Reproductive and Vegetative Characteristics of Pecan Cultivars

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Abstract. Staminate and pistillate flower maturity of 80 cultivars of young (<15 years old) pecan [*Carya illinoensis* (Wangenh.) K. Koch] trees are presented. These patterns show that pollination and receptivity windows within the flowering season can be divided into very early, early, mid, late, and very late season protandrous (Type I) and protogynous (Type II) types. This system therefore provides a seasonally based 30-class Type I and Type II alternative to the standard two-class Type I and Type II system, thus offering enhanced resolution of flowering intervals and an improved means of selecting cultivars to ensure cross-pollination of yard and orchard trees. Scott-Knott cluster analysis of budbreak, nut ripening date, and date of autumn leaf drop segregated cultivars into one of several categories.

Pecan is a wind-pollinated, monoecious tree-nut crop exhibiting heterodichogamy (Adrian, 1930; Grauke and Thompson, 1996); hence, complementarity of pollination and receptivity periods is generally requisite for good yields. Many commercial orchards yield poorly as a result of either poor cross-pollination or from excessive self-pollination (Marquard, 1988; Wood and Marquard, 1992; Wood, 1996), even though pistillate flowers are often fertilized by pollen originating from great distances (Woodroof and Woodroof, 1927). Prevention of incompatibilities and undesirable xenia effects generally requires good cross-pollination (Madden and Brown, 1975; Marquard, 1988; Romberg and Smith, 1946; Sparks and Heath, 1972; Wolstenholme, 1969; Wood and Marquard, 1992).

Pollination is especially important because pecan is becoming increasingly popular throughout much of the world as an exotic horticultural crop (Wood and Payne, 1991). Pecan is also being planted outside of its native range in the southeastern and southwestern United States. In an attempt to ensure proper pollination in orchards and yard trees, Worley et al. (1992) identified the flower maturity windows for several major cultivars. These phenograms generally reflected pollination and

receptivity windows of relatively large or old trees. Subsequent work by Wood (1996) identified a substantial shift in flower maturity characteristics as trees age or increase in size; therefore, the interactions associated with pollination and receptivity periods among cultivars change as orchards mature. Several tree fruit crops exhibit a similar relationship (Soltesz, 1996).

The criteria regulating cultivar mix traditionally have been based on the assumptions that 1) essentially all Type I (protandrous) and Type II (protogynous) cultivars are reciprocally compatible, or 2) ambient pollen is sufficiently abundant to nullify the need for special attention to pollination. Worley et al. (1992) showed that reliance on a generalized two-class Type I/Type II flowering classification system for selection of compatible cultivars is flawed for mature (greater than ~30 years old) pecan trees. An improved system for designating flower maturity patterns is therefore needed.

A variety of factors related to ripening, foliation, and flowering influences the economic returns from pecan. For example, ripening date can greatly influence the price received for nuts (Wood, 1993), and degree of leaf retention can influence return bloom, nut production, and nut quality the following year (Monselise and Goldschmidt, 1982; Smith et al., 1986). These traits of the major pecan cultivars are poorly characterized, and information about the interrelationships among these and other traits is limited.

The present study 1) identifies and com-

pares the pollinating and receptivity windows exhibited by young trees (<15 years old) of 79 pecan cultivars grown in the southeastern United States, 2) proposes a new 30-class flowering classification system with greater resolution than the presently used two-class system, and 3) compares flowering, fruit ripening, leaf retention, and budbreak characteristics among cultivars and the interrelationships among characteristics.

Materials and Methods

Evaluation sites. Performance of cultivars at four locations transecting the heart of the southeastern pecan belt in the United States was evaluated. All four locations (Byron, Tifton, and Attapulgus, Ga., and Monticello, Fla.) were along the Coastal Plain geomorphological province, an extensive seaward-sloping plain. The mean length of the freeze-free period varied from 240 d at Byron to 265 d at Monticello. Trees at all locations were grown under commercial orchard conditions (Crocker, 1995) and were evaluated for vegetative and reproductive characteristics for each of 4 to 6 years.

