Fruit Growth and Development of 'Ideal' and 'Western' Pecans

Esteban A. Herrera

Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, NM 88003-0003

Additional index words. *Carya illinoensis*, endosperm development, cotyledon thickening, embryo growth, watery stage, gel stage, dough stage

Abstract. Pecan [*Carya illinoensis* (Wangenh.) K. Koch] fruit development was evaluated over three growing seasons (1981-83) to determine the seasonal growth patterns in the cultivars Ideal and Western. Gross morphological stages were examined weekly in fruit dissected in cross and longitudinal sections. Free-nucleate endosperm was first observed in mid-July when fruit had grown to 50% of their final length, occurring at 67 days after stigma receptivity (DASR) for 'Ideal' and 76 DASR for Western'. Maximum content of free-nucleate endosperm occurred 100 DASR in 'Ideal' and 109 DASR in Western' fruit. Ovary wall Signification was completed 119 DASR in 'Ideal' and 132 DASR in 'Western'. At this time, nut enlargement was complete. Cotyledon thickening required 36 and 43 days for 'Ideal' and Western', respectively. The time from stigma receptivity to completion of cotyledon thickening in mid-October was 13 days longer for Western' than for 'Ideal'. Because of a cool spring in 1983, all stages required a longer time in 1983 than in the previous 2 years. Most aspects of fruit development were similar between 'Ideal' and Western' over the 3-year study.

Fruit development in pecans can be divided into two phases, endosperm development and embryo growth (Crane and Hardy, 1934; McKay, 1945; Thor and Smith, 1935). During phase 1, the fruit enlarges and the volume of endosperm increases. Nut size at maturity is affected by environmental conditions occurring at this time. As a result, growers should optimize growing conditions during phase 1 to produce large pecans (Crane and Hardy, 1934; McKay, 1945; Thor and Smith, 1935). Phase 2 is the period of embryo growth. This phase is marked by the development of the cotyledons and is correlated with nut filling. Conditions late in the season are critical to production of well-filled kernels because this is the time when cotyledons lengthen and thicken (Crane and Hardy, 1934; Dozier and Amling, 1974; Finch and Van Horn, 1936; Thor and Smith, 1935; Woodroof and Woodroof, 1927).

Pecan orchard management practices (Hunter and Hammar, 1961; Malstrom et al., 1983; Mielke, 1984; Worley et al., 1972) can affect fruit development. Determination of the time the phases of fruit development begin and the rate at which they are completed are important in designing protocols to improve orchard management practices for optimizing maximum fruit size and quality. The objective of this study was to compare the temporal phases of fruit growth and development of 'Ideal' ('Bradley'), a pollinator, and 'Western', the main cultivar planted in New Mexico.

Materials and Methods

Fruit were collected during the 1981 through 1983 growing seasons in a well-managed commercial pecan orchard in the Mesilla Valley, 12 km south of Las Cruces, N.M. Pecan trees were 15 years old in 1981. Trees were healthy and uniform in size. Sampling began in early June, when fruit were ≈ 10 mm long, and continued until late October. Samples consisted of 30 fruit that were harvested at random every week from randomly selected trees in the southern section of a 16-ha block. Each sample was divided into three groups of 10 fruit each. Each

group was assigned one type of cut: a) cross section made at the midpoint of the fruit, perpendicular to the longitudinal dimensions, b) longitudinal IPMS, and c) longitudinal RAMS. Two fruit representing the average developmental stage for a given week were chosen from each group. Observations were recorded from the selected pecans. Another cut, IPMSE, was periodically made to observe the middle septum extension (grooves) in the developing kernels.

Fruit were dissected with a sharp knife in the first half of the growing season. Later in the season, as the shell hardened, fruit were sectioned with a miniature, hobby-type saw. Dissected fruit were placed on petri dishes containing 95% ethanol to prevent darkening of tissues.

Gross morphology of endosperm and embryo growth was monitored to determine dates of initiation and completion of specific developmental stages. Stages analyzed included free-nucleate endosperm (liquid), cytokinesis (gel), kernel deposition (dough), ovary wall (shell) Signification, cotyledon thickening (nut filling), and fruit maturity, as judged by involucre (hull) dehiscence. Ovule growth increments were based on the proportion of the ovule's length, at the time of sampling, relative to its ultimate length at maturity. Ovary wall and involucre thickness were also measured in 1981 and 1982. The average date of stigma receptivity was used as the base date for timing developmental stages for each cultivar. Average stigma receptivity occurred around 10 May for 'Ideal' and 7 May for 'Western' in 1981, 15 May for 'Ideal' and 8 May for 'Western' in 1982, 9 May for 'Ideal' and 1 May for 'Western' in 1983.

