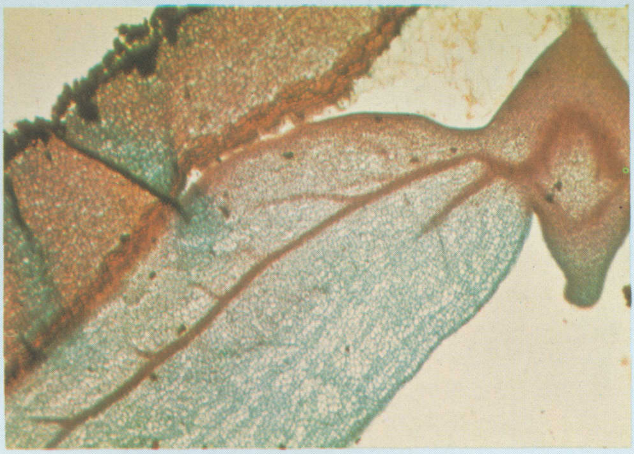

FRUIT GROWTH and EMBRYOLOGICAL DEVELOPMENT of the STUART PECAN

Carya Illinoensis

BULLETIN 463/DECEMBER 1974

AGRICULTURAL EXPERIMENT STATION / AUBURN UNIVERSITY
R. Dennis Rouse, Director/Auburn, Alabama

COVER ILLUSTRATIONS: Top—longitudinal section of embryo on August 9 showing the vascular system within the cotyledon; center—embryo development at beginning of cotyledon expansion (August 2) surrounded by cellular endosperm; bottom—cross-sectional view of embryo and cotyledon development on August 6.

SUMMARY

Growth and development studies on 'Stuart' pecan fruit indicated that growth was divisible into three stages: (1) from appearance of pistillate flowers to about the third week in June; (2) from third week in June until first week in August; (3) from first week of August to third week of October.

During the first period pollination, fertilization, and development of the free nucleate endosperm occurred. This was accompanied by a slow increase in size of ovule and nut.

Beginning of the second period of growth and development was when the nut began increasing rapidly in size parallel with appearance of cellular endosperm in the chalazal end of the ovule (about third week in June). The ovule increased in size until the first week in July, when ovule lobes began to develop basipetally. By the first week in August the nuts had completed size growth and lobes of the ovule had completely filled the shell cavity, ending the second growth stage. Shell hardening was initiated and completed during the 3-week period from the last week in July until the second week in August. Thus, shell lignification signaled the end of the second period and the beginning of the third.

The third period of growth and development was the time of nut filling or embryo growth and maturity. The cotyledons began developing basipetally from the embryo between the ovule wall and the cellular endosperm during the first week in August. By mid-August the cotyledons had reached the distal end of the ovule, began thickening, and were growing around the middle septum encircling the cellular endosperm as they grew. By the beginning of the fourth week in August, the cellular endosperm had formed a thick succulent pad of material that encircled the remaining liquid, which previously had filled the ovule. During the last week in August the liquid substance within the ovule cavity rapidly disappeared and the cellular endosperm was dehydrated to a thin transparent layer. This was reflected by a rapid decrease in fresh weight of the ovule. The cotyledons thickened rapidly from the first week in September through the first week in October. At this time the kernel (the embryo plus the integument of the ovule) was filled. The shucks began dehiscing from the nut and fresh weight of the kernel decreased from the third week in October until harvest.

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Fruit Growth and Embryological Development of the "Stuart" Pecan, *Carya Illinoensis*

W. A. DOZIER, JR., and H. J. AMLING[1]

MORPHOLOGICAL AND EMBRYOLOGICAL development of the pecan fruit has been the subject of several investigations *(2,3,5,6,7, 8,9,10,11)*. However, there were numerous discrepancies among these reports concerning rate and sequence of the developmental processes. No more recent and comprehensive an investigation on this subject has been made than McKay's in 1947 *(5)*. He resolved many of the discrepancies on the rate and sequence of the developmental processes using the cultivar 'Greenbriar' grown at Beltsville, Maryland. McKay's work is the only detailed investigation in which both morphological and embryological development have been considered concurrently for the entire period of fruit development. Chronologically and in some cases sequentially the developmental processes for Greenbriar as shown

[1] Assistant Professor and Professor, Department of Horticulture.

by McKay were not observed to be the same for the cultivar 'Stuart', the predominant one grown in Alabama. Therefore, information was needed on abnormal pecan fruit growth and development and hormonal control of pistillate flower formation, fruit set, and fruit maturity of the cultivar Stuart. The investigation reported here was done to determine the normal rate and sequence of fruit growth and development of the Stuart pecan under Alabama conditions.

