Masting in Pecan

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Abstract. Annual variation in fruiting by pecan [*Carya illinoensis* (Wangenh.) K. Koch] obtained from anecdotal records and state, district, county, and orchard data from Texas indicate exceptionally high synchronous fluctuations typically occurred every 34 years with a range of 2-7 years over the 66-year data base examined. Synchrony in fruit production was inversely related to the spatial distribution of pecans reflected in coefficients of variation ranging from about 60 at the state level to about 120 for two 10-ha orchards. These characteristics show that pecan exhibits roasting and that the species warrants further examination vis a vis interactions with nut feeders.

Masting is the irregular, synchronous production of fruit by a population over a wide geographical area (Janzen, 1971 b). In natural systems the roasting syndrome has been ascribed to a species based on limited, often short-term and/or anecdotal information (Ashton et al., 1988; Fox, 1981; Janzen, 1971a, 1974, 1976; McCarthy and Quinn, 1989; Silvertown, 1980; Wailer, 1979; Willson, 1983; Wood et al., 1990). Because of its commercial value as a food crop and its relatively recent domestication and subsequent commercial cultivation adjacent to its wild relatives, pecan may be a useful model for characterizing the phenomena of roasting. In this paper, we assess the process of pecan domestication and analyze the extensive nut production records from Texas to quantify and define the spatial and temporal patterns of nut production.

Anecdotal records over the past 400 years indicate that natural stands of riparian pecan are abundant and produce large crops of nuts at irregular intervals (Cabeza de Vaca, 1983; Smith, 1950). *Carya* today comprises 39% or more of the tree density and averages 1.6-3.1 ha of canopy/km² in two extensive habitats examined in Texas (Table 1). Wild *Carya* currently represent 20-22% of the total area covered by all trees in mixed species stands (Table 1). This is a true reflection of aboriginal *Carya* density (pecan plus other *Carya* species) on the poorer sites where domestication practices were not evident from aerial photographs (Maggio et al., 1983, 1991). Direct extrapolation of 20%-22% *Carya* density throughout the wooded aboriginal riparian habitat would probably underestimate the incidence of *Carya* in the natural system because deliberate thinning would have proceeded from stands densest in pecan to those representing the species more sparingly.

Pecans are long lived, with examination of annual rings (M.K. Harris, unpublished data) showing that century-old trees are common and that individuals with over 200 rings have been found. Estimates of maximum longevity in excess of 300 years are accepted (Brison, 1974; Smith, 1950), and Bruce Wood (U.S. Dept. of Agriculture-Agricultural Research Service, personal

communication) reports a tree in Jiminez, Mexico, over 400 years old. Thus, pecan longevity, commercial value of wild nuts, erosion control, and compatibility with respected agrarian practices have ensured a slower transition of wild pecan to the genetically uniform intensively managed monoculture characteristic of modern agriculture in Texas.

Pecan nut harvesting and utilization has progressed from subsistence by Indians, to barter, to sophisticated commercial operations (Brison, 1974). This cash convertibility of wild pecans occurred in Texas even during the depression years of the 1930s, with the lowest price averaging 4¢/lb. (8.84¢/kg) in 1932 [(TDA, 1981) and one person could gather more than 45 kg/day from a harvestable crop (Smith, 1950).

These factors are pertinent to assessing the reliability of pecan yield and price estimates for pecan made annually by mail and telephone with growers, shellers, and processors by the TDA since 1919 (Schafer and Hertel, 1981; TDA, 1981). The economic incentives and market mechanisms to exploit nut production of the wild pecan have developed over centuries (Smith, 1950; Thompson and Young, 1985), and the formal monitoring begun by TDA in 1919 represents a useful reflection of the actual productivity that has occurred since that time.

Table 1. Canopy of wild, native, and orchard *Carya* and other trees in hectares within 1 km of the river channel in the Brazes river system from Proctor, Texas, to the Gulf of Mexico and in the Colorado river system from Junction, Texas, to the Gulf of Mexico (Maggio et al., 1991).