Cultivar performance depending on location. The establishment of twenty "southern" cultivars at these locations allowed for assessment of interactions of cultivar with location and cropping season. Trees at Byron were established in 1981; at Tifton in 1979-80; at Attapulgus in 1976-77; and at Monticello in 1977-78. Seedlings from open-pollinated 'Curtis' trees served as rootstocks for all scion cultivars. Four trees were established per site with replicates consisting of 2 to 4 blocks of either single or double tree plots, and were observed from 1985 to 1989. Evaluated traits were dates of budbreak (defined as time when 50% of the shoots exhibited inner bud scale split), onset and end of pollen shedding, onset and end of pistillate flower receptivity (assessed by adherence of pollen to the stigmatic surface), 50% leaf drop, and nut ripening (when 80% of nuts exhibited some degree of shuck split). Duration of pollen shedding and stigma receptivity and the date of reproductive maturity (the onset of pollen shedding by staminate flowers or of stigma receptivity of pistillate flowers) were determined from these parameters.

Experimental design was completely randomized, with four replicates of 20 cultivars at four locations for four years. Data were analyzed by ANOVA-GLM, correlation analysis, and calculated means separated by Tukey's HSD test as calculated by SAS-PC software (SAS Institute, 1988). ANOVA-GLM analysis was such that "year" was fixed and Type I sum of squares was used. Scott-Knott cluster analysis (Gates and Bilbro, 1978; Scott and Knott, 1974; Willavize et al., 1980) allowed grouping of cultivars within each parameter.

Flowering maturity windows. The relative performance of 80 commercially significant cultivars (about 95% of total group) was evaluated at Byron, Ga., in 1981. Trees were established and managed as described above. Observations on vegetative and reproductive char-

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acteristics were made from 1985 to 1989, and in 1991. The beginning of pollen shedding was noted when shaking of several lower limbs resulted in release of pollen, and the end of pollination when pollen was no longer released. Pistillate flower receptivity was assessed based on a random selection of several flower clusters on the lower limbs of the tree. The beginning and ending of receptivity were ascertained by brushing pollen on the stigmatic surface and noting its retention after vigorous blowing (Smith and Romberg, 1941). Because trees could not be monitored for flower maturity on a daily basis, pollinating/receptivity assessments were generally based on three observations per week.

Results and Discussion

Cultivar performance and intercorrelations. All main and interactive sources of variation were significant for almost all vegetative and reproductive traits (Table 1). Traits of trees growing within this relatively confined region of the southeastern pecan belt differed depending upon location, with development being delayed as distance from the Gulf of Mexico increased. Pecan cultivars exhibited substantial differences in the timing of developmental traits, and cultivar $\times$ location was evident in all traits except duration of stigma receptivity. Thompson et al. (1989) reported similar genotype $\times$ location interactions for pecan kernel and color characteristics, although the locations provided a much greater diversity in environment than in the present study. The timing of developmental traits also differed greatly from one year to the next and interacted with location and cultivar. A three-way interaction (location $\times$ cultivar $\times$ year) was evident for most traits; thus the relative reproductive and vegetative charac-

teristics of pecan cultivars varied with both location and year. Pecan development therefore seems to be fairly sensitive to environmental factors. This indicates that the relative timing of key events, such as flower maturity, may differ enough from year to year to cause failure of otherwise complementary cultivars to cross-pollinate. This could lead to crop failures in years with abnormal weather.

These data indicate that vegetative and reproductive characteristics of certain cultivars differ at different locations even within the relatively compact heart of the southeastern U.S. pecan belt. About 250 km in distance and 70 m in elevation, on an approximate N-S line, separated test locations. Differences are therefore likely to be even greater when cultivars are grown over a broader range of environments. The primary environmental factors differing among locations are winter and spring temperatures associated with proximity to the Gulf of Mexico. Therefore, differences in chilling or heat requirements among cultivars in the winter (Grauke and Thompson, 1993) or spring may be associated with the observed differences in location.

The progenitors of the cultivars used in this study originated in different portions of the native range of pecan, and the test locations were far enough apart to present different abiotic and biotic environments; therefore genotype $\times$ environment interactions occurred. For example, because the interaction between temperatures in winter vs. spring (Sparks, 1993) influences pecan budbreak, cultivar performance differed with location. This genotype $\times$ location interaction, especially regarding dichogamy and flowering characteristics, indicates that published tables on flowering compatibility (e.g., Gray, 1973; Haulik and Holtzhausen, 1987; Smith and Romberg, 1940; Sparks, 1986, 1987; Wolstenholme, 1968),

while providing important information, require interpretation regarding their application to other locations. The best indicator of performance at a particular location is probably the performance of cultivars growing nearby (Grauke and Thompson, 1993). Data from the present study indicated that the type of dichogamy (protandrous or protogynous) exhibited by cultivars was constant for each location over the study period, although the degree of completeness or incompleteness in pollination and receptivity windows sometimes varied among years and locations.