Photomicrographs were taken through a dissecting microscope with a built-in micrometer. A $\times 12$ lens was used early in the season and $\times 6$ and $\times 3$ lenses were used later in the year.

Each year, 30 fruit of each cultivar and age group were tagged in the orchard. Fruit length and width were recorded weekly. Fruit growth curves were obtained using a linear regression model. Appropriate comparisons were made each year between cultivars.

Received for publication 14 Aug. 1989. New Mexico Agricultural Experiment Station Journal Article 1236. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Abbreviations: DASR, days after stigma receptivity IPMS, in plane to the middle septum; IPMSE, in plane to the middle septum extension; RAMS, at right angles to the middle septum.

Results

'Ideal'—Endosperm growth and development (1981). There was no evidence of liquid endosperm when the first measurement was taken on 3 June (24 DASR). Fruit length was 23% and fruit width 14% of final dimensions (Fig. 1). Parts of fruit evident in cross sections included the involucre (hull or shuck) and ovarian tissue (packing and shell) (Fig. 2A). In RAMS sections, the ovule was identifiable. The fissure that separates the packing tissue from the interior portions of the ovary was also visible (Fig. 2B).

The first clear indication of free-nucleate endosperm in the ovule was on 14 July (65 DASR), when fruit length was 52% and fruit width 45% of the final size (Fig. 1). The increase in volume of the endosperm forces the enlarging integument into the ovarian cavities forming the crevice or fissure mentioned by others (Shuhart, 1932; Woodroof and Woodroof, 1927). Due to expansion of the fissure and compression of the packing tissue, the future kernel shape can be distinguished in cross sections (Fig. 2C). This shape is determined by the differential growth of ovarian tissue (Shuhart, 1932). An increase in the size of the fissure and the development of two lobes on the ovule were apparent in RAMS sections (Fig. 2D). By 21 July (72 DASR), the fissure had become even further extended (Fig. 2E) and the ovule was turgid (Fig. 2F). The ovule was only about one-fourth of the fruit's length so that the integument of the ovule had not yet reached the midpoint of the fruit. Fruit had enlarged by more than 10% in length and =9% in width since the previous sample, date (Fig. 1). The ovule was about half the width (Fig. 3A) and length of the final kernel dimensions on 28 July (79 DASR) (Table 1). Fruit size was 71% of final length and 64% of final width. Only 1 week later, on 4 Aug. (86 DASR), the ovule had greatly increased in width (Fig. 3B) and had grown to about three-fourths of the fruit length (Table 1). However, fruit length and width only increased 7.5% and 6%, respectively, over the previous week's measurements.

When maximum content of free-nucleate endosperm (watery stage, according to Thor and Smith, 1935) was reached on 11 Aug. (93 DASR), fruit size was 85% of final length and 79% of final width (Fig. 1). The central vacuole had expanded to the full width of the fruit (Fig. 3C) and the ovule to almost full length, as demonstrated in fruit sectioned at RAMS (Fig. 3D). Ovary wall Signification had begun on this date and maximum ovary wall thickness was achieved. Involucre thickness began

Fig. 1. Average fruit length and width on 'Ideal' pecan trees in the Mesilla Valley, N. M., during the 1981 through 1983 seasons.

to increase and continued to do so for the next 6 weeks; most of the involucre thickening occurred during this period (Fig. 4). On 18 Aug. (100 DASR), fruit were 89% of final length and 83% of final width (Fig. 1). A layer of cellular endosperm had formed from the free-nucleate endosperm and was deposited on the inner wall of the integument. Researchers refer to this thin transparent layer of cells as the gel layer (Finch and Van Horn, 1936; McKay, 1945). As this layer thickens, it becomes more visible; this period of pecan fruit development has been commonly named the gel stage (Cooper et al., 1983; Ring, 1978) (Fig. 3 E and F).