River system	Wild	Native	Orchard	Other trees	km of river channel
Brazes	2162	3338	70	8870	897
Colorado	798	1365	150	2866	727

The Texas pecan industry is still founded on production from native trees, which contributed >90% before 1940 to ≈69% of the harvest from 1967-87 (TDA, 1981, 1968-88; Fig. 1). The enduring commercial value of the wild nut increases confidence in the relationship between actual production of wild trees and that reported by TDA. Gemoets et al. (1976) reported finding a 2.5- and 4-year cycle of production using United States pecan yield data. Wood (1993) using autoregressive analysis found evidence for a 2- and 9-year cycle for United States seedling production. The examination of Texas data for exceptional fluctuating yield, synchrony of populations in space, intermast period, synchrony of individual trees, and production patterns should provide an even more focused insight into the biology of the pecan.

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Data used for this study were obtained from Statistical Reporting Service (1971, 1972, 1977), and the TDA (1981, 1968-1988). State records of United States and Texas pecan production have been kept since 1919; Texas data have been separated into native (naturally occurring pecans that typically have been partially thinned of competing trees and brush and may receive additional management like pesticides, especially when nut crops are present) and improved (specially selected, vegetatively propagated and usually intensively managed cultivars) pecans; and district and county records have been reported since 1968 (TDA, 1981, 1968-88). Records of production from individual improved trees have been kept for two Texas A&M Univ. orchards near College Station since they first came into bearing in 1966. These are the only consistent and continuous data sets of significant duration known to us from Texas. These data were examined to evaluate roasting in pecan.

Effects of time on fruiting of pecan

Linear regression showed a positive relationship between yield and time for Texas improved pecan production (Fig. 1A; $R^2 = 0.6758$; $P < 0.01$; $F = 139.7$) and no relationship for native production (Fig. 1B; $R^2 = 0.0479$; $P = 0.071$; $F = 3.4$). Improved orchards have been planted at an increasing rate since 1919, while the long-lived native pecans have been a more stable population during this period. Improved pecan data from the Texas data base were not included further in this initial analysis of roasting because fluctuations in production (roasting) were confounded by production from increasing acreage (Fig. 1).

Native yield frequencies from 1919-53 were compared with those from 1954-87 (Fig. 2) in an attempt to examine if the effects of better technologies like air blast sprayers, application of nutrient amendments, pesticides for insect and disease control, and herbicides for weed control had affected the temporal pattern of native pecan

Fig. 1. Vegetatively propagated (improved) and native pecan fruiting in Texas, 1919-87.

Fig. 2. Frequencies of native pecan fruiting in Texas.

production. Before 1945, intensive management of native pecans was not generally practical. The advent of pesticides, fertilizers, and suitable equipment in the decade that followed allowed more intensive programs to be developed and applied (Harris, 1983, 1991). Adoption was gradual and 1953-54 was chosen as the dividing point because it occurred within the decade where technological advances were being implemented and this allowed the data base to be split evenly as well. State native pecan yields have been higher in the recent 34-year period compared to the previous one and the recent period contains 13 mast years compared to 9 in the earlier period. The general yield patterns are not, however, distinctively different between these two periods and indicate that intensive management of native pecans has not yet been so widely adopted or effective as to obscure the fruiting pattern.

Native pecan production in Texas averaged $11.8 \times 10^6 \pm 7.1 \times 10^6$ kg (mean $\pm$ SD) annually, with a coefficient of variation of 59.94. Analysis of the native data for roasting assumes 1) the population productivity potential was relatively constant; 2) yield patterns were due to intrinsic properties of the population during this period; and 3) accuracy of yield records. These assumptions were made based on the 150+ year longevity of wild pecan trees, the reliance by mixed agriculture producers on revenues produced in bearing years and the inability or at least widespread reluctance to fertilize, irrigate, and use pesticides, especially in years of low native production.

Test for exceptional yields

Annual yield of native pecan trees in Texas has not been regular (Fig. 1). The criteria initially chosen for yield evaluation were to determine the annual mean yield and SD. The SD was used to delineate limits for determining exceptionally high or low yields by designating low yields as those occurring below 7.1×10^6 kg ($1 \times$ SD) and high yields as those greater than 14.2×10^6 kg ($2 \times$ SD). The SD was used because that unit can be uniformly applied to almost any sample size and 1 SD unit from zero should include all

low yields for any roasting species due to the nature of roasting. The upper limit of yield above $2 \times$ SD to define mast years was used because it approximated the upper limit of the 95% confidence interval (CI) for this data set while retaining the statistical uniformity provided by the SD. We expect these criteria using the SD to be robust for other pecan data sets as they become available and not necessarily to be applicable in establishing upper limits for other species. Fig. 1B shows yields exceeded the upper boundary in 22 years and were below the lower boundary in 18 years. Inspection further shows many years throughout the series where yields were very low and very high, thereby meeting the exceptional criterion consistent with roasting. Simultaneously, synchrony is also implied across the Texas data set, although this feature will be examined in more detail later.

