Crapemyrtle Genotype × Environment Interactions, and Trait Stability for Plant Height, Leaf-out, and Flowering

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Abstract. This study reports on the performance of 34 clones of crapemyrtle (*Lagerstroemia indica* L., *L. fauriei* Koehne, and *L. indica* × *L. fauriei* hybrids) grown in field plots at four locations representative of different environments in the southeastern United States. Traits evaluated were spring leaf-out and initiation of flowering in the second season after field planting and plant height after 3 years of growth. Cluster analysis (Ward's method) was used for grouping and comparison of means across locations for each trait. Best linear unbiased prediction was used for estimating random effects in linear and generalized linear mixed models to better determine the general performance of the clones under a variety of environmental conditions. Each clone's trait stability was quantified using the regression of an individual genotype's performance for each of the three studied traits on an environmental index based on the trait mean for all genotypes grown in an environment. Sequence of clone leaf-out and size rankings were more stable across the environments than the sequence in which the various clones initiated flowering. *L. fauriei* clones and clones originating from the initial cross between *L. indica* and *L. fauriei* were generally later to leaf out, earlier to flower, and more vigorous growers than *L. indica* or the complex *L. indica* × *L. fauriei* clones that were evaluated. First flowering was affected by environmental variation more with interspecific hybrids than with *L. fauriei* and *L. indica* clones. Performance, particularly with respect to plant height, of several clones did not agree with previously published classifications. Information generated by this study will allow crapemyrtle breeders, landscape professionals, and consumers to better select the most appropriate crapemyrtle clone for a particular application.

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Crapemyrtles (*Lagerstroemia indica*, *L. fauriei*, and *L. indica* × *L. fauriei* hybrids) are popular flowering shrubs and small trees in US landscapes in regions with hot summers in USDA plant hardiness zones 6 to 10 and heat zones 7 to 10 (AHS Heat Zone Map, 2009; USDA Hardiness Zone Map, 2009). Because the commonly grown species have barriers to production of seed lines with uniform traits (Pounders et al., 2006), commercial crapemyrtle production is based on asexual propagation of named clones (Byers, 1997). To serve various landscape objectives, numerous clones that vary in growth rate, plant habit, pest tolerance, and flower color

have been selected over the past century (Dix, 1999). Heirloom cultivars were selected as chance seedlings based on unique flower color or growth habit (Egolf and Andrick, 1978). Otto Spring of Okmulgee, OK, and Donald Egolf at the U.S. National Arboretum (USNA) pioneered controlled breeding of crapemyrtles in the United States and many cultivars released during the past 40 years originated from their efforts. Research at the USNA indicated that *L. fauriei* was cold-hardy and resistant to powdery mildew, coupled with the discovery of a chance interspecific hybrid between this species and *L. indica* in Texas (Egolf and Andrick, 1978), led to the introgression of *L. fauriei* into the USNA breeding program as a source of powdery mildew resistance. After selection of powdery mildew-resistant interspecific progeny, breeding focused on half-sib and backcrosses to introduce resistance into predominantly *L. indica* germplasm. More than 20 cultivars with high levels of powdery mildew resistance (Egolf, 1967, 1981a, 1981b, 1986a, 1986b, 1987a, 1987b, 1990; Pooler, 2006; Pooler and Dix, 1999) have been released by the USNA. Several popular cultivars with unique flower colors were derived by continued breeding with Otto Spring's germplasm (Whitcomb, 1985, 1999, 2000a, 2000b, 2004; Whitcomb et al., 1984).

Crapemyrtle cultivars have been evaluated for a number of traits, including growth (Bolques and Knox, 1997; Cabrera and Devereaux, 1999; Creech et al., 1999; Knox, 1996; Knox and Norcini, 1991; Laiche and Anderson, 1996), cold tolerance (Davis and Fare, 1995; Hayes and Lindstrom, 1992; Lindstrom et al., 2002), nutrient use (Cabrera, 2003; Cabrera and Devereaux, 1998; Devereaux, 1996; Martin and Ruter, 1996), flowering (Bolques and Knox, 1997; Fare, 1984; Goi and Tanaka, 1976; Guidry, 1977; Pair and Parsons, 1996; Stimart, 1986), resistance to disease (Hagan et al., 1998; Holcomb, 1994; Knox et al., 1993), and insect feeding preferences (Cabrera et al., 2008; Mizell and Knox, 1993; Pettis et al., 2004). Most of these evaluations were based on data from one site over multiple years.

Size categories based on plant height at maturity were first proposed by Egolf and Andrick (1978). Johnson and Dix (1993) pointed out that "at maturity" is a vague term that can lead to misclassification without designation of the age of specimens when the size would be realized. Under the improved system, cultivars are divided into four size categories: dwarf cultivars (less than 1.5 m at 5 years), semidwarf (1.5 to 3 m), intermediate (3 to 6 m), and tree forms (greater than 6 m) based on expected height after 10 years for the larger three classes. The revised classification system has been widely used in extension publications and other references comparing crapemyrtle landscape traits (Byers, 1997, 2000; Franklin et al., 2006; Gill and Owens, 2007; Knox, 2008; Wade and Williams-Woodward, 2001; Williams et al., 2000). Classification into the various size categories appears to be based on height data

reported in the published cultivar releases (Egolf 1967, 1981a, 1981b, 1986a, 1986b, 1987a, 1987b, 1990; Pooler, 2006; Pooler and Dix, 1999; Whitcomb, 1985, 1999, 2000a, 2000b, 2004; Whitcomb et al., 1984) and extrapolation for other cultivars rather than replicated side-by-side comparisons of cultivars at multiple sites. This implies that popular cultivars can be expected to perform in a similar manner in all areas of the United States where crapemyrtle is adapted. None of the growth studies were replicated at multiple locations to determine how sensitive observed traits were to different environments.

Plant phenotypes vary according to the environments where they are evaluated (Hill, 1975). Evaluation of plant traits in diverse environments produces an understanding of genotype $\times$ environment ($G \times E$) interactions that affect performance of a particular clone. Such information is important to horticulturists and plant breeders for proper selection of the most appropriate crapemyrtle clone for a particular application. Generally, genotypes with consistent performance in many environments are preferred over those that excel in restricted environments.

Observation of crapemyrtle clones in multiple random environments within the normal range of hardiness would give a much better understanding of the ultimate landscape performance of a clone. This study reports the variation for three traits (week of leaf-out, week of first flowering, plant height)

in 34 common crapemyrtle clones (genotypes) observed in four diverse environments within the southeastern United States. Additionally, variation and phenotypic stability were identified for the three traits among the clones.

Materials and Methods

Thirty-four commonly produced crapemyrtle clones (Table 1) were selected from available clones representing a range of traits from each of the semidwarf (1.5 to 3 m), medium (3 to 6 m) and tall (greater than 6 m) groupings for expected mature size (Franklin et al., 2006). Cuttings from the same ortet of a clone were rooted in the summer of 2002 in 36-cell trays at Poplarville, MS, in ground pine bark supplemented with Osmocote 18N-2.6P-10K (18-6-12) (6-8 month; The Scotts Co., Marysville, OH) incorporated at a rate of 5.3 kg-m⁻³. Rooted cuttings of the selected clones were distributed to cooperators at four locations (Table 2) in Jan. 2003. Cooperators grew the clones for one growing season in 11.3-L (#3) nursery containers and then transplanted into field plots in Spring 2004. Immediately after planting, plants at all locations were pruned to a height of 10 cm before spring budbreak. Cooperators were instructed to follow accepted production practices (fertilization, pest control, supplemental watering) for crapemyrtle production in their area. Growing practices and climatic

conditions at the four locations (Table 2) constituted four random growing environments within the southeastern United States. The field layout at each of the four locations was a randomized complete block design with six blocks containing a single plant of each clone (a total of 204 plants with six replicates per clone at each location).