'Ideal'—Embryo growth and development (1981). Free nucleate endosperm was absent on 1 Sept. (114 DASR), fruit length was 94% and fruit width 91% of final measurements (Fig. 1). A thick layer of cellular endosperm (gel) was completely surrounded by the folds of the cotyledon (Fig. 5A). This stage was the first indication of cotyledon thickening, as a solid white cotyledonary material began replacing the cellular endosperm. The middle septum extension had not reached its final shape (Fig. 5B). Ovary wall signification was also finished 114 DASR, completing final nut size.

Fruit length was 96% of final and fruit width 94% of final by 10 Sept. (123 DASR). Although ovary wall Signification was completed by 1 Sept., fruit grew for 3 more weeks because the involucre continued to increase in width. Also by 10 Sept., most cellular endosperm was consumed due to embryo development, leaving only a slightly transparent layer. Only solid white cotyledonary material was observed in fruit cross sections (Fig. 5C). Cotyledon thickening was visible in RAMS sections (Fig. 5D), but was more evident in the fruit apex in IPMS sections (Fig. 5E). This early period of kernel maturation has been commonly defined as the dough stage (Cooper et al., 1983; Ring, 1978).

On 24 Sept. (137 DASR), final fruit size was attained, with a mean length of 45.9 mm and a mean width of 30.5 mm (Fig. 1). Remnants of the ovarian wall tissue adhered to the integument of the ovule (kernel coat). The kernel's middle septum extension appeared to have reached its final length and width (Fig. 5F). In both cross sections and in RAMS dissections, cotyledon thickening was more obvious toward the ovary wall (Fig. 6 A and B). On 1 Oct. (144 DASR), cotyledon thickening was about complete so that most of the white ovarian tissue was pushed against the ovarian wall or the middle septum and the middle septum extension (Fig. 6 C and D). By 8 Oct. (151 DASR), splitting of the involucre along the sutures had begun in the field (Table 1). Fruit dissected in cross section (Fig. 6E) and at RAMS (Fig. 6F) were completely filled. Therefore, completion of cotyledon thickening to produce a well-filled nut required 151 DASR, or 37 days counting from the time free-nucleate endosperm was consumed by the developing embryo.

'Ideal'—Fruit growth and development (1982, 1983). The pattern of morphological development associated with fruit growth was similar to that in 1981 (Fig. 1), but the dates of occurrence and DASR varied for some stages (Table 1). In both years, fruit continued growing after ovary wall Signification was completed because the involucre grew in thickness for two more weeks. The longest season was in 1983 because of a cooler spring than the two previous years. For the 3-year average, the first indication of free-nucleate endosperm occurred 67 DASR, maximum content of free-nucleate endosperm 100 DASR, and completion of ovary wall signification 118 DASR (Table 1). Cotyledon thickening or embryo growth was completed 35 days after the disappearance of the free-nucleate endosperm. Completion of ovary wall Signification coincided in all 3 years with

Fig. 2. Gross morphology of endosperm growth and development in 'Ideal' pecans: (A) Cross section (CS), 3 June 1981, 24 DASR. ($\times 7.5$) (B) RAMS, 24 DASR. ($\times 10$) (C) CS, 14 July 1981, 65 DASR. ($\times 1.5$) (D) RAMS, 65 DASR. ($\times 1.5$) (E) CS, 21 July 1981, 72 DASR. ($\times 1.5$) (F) Ovule IPMSE on left and RAMS on right, 72 DASR. ($\times 1$) cv = Central vacuole, fi = fissure, hu = hull (involucre), io = integument of ovule, me = middle septum extension, ms = middle septum, ov = ovule, pk = packing (ovarian) tissue, sh = shell (ovarian wall).

the beginning of cotyledon thickening. On the average, 138 DASR were required for the fruit to reach final size and 155 DASR for the fruit to be completely filled.

'Western' -Endosperm and embryo growth and development (1981 to 1983). Fruit growth and development followed a pattern similar to that of 'Ideal' pecans. Slight differences existed, mainly in the duration of some stages (Table 2). Like 'Ideal' fruit, few gross morphological changes were evident early in the season, but fruit growth rate was clearly rapid. When free-

nucleate endosperm was first visible on 14 July 1981 (65 DASR) (Table 2), the fruit dimensions were 50% of final length and 43% of final width (Fig. 7). In 1982 and 1983, the same stage was reached 20 July (73 DASR) and 26 July (86 DASR), respectively, when fruit was =55% of final length (Table 2) (Fig. 7). Maximum content of free-nucleate endosperm and initiation of ovary wall Signification were estimated in 1981 because they occurred between sampling dates (Table 2). These stages occurred =100 DASR, when fruit were =87% of final length and