MATERIALS AND METHODS

Stuart pecan fruit were collected from trees on the Auburn University Horticulture Farm at 4-day intervals from April 30 until October 22, 1963, and from May 22 until June 29, 1964. Collections were at 7-day intervals for the remainder of the 1964 season (until September 28). Each sample consisted of fruit collected at random from clusters located on the lower third of six, 30-year-old trees. A sample of fruit from each collection was prepared by techniques similar to those suggested by Johansen *(4)*. Each sample was placed in Craf's Solution (Randolph's Modified Navashin Fluid) for 24 hours, dehydrated with tertiary butyl alcohol, and embedded in paraffin. Serial sections, 12-microns thick, were mounted with Haupt's adhesive and stained with safranin and fast green.

Growth and development data were obtained for each sample consisting of an average of 10 fruits. Data included shuck thickness, fresh and dry weight of nuts, shucks, and ovules, and length and width of shucks, shells, and ovules. Fresh and dry weights of the ovules included the integument, embryo, and endosperm. The integument, which in later stages of development forms the seedcoat, was considered part of the ovule.

Shell lignification was recorded from date of initiation until the shell was completely lignified. Observations on growth and development of endosperm and cotyledons were recorded for each sampling date. Development of shell color markings was observed and recorded.

RESULTS

Growth and development of the various segments of the Stuart pecan fruit was cyclic and divisible into three stages. Time of occurrence and length of embryological stages varied between years, but sequence of developmental stages was consistent. There was an overlapping of some developmental processes between stages. Data presented in figures are given by years to illustrate variations between years.

Shuck Thickness

A gradual increase in thickness of shuck occurred in 1963 from appearance of pistillate flowers until June 7, at which time the shuck had reached 14 percent of the final thickness, Figure 1 and Appendix Table 1. There was a rapid increase in shuck thickness from June 7 until August 29, at which time 85 percent of the final shuck thickness was attained. Shuck thickness growth during the 83-day period from June 7 until August 29 amounted to 71 percent of the final thickness. A gradual increase in thickness of the shuck continued until October 4 when the shucks started splitting at the sutures.

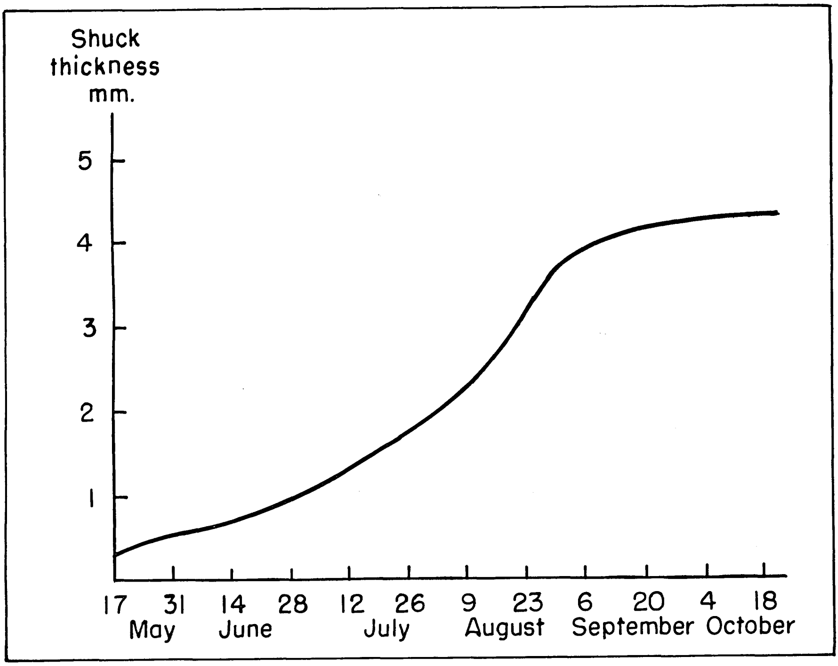

FIG. 1. Increase in shuck thickness during nut development in 1963.

Shuck Fresh and Dry Weight

Fresh and dry shuck weights obtained for the 1963 season showed a gradual increase in both from blossoming until June 28, Figure 2 and Appendix Table 2. On June 28, the fresh and dry weights were each 11 percent of final weights. A rapid increase in fresh and dry weight occurred after June 28. Fresh weight continued to increase until October 4 when it reached 120 percent of final fresh weight, followed by a 20 percent decrease between October 4 and October 22. At that time the shucks started splitting at the sutures and drying out. Dry weight increased at a rapid rate until July 26, when it was 60 percent of the final dry weight. This was followed by a 49 percent increase in total dry weight during the 28-day period from June 28 until July 26, and then a gradual increase for the duration of the season.