Data were collected for week of leaf-out (LO) and initiation of flowering (FR) during the 2005 growing season. Plant height (HT) was measured after the 2006 growing season (3 years in the field) when plants were dormant. Weekly readings on LO started at each location beginning when the first plant of any clone displayed fully expanded leaves (Week 1) until the last plant of any clone displayed fully expanded leaves (Week 5 being the latest). Consequently, the week of LO for each plant at a location was designated by a single value from 1 to 5. During 2005, there were no killing frosts at any location to disrupt the normal sequence of LO for the 34 clones. FR was rated weekly beginning when any plant at a location began flowering (Week 1) until the last plant at the location began flowering (Week 8 being the latest). Therefore, each plant at a location was designated by a single FR value from 1 to 8.

Preliminary analysis of data was conducted using location, clone, and location $\times$ clone as fixed factors and block(location) as a random factor to confirm our expectations of overall differences in response variables

Table 1. Flower color, parentage, and selector (name and location) of 34 *Lagerstroemia* clones.

Clone	Code	Flower color	Species parentage	Selector ²	Selector's location ²
Acoma	ACO	White	<i>L. indica/L. fauriei</i>	Egolf	DC
Apalachee	APA	Lavender	<i>L. indica/L. fauriei</i>	Egolf	DC
Arapaho	ARA	Red	<i>L. indica/L. fauriei/L. limii</i>	Pooler	DC
Carolina Beauty	CAB	Red pink	<i>L. indica</i>	Dailey	SC
Catawba	CAT	Purple	<i>L. indica</i>	Egolf	DC
Centennial Spirit	CES	Red	<i>L. indica</i>	Whitcomb	OK
Cheyenne	CHE	Red purple	<i>L. indica/L. fauriei/L. limii</i>	Pooler	DC
Choctaw	CHO	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Christiana	CHR	Red pink	<i>L. indica</i>	Egolf	DC
Country Red	COU	Red pink	<i>L. indica</i>	Durant	OK
Fantasy	FAN	White	<i>L. fauriei</i>	Raulston	NC
Kiowa	KIO	White	<i>L. fauriei</i>	Pooler	DC
Miami	MIA	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Muskogee	MUS	Lavender	<i>L. indica/L. fauriei</i>	Egolf	DC
Natchez	NAT	White	<i>L. indica/L. fauriei</i>	Egolf	DC
Osage	OSA	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Pecos	PEC	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Powhatan	POW	Purple	<i>L. indica</i>	Egolf	DC
Sarahs Favorite	SAR	White	<i>L. indica/L. fauriei</i>	Egolf	DC
Sioux	SIO	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Splash of Pink	SPP	Pink/white	<i>L. indica</i>	Bond	TX
Tonto	TON	Red pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Townhouse	TOW	White	<i>L. fauriei</i>	Raulston	NC
Tuscarora	TUS	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Tuskegee	TKE	Pink	<i>L. indica/L. fauriei</i>	Egolf	DC
Twilight	TWI	Purple	<i>L. indica</i>	Fitzpatrick	TX
Velmas Royal Delight	VRD	Purple	<i>L. indica</i>	McDaniel	KS
Whit I	RAS	Pink/white	<i>L. indica</i>	Whitcomb	OK
Whit II	DYN	Red	<i>L. indica</i>	Whitcomb	OK
Whit IV	RER	Red	<i>L. indica</i>	Whitcomb	OK
Whit VI	BUC	Blush pink	<i>L. indica</i>	Whitcomb	OK
Whit VII	SIR	Red	<i>L. indica</i>	Whitcomb	OK
Wm. Toovey	WMT	Red pink	<i>L. indica</i>	Howell	TN
Woodlanders Chocolate Soldier	WCS	White	<i>L. fauriei</i>	Mitchell	SC

²Selector (name and location) as reported by Dix (1999).

Table 2. Characterization of environmental conditions over three years at sites in four southeastern U.S. states where 34 clones of *Lagerstroemia* were evaluated.

State	City	Elevation (m)	Latitude	Longitude	USDA hardiness zone ^e	AHS heat zone ^g	USDA soil classification ^s	Irrigation source	Yr	Precipitation (mm)	Avg yearly temp (°C) ^w	High daytime temp (°C) ^v	Low nighttime temp (°C) ^v	Freeze-free days ^y	Cooling degree days ^u
Alabama	Cullman	243.8	34.12 N	86.48 W	7A	8	Hartselle fine sandy loam	Rainfall	2004	172.5	15.4	33.3	-10.6	248	1305
Florida	Quincy	74.7	30.33 N	84.36 W	8B	9	Ruston fine sandy loam	Rainfall	2005	135.1	15.4	35.1	-8.9	183	1579
								Rainfall	2006	142.1	15.8	37.2	-10.6	210	1704
Mississippi	McNeill	66.1	30.39 N	89.38 W	8B	9	Ruston fine sandy loam	Drip ⁱ	2004	147.8	19.8	36.1	-5.1	264	2716
								Drip	2005	138.7	20.1	37.2	-7.2	264	2751
Tennessee	McMinnville	286.5	35.40 N	85.47 W	6B	7	Waynesboro silt loam	Drip	2006	104.7	20.3	37.2	-6.1	252	2696
								Rainfall	2004	186.2	18.8	36.1	-5.6	298	2430
								Rainfall	2005	181.6	19.7	36.1	-5.1	244	2415
								Rainfall	2006	180.4	19.8	36.7	-5.1	244	2520
								Drip ^s	2004	149.4	15.6	33.3	-11.7	215	1452
								Drip ^s	2005	94.7	15.5	35.1	-11.1	183	1609
								Rainfall	2006	120.1	14.5	36.1	-12.8	200	1386

^zUSDA Hardiness Zone Map developed to detail the lowest temperatures that can be expected each year in the United States, Canada, and Mexico (USDA Hardiness Zone Map, 2009).

^yAHS Heat Zone Map developed by the American Horticulture Society to show the average number of days each year that a given region experiences "heat days," temperatures over 30 °C (86 °F) (AHS Heat Zone Map, 2009).

^wUSDA Soil Classification (2009).

^vYearly average temperature = (average daytime temperature + average nighttime temperature)/2.

^uHigh daytime and low nighttime temperature and freeze free days provided by NOAA Satellite and Information Service, National Environmental Satellite, Data, and NOAA Information Service (NESDIS) (2009).

^sCooling degree days = average daily temperature - 65. For example, if the daily high temperature is 90 °F and the daily low is 70 °F, the day's average is 80 °F. Eighty minus 65 is 15 cooling days.

ⁱDrip irrigation was applied April through October with each plant receiving 24 L per week.

^sDrip irrigation was applied June through September to supplement rainfall.

(week of LO, week of first flower, and plant HT traits) among locations and to provide least squares means of the three response variables for each location (across all clones) for later use in analyzing stability of traits for the clones across locations. Subsequent analysis of response data was conducted using clone as a fixed factor and location, location × clone, and block(location) as random factors.

Plant height data were analyzed using a linear mixed model with the MIXED procedure of SAS (Version 9.2; SAS Institute, Inc., Cary, NC). Week of LO data and week to first flowering data were analyzed using a generalized linear mixed model with a Poisson distribution and a log link function with the GLIMMIX procedure of SAS. Least squares means of the response variables were determined for each clone across all locations for later use in cluster analysis and for correlation analysis. Pearson correlation coefficients between pairs of the response variables were obtained using the CORR procedure of SAS.

Best linear unbiased predictions (BLUPs) for the three response variables provided estimated values of the response variables for each clone at each location taking into account both the fixed and random effects through estimable linear functions (Robinson, 1991). Rather than using the four locations as the entire population and calculating means as simple averages, the locations were considered to be a random sample from a normally distributed population with the BLUPs providing regression toward the overall mean (shrinkage estimation) based on the variance components of the model effects (Littell et al., 2006).