Fig. 3. Gross morphology of endosperm growth and development in 'Ideal' pecans. (A) Cross section (CS), 28 July 1981, 79 DASR. (x 1.5) (B) CS, 4 Aug. 1981, 86 DASR. (x 2) (C) CS, 11 Aug. 1981, 93 DASR. (x 2) (D) RAMS, 93 DASR. (x 1.5) (E) CS, 18 Aug. 1981, 100 DASR. (x 1.5) (F) RAMS, 100 DASR. (x 1) cv = Central vacuole, fi = fissure, hu = hull (involucre), io = integument of ovule, me = middle septum extension, ms = middle septum, ov = ovule, pk = packing (ovarian) tissue, sh = shell (ovarian wall).

77% of final width (Fig. 7). These stages were estimated again in 1982, but not in 1983 (Table 2). In contrast to 'Ideal', cotyledon thickening started 1 week before ovary wall signification for all 3 years observed (Tables 1 and 2).

During the 1981 season, signification and maximum thickness of the ovary wall were reached 10 Sept. (126 DASR) (Table 2). Fruit had reached 97% of final length and 91% of final width (Fig. 7). Completion of ovary wall Signification occurred 14 Sept. (129 DASR) in 1982 and 20 Sept. (142 DASR) in 1983 (Table 2). Fruits of 'Western' required more days to reach this

stage than 'Ideal'. For fruit to reach final size, 140 DASR were required in 1981, 143 DASR in 1982, and 149 DASR in 1983. Final mean fruit lengths were 53.2, 57.2, and 57.6 mm, respectively, for the same 3 years. Final fruit widths were 29.1, 34.1, and 32.0 mm for 1981, 1982, and 1983, respectively. The involucre continued to thicken for 2 weeks after the ovary wall was lignified (Fig. 4). In some fruit, involucre separation from the ovary wall started in the field around the same dates as in 'Ideal' pecans. However, for 'Western', it was more widespread 1 week later, when fruit appeared to be completely filled.

Table 1. Dates of occurrence of fruit development stages of 'Ideal' (Bradley) pecans in the Mesilla Valley, N.M.

Fruit development stage	1981		1982		1983		3-Year average	
	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity
First observation	3 June	24	8 June	24	14 June	36	8 June	28
First indication of free-nucleate endosperm	14 July	65	20 July	66	19 July	71	18 July	67
Ovule								
One-fourth of fruit's length	21 July	72	27 July	73	26 July	78	25 July	74
One-half of fruit's length	28 July	79	3 Aug.	80	9 Aug.	92	3 Aug.	84
Three-fourths of fruit's length	4 Aug.	86	10 Aug.	87	16 Aug.	99	10 Aug.	91
Ovary wall lignification started	11 Aug.	93	17 Aug.	94	23 Aug.	106	17 Aug.	98
Maximum content of free-nucleate endosperm	11 Aug.	93	24 Aug.	101	23 Aug.	106	19 Aug.	100
Visible layer of cellular endosperm on the inner wall of the integument of ovule (gel stage)	18 Aug.	100	31 Aug.	108	30 Aug.	113	26 Aug.	107
Ovule full length	18 Aug.	100	31 Aug.	108	30 Aug.	113	26 Aug.	107
Free-nucleate endosperm absent; cotyledon surrounds a thick layer of cellular endosperm	1 Sept.	114	7 Sept.	115	13 Sept.	127	7 Sept.	119
Ovary wall lignification complete	1 Sept.	114	7 Sept.	115	13 Sept.	127	7 Sept.	119
Kernel deposition (dough stage); cellular endosperm absent, only white cotyledonary material present	10 Sept.	123	14 Sept.	122	20 Sept.	134	15 Sept.	126
Cotyledon thickening (filling of kernel)								
Ovarian tissue and extension of middle septum pushed toward ovary wall, middle septum pushed inward	1 Sept. to 8 Oct.	114-151	7 Sept. to 12 Oct.	115-150	13 Sept. to 18 Oct.	127-162	7 Sept. to 13 Oct.	119-154
Involucre separation from ovary wall started in the field	8 Oct.	151	12 Oct.	150	18 Oct.	162	13 Oct.	154
Fruit appeared completely filled	8 Oct.	151	12 Oct.	150	18 Oct.	162	13 Oct.	154
Leaf fall	10 Nov.	184	19 Nov.	188	20 Nov.	195	16 Nov.	189

¹Stigma receptivity occurred around 10 May 1981.