Intermast period

To examine further whether these yields were a repetitive characteristic, 1-, 2-, 3-, 4-, 5-, and 6-year cycles were examined using the following method: yield in the present year was plotted against yield in the previous year for the data base with the outcomes expected outlined in Fig. 3. For example, if productivity were regular, yields would be expected to occur between 7.1 and 14.1 million kg every year and the plot in Fig. 3 should result in 68 occurrences in sector E and zero in remaining sectors. The observed outcome of 11 data points in sector E and 57 outside the range was subjected to a chi-square goodness-of-fit test (Table 2) and the null hypothesis of an annual cycle was rejected. A biennial cycle would result in 68 data points being clustered in sectors A, B, F, and I (Fig. 3), but 39 occurred in these sectors and 29 elsewhere resulting in rejection of this null hypothesis as well (Table 2). Applying the same procedure to the remaining yield cycle possibilities resulted in rejection of 5- and 6-year cycles but failure to reject the 3- and 4-year cycles (Table 2). These analyses show native pecan production in Texas occurs most commonly on a 3- or 4-year cycle.

Expected:

Yield Cycle	Data Points/Sector
One year	E=68; A+B+C+D+F+G+H+I=0
Two year	A+B=34; F+I=34; C+D+E+G+H=0
Three year	D+E+G+H=23; A+B=23; F+I=22; C=0
Four year	D+E+G+H=34; A+B=17; F+I=17; C=0
Five year	D+E+G+H=40; A+B=14; F+I=14; C=0
Six year	D+E+G+H=44; A+B=12; F+I=12; C=0

Fig. 3. The number of observed data points obtained by plotting yield in year X against yield in year X-1 from native pecan production in Texas from 1919-87. The expected distribution of data points/sector is listed below for various cycles of fruiting.

Test for irregularity on Texas pecan data

Many fields, such as ecology and meteorology, are concerned with temporal patterns in fluctuating physical and biological phenomena. Colwell (1974) reported that measures of predictability, constancy, and -contingency are sufficient to describe the general characteristics of periodic phenomena. Raveh and Tapiero (1980) presented a simple method for analyzing qualitative time series based on modes and stated that measures of periodicity, constancy and heterogeneity describes some aspects of periodic phenomena. Here, Raveh and Tapiero's method was used to examine predictability of pecan fruiting.

Quantitative data of native pecan from 1919 to 1987 were converted into qualitative data by using the confidence interval and yield frequency (Fig. 1B). Triennial pattern is defined as aperiodic qualitative time series with period length 3, and quadrennial pattern with period length 4, and so on. Measures of predictability, constancy, and contingency obtained by Raveh and Tapiero's method for native pecan production resulted in the highest values being 0.285, 0.166, and 0.12, respectively, with 1.0 indicating a perfect correspondence. These low values indicate no regular yield pattern was predictable from the data. Thus, the statewide native pecan data show that high fruit crops occur irregularly and unpredictably with typical intervals being 3-4 years and, thus, meet the

roasting criterion of irregularity. This roasting pattern should also be evident in geographical subdivisions of the state.

Masting as evidenced by district and county data

District and county data gathered since 1968 (TDA 1968-88) were analyzed to evaluate the consistency of roasting across subdivisions of Texas. Production records were reported as native and improved production combined. Due to the predominance of the former in contributing to fruiting data the potential bias resulting from inclusion of the improved pecan yield data was felt to be small. Figure 4 shows Texas pecan production from 1968-85

Table 2. Chi-square goodness-of-fit test on native pecan production in Texas from 1919-87 (Fig. 3).

Null hypothesis	Chi-square test statistic
One-year cycle	46.81* (3.84)
Two-year cycle	11.06* (5.99)
Three-year cycle	1.84 ^{ns} (7.82)
Four-year cycle	2.98* (9.49)
Five-year cycle	12.12* (11.07)
Six-year cycle	21.74* (11.67)

*Significant at $P = 0.05$. Numbers in parentheses show 0.95 significance level.

Fig. 4. Pecan fruiting in leading production districts and counties of Texas.

Fig. 5. Mean fruiting per tree in Adriance and Brison orchard, College Station, Texas, from 1966-84.