Cluster analysis was used to investigate potential groupings of clones for similarity of week of LO, week of first flowering, and plant height using the least squares means calculated for each clone across all locations. Cluster analysis was conducted using Ward's method with the CLUSTER and TREE procedures of SAS, the number of clusters being determined using R^2 , semipartial R^2 , and between-cluster sum of squares statistics (Blythe and Merhaut, 2007). Descriptive statistics for each cluster for each of the three variables were obtained using the MEANS procedure of SAS.

Stability of traits for the 34 clones across locations was quantitatively assessed for each clone by simple linear regression of each response variable against the means of the respective variable from each location (environmental index), a method that has been useful for evaluating performance and adaptation of agronomic and horticultural crops in different locations and environments (Eberhart and Russell, 1966; Finlay and Wilkinson, 1963; Ortiz and Izquierdo, 1994). Linearity of the regression was checked using both the original data values and the natural logarithm of the data values (Finlay and Wilkinson, 1963). Linearity was improved using the logarithm for week of LO and plant height, but not for week of flowering.

A clone was considered to be stable if b_1 (coefficient of regression) was not significantly different from 1, s_d^2 (deviation from linearity) = 0, and r^2 (coefficient of deter-

mination) greater than 0.50 following the criteria of Ortiz and Izquierdo (1994). The stability characteristic b_1 was considered consistent if its SE (s_b) was not significantly

different from zero as indicated by deviation of the regression from linearity (s_d^2).

Stability analysis in this study follows the concept of dynamic stability under which a stable genotype exhibits a varying, but predictable, response to different environments as opposed to the static concept of stability, under which a stable genotype responds at a constant level in different environments (Becker and Leon, 1988). Clones with values of $b_1 \approx 1$ are considered stable with the response of the clone in different environments being similar to the environmental index (described previously). Values of b_1 greater than 1 indicate clones that are more sensitive to environment, whereas values of b_1 less than 1 (and approaching zero) are less sensitive to environment among all clones being evaluated.

To complete the analysis, the stability characteristic b_1 was plotted against the least squares mean for each clone (across all locations) to assess both characteristics for all clones simultaneously with one plot for each of the three response variables. Horizontal lines were added to the plots to indicate values of b_1 on the y axis that were statistically different from 1 at the 0.05 significance level, whereas vertical lines were added to the plots for mean values on the x axis statistically different from the grand mean at the 0.05 significance level, similar

Table 3. Tests of fixed effects in linear mixed models evaluating plant height, time to leaf-out^a and time to first flower^b of 34 clones of *Lagerstroemia* grown at four locations in the southeastern United States (Quincy, FL; McNeill, MS; Cullman, AL; and McMinnville, TN).

Fixed effect	Numerator df	Denominator df	F value	Probability > F ^x
<i>Week of leaf-out (location as a fixed effect)</i>				
Location	3	20	16.82	<0.001
Clone	33	646	3.91	<0.001
Location × clone	99	646	0.41	1.000
<i>Week of leaf-out (location as a random effect)</i>				
Clone	33	646	3.81	<0.001
<i>Week of first flower (location as a fixed effect)</i>				
Location	3	20	27.94	<0.001
Clone	33	646	8.09	<0.001
Location × clone	99	646	1.76	<0.001
<i>Week of first flower (location as a random effect)</i>				
Clone	33	646	5.98	<0.001
<i>Plant height (location as a fixed effect)</i>				
Location	3	20	137.69	<0.001
Clone	33	647	66.46	<0.001
Location × clone	99	647	4.51	<0.001
<i>Plant height (location as a random effect)</i>				
Clone	33	647	66.46	<0.001

^aWeek of leaf-out at each location was recorded relative to the first plant at that location to leaf-out.

^bTime to first flower at each location was recorded relative to the first plant at that location to flower.

^xP values from F tests.

Table 4. Least squares means and best linear unbiased predictions (BLUPs) with 95% confidence intervals for week of leaf-out of 34 clones of *Lagerstroemia* grown at four locations in the southeastern United States.^a

Clone	All locations ^c	Quincy, FL	McNeill, MS	Cullman, AL	McMinnville, TN
ACO	2.56 (1.86–3.51)	2.00 (1.54–2.60)	2.89 (2.23–3.74)	2.84 (2.19–3.68)	2.61 (2.01–3.38)
APA	1.73 (1.21–2.48)	1.35 (0.99–1.86)	1.96 (1.44–2.67)	1.92 (1.41–2.62)	1.77 (1.29–2.41)
ARA	1.77 (1.24–2.53)	1.39 (1.02–1.89)	2.00 (1.47–2.72)	1.97 (1.45–2.68)	1.81 (1.33–2.46)
CAB	1.86 (1.31–2.63)	1.45 (1.07–1.97)	2.10 (1.55–2.83)	2.06 (1.52–2.78)	1.89 (1.40–2.56)
CAT	1.94 (1.37–2.74)	1.52 (1.12–2.04)	2.19 (1.63–2.94)	2.15 (1.60–2.89)	1.98 (1.47–2.66)
CES	2.58 (1.86–3.57)	2.01 (1.53–2.65)	2.91 (2.23–3.81)	2.86 (2.18–3.74)	2.63 (2.00–3.45)
CHE	1.81 (1.28–2.58)	1.42 (1.04–1.93)	2.05 (1.51–2.78)	2.01 (1.49–2.73)	1.85 (1.36–2.51)
CHO	2.27 (1.63–3.15)	1.77 (1.34–2.34)	2.56 (1.95–3.37)	2.52 (1.91–3.31)	2.31 (1.76–3.04)
CHR	3.23 (2.39–4.37)	2.52 (1.98–3.22)	3.65 (2.88–4.62)	3.58 (2.83–4.54)	3.29 (2.59–4.18)
COU	3.26 (2.42–4.39)	2.55 (2.01–3.23)	3.68 (2.92–4.64)	3.62 (2.87–4.56)	3.32 (2.63–4.19)
FAN	3.84 (2.86–5.16)	3.00 (2.39–3.78)	4.34 (3.48–5.43)	4.26 (3.41–5.34)	3.92 (3.13–4.91)
KIO	3.78 (2.80–5.10)	2.95 (2.32–3.76)	4.27 (3.39–5.38)	4.19 (3.33–5.29)	3.85 (3.04–4.88)
MIA	2.52 (1.83–3.46)	1.97 (1.51–2.57)	2.84 (2.19–3.69)	2.79 (2.15–3.62)	2.57 (1.97–3.33)
MUS	2.64 (1.93–3.62)	2.06 (1.59–2.68)	2.98 (2.31–3.85)	2.93 (2.27–3.78)	2.69 (2.08–3.48)
NAT	2.72 (1.99–3.72)	2.13 (1.65–2.75)	3.08 (2.39–3.95)	3.02 (2.35–3.88)	2.78 (2.16–3.57)
OSA	3.01 (2.21–4.10)	2.36 (1.84–3.02)	3.41 (2.67–4.35)	3.34 (2.62–4.27)	3.07 (2.40–3.93)
PEC	2.14 (1.54–2.99)	1.68 (1.26–2.23)	2.42 (1.83–3.21)	2.38 (1.80–3.15)	2.19 (1.65–2.90)
POW	2.10 (1.50–2.94)	1.64 (1.23–2.19)	2.38 (1.79–3.15)	2.33 (1.76–3.10)	2.14 (1.61–2.85)
SAR	3.38 (2.51–4.55)	2.64 (2.09–3.34)	3.82 (3.05–4.80)	3.75 (2.99–4.71)	3.45 (2.74–4.34)
SIO	2.42 (1.75–3.36)	1.89 (1.44–2.50)	2.74 (2.09–3.59)	2.69 (2.05–3.52)	2.47 (1.88–3.24)
SPP	2.80 (2.06–3.82)	2.19 (1.70–2.82)	3.17 (2.47–4.06)	3.11 (2.43–3.99)	2.86 (2.23–3.67)
TON	2.14 (1.54–2.99)	1.68 (1.26–2.23)	2.42 (1.83–3.21)	2.38 (1.80–3.15)	2.19 (1.65–2.90)
TOW	3.88 (2.90–5.17)	3.03 (2.43–3.78)	4.38 (3.54–5.42)	4.30 (3.47–5.33)	3.95 (3.19–4.90)
TUS	2.23 (1.60–3.10)	1.74 (1.31–2.31)	2.52 (1.91–3.32)	2.47 (1.88–3.26)	2.27 (1.72–3.00)
TKE	2.23 (1.60–3.10)	1.74 (1.31–2.31)	2.52 (1.91–3.32)	2.47 (1.88–3.26)	2.27 (1.72–3.00)
TWI	3.46 (2.58–4.65)	2.71 (2.15–3.41)	3.91 (3.13–4.90)	3.84 (3.07–4.81)	3.53 (2.82–4.43)
VRD	3.18 (2.35–4.29)	2.48 (1.95–3.16)	3.59 (2.84–4.53)	3.52 (2.79–4.45)	3.24 (2.56–4.10)
RAS	2.93 (2.15–3.98)	2.29 (1.79–2.94)	3.31 (2.60–4.22)	3.25 (2.55–4.14)	2.99 (2.34–3.81)
DYN	2.35 (1.70–3.25)	1.84 (1.40–2.42)	2.66 (2.03–3.48)	2.61 (1.99–3.41)	2.40 (1.83–3.14)
RER	2.43 (1.76–3.36)	1.90 (1.45–2.49)	2.75 (2.11–3.58)	2.70 (2.07–3.52)	2.48 (1.90–3.24)
BUC	2.82 (2.05–3.87)	2.20 (1.69–2.87)	3.18 (2.47–4.11)	3.13 (2.42–4.05)	2.87 (2.22–3.72)
SIR	2.42 (1.75–3.36)	1.89 (1.44–2.49)	2.74 (2.09–3.59)	2.69 (2.05–3.53)	2.47 (1.88–3.24)
WMT	2.89 (2.12–3.93)	2.26 (1.76–2.90)	3.26 (2.56–4.17)	3.20 (2.51–4.09)	2.94 (2.30–3.76)
WCS	4.37 (3.30–5.80)	3.42 (2.77–4.21)	4.94 (4.04–6.05)	4.85 (3.96–5.94)	4.46 (3.63–5.47)
All clones		2.06 C ^y	3.07 A	3.01 A	2.73 B