Correlation coefficients among the various growth and reproductive parameters were generally low (Table 2). The strongest association ($r = 0.88$) was between the date of the beginning of pollen shedding (BP) and date of reproductive maturity (RM); thus, cultivars with early maturing flowers of either sex are likely to be protandrous. Similarly, date of reproductive maturity was inversely correlated with duration of pollen shedding ($r = -0.46$); thus, genotypes exhibiting early staminate or pistillate flower maturity also tended to exhibit longer pollination windows. The beginning date of either pollen shedding or stigma receptivity was inversely related to the duration of pollen shedding ($r = -0.46$ and -0.37 , respectively). Intercorrelations indicated that the beginning date and duration of both pollen shedding and pistil receptivity, and the dates of leaf drop and nut ripening, exhibited weak positive associations with date of budbreak. The absence of strong linkages among these traits indicates that singular indirect selection for any one of these traits by any one of the others probably will yield slow progress in selection efforts. For example, the selection of genotypes breaking bud early in the spring would have only slight effects on enhancing early ripening ($r = 0.23$) and prolonging leaf retention ($r = 0.15$).

Table 1. F values following ANOVA-GLM analysis of phenological parameters of 20 pecan cultivars planted at four locations over four seasons.^z

Source ^a	df	F value							
		BB ^b	BPS	BSR	DP	DR	RM	LD	RD
Location (L)	3	52.3***	12.2***	9.8***	24.7***	20.9***	23.0***	29.2***	22.8***
Cultivar (C)	19	13.3**	36.9***	5.3***	3.7***	1.2 ^{ns}	18.4**	10.7**	19.0***
L $\times$ C	34	3.2***	3.1***	1.8*	2.8***	1.4 ^{ns}	2.1***	2.7***	3.5***
Rep (L $\times$ C)	165	1.9***	1.6**	1.6*	1.0 ^{ns}	0.8 ^{ns}	1.9**	1.7***	1.7***
Year (Y)	3	817.8***	334.3***	84.7***	78.0***	58.2***	326.6***	442.0***	32.9***
L $\times$ Y	9	12.3***	15.6***	5.0**	4.6**	7.6***	23.4***	53.1***	9.3***
C $\times$ Y	57	1.5*	2.7***	1.7**	1.4 ^{ns}	1.6*	3.2***	2.2***	3.8***
L $\times$ C $\times$ Y	101	2.0***	2.5***	2.5***	1.4 ^{ns}	1.0 ^{ns}	4.1***	2.3***	2.0***

^aByron, Tifton, and Attapulgus, Ga., and Monticello, Fla., for 1986, 1987, 1988, and 1989. Type I sum of squares was used and "year" was fixed.

^bAnalysis with Rep(L $\times$ C) as error term for 'L', 'C', terms and L $\times$ C; Rep(L $\times$ C $\times$ Y) as error term for Y, L $\times$ Y, and C $\times$ Y; and L $\times$ C $\times$ Y.

BB = date of budbreak; BPS = date of beginning of pollen shedding; BSR = date of beginning of stigma receptivity; DP = duration of pollen shedding; DR = duration of stigma receptivity; RM = date of reproductive maturity; LD = date of 50% leaf drop; RD = ripening date.

^{ns}, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Pearson correlation coefficient matrix of phenological parameters for 20 pecan cultivars at four locations over 4 years.

Parameter	BP	BR	DP	DR	RM	LD	RD
Budbreak (BB)	0.63***	0.45***	-0.36 ^{ns}	-0.06 ^{ns}	0.64***	0.15***	0.23***
Begin pollinizing (BP)	---	0.26***	-0.46***	0.02 ^{ns}	0.88***	0.27***	0.23***
Begin receptivity (BR)	---	---	-0.37***	-0.18***	0.53***	0.19***	0.15***
Duration pollinizing (DP)	---	---	---	0.14*	-0.46***	-0.08 ^{ns}	0.02 ^{ns}
Duration receptivity (DR)	---	---	---	---	-0.11*	-0.18**	0.11 ^{ns}
Reproductive maturity (RM)	---	---	---	---	---	0.33***	0.26***
Leaf drop (LD)	---	---	---	---	---	---	0.11*
Ripening date (RD)	---	---	---	---	---	---	---