²Stigma receptivity occurred around 15 May 1982.

³Stigma receptivity occurred around 9 May 1983.

Fig. 4. Average involucres and ovary wall thickening on fruit from 'Ideal' (I) 'Western' (WS) pecan trees in Mesilla Valley, N. M., during the 1981 and 1982 seasons.

For the 3-year average, the first indication of free-nucleate endosperm was 76 DASR, with maximum content 109 DASR (Table 2). Both stages needed 9 days more to be accomplished in 'Western' fruit than in fruit from 'Ideal' trees (Tables 1 and

2). Ovary wall signification was completed 132 DASR, and cotyledon thickening, from initiation to completion, in 43 days (Table 3). In contrast to 'Ideal', 'Western' pecans began cotyledon thickening 1 week before the ovary wall was completely lignified (Tables 1 and 2). On average, nuts were completely filled 167 DASR; 13 days later than for 'Ideal' fruit (Tables 1 and 2). In all 3 years and for both cultivars, fruit length mostly appeared to increase faster than fruit width in the first half of the season. While free-nucleate endosperm was present, fruit length increased 40% and fruit width increased 45%. During the second half of the season, growth was parallel for fruit width and fruit length. Width of involucre and ovary wall was similar for both cultivars and remained this way throughout the season. However, there was a trend for the involucre in 'Ideal' fruit to be thicker than in 'Western' (Fig. 4). Relative fruit growth rates and average dates of occurrence of critical fruit development stages are shown in Fig. 8.

Discussion

Many aspects of fruit development were similar for 'Ideal' and 'Western' over the 3-year study, even though the time span from stigma receptivity until fruit maturity was =13 days longer for 'Western'. These year-to-year similarities between the two cultivars have implications relative to the effects of the environmental conditions during the growing season on determining

Fig. 5. Embryo growth and development in 'Ideal' pecans. (A) Cross section (CS), 1 Sept. 1981, 114 DASR. (x 1.5) (B) IPMSE, 114 DASR. (x 1) (C) CS, 10 Sept. 1981, 123 DASR. (x 1.5) (D) RAMS, 123 DASR. (x 1) (E) IPMS, 123 DASR. (x 1) (F) IPMSE, 24 Sept. 1981, 137 DASR. (x 1) co = Cotyledon, hu = hull, io = integument of ovule, ke = kernel, me = middle septum extension, ms = middle septum, ov = ovule, pk = packing (ovarian) tissue, sh = shell (ovarian wall).

final fruit size, kernel size, nut size, and kernel quality. These four structural features can be correlated with four distinct developmental periods of the pecan fruit.

Before free-nucleate endosperm was present in mid-July, fruit reached about half of its total growth in size with fruit length being =50% and fruit width =40%, of the final dimensions. This pattern of early fruit enlargement indicates that final fruit size may be strongly influenced by growing conditions early in the season. Other researchers have stated that conditions favoring fruit growth during early season growth are necessary to

produce large pecans (Crane and Hardy, 1934; McKay, 1945; Thor and Smith, 1935).

The initiation of the free-nucleate endosperm stage marks the beginning of rapid expansion of the integument of the ovule to accommodate this watery fluid (McKay, 1945; Shuhart, 1932; Woodroof and Woodroof, 1927). Maximum expansion of the ovule had occurred by the 2nd week in August. Therefore, the time from free-nucleate endosperm visibility in mid-July to its maximum size in August, marks the period in which the final kernel dimensions are determined. The time span over which

Fig. 6. Embryo growth and development in 'Ideal' pecans. (A) Cross section (CS), 24 Sept. 1981, 137 DASR. ($\times 1.5$) (B) RAMS, 137 DASR. ($\times 1$) (C) CS, 1 Oct. 1981, 144 DASR. ($\times 1$) (D) RAMS, 144 DASR. ($\times 1$) (E) CS, 10 Oct. 1981, 151 DASR. ($\times 0.5$) (F) RAMS, 151 DASR. ($\times 0.5$) co = Cotyledon, hu = hull, ke = kernel, me = middle septum extension, ms = middle septum, pk = packing (ovarian) tissue, sh = shell (ovarian wall).