^aLeast squares means were calculated for each clone across all locations and BLUPs were calculated for each clone at each location (with location as a random effect). Least squares means were calculated for each location across all clones (with location as a fixed effect in preliminary analysis).

^yMeans at each location for all clones combined followed by the same letter are not significantly different according to the simulation-stepdown method at $\alpha = 0.05$.

to the method of Ortiz and Izquierdo (1994). These features were added to the plots to facilitate general identification of clones that were relatively stable (values of b_1 close to 1), sensitive, or insensitive to environment and clones that were similar, higher, or lower in mean response compared with the overall mean; they were not intended for development of strict statistical inferences.

Results and Discussion

Crapemyrtle clones at the four locations were exposed to a wide range of climatic variation typical of the southeastern United States (Table 2). The Alabama and Tennessee locations had shorter growing seasons, colder winter minimum temperatures, and cooler summers than the Florida and Mississippi locations. During the three growing seasons, the Alabama, Florida, and Tennessee locations experienced severe summer droughts, whereas the Mississippi location was in the path of Hurricane Katrina in Aug. 2005.

Correlations between LO and FR, HT and FR, and HT and LO were statistically significant ($P < 0.01$), but weak. The strongest as-

sociation was between HT and FR ($r = -0.25$) followed by HT and LO ($r = 0.12$); therefore, no strong linear relationship among the three traits was indicated. Test of fixed effects in statistical models indicated significant differences in LO, FR, and HT for the 34 clones across the four locations (Table 3).

Late spring frosts periodically damage crapemyrtles as plants break dormancy and begin growth. Plants that LO later in the spring should be less prone to the unsightly burn and growth delays associated with such damage. In 2005, LO began during the week of 14 Mar. in Mississippi, 21 Mar. in Florida and Alabama, and 11 Apr. in Tennessee. When location was treated as a fixed effect to evaluate difference at the four locations (Table 3), the location $\times$ clone interaction was nonsignificant indicating the sequence in which clones leafed out was very stable regardless of environment. BLUPs for all locations ranged from 1.73 for APA to 4.37 for WCS or ≈ 2.5 weeks difference in LO (Table 4). Plants leafed out over 4 weeks in Florida, whereas the other locations required 5 weeks. Overall, location LO means for all clones indicate plants leafed out over a shorter

duration in Florida and Tennessee than in Mississippi and Alabama. Cluster analysis of the means developed a three-cluster solution (Table 5). Seven of the *L. indica* clones were grouped into Cluster 1, the earliest LO group, whereas eight were in Cluster 2, the intermediate LO group. Eleven of the interspecific clones were in Cluster 1, whereas four were in Cluster 2. NAT, MUS and SAR, the only three interspecific hybrids resulting from a direct cross between *L. indica* and *L. fauriei* (Egolf, 1981a), clustered together in the intermediate group with the complex interspecific hybrid, OSA. The four *L. fauriei* clones (FAN, KIO, TOW, WCS) in the study clustered together into Cluster 3, the last group to LO. Apparently, *L. fauriei* germplasm has a greater tendency to maintain dormancy later in the spring than germplasm of *L. indica*.

Stability analysis showed the majority of the clones in this study to have b_1 values ≈ 1 , indicating relative stability (Table 6; Fig. 1A). However, departures from linearity (s_d^2) and low r^2 values indicated inconsistent stability or lack of definite stability for most clones. It appeared that the latter situation

Table 5. Spring leaf-out, flowering, and growth comparisons of 34 *Lagerstroemia* cultivars.

Code	Cluster for leaf-out ^z	Flowering period ^y	Cluster for week of first flower ^x	Reported ht ^w	Reported growth class ^w	Reported growth scale ^w	Cluster for plant ht ^v
ACO	1	2	3	1.5–3	Semidwarf	1	1
APA	1		3	3–6	Intermediate	2	2
ARA	1		2	>6	Tree	3	1
CAB	1	3	3	>6	Tree	3	2
CAT	1		2	3–6	Intermediate	2	1
CES	1		3	3–6	Intermediate	2	1
CHE	1		2	3–6	Intermediate	2	1
CHO	1	3	2	>6	Tree	3	3
CHR	2		2	1.5–3	Semidwarf	1	1
COU	2		3	3–6	Intermediate	2	3
FAN	3	2	1	>6	Tree	3	3
KIO	3	2	1	>6	Tree	3	3
MIA	1	2	2	>6	Tree	3	3
MUS	2	1	1	>6	Tree	3	3
NAT	2	1	1	>6	Tree	3	3
OSA	2	2	2	3–6	Intermediate	2	3
PEC	1	1	2	1.5–3	Semidwarf	1	1
POW	1	3	2	3–6	Intermediate	2	1
SAR	2		2	>6	Tree	3	3
SIO	1	3	3	3–6	Intermediate	2	2
SPP	2		2	Not published	Not published		1
TON	1	3	2	1.5–3	Semidwarf	1	2
TOW	3	2	1	>6	Tree	3	3
TUS	1	2	3	>6	Tree	3	3
TKE	1	2	3	3–6	Intermediate	2	3
TWI	2		3	>6	Tree	3	2
VRD	2	2	2	<1.5	Dwarf	–1	1
RAS	2	3	3	3–6	Intermediate	2	2
DYN	1	3	3	3–6	Intermediate	2	2
RER	1	3	3	>6	Tree	3	2
BUC	2		3	3–6	Intermediate	2	1
SIR	1		3	1.5–3	Semidwarf	1	1
WMT	2	3	2	3–6	Intermediate	2	2
WCS	3		2	Not published	Not published		3

^zClusters of clones were determined using least squares means for week of leaf-out (across all locations) with hierarchical cluster analysis (Ward's method) with values for Cluster 1 ranging from 1.73 to 2.58, values for Cluster 2 ranging from 2.64 to 3.46, and values for Cluster 3 ranging from 3.78 to 4.37.