^{ns}, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Scott-Knott cluster analysis of phenological parameters for 80 pecan cultivars at Byron, Ga. Data are dates (1 Jan. = 1) of budbreak, fruit ripening, and leaf drop.^a

Cultivar	Date of		
	Budbreak	Ripening	Leaf drop
Alley	96 a ^z	303 b	327 e
Apache	98 b	304 b	323 d
Barton	103 c	287 b	330 d
Brooks	98 b	298 b	322 d
Burkett	98 b	---	318 d
Caddo	98 b	293 a	318 d
Candy	96 a	289 a	320 d
Cape Fear	99 b	314 c	327 e
Centennial	100 b	302 b	315 c
Cherokee	100 b	299 b	328 e
Cheyenne	102 c	296 b	322 d
Chickasaw	101 b	297 b	316 c
Choctaw	102 c	302 b	322 d
Colby	100 b	285 a	316 c
Comanche	102 c	312 c	325 e
Cowley	105 c	311 c	326 e
Curtis	101 b	313 c	324 e
Dependable	101 b	305 b	320 d
Desirable	101 b	316 c	326 e
Delmas	96 b	316 c	320 d
Dooley	106 c	295 b	307 b
Elliott	98 b	294 a	320 d
Evers	100 b	---	322 d
Forkert	102 c	314 c	324 e
Farley	101 b	312 c	327 e
Frotscher	98 b	309 c	309 b
Giles	106 c	295 b	313 c
Gloria Grande	96 a	312 c	320 d
GraBohls	100 b	296 b	323 d
GraCross	100 b	296 b	326 e
GraKing	100 b	309 c	325 e
GraTex	111 c	303 b	324 e
Harris-Super	102 c	310 c	325 e
Hirsch	104 c	295 b	310 b
Ideal	106 c	306 c	320 d
Jackson	101 b	317 c	324 e
Johnson	103 b	282 a	315 c
Kernoodle	101 b	311 c	324 e
Kiowa	101 b	310 c	328 e
Love	97 a	290 a	314 c
Mahan	101 b	309 c	327 e
Major	105 c	295 b	313 c
Maramec	103 c	305 b	326 e
Melrose	103 c	306 c	328 e
Mobile	100 b	316 c	320 d
Mohawk	98 a	298 b	325 e
Moose	105 c	298 b	329 e
Moneymaker	99 b	300 b	325 e
Moreland	103 c	306 c	326 c
Nelson	99 b	296 b	322 d
Norton	103 c	276 a	305 b
Odom	98 a	304 b	324 e
Owen	99 b	301 b	325 e
Pabst	104 c	311 c	320 d
Pawnee	98 b	286 a	320 d
Pensacola Clu.	104 c	309 c	322 d
Peruque	104 c	291 a	314 c
Podsednik	104 c	318 c	327 e
Posey	104 c	291 a	317 d
Riverside	99 b	302 b	315 c
Russell	101 b	353 e	322 d
San Saba	99 b	315 c	325 e
San Saba Imp.	100 b	297 b	312 c
Schley	105 c	326 d	328 e
Shawnee	102 c	296 b	330 e
Shoshone	96 a	287 a	324 e
Sioux	97 b	292 a	329 e
Starking H.G.	102 c	---	297 a
Stuart	107 c	305 b	322 d
Success	106 c	304 b	324 e
Sumner	104 c	317 c	327 e
Squirrels Del.	100 b	291 a	306 b
Teche	100 b	309 c	321 d
Tejas	102 c	292 a	308 b
Van Deman	101 b	301 b	318 d
Waukeenah	97 b	320 c	328 e
Western Sch.	105 c	301 b	319 d
Wichita	99 b	300 b	320 d
Woodard	101 b	326 d	323 d
Woodroof	95 a	306 c	326 e

^aMean separation within columns by Scott-Knott cluster analysis, $P < 0.05$.

These data indicate that, in pecan, the horticultural traits evaluated in this study are generally only weakly interrelated, and that these relationships are probably not useful in univariate models for forecasting or predicting important phenological events, such as date of ripening or harvest, although they may be useful in multivariate models. Nor are these traits likely to be of much singular value in terms of indirect selection strategies.