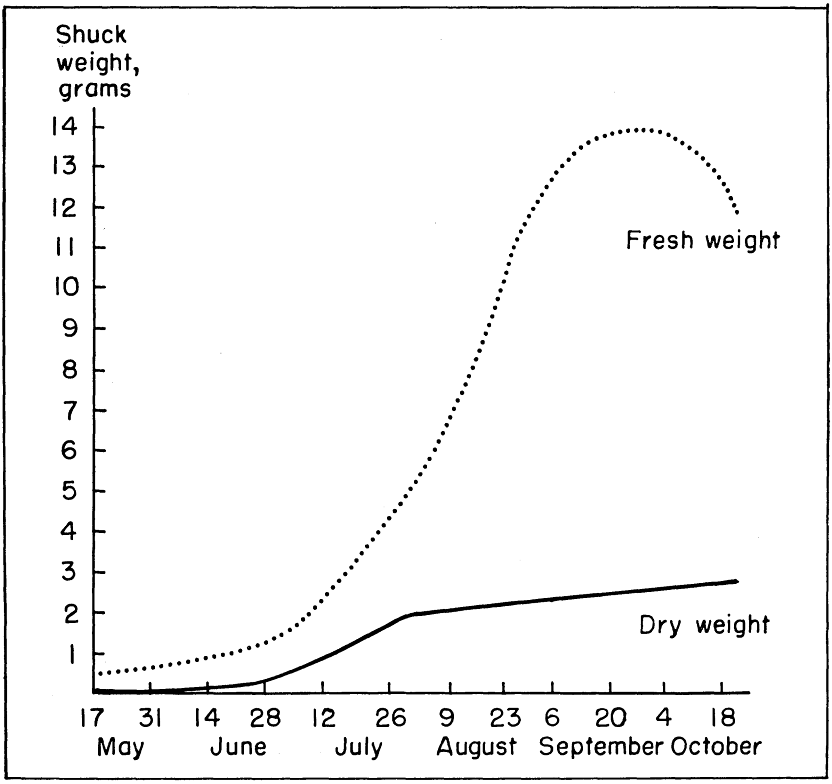

FIG. 2. Increase in fresh and dry weight of pecan shucks in 1963.

Shuck Length and Width

Length and width of the shuck were obtained for both the 1963 and 1964 seasons. Shuck development was cyclic and could be divided into three periods. In 1963 the first period comprised the time from blossoming until June 21. The second period was from June 21 until August 2, at which time 54 percent of the shell was lignified. The third period was from August 2 until maturity. Shuck length and width were 46 percent and 29 percent of the final length and width, respectively, on June 21, Figure 3 and Appendix Table 3. The 42-day period from June 21 until August 2 was the period of most rapid growth, accounting for 54 percent and 52 percent of the total increase in length and width, respectively. On August 2, the shuck length was 100 percent and the shuck width was 83 percent of final length and width, respectively. The shuck continued to gradually increase in width until October 15. In 1964, the first period was from blossoming until June 4, Figure 4 and Appendix Table 4. The second period was comprised of the 75 days from June 4 until August 17. Length

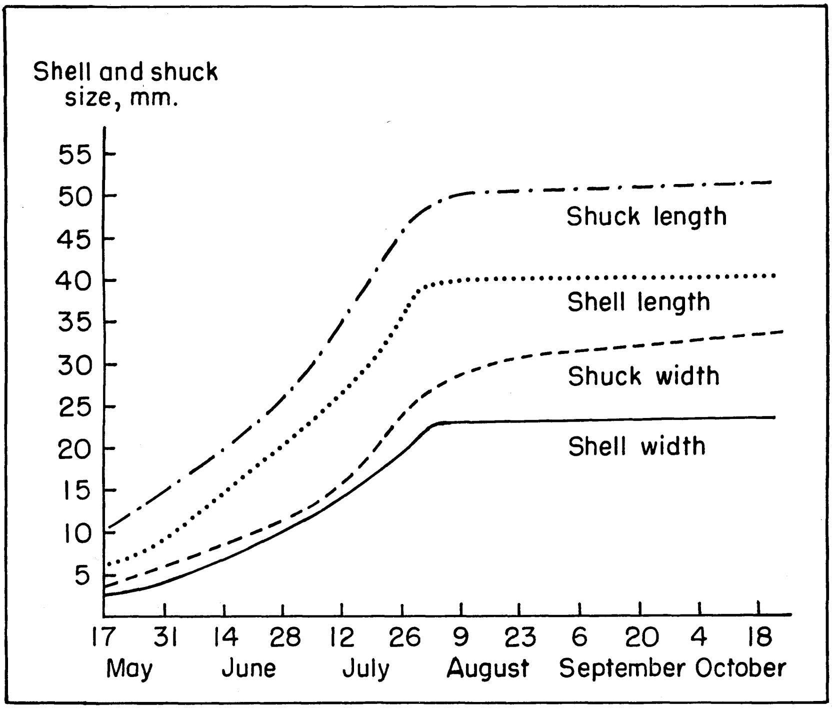

FIG. 3. Growth of pecan shell and enclosing shuck in 1963.

and width of shuck increased until September 28, when the last sample was obtained.