^yFlowering season scale based on observations by Byers (2000) and Fare (1984) in which 1 = early and mid-June (early); 2 = late June and early July (midseason); and 3 = mid- and late July (late).

^xClusters of clones were determined using least squares means for week of first flower (across all locations) with hierarchical cluster analysis (Ward's method) with values for Cluster 1 ranging from 1.84 to 2.86, values for Cluster 2 ranging from 3.38 to 4.52, and values for Cluster 3 ranging from 4.72 to 7.00.

^wHeight and growth class and growth scale [1 = 1.5–3 m (semidwarf); 2 = 3–6 m (intermediate); and 3 = greater than 6 m (tree)] reported by Franklin et al. (2006).

^vClusters of clones were determined using least squares means for plant height (across all locations) with hierarchical cluster analysis (Ward's method) with values for Cluster 1 ranging from 113.0 to 164.8 cm, values for Cluster 2 ranging from 187.8 to 215.5 cm, and values for Cluster 3 ranging from 229.0 to 301.1 cm.

Table 6. Stability characteristics^z for week of leaf-out, week of first flower, and plant height for 34 clones of *Lagerstroemia* grown at four locations in the southeastern United States.

Clone	Week of leaf-out ^y			Week of first flower			Plant ht ^y		
	b ₁ ^x	s _b ^w	r ²	b ₁ ^x	s _b ^w	r ²	b ₁ ^x	s _b ^w	r ²
ACO	1.91**	0.26**	0.71	1.35	0.37**	0.37	1.49	0.31**	0.51
APA	1.43	0.31**	0.48	1.46	0.44**	0.34	1.26	0.24**	0.55
ARA	0.90	0.34*	0.24	1.63*	0.25**	0.66	1.49	0.41**	0.38
CAB	0.75	0.43	0.12	0.81	0.24**	0.35	0.80	0.22**	0.37
CAT	0.96	0.27**	0.36	1.06	0.12**	0.78	0.65	0.25**	0.24
CES	1.79**	0.30**	0.64	1.13	0.29**	0.43	0.90	0.46*	0.16
CHE	1.20	0.32**	0.39	1.45	0.33**	0.47	1.07	0.30**	0.36
CHO	1.51	0.39**	0.41	2.35**	0.29**	0.74	0.50	0.32	0.10
CHR	0.26**	0.28	0.04	2.09*	0.47**	0.49	0.50	0.29	0.12
COU	0.34**	0.20	0.12	0.80	0.38*	0.17	0.57	0.23*	0.23
FAN	1.06	0.34**	0.33	0.70	0.46	0.11	1.54*	0.41**	0.41
KIO	0.34*	0.26	0.09	0.37*	0.24	0.12	1.44	0.21**	0.73
MIA	1.34	0.21**	0.64	0.92	0.28**	0.33	0.78	0.19**	0.43
MUS	0.14**	0.23	0.02	0.41*	0.34*	0.06	1.52*	0.19**	0.75
NAT	1.31	0.31**	0.45	0.17**	0.54	0.00	0.81	0.43*	0.14
OSA	0.50	0.30	0.12	0.84	0.51*	0.11	0.67	0.19**	0.35
PEC	1.84**	0.28**	0.67	-0.19**	0.58	0.00	2.08*	0.51**	0.43
POW	1.23	0.36**	0.35	1.45	0.24**	0.62	1.47	0.31**	0.51
SAR	0.54	0.22**	0.21	2.51**	0.38**	0.67	0.69	0.23**	0.29
SIO	1.77**	0.25**	0.70	2.32**	0.37**	0.65	1.13	0.32**	0.37
SPP	0.87	0.22**	0.42	1.53	0.31**	0.53	0.94	0.43*	0.18
TON	0.93	0.40*	0.20	-1.20**	0.26**	0.48	1.04	0.21**	0.54
TOW	0.15**	0.20	0.02	1.54	0.36**	0.45	0.70	0.41	0.12
TUS	1.67*	0.22**	0.72	1.60*	0.26**	0.63	1.35	0.22**	0.62
TKE	0.82	0.47	0.12	0.61	0.50	0.06	1.13	0.29**	0.41
TWI	0.77	0.25**	0.30	0.85	0.19**	0.47	0.14*	0.30	0.01
VRD	0.43*	0.20*	0.17	1.41	0.26**	0.57	0.11**	0.41	0.00
RAS	1.08	0.28**	0.41	0.11**	0.30	0.01	1.32	0.25**	0.56
DYN	1.32	0.35**	0.39	0.43*	0.24**	0.12	1.27	0.25**	0.53
RER	0.76	0.25**	0.30	0.19**	0.22	0.03	1.02	0.24**	0.44
BUC	1.21	0.26**	0.52	1.52	0.40**	0.42	0.86	0.28**	0.32
SIR	1.23	0.31**	0.42	0.40*	0.24	0.12	0.82	0.26**	0.32
WMT	1.00	0.42*	0.20	-1.37**	0.41**	0.34	0.73	0.27**	0.25
WCS	0.26**	0.11**	0.21	2.49**	0.31**	0.74	1.53*	0.22**	0.69

^zStability characteristics: b₁, coefficient of regression; s_b, SE of coefficient of regression; r², coefficient of determination.

^yCalculated using the natural log of the response variable.

^xb₁ is statistically different from 1 at α = 0.05 (*) or 0.01 (**).

^wDeviation from linearity (s_d²) is statistically different from 0 at α = 0.05 (*) or 0.01 (**).

was attributable, in good part, to week of LO being measured on a discrete scale (as opposed to a continuous scale), making s_d² and r² less useful than b₁ for evaluating stability for this response variable. In addition, the limited number of environments (locations) used in this study may also make s_d² less useful for evaluating stability (Eberhart and Russell, 1966). Clones that tended to LO later, on average, than the other clones (including three of the *L. fauriei* clones: KIO, TOW, and WCS), exhibited values of b₁ closer to 0, indicating greater insensitivity to environment. Clones with higher values of b₁, indicating relatively greater sensitivity to environment among the clones included in this study, included mostly interspecific hybrids (ACO, PEC, SIO, and TUS) and only one clone of *L. indica* (CES).

Time of flowering is an important trait of many ornamental plants, including crape-myrtle. Earlier-flowering cultivars of summer flowering perennials are desired by retailers to stimulate sales before hot weather dampens customer enthusiasm. Landscape designers are interested in extending the flowering season by using a variety of clones that together extend the flowering season. Flowering in 2005 began the weeks of 2 May

in Mississippi, 23 May in Florida, 13 June in Tennessee, and 20 June in Alabama. Flowering was probably delayed in Florida as compared with Mississippi by a more intensive cultural management program in Florida (trickle irrigation and higher levels of fertilization) that favored vegetative growth. BLUPs show two *L. fauriei* clones, KIO and FAN, had the earliest average flowering date across locations, whereas two *L. indica* clones, COU and RAS, were the latest to begin flowering (Table 7). When location was treated as a fixed effect to evaluate differences at the four locations (Table 3), the location × clone interaction was significant indicating the sequence in which clones flowered was sensitive to environment differences. There was an approximate 5-week difference between the earliest and latest clones to initiate flowering. Overall, location FR means for all clones at a location indicated that clones began flowering over a shorter duration in Florida and Mississippi than in Tennessee and Alabama (Table 7).

Cluster analysis of the FR means developed a three-cluster solution (Table 5). Three of the four *L. fauriei* clones (FAN, KIO, TOW) and two of the three initial interspe-

cific crosses (NAT, MUS) comprised Cluster 1 with mean FRs ranging from 1.84 to 2.86 and were the earliest clones to begin flowering. Cluster 2 had intermediate mean FRs ranging from 3.38 to 4.52 and included one *L. fauriei* clone (WCS), eight interspecific clones (ARA, CHE, CHO, MIA, OSA, PEC, SAR, TON), and six *L. indica* clones (CAT, CHR, POW, SPP, VRD, WMT). Cluster 3, which included the last clones to initiate flowering, included nine *L. indica* clones (CAB, CES, COU, TWI, RAS, DYN, RER, BUC, SIR) and five interspecific clones (ACO, APA, SIO, TUS, TKE) with mean FRs ranging from 4.72 to 7.00. Seventy-five percent of the *L. fauriei* clones were in the early-flowering cluster, whereas 64% of the *L. indica* clones were in the late-flowered cluster. There is a discernible tendency for *L. fauriei* germplasm to flower earlier than germplasm of *L. indica*.

Comparison of the three clusters generated during analysis of this study using early-season (1), midseason (2), and late-season (3) designations for time of flowering with observations of 21 of the same clones in central Alabama (Fare, 1984) and north Alabama (Byers, 2000) indicated agreement on 10 clones (CAB, MIA, MUS, NAT, OSA,

Fig. 1. Regression coefficients (b_1) of least squares means over environmental index plotted against least squares means (across four locations in the southeastern United States) for 34 clones of *Lagerstroemia* for (A) natural log of the week of leaf-out, (B) week of first flower, and (C) natural log of plant height. Codes refer to names of clones (cultivars) indicated in Table 1. Solid circles refer to *L. fauriei* clones, hollow circles refer to *L. indica* clones, and crosses refer to interspecific hybrids.

VRD, RAS, DYN, RER, SIO), whereas seven clones were indicated to flower earlier in this study (CHO, FAN, KIO, POW, TON, TOW, WMT) and four were indicated to flower later (ACO, PEC, TUS, TKE) (Table 5), which approximated the differences observed at individual locations within this study (Table 7). Another 3-year study conducted in central Alabama (Creech et al., 1999) evaluated flowering of 17 tall clones, including 10 evaluated in this study (NAT, FAN, SAF, MIA, TUS, CHO, OSA, TKE, MUS, CAB) and observed that, on average, initiation of flowering occurred over 2 weeks centered on 1 July. Bolques and Knox (1997) reported flowering started from late May to mid-June for ACO, TON, APA, SIO, NAT, and MIA in north Florida.

Stability analysis indicated that approximately half of the clones in this study were moderately stable (values of $b_1 \approx 1$) with respect to week of first flower (Table 6; Fig. 1B). Departures from linearity (s_d^2) were most often noted among clones having higher values of b_1 ; however, these same clones often tended to have higher r^2 values (greater than 0.50) compared with clones with lower values of b_1 . However, as also noted previously regarding week of LO, week of first flower was measured on a discrete scale and a limited number of environments (locations) were used in this study, making s_d^2 and r^2 of questionable value in assessing stability of this trait. Two clones, TON and WMT, differed notably from the other clones by having b_1 values less than -1.0, indicating a trend in sensitivity that was opposite to that of most other clones. The clones CHO, CHR, SIO, SAR, and WCS were the most sensitive to environment (values of b_1 greater than 2), whereas NAT, RER, and RAS were the most insensitive (values of b_1 closest to zero). Overall, it appeared that week of first flower was a less stable trait than week of LO or plant height.

Several researchers (Goi and Tanaka, 1976; Guidry, 1977; Stimart, 1986) have studied initiation of flowering in crape myrtle in efforts to investigate its potential as a flowering pot plant. These studies found that temperature rather than photoperiod determined flowering but tests were unable to separate the interactions between light intensity and production temperature on flower initiation. Other self inductive crops such as azaleas (Criley, 1975) and roses (Moe and Kristoffersen, 1969) flower well in diverse climates with cool or warm summers, whereas crape myrtle fails to flower in climates such as the United Kingdom and the Pacific Northwest with low heating degree days. In woody perennial genera such as *Rubus*, which have been studied extensively to determine the interactions between flowering and heat units, it was found that species and clones vary in their requirements and that factors such as plant vigor and cold damage can modify responses (Black et al., 2008).

Plant size is an important trait in crape myrtle clones because it determines where plants can be properly situated in landscapes

Table 7. Least squares means and best linear unbiased predictions (BLUPs) with 95% confidence intervals for week of first flower of 34 clones of *Lagerstroemia* grown at four locations in the southeastern United States.^z

