis* would not perform well in landscapes in the southern United States.

Of the six birch genotypes recommended for the southern United States, *Betula nigra* 'Cully', *B. nigra* 'BNMTF', and *B. davurica* have creamy white to reddish brown peeling bark. *Betula ×* 'Royal Frost', *B. pendula*, and *B. papyrifera* have distinguished white bark. Leaves on *B. ×* 'Royal Frost' are burgundy red in spring and the color fades off slightly during summer, and turned to red or orange-red in the fall. The other five genotypes have yellow fall foliage. All six genotypes have pyramidal habit and could be used as specimen or shade tree in the landscape.

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LITERATURE CITED

- Atkinson, M.D. 1992. *Betula pendula* Roth (*B. verrucosa* Ehrh.) and *B. pubescens* Ehrh. *Journal of Ecology* 80: 837–870.
- Dirr, M.A. 1998. *Manual of woody landscape plants: Their identification, ornamental characteristics, culture, propagation and uses*. 5th ed. Stipes Publishing L.L.C., Champaign, IL.
- Farrar, J.L. 1995. *Trees of the northern United States and Canada*. 1st ed. Iowa State University Press, Ames, IA.
- Fort, C., F. Muller, P. Label, A. Granier, and E. Dreyer. 1998. Stomatal conductance, growth and root signaling in *Betula pendula* seedlings subjected to partial soil drying. *Tree Physiology* 18:769–776.
- Furlow, J.J. 1990. The genera of *Betulaceae* in the southeastern United States. *Journal of the Arnold Arboretum* 71: 1–67.
- Krussmann, G. 1984. *Manual of cultivated broad-leaved trees and shrubs*. 1st ed. Timber Press, Beaverton, OR.
- Ladjal, M., D. Epron, and M. Ducrey. 2000. Effect of water deficit preconditioning on thermotolerance of photosystem II and susceptibility of photosynthesis to heat stressing cedar seedlings. *Tree Physiology* 20:1235–1241.
- Pääkkönen, E., J. Vahala, M. Pohjolai, T. Holopainen, and L. Kärenlampi. 1998. Physiological, stomatal and ultrastructural ozone responses in birch (*Betula pendula* Roth.) are modified by water stress. *Plant, Cell & Environment* 21: 671–684.
- Ranney, T.G., R.E. Bir, and W.A. Skroch. 1991. Comparative water deficit resistance among six species of birch (*Betula*): Influence of mild water stress on water relations and leaf gas exchange. *Tree Physiology* 8:351–360.
- Ranney, T.G., and M.M. Peet. 1994. Heat tolerance of five taxa of birch (*Betula*): Physiological responses to supra-optimal leaf temperatures. *Journal of the American Society for Horticultural Science* 119:243–248.
- Santamour, F.S. Jr. 1999. Progress in the development of borer-resistant white-barked birches. *Journal of Arboriculture* 25:151–162.
- Santamour, F.S. Jr., and L.N. Lundgren. 1997. Rhododendrin in *Betula*: A reappraisal. *Biochem. Systemat. Ecol.* 25: 335–341.
- Wang, J.R., C.D.B. Hawkins, and T. Letchford. 1998. Relative growth rate and biomass allocation of paper birch (*Betula papyrifera*) populations under different soil moisture and nutrient regimes. *Canadian Journal of Forest Research* 28:44–55.
- Zwack, J.A., and W.R. Graves. 1998. Leaf water relations and plant development of three freeman maple cultivars subjected to water deficit. *Journal of the American Society for Horticultural Science* 123:371–375.

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Résumé. Vingt génotypes de bouleaux ont été planté en champ en avril 2002 pour évaluer leur taux de survie et de croissance à Fayetteville et Hope en Arkansas, et aussi pour évaluer leur réponse en regard de deux régimes différents d'irrigation à Fayetteville. Après quatre saisons de croissance, le taux global de survie des arbres était de 62% et 30% respectivement à Fayetteville et Hope. *Betula pendula* 'Trost's Dwarf', *B. ermanii* et *B. albosinensis* comptaient parmi les génotypes avec les plus faibles taux de survie aux deux endroits. *Betula populifolia*, *B. nigra* 'BNMTF', *B. nigra* 'Cully' et *B. × 'Royal Frost'* avaient les plus hauts taux de survie après quatre saisons de croissance par rapport aux autres génotype testés. *Betula nigra* 'BNMTF' et *B. nigra* 'Cully' étaient plus grands et avaient un plus fort calibre de tronc que les autres génotypes de bouleaux aux deux endroits après quatre saisons de croissance. À la fin de 2005, *B. utilis* var. *jacquemontii* était le plus petit et avait le plus calibre de tronc le plus faible parmi les 18 génotypes ayant survécus à Fayetteville, et *B. papyrifera* 'Uenci' ainsi que *B. populifolia* 'Whitespire', *B. maximowicziana* et *B. lenta* étaient les plus petits et avaient les plus calibres de tronc les plus faibles parmi les 18 génotypes ayant survécus à Hope. À Fayetteville, *B. nigra* et *B. davurica* avaient les plus grands changements annuels quant à la croissance en hauteur à la fois en 2004 et en 2005, tandis que *B. davurica* était parmi les génotypes qui avaient les plus grands changements annuels de calibre de tronc en 2002, 2004 et 2005. À Hope, *B. papyrifera* avait les plus grands changements annuels quant à la croissance en hauteur à la fois en 2004 et en 2005, tandis que *B. davurica* avait les plus grands changements annuels de calibre de tronc en 2004. En 2005, le changement annuel n'était pas significatif parmi les génotypes de bouleaux à Hope. À Fayetteville, le traitement lié à limitation de l'irrigation a diminué la hauteur et le calibre final des troncs chez les bouleaux.