Shell Length and Width

Data on length and width of the shell, obtained during the 1963 and 1964 seasons, showed that the growth pattern could be divided into three distinct periods. In 1963 the first period was from appearance of pistillate flowers until June 21, at which time shell length and width were, respectively, 49 percent and 34 percent of final length and width, Figure 3 and Appendix Table 3. The second period was from June 21 until August 2, at which time 54 percent of the shell was lignified, see table. This was also the period of most rapid growth. Lignification of the shell was complete by August 13 and no further growth was made. The third period was from August 2 until harvest.

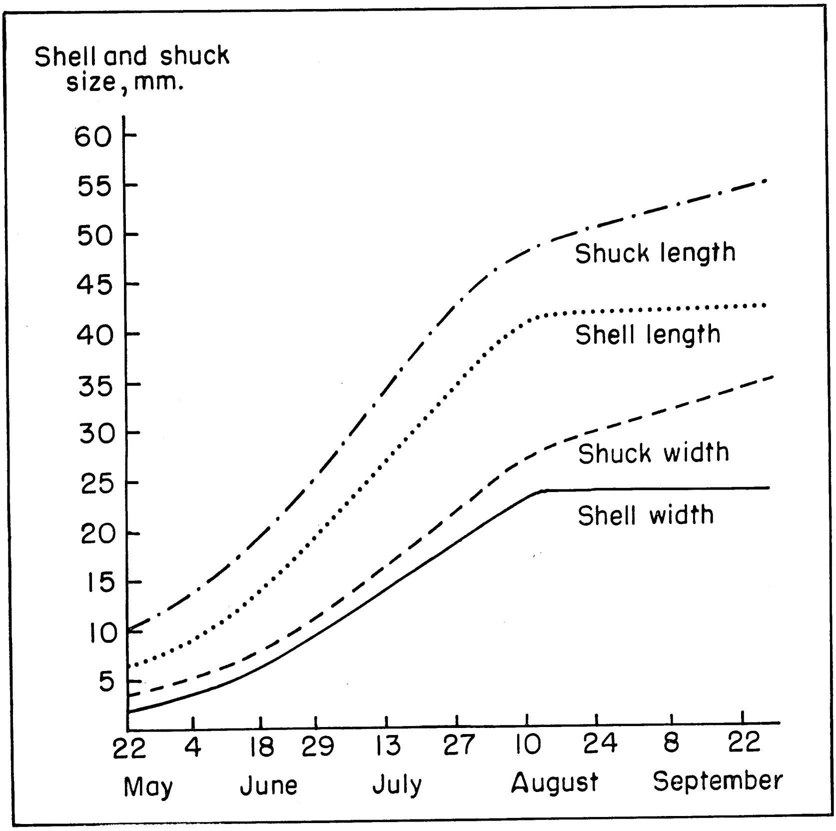

FIG. 4. Growth of pecan shell and enclosing shuck in 1964.

The three periods of the growth cycle of the shell in 1964 were: (1) from appearance of pistillate flowers until June 4, Figure 4 and Appendix Table 4, (2) from June 4 until August 17, and (3) from August 17 until the last sample date, September 28. There was no further increase in shell length or width after August 17, at which time the shell was completely lignified.

Shell Lignification

Lignification of the shell occurred in approximately 3 weeks, see table. In 1963, 28 percent of the shell was lignified by July 26 and lignification was completed by August 13. Only 17 percent of the shell was lignified by July 27, 1964, and the process of lignification was completed that year by August 17.

LIGNIFICATION OF THE SHELL EXPRESSED AS A PERCENTAGE OF LENGTH OF NUT AND THE INCREASE IN LENGTH AND WIDTH OF NUT AFTER LIGNIFICATION HAD BEGUN, 1963 AND 1964

Date	Shell length lignified	Length of nut	Width of nut
	Pct.	*mm.*	*mm.*
1963			
July 19	0	32.8	17.4
26	28.3	33.6	19.0
30	32.3	37.8	20.3
August 2	53.4	42.1	23.1
6	63.7	38.3	23.0
9	75.7	37.5	22.0
13	100.0	40.1	23.2
1964			
July 20	0	34.1	17.4
27	16.5	34.8	18.3
August 3	40.1	38.7	21.3
10	58.1	39.3	21.6
17	100.0	43.0	26.0

The current studies show that lignification begins at the apex and progresses toward the base of the shell, with the regions immediately surrounding the sutures hardening in advance and the shell being divided by the sutures into two equal