free-nucleate endosperm was conspicuous does not appear to be affected by weather conditions for 'Western', as the period covered by the free-nucleate stage did not vary from year to year. Good cultural practices, especially ensuring adequate soil moisture, are required during this period for production of a large kernel. A conspicuous fruit drop was observed at the end of this stage, as reported by others (Sparks and Madden, 1985). Pecans are very susceptible to injury from outside influences during this period because of the high turgidity of the ovule (McKay, 1945). For example, drought stress followed by heavy rainfall

or irrigation will cause a heavy fruit drop (Hunter and Hammar, 1961). Insect damage and other injuries to the fruit that can affect the ovary wall will also cause pecans to fall (Cooper et al., 1983).

Shell signification was completed an average of 118 DASR for 'Ideal' and 132 DASR for 'Western', usually within the first half of September. Therefore, orchard management practices can influence nut size only until early September for these two cultivars under the Mesilla Valley conditions. Fruit continued to grow, however, because the involucre continued to thicken for 2 to 3 weeks

Table 2. Dates of occurrence of fruit development stages of 'Western' pecans in the Mesilla Valley, N.M.

Fruit development stage	1981		1982		1983		3-Year average	
	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity	Dates of occurrence	Days from stigma receptivity
First observation	3 June	27.	8 June	31	14 June	44	8 June	34
First indication of free-nucleate endosperm	14 July	68	20 July	73	26 July	86	20 July	76
Ovule								
One-fourth of fruit's length	21 July	75	27 July	80	9 Aug.	100	29 July	85
One-half of fruit's length	4 Aug.	89	10 Aug.	94	16 Aug.	107	10 Aug.	97
Three-fourths of fruit's length	11 Aug.	96	17 Aug.	101	23 Aug.	114	17 Aug.	104
Ovary wall lignification started	15 Aug. ^w	100	21 Aug. ^w	105	30 Aug.	121	22 Aug.	109
Maximum content of free-nucleate endosperm (watery stage)	15 Aug. ^w	100	21 Aug. ^w	105	30 Aug.	121	22 Aug.	109
Visible layer of cellular endosperm on the inner wall of the integument of ovule (gel stage)	18 Aug.	103	24 Aug.	108	6 Sept.	126	26 Aug.	112
Ovule full length	1 Sept.	117	7 Sept.	122	13 Sept.	135	7 Sept.	125
Free-nucleate endosperm absent; cotyledon surrounds a thick layer of cellular endosperm	1 Sept.	117	7 Sept.	122	13 Sept.	135	7 Sept.	125
Ovary wall lignification complete	10 Sept.	126	14 Sept.	129	20 Sept.	142	15 Sept.	132
Kernel deposition (dough stage); cellular endosperm absent, only white cotyledonary material present	17 Sept.	133	21 Sept.	136	27 Sept.	149	22 Sept.	139
Cotyledon thickening (filling of kernel)								
Ovarian tissue and extension of middle septum pushed toward ovary wall, middle septum pushed inward	1 Sept. to 15 Oct.	117-161	7 Sept. to 19 Oct.	122-164	13 Sept. to 25 Oct.	135-177	7-20 Sept.	125-167
Involucre separation from ovary wall started in the field	8 Oct.	154	12 Oct.	157	18 Oct.	170	13 Oct.	160
Fruit appeared completely filled	15 Oct.	161	19 Oct.	164	25 Oct.	177	20 Oct.	167
Leaf fall	10 Nov.	187	19 Nov.	195	20 Nov.	203	16 Nov.	195

¹Stigma receptivity occurred around 7 May 1981.²Stigma receptivity occurred around 8 May 1982.³Stigma receptivity occurred around 1 May 1983.^wEstimated.

Fig. 7. Average fruit length and width on 'Western' pecan trees in the Mesilla Valley, N. M., during the 1981 through 1983 seasons.

after the ovary wall had hardened. Ovary wall thickness was similar for both cultivars. As expected, 'Western' fruit were signifi-

cantly longer than 'Ideal' in all 3 years, but 'Ideal' pecans were wider than 'Western' fruit two out of three seasons.