Clone	All locations	Quincy, FL	McNeill, MS	Cullman, AL	McMinnville, TN
ACO	5.35 (4.10–6.98)	4.44 (3.42–5.76)	4.73 (3.66–6.11)	6.07 (4.77–7.73)	6.43 (5.07–8.16)
APA	5.26 (4.03–6.87)	4.62 (3.57–5.99)	4.47 (3.44–5.79)	5.52 (4.31–7.07)	6.73 (5.31–8.51)
ARA	4.43 (3.37–5.84)	3.59 (2.73–4.74)	3.91 (2.98–5.13)	4.95 (3.83–6.41)	5.54 (4.31–7.12)
CAB	5.20 (3.98–6.79)	4.34 (3.34–5.64)	4.80 (3.71–6.20)	5.66 (4.42–7.24)	6.20 (4.87–7.89)
CAT	3.91 (2.95–5.19)	3.25 (2.44–4.32)	3.51 (2.65–4.65)	4.23 (3.23–5.55)	4.84 (3.72–6.30)
CES	5.92 (4.54–7.72)	5.01 (3.89–6.45)	5.28 (4.11–6.78)	6.60 (5.15–8.45)	7.06 (5.53–9.00)
CHE	4.20 (3.17–5.56)	3.41 (2.57–4.52)	3.75 (2.84–4.95)	4.67 (3.59–6.09)	5.20 (3.98–6.80)
CHO	3.38 (2.52–4.53)	2.80 (2.08–3.77)	2.69 (2.00–3.63)	3.85 (2.91–5.10)	4.50 (3.43–5.90)
CHR	3.93 (2.95–5.23)	3.11 (2.33–4.15)	3.42 (2.58–4.55)	4.44 (3.40–5.82)	5.03 (3.83–6.61)
COU	6.44 (4.98–8.33)	5.80 (4.55–7.38)	5.70 (4.47–7.27)	6.57 (5.20–8.31)	7.93 (6.35–9.90)
FAN	1.91 (1.34–2.74)	1.60 (1.11–2.31)	1.62 (1.13–2.33)	2.28 (1.59–3.25)	2.25 (1.58–3.22)
KIO	1.84 (1.26–2.68)	1.60 (1.08–2.37)	1.57 (1.07–2.29)	2.06 (1.43–2.97)	2.20 (1.51–3.22)
MIA	4.49 (3.41–5.91)	3.67 (2.78–4.82)	4.22 (3.23–5.51)	4.79 (3.69–6.21)	5.50 (4.28–7.07)
MUS	2.39 (1.73–3.30)	2.08 (1.50–2.89)	2.00 (1.43–2.78)	2.85 (2.08–3.90)	2.74 (2.00–3.76)
NAT	2.51 (1.83–3.45)	2.04 (1.47–2.83)	2.29 (1.66–3.16)	3.09 (2.27–4.20)	2.75 (2.01–3.75)
OSA	3.41 (2.54–4.57)	3.02 (2.25–4.05)	2.74 (2.03–3.69)	4.13 (3.13–5.45)	3.95 (2.98–5.22)
PEC	4.38 (3.33–5.78)	4.21 (3.22–5.51)	3.67 (2.79–4.83)	4.74 (3.65–6.16)	5.04 (3.90–6.52)
POW	4.52 (3.43–5.94)	3.61 (2.74–4.76)	4.16 (3.18–5.44)	4.89 (3.78–6.34)	5.66 (4.41–7.27)
SAR	4.40 (3.34–5.80)	3.47 (2.63–4.59)	3.72 (2.82–4.89)	5.11 (3.95–6.60)	5.70 (4.44–7.32)
SIO	5.00 (3.81–6.56)	4.03 (3.08–5.26)	4.27 (3.24–5.62)	5.69 (4.44–7.30)	6.39 (5.02–8.13)
SPP	3.94 (2.97–5.23)	3.27 (2.46–4.34)	3.37 (2.54–4.47)	4.45 (3.41–5.82)	4.91 (3.78–6.38)
TON	3.82 (2.87–5.08)	3.38 (2.54–4.49)	3.72 (2.81–4.91)	4.23 (3.23–5.56)	4.01 (3.04–5.27)
TOW	2.86 (2.11–3.89)	2.51 (1.84–3.42)	2.31 (1.69–3.17)	3.03 (2.25–4.10)	3.81 (2.86–5.09)
TUS	4.72 (3.60–6.20)	3.85 (2.94–5.05)	4.26 (3.27–5.56)	5.01 (3.88–6.47)	6.04 (4.73–7.72)
TKE	5.61 (4.32–7.30)	4.56 (3.52–5.90)	5.49 (4.28–7.03)	5.98 (4.69–7.61)	6.64 (5.25–8.41)
TWI	5.16 (3.95–6.74)	4.39 (3.38–5.71)	4.68 (3.62–6.06)	5.49 (4.28–7.03)	6.27 (4.93–7.97)
VRD	4.23 (3.20–5.59)	3.50 (2.64–4.62)	3.74 (2.84–4.92)	4.62 (3.55–6.01)	5.31 (4.12–6.86)
RAS	7.00 (5.43–9.03)	6.10 (4.80–7.73)	6.67 (5.29–8.42)	7.35 (5.86–9.21)	8.05 (6.46–10.04)
DYN	5.87 (4.52–7.62)	5.15 (4.01–6.62)	5.43 (4.24–6.95)	6.01 (4.73–7.65)	7.07 (5.61–8.91)
RER	5.63 (4.33–7.32)	4.91 (3.81–6.33)	5.27 (4.10–6.76)	5.89 (4.62–7.51)	6.60 (5.22–8.36)
BUC	4.86 (3.69–6.40)	3.97 (3.00–5.26)	4.36 (3.34–5.69)	5.32 (4.08–6.92)	6.07 (4.75–7.75)
SIR	5.58 (4.28–7.28)	4.83 (3.74–6.24)	5.14 (4.00–6.62)	5.95 (4.61–7.67)	6.56 (5.18–8.32)
WMT	4.48 (3.41–5.90)	4.02 (3.07–5.26)	4.33 (3.32–5.65)	5.08 (3.93–6.57)	4.57 (3.52–5.94)
WCS	3.66 (2.75–4.88)	2.93 (2.19–3.93)	3.11 (2.33–4.16)	3.88 (2.94–5.12)	5.08 (3.91–6.60)
All clones		3.72 C ^y	3.93 C	4.86 B	5.45 A

^zLeast squares means were calculated for each clone across all locations and BLUPs were calculated for each clone at each location (with location as a random effect). Least squares means were calculated for each location across all clones (with location as a fixed effect in preliminary analysis).

^yMeans at each location for all clones combined followed by the same letter are not significantly different according to the simulation-stepdown method at $\alpha = 0.05$.

and how fast producers can expect a particular clone to reach a marketable size. After 3 years in the field, BLUPs for clones in this study ranged from 113 cm for CHR to 301 cm for WCS (Table 8). Plants in Florida were greatest in height. The physical environmental at the Mississippi and Florida locations is very similar (Table 2), but plants in Florida were on a production regimen with supplemental irrigation and higher fertility, whereas plants in Mississippi were maintained on a postproducer regimen typical of landscape conditions. When location was treated as a fixed effect to evaluate differences at the four locations (Table 3), the location $\times$ clone interaction was significant indicating variation in how fast the clones grew in the various environments.

Cluster analysis of the HT means developed a three-cluster solution (Table 5). Cluster 1 means ranged from 113 to 164.8 cm and included four interspecific clones (ACO, CHE, ARA, PEC) and eight *L. indica* clones (CAT, CES, CHR, POW, SPP, VRD, BUC, SIR). Cluster 2 means ranged from 187.8 to 215.5 cm, including three interspecific (APA, SIO, TON) and six *L. indica* clones (CAB, TWI, RAS, DYN, RER, WMT). Cluster 3 means ranged from 229 to 301.1 cm with all four *L. fauriei* clones (FAN, KIO, TOW,

WCS), one *L. indica* (COU), the initial interspecific hybrids (MUS, NAT, SAR), and the complex interspecific hybrids (CHO, OSA, TUS, TKE) in this cluster. Interspecific and *L. fauriei* clones selected for this study tended to be more vigorous than *L. indica* clones.

Johnson and Dix (1993) indicated that size classifications are indications of speed of growth rather than ultimate growth. Comparison of the three clusters generated during analysis of this study with the most recently published size groupings (Franklin et al., 2006) indicated agreement on 18 (ACO, APA, CHO, CHR, FAN, KIO, MIA, MUS, NAT, PEC, SAR, SIO, TOW, TUS, RAS, SIR, WMT, DYN) of 32 clones classified (Table 5). Our clusters indicated nine clones (ARA, CAB, CAT, CES, CHE, POW, TWI, RER, BUC) had a growth classification that was smaller than the published grouping, whereas our results grouped five clones (COU, OSA, TON, TKE, VRD) with larger growing clones. The difference in classification was most dramatic for ARA, which was reported to be a tree form (greater than 6 m) but grew at a rate equivalent to the smaller growing clones grouped in Cluster 1 in this study. The clones SPP and WCS were found to produce growth equivalent to Clusters

1 and 3, respectively. This study is the first report on expected growth of these two clones.

Stability analysis indicated that most clones in this study were moderately stable (values of $b_1 \approx 1$) with respect to plant height (Table 6; Fig. 1C). Most clones exhibited some departure from linearity (s_d^2), indicating inconsistent stability; however, clones with b_1 values greater than 1.0 tended to have r^2 values greater than 0.50, providing some stronger evidence for stability among these clones. Most *L. fauriei* and interspecific clones tended to have b_1 values greater than 1.0, whereas most *L. indica* clones had b_1 values less than 1.0. The interspecific clone PEC exhibited a value of b_1 greater than 2.0, indicating that its growth rate in more favorable environments tends to exceed that of the other clones. The *L. indica* clones TWI and VRD had b_1 values less than 0.15, indicating less sensitivity to environment than the other clones. Overall, most clones exhibited stability in plant height in different environments, but the stability was generally not consistent with the average response of all clones in these environments.