Fig. 6. Fruiting proportion of individual trees (N= 252) in Adriance orchard from 1966-84.

in districts 3, 4, 7, and 8-N. Linear regression showed no relationship between annual yields and time in each leading district and leading counties in these districts, except Hood and Lampasas. These yield patterns were very similar to the state pattern (Fig. 1), indicating that roasting was consistently expressed as geographical area decreases. Yield fluctuations, as measured by the coefficient of variation, also increased as the geographical area decreased, showing that synchrony of production in the smaller populations was higher compared to that observed at the state level (Fig. 1B vs. Fig. 4).

Synchrony of individual trees

Annual yield data from two improved ('Mahan', 'Desirable', 'Stuart', 'Success') orchards are shown in Fig. 5. Adriance orchard was planted on 10 ha in Burleson County, Texas in 1958 on a 15.2 × 15.2-m spacing. Brison orchard was planted on 4 ha in 1953 on a 15.2 × 15.2-m spacing and not well managed until 1957. The orchards are within 1 km of one another on the alluvial Westwood silty and silty clay loam soil of the Brazes river flood plain. Standard commercial dryland management practices of

Fig. 7. Mean coefficient of variation of nut production through time from different geographical areas decreasing in size from the United States to individual cultivars in a single orchard.

fertilization, zinc amendments, fungicides, insecticides, and weed control have been used except for blocks reserved for other experimentation.

Fruiting patterns from trees that received consistent commercial management during this period were analyzed. Pecan production began in 1966 in these orchards and yield for the first 7–9 years is representative of young trees provided a surplus of nutrients and free of intraspecific competition, especially for sunlight. Beginning about 1973, tree canopies began to shade one another during part of the day and this increased in subsequent years to more closely approximate the dense tree stands typical of natural pecan. The synchronous fruiting of these orchard trees (Fig. 5), in concert with leading counties and districts (Fig. 3), and state (Fig. 1) yields, indicates roasting is initiated at the individual tree level.

Figure 6 presents the yield frequencies of individual trees in Adriance from 1966–84. The degree of fruiting synchrony among the 252 individuals from 1976–83 is illustrated by comparing average fruiting in even years with those in odd years, namely 1.107 vs. 30.60 kg/tree, resulting in a 26-fold average difference between fruiting and barren years. An average of 20 trees or 8% of the population bore nuts in even numbered years while 230, or 92% of the population, bore nuts in odd numbered years. Finally, 97% of the production from 1976–83 occurred in the odd numbered years. Thus, yield in nearly barren years was restricted to about 8% of the population that produced 3% of the yield for the entire period showing that the violation of synchrony was limited to just a few trees that fruit at about one-half the average level of the population in bearing years. Asynchronous trees appear to be substantially less capable of producing nuts than average trees in the population. Assuming this characteristic can be extrapolated to wild trees, this reduced fecundity of asynchronous trees would reduce their ability to reproduce given equal probabilities for nut survival through time.

Fruiting synchrony across geographic areas

The high level of synchrony in fruiting and barren production results in a high cv in fruiting across years. This provides a measure of how variability occurs across geographical areas as shown in Fig. 7. Variation at the orchard level is highest indicating the greatest fruiting fluctuations occur in the smallest geographical areas, with county, district, state, and national fruiting showing decreasing amounts of variation. Even though the state cv is just about half the orchard cv, the synchronous variation in fruiting is still substantial about 250,000 km² area of pecan production in Texas. This indicates the mechanisms responsible for preserving roasting in the tree population are maintained over linear distances in excess of hundreds of km.

Pecan occurs in dense populations throughout much of Texas (Maggio et al., 1983) and nut production is synchronous at irregular intervals ranging from 2–7 years throughout the state (Fig. 1). Chi-square analyses of state yields of native pecan indicate typical roasting intervals of 3–4 years from 1919–87 (Table 2). Variation in fruiting through time increases as the geographical area examined decreases (Fig. 7), indicating the integrity of roasting is highest in smaller geographical areas. One measure of the integrity of roasting from orchard trees indicates 92% of the tree population fruits in synchrony and that the 8% that produce nuts out of synchrony only contribute 3% of the total (Fig. 6). These results show that pecan exhibits roasting and provides a basis of evaluating fruiting intervals and levels in pecan populations through time, and evaluating those effects on the pecan itself and for associated organisms.

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