About 60% to 70% of the fruit's final mass is accumulated in the 4 to 6 weeks while the cotyledons are developing (Thor and Smith, 1935; Woodroof and Woodroof, 1927). Tree assimilates must be available if the cotyledons are to develop properly. On average, the time required for filling was 7 days longer for 'Western' than for 'Ideal' pecans. The first period of cotyledon thickening occurs when the endosperm is nourishing the embryo (Dozier and Amling, 1974; Finch and Van Horn, 1936; McKay, 1945; Thor and Smith, 1935). Not only is a good nutrient supply needed at this time, but also a good water supply to provide favorable conditions for foodstuff translocation from the tree. The fact that the involucre continues to grow after the ovary wall has been lignified may indicate that the involucre has a role in supplying the necessary nutrients for adequate nut filling during initial cotyledon thickening. Sap has been reported to pass through the involucre to get into the elaborate vascular system of the seed coat (Dozier and Amling, 1974; Finch and Van Horn, 1936). The final period of cotyledon thickening is probably the most important stage of embryo growth for the formation of well-filled kernels. Consequently, good nutrient and water supplies are also required during the portion of the season to ensure thorough filling of kernels.

Table 3. Days from initiation to completion of selected fruit development stages of 'Ideal' (Bradley) and 'Western' pecans in the Mesilla Valley, N.M.

Fruit development stage	1981		1982		1983		3-Year average	
	'ideal'	'Western'	'Ideal'	'Western'	'Ideal'	'Western'	'Ideal'	'Western'
Free-nucleate endosperm	49	49	49	49	56	49	51	49
Ovary wall Signification	21	26 ^e	21	24 ^e	21	21	21	25
Cotyledon thickening from initiation to completion	37	44	35	42	35	42	36	43

^e Estimated.

Fig.8. Relative fruit growth rates and average fruit development stages for 'Ideal' and 'Western' pecans in the Mesilla Valley, N. M., based on data for 1981 through 1983.

Literature Cited

- Cooper, J. N., J.D. Johnson, G.R. McEachern, and G.M. McWhorter. 1983. Texas pecan integrated pest management manual. Texas Agr. Ext. Serv. Publ. D-1216.
- Crane, H.L. and M.B. Hardy. 1934. Interrelation between cultural treatment of pecan trees, the size and degree of filling of the nuts and the composition of the kernels. J. Agr. Res. 49:643-661.
- Dozier, N.A. and H.J. Amling. 1974. Fruit growth and embryological development of the 'Stuart' pecan, *Carya illinoensis*. Auburn Agr. Expt. Sta. Bul. 463.
- Finch, A.H. and C.N. Van Horn. 1936. The physiology and control of pecan nut filling and maturity. Arizona Agr. Expt. Sta. Tech. Bul. 419.
- Hunter, J.H. and H.E. Hammar. 1961. Effects of different grades and rates of fertilizer applied to 'Schley' pecan trees as influenced by other factors. Southeastern Pecan Growers Assn. Conf. Proc. 54:30-41.
- Malstrom, H. L., W. White, and T.D. Riley. 1983. Effect of irrigation on nut quality and nut drop. Western Irr. Pecan Growers Assn. Conf. Proc. 17:24-43.
- McKay, J.W. 1945. Embryology of pecan. J. Agr. Res. 74:263-283.
- Mielke, E.A. 1984. Effect of hedge pruning on fruit placement, nut size and degree of filling. Western Irr. Pecan Growers Assn. Conf. Proc. 18:100-116.
- Ring, D.R. 1978. Biology of the pecan weevil emphasizing the period from oviposition to larval emergence. MS Thesis, Texas A&M Univ., College Station.
- Shuhart, D.V. 1932. Morphology and anatomy of the fruit of *Hicoria* pecan. Bet. Gaz. 93:1-20.
- Sparks, D. and G.D. Madden. 1985. Distillate flower and fruit abortion in pecan as a function of cultivar, time and pollination. J. Amer. Soc. Hort. Sci. 110:219-223.
- Thor, C.J.B. and C. Smith. 1935. A physiological study of seasonal changes in the composition of the pecan during fruit development. J. Agr. Res. 50:97-121.
- Woodroof, J.G. and N.C. Woodroof. 1927. The development of the pecan nut (*Hicoria Pecan*) from flower to maturity. J. Agr. Res. 34:1049-1063.
- Worley, R. E., S.A. Harmon, and R.L. Carter. 1972. Correlation among growth, yield and nutritional factors for pecan (*Carya illinoensis* W. cv. Stuart): Correlations with yield, quality, and terminal shoot growth. J. Amer. Soc. Hort. Sci. 97:511-514.