Cultivar performance was separated into different general groupings by using three horticulturally important parameters (Table 3). Scott-Knott cluster analyses separated the population into three distinct groups for budbreak, five groups for ripening date of the fruit or nut, and five groups for date of leaf drop. The cultivar with earliest budbreak was 'Woodroof' at day 95 of the year (4 Apr.) whereas the latest was 'GraTex' at 111 d (20 Apr.), a range of 16 d. Ten percent of these cultivars comprised the earliest budbreak group, whereas 51% and 39% comprised the mid and late groups. Early budbreak was not associated with latitude of origin. The maturity, or ripening date, as determined by date of 80% shuck split, ranged from 276 for 'Norton' to 353 for 'Russell', a span of 77 d. About 18% of these cultivars were early, 42% medium early, 36% mid-season, 3% late, and 1% very late. Date of 50% leaf drop of these cultivars ranged from day 297 (23 Oct.) for 'Starking's Hardy Giant' to 330 (25 Nov.) for 'Shawnee', a span of 33 d. About 1% of the cultivars dropped leaves early, 8% medium early, 12% mid-season, 35% late, and 44% very late.

Flower maturity windows. The maturity patterns and windows differed greatly depending upon cultivar (Figs. 1 and 2). Cultivars typically recognized as "southern" or "northern" segregated into the typical protandrous and protogynous dichogamy classes. Most cultivars in this study were protogynous since a single gene largely controls dichogamy, with protogyny being dominant (Thompson and Romberg, 1985). The flower maturity windows of these young trees differed markedly from those of older trees of the same cultivars growing only 150 km away (Worley et al., 1992), thus illustrating the need for caution when using flower maturity data from mature trees as the sole criterion for establishing plantings.

For the "southern" cultivars, the first of the protandrous cultivars to shed pollen was 'Evers' (22 Apr.), whereas the last was 'Podsednik'. For "northern" cultivars, 'Pawnee' was first and 'Russell' was last. Some combination of these cultivars therefore could have cross-pollinated over this 25-d period. Within this group of 28 protandrous cultivars, four ('Western Schley', 'Kiowa', 'Forkert', and 'Farley') dispersed pollen only 1 to 2 d before the beginning of stigma receptivity; hence, these cultivars exhibited incomplete dichogamy patterns, are subject to substantial self-pollination as young trees, and are barely classifiable as protandrous cultivars. About one-third of all protandrous cultivars exhibited partial overlap of flower maturity, or incomplete dichogamy, therefore potentially

Fig. 1. Flowering phenogram comparing temporal aspects of pollen dispersal and receiving periods for "southern" pecan cultivars cultivated at Byron, Ga. Trees were established in 1981 and flowering data are from 1985-89 and 1991.

permitting self-pollination. Fifteen of these 28 cultivars exhibited complete dichogamy as young trees with the span between mature male and female flowers being as much as 10 d (e.g., 'Harris Super').

The protogynous group of southern cultivars was as highly variable in flower maturity, as were the protandrous cultivars (Fig. 1). Only 1 to 2 d typically separated trees exhibiting complete dichogamy; hence, the mechanism determining maturity separation in protogynous cultivars is not nearly as pronounced as in most protandrous cultivars. The maturity windows of pistillate and staminate inflorescences therefore overlap more in protogynous than in protandrous cultivars (Grauke and Thompson, 1993). Thus, protandrous cultivars, as a group, are more likely to self-pollinate than are protogynous cultivars. Stigma receptivity was first exhibited by 'Elliott' (18 Apr.) and last exhibited by 'GraTex' (17 May), a range of 32 d. Only 5 of 35 of the protogynous cultivars exhibited complete dichogamy as young trees, whereas overlapping occurred in 17 of them during at least 25% of the receptivity period. This indicates the possibility for self-pollination in most protogynous cultivars, with 'Candy', 'Teche', 'Waukeenah', 'Shoshone', 'Van Deman', 'GraBohls', and 'Pensacola Cluster' having the greatest potential. Additionally, the stigmatic surface of pistillate flowers of protogynous cultivars remains receptive for a few days longer than usual in humid environments (Grauke and Thompson, 1993). Thus protogynous cultivars are much more likely to self-pollinate if pollen of other cultivars is unavailable. Therefore they tend to exhibit more nutlet abortion during the third fruit-drop phase, which extends from about 21 June until 1 Aug. in the southeastern United States (Sparks and Madden, 1985) and to suffer from xenia-related losses in yield due to reduced kernel percentages or filling (Romberg and Smith, 1946).