This study provides insight into the performance of selected crapemyrtle clones in the southeastern United States and identifies

Table 8. Least squares means and best linear unbiased predictions (BLUPs) with 95% confidence intervals for plant height (cm) of 34 clones of *Lagerstroemia* grown for 3 years in field plots at four locations in the southeastern United States.^z

Clone	All locations	Quincy, FL	McNeill, MS	Cullman, AL	McMinnville, TN
ACO	153.8 (108.8–198.9)	207.0 (184.6–229.5)	125.7 (103.3–148.2)	130.2 (107.8–152.6)	152.4 (129.9–174.8)
APA	191.6 (146.5–236.6)	243.6 (221.1–266.0)	173.1 (150.7–195.5)	176.1 (153.7–198.5)	173.6 (151.2–196.0)
ARA	140.1 (95.1–185.2)	190.1 (167.7–212.5)	128.6 (106.2–151.0)	118.7 (96.3–141.1)	123.0 (100.6–145.5)
CAB	187.8 (142.8–232.9)	221.4 (198.9–243.8)	167.0 (144.6–189.5)	192.4 (169.9–214.8)	170.6 (148.2–193.0)
CAT	149.1 (104.0–194.1)	172.4 (149.9–194.8)	124.1 (101.6–146.5)	152.9 (130.5–175.3)	147.0 (124.6–169.4)
CES	164.8 (119.7–209.9)	199.1 (176.7–221.6)	160.1 (137.6–182.5)	171.1 (146.9–195.3)	128.9 (104.7–153.1)
CHE	121.6 (76.6–166.7)	153.0 (130.5–175.4)	104.4 (82.0–126.8)	110.0 (87.6–132.4)	119.1 (96.7–141.6)
CHO	229.0 (183.9–274.0)	250.6 (228.2–273.1)	185.8 (163.4–208.2)	235.5 (213.1–257.9)	244.0 (221.5–266.4)
CHR	113.0 (67.9–158.1)	130.9 (108.5–153.3)	105.1 (82.7–127.6)	112.2 (89.8–134.6)	104.0 (79.8–128.1)
COU	242.9 (197.8–287.9)	275.3 (252.9–297.7)	226.0 (203.5–248.4)	249.5 (227.0–271.9)	220.8 (198.3–243.2)
FAN	252.3 (207.2–297.5)	331.2 (308.8–353.7)	249.5 (227.1–272.0)	232.4 (208.2–256.6)	196.1 (171.9–220.3)
KIO	268.0 (222.7–313.2)	346.1 (319.6–372.6)	245.1 (222.7–267.6)	248.4 (225.9–270.8)	232.3 (205.9–258.8)
MIA	235.2 (190.1–280.2)	274.8 (252.4–297.2)	205.4 (183.0–227.8)	223.0 (200.6–245.4)	237.5 (215.1–259.9)
MUS	262.4 (217.3–307.4)	347.0 (324.6–369.4)	238.0 (215.6–260.4)	230.2 (207.8–252.6)	234.3 (211.8–256.7)
NAT	241.8 (196.7–286.8)	291.8 (269.4–314.2)	233.6 (211.1–256.0)	186.6 (164.2–209.0)	255.2 (232.8–277.6)
OSA	238.6 (193.5–283.6)	277.5 (255.1–299.9)	227.6 (205.2–250.1)	215.4 (193.0–237.8)	233.8 (211.4–256.2)
PEC	141.1 (96.0–186.1)	202.6 (180.2–225.0)	100.1 (77.7–122.6)	105.9 (83.5–128.3)	155.7 (133.3–178.1)
POW	154.3 (109.3–199.4)	199.6 (177.2–222.0)	135.0 (112.6–157.4)	164.1 (141.7–186.5)	118.7 (96.3–141.1)
SAR	264.0 (219.0–309.1)	299.7 (277.3–322.2)	231.2 (208.8–253.6)	269.7 (247.3–292.1)	255.5 (233.1–277.9)
SIO	215.5 (170.4–260.6)	267.3 (244.9–289.7)	217.9 (193.7–242.1)	204.0 (181.6–226.4)	173.0 (150.5–195.4)
SPP	136.2 (91.1–181.2)	163.4 (141.0–185.8)	109.5 (87.1–131.9)	151.8 (129.4–174.2)	120.0 (97.5–142.4)
TON	206.9 (161.8–251.9)	254.3 (231.9–276.7)	181.0 (158.5–203.4)	181.9 (159.5–204.3)	210.3 (187.9–232.7)
TOW	251.8 (206.8–296.9)	297.2 (274.8–319.6)	239.0 (216.6–261.4)	210.3 (187.9–232.7)	260.8 (238.4–283.2)
TUS	231.2 (186.1–276.2)	296.1 (273.7–318.5)	204.5 (182.1–226.9)	215.7 (193.3–238.2)	208.3 (185.9–230.7)
TKE	276.0 (231.0–321.0)	345.4 (323.0–367.8)	248.8 (226.4–271.2)	237.7 (215.3–260.2)	272.0 (249.6–294.5)
TWI	202.4 (157.4–247.5)	213.7 (191.3–236.1)	174.1 (151.7–196.5)	218.0 (195.5–240.4)	203.9 (181.5–226.3)
VRD	143.5 (98.4–188.5)	154.8 (132.4–177.3)	124.8 (102.4–147.2)	151.5 (129.1–174.0)	142.7 (120.3–165.1)
RAS	201.5 (156.4–246.5)	256.7 (234.2–279.1)	187.6 (165.2–210.0)	194.3 (171.9–216.7)	167.3 (144.9–189.7)
DYN	188.2 (143.2–233.3)	233.4 (211.0–255.9)	161.3 (138.8–183.7)	202.1 (179.7–224.5)	156.1 (133.6–178.5)
RER	191.0 (145.9–236.0)	231.6 (209.1–254.0)	181.4 (159.0–203.8)	197.9 (175.4–220.3)	153.0 (130.6–175.4)
BUC	145.0 (99.9–190.2)	174.3 (150.1–198.5)	134.3 (111.8–156.7)	148.0 (123.8–172.2)	123.6 (101.2–146.0)
SIR	146.5 (101.4–191.6)	172.3 (149.9–194.7)	133.3 (110.8–155.7)	160.2 (136.0–184.4)	120.1 (97.7–142.5)
WMT	204.5 (159.5–249.6)	232.3 (209.9–254.7)	163.5 (141.1–185.9)	216.7 (194.3–239.1)	205.6 (183.2–228.1)
WCS	301.1 (256.1–346.1)	394.4 (372.0–416.8)	287.5 (265.1–309.9)	278.5 (256.1–301.0)	243.9 (221.4–266.3)
All clones		243.8 A ^y	179.5 B	191.2 B	184.2 B

^zLeast squares means were calculated for each clone across all locations and BLUPs were calculated for each clone at each location (with location as a random effect). Least squares means were calculated for each location across all clones (with location as a fixed effect in preliminary analysis).

^yMeans at each location for all clones combined followed by the same letter are not significantly different according to the simulation-stepdown method at $\alpha = 0.05$.

clones that should be promoted more in this geographic region as a result of LO and date of flowering. We found that changes in the growing environment affected time of flowering more than spring LO and growth rate in the majority of clones. First bloom was affected by environmental variation more with interspecific hybrids than with *L. fauriei* and *L. indica* clones. Evaluation in multiple environments refined the classification of the expected LO, first flower, and landscape size for tested clones. Clones of *L. fauriei* and clones originating from the initial cross between *L. indica* and *L. fauriei* were generally later to LO, earlier to flower, and more vigorous growers than *L. indica* or the complex *L. indica* × *L. fauriei* clones.

Because this study was conducted in multiple environments and subjected to more rigorous statistical standards, consideration should be given to updating projected growth for clones, which this study indicates are misclassified. Information generated by this study will allow crapemyrtle breeders, landscape professionals, and consumers to better select the most appropriate crapemyrtle clone for a particular application.

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