Zusammenfassung. Zwanzig Birken-Genotypen wurden im April 2002 in Feldversuchen ausgepflanzt, um ihr Überleben und Wachstum in Fayetteville und Hope, Arkansas zu bewerten, und ihre Reaktion auf zwei Bewässerungssysteme in Fayetteville zu bewerten. Nach vier Wachstumsperioden war die Überlebensrate 62 %

und 30 % in Fayetteville und Hope. *Betula pendula* Trosts Dwarf, *B. ermanii* und *B. albosinensis* waren die Genotypen mit der niedrigsten Überlebensrate an beiden Standorten. *B. populifolia*, *B. nigra* BNMTF, *B. nigra* Cully und *B. × Royal Frost* hatten nach vier Wachstumsperioden ein stärkeres Überleben als die anderen untersuchten Genotypen. *B. nigra* BNMTF und *B. nigra* Cully waren nach vier Wachstumsperioden an beiden Standorten größer und einen größeren Stammdurchmesser als die andern überlebenden Genotypen. Am Ende von 2005 war *B. utilis* var. *jacquemontii* die kleinste und dünnste Birkenart von 18 überlebenden Genotypen in Fayetteville und *B. papyrifera* Uenci, *B. populifolia* Whitespire, *B. maximowicziana* und *B. lenta* waren die kürzesten und dünnsten Birken von 13 überlebenden Genotypen in Hope. 2004 und 2005 hatten in Fayetteville *B. nigra* und *B. davurica* den größten jährlichen Höhenzuwachs und *B. davurica* war unter den Genotypen mit dem größten jährlichen Dickenzuwachs in den Jahren 2002, 2004 und 2005. In Hope hatte *B. papyrifera* den größten jährlichen Höhenzuwachs in 2004 und 2005 und *B. davurica* hatte den größten jährlichen Dickenzuwachs in 2004. In 2005 war der jährliche Zuwachs unter allen Genotypen in Hope nicht signifikant. In Fayetteville begrenzte der Wasserstress unter der Behandlung die Baumhöhe und den Dickenzuwachs bei den Birken.

Resumen. Se plantaron 20 genotipos de abedul en Abril de 2002 para evaluar su supervivencia y crecimiento en Fayetteville y Hope, Arkansas; y valorar su respuesta a dos regímenes de riego en Fayetteville. Después de cuatro estaciones de crecimiento, la supervivencia total fue 62% y 30% en Fayetteville y Hope, respectivamente. *Betula pendula* 'Trost's Dwarf', *B. ermanii*, y *B. albosinensis* estuvieron entre los genotipos con la supervivencia más baja en ambas localidades. *Betula populifolia*, *B. nigra* 'BNMTF', *B. nigra* 'Cully', y *B. × 'Royal Frost'* tuvieron mayor supervivencia después de cuatro estaciones de crecimiento que los otros genotipos investigados de abedul. *Betula nigra* 'BNMTF' y *B. nigra* 'Cully' fueron árboles más altos y tuvieron mayores diámetros del tronco que los otros genotipos en las dos localidades después de las cuatro estaciones de crecimiento. Al final del 2005, *B. utilis* var. *jacquemontii* fue el árbol más pequeño y tuvo el diámetro del tronco más pequeño entre los 18 genotipos que sobrevivieron en Fayetteville; y *B. papyrifera* 'Uenci', *B. populifolia* 'Whitespire', *B. maximowicziana*, y *B. lenta* tuvieron el más corto y el más pequeño diámetro del tronco entre los 13 genotipos sobrevivientes en Hope. En Fayetteville, *B. nigra* y *B. davurica* tuvieron el mayor cambio anual en altura del árbol tanto en 2004 como en 2005, y *B. davurica* estuvo entre los genotipos con el mayor cambio anual en diámetro del tronco en 2002, 2004 y 2005. En Hope, *B. papyrifera* tuvo el mayor cambio anual en altura en 2004 y 2005, y *B. davurica* tuvo el mayor cambio anual en diámetro del tronco en 2004. En 2005, el cambio anual no fue significativo entre los genotipos en Hope. En Fayetteville, los tratamientos de estrés hídrico redujeron la altura final y el diámetro del tronco en los árboles de abedul.