Cultivars clearly varied in duration of pollen shedding or stigma receptivity (Fig. 1). Stigmas of some, e.g., 'Riverside' and 'Mobile', were receptive only half as long as those of others, e.g., 'Western Schley' and 'Gloria Grande'. The same was true for protogynous cultivars; the receptivity period for 'Elliott', for example, was about twice as long as that of 'Schley'.

All protandrous cultivars are not suitable pollinizers for all protogynous cultivars and vice versa (Fig. 1). For example, 'Pawnee' (Type I) would not pollinate 'Sumner' (Type II), nor would 'Sumner' pollinate 'Pawnee'. Many cultivar combinations in young plantings in the southeastern U.S. involve 'Desirable' as the primary cultivar, with either 'Stuart', 'Sumner', 'Cape Fear', 'Elliott', 'Curtis', 'Gloria Grande', or 'Moreland' as the pollinizer. Our data indicate that 'Desirable' will generally pollinate 'Stuart', 'Curtis', 'Gloria Grande', and 'Moreland' fairly well, but not 'Cape Fear', 'Elliott', and 'Sumner'. Conversely, 'Desirable' would be pollinated well by 'Gloria Grande', 'Curtis', 'Stuart', 'Moreland', and 'Sumner', but poorly by 'Elliott' and not at all by 'Cape Fear'.

Average flowering patterns within the generalized protandrous and protogynous categories of pecan cultivars are highly variable (Figs. 1 and 2). Therefore, reliance on the commonly used Type I-Type II, or two-class, flowering classification system for selecting supposedly complementary cultivars would probably result in inadequate cross-pollination. Examples include 'Caddo' with 'Stuart', 'Sumner', 'Schley', 'Moreland', or 'Mohawk'; 'Pawnee' with 'Moreland', 'Mohawk', 'Melrose', 'Sumner', or 'Ideal'; 'Desirable' with 'Elliott' or 'Farley'; and 'Forkert' with 'Elliott', 'Gloria Grande', 'Shawnee', or 'Delmas'. This problem will vary with tree age

or size because the dichogamy patterns exhibited by these young trees differed substantially from that of older trees of the same cultivars (Worley et al., 1992).

Inspection of these phenograms for young trees (Figs. 1 and 2) reveals an average range in flowering of about 35 d. The duration of pollen dispersal and receiving windows was ≈ 7 d, although it varied somewhat with cultivar and with year of observation. This 35-d span is therefore divisible into five generalized 7-d windows within each dichogamy class. In practice, these five windows can be termed "very early," "early," "mid," "late," and "very late." This potentially provides 15

flowering classes for each type (protandrous and protogynous) from very early/very early to very late/very late, the first and second terms indicating time of releasing/receiving pollen, or a total of 30 classes. For example, a Type I-early/mid cultivar termed would require a Type II-early/mid cultivar to ensure the greatest likelihood of complementary pollination (Table 4). This 30-class flowering system provides a degree of resolution sufficient to ensure complementarity of pollination among two or more cultivars.

Pollination/receptivity periods in the hot/arid environments of the southwestern United States are compressed relative to those in the hot/humid southeastern United States (Grauke and Thompson, 1992, 1993; Nakayama, 1967). Nevertheless pecan cultivars can be separated into several pollen shedding/receiving classes. Because cultivars generally maintain the same approximate dichogamy pattern across seasons and locations (Grauke and Thompson, 1996; Sparks 1987; Worley et al., 1992), this 30-class flowering classification should be valid for cultivars over a wide range of environments and locations.

Cultivation of at least two cultivars, one from each of the complementary subclasses of the two dichogamy class types, ensures both good pollination and good cross-pollination. Thus Type I-mid/late and Type II-mid/late cultivar combinations should provide good complementary cross pollination. While this system may not always prove effective, it is approximately valid for the vast majority of cultivars and appears to provide a far greater probability of achieving complementarity than the presently used two-class Type I and Type II classification. For the 80 cultivars in the present study, adoption of this 30-class system enables selection of cultivar combinations that are more likely to be complementary as young trees than if selected based on the traditional "Type I-Type II" system. Although there are

Fig. 2. Flowering phenogram comparing temporal aspects of pollen dispersal and receiving periods for "northern" pecan cultivars cultivated at Byron, Ga. Trees were established in 1981 and flowering data are from 1985-89 and 1991.

Table 4. A seasonally based classification of pollinating and receptivity windows of "young" pecan trees (<15 years old) based on average performance at Byron, Ga. (from Figs. 1 and 2). Designations are based on a "30-class" system where: I = protandrous and II = protogynous, VE = very early, E = early, M = mid, L = late, VL = very late.

Protandrous (Type-I)				Protogynous (Type-II)			
Cultivar	Class	Cultivar	Class	Cultivar	Class	Cultivar	Class
(Pollinating/receiving)				(Receiving/pollinating)			
Cape Fear	E/M	Forkert	M/M	Frotsher	VE/E	Shoshoni	M/M
Centennial	E/M	Kiowa	M/M	Elliott	VE/M	Sioux	M/M
Cherokee	E/M	Western Schley	M/M	Candy	E/M	Odom	M/M
Cheyenne	E/M	Giles	M/L	Chickasaw	E/M	Van Deman	M/M
Dependable	E/M	Gra Cross	M/L	Delmas	E/M	Burkett	M/L
Evers	E/M	Major	M/L	Gloria Grande	E/M	Choctaw	M/L
Owens	E/M	Nelson	M/L	Hirschi	E/M	Colby	M/L
Pawnee	E/M	Pabst	M/L	Kernoodle	E/M	Comanche	M/L
Alley	E/L	Podsednik	M/L	San Saba	E/M	Curtis	M/L
Caddo	E/L	Riverside	M/L	Shawnee	E/M	Ideal	M/L
Desirable	E/L	Starking H.G.	M/L	Teche	E/M	Melrose	M/L
Jackson	E/L	Squirrel's Del.	M/L	Waukeenah	E/M	Moneymaker	M/L
Mobile	E/L	Success	M/L	Wichita	E/M	Moreland	M/L
Moore	E/L	Woodard	M/L	Cowley	E/L	Norton	M/L
San Saba Improved	E/L	Dooley	M/VL	Tejas	E/L	Posey	M/L
Harris Super	E/VL	Pereque	L/L	Apache	M/M	Pensacola Clu.	M/L
Barton	M/M	Russell	L/VL	Gra Bohls	M/M	Stuart	M/L
				Mahan	M/M	Sumner	M/L
				Mohawk	M/M	Green River	M/L
						GraTex	L/L

more than 1000 pecan cultivars (Thompson and Young, 1985), the 80 categorized in this study represent about 95% of the commercially significant cultivars.

The proposed "seasonally based Type I-Type II" (Table 4) designation generally allows for complete coverage of the flowering period of pecan (from 22 Apr. to 28 May, or ≈ 37 d). Enhanced cross-pollination should occur after incorporating a third cultivar from the same or a similar subclass for either the pollination or receiving period or both. Because flower maturity patterns can vary depending upon a cultivar's interaction with environmental factors or as trees age (Wood, 1996), any two supposedly complementary cultivars may not cross-pollinate adequately throughout the long life span of the orchard. The resulting economic losses could be catastrophic; therefore, orchards consisting of three or four cultivars may be preferable. Because economic and marketing factors favor a particular cultivar, the cultivar mix and spatial arrangement may differ from orchard to orchard and region to region.

This study indicates that the flowering characteristics of pecan cultivars can vary with location and that the range and variability of flower maturity windows exhibited generally invalidate the traditional Type I-Type II classification system for ensuring good cross-pollination. The best strategy for avoiding pollination problems is to 1) select cultivars based on the performance of targeted cultivars growing at, or near, the proposed establishment site, and 2) plant two or more complementary cultivars, targeting the pistillate flower receptivity period of the primary cultivar(s). Because this is often impossible, especially for producers outside the United States, an alternative is the selection of cultivars based on the proposed 30-class system. The phenogram of 80 cultivars presented in this report should be considered as a point of reference for the identification of flowering characteristics of young trees and serve to supplement the flowering characteristics of older trees as previously reported by Worley et al. (1992). We shall term our 30-class flower maturity system the "seasonally based Type I-Type II" system and propose that it be adopted for classifying the generalized flowering patterns of pecan cultivars. Similar systems exist

for other fruit crops (Soltesz, 1996), thus simplifying the selection of complementary cultivar mixes and enhancing economic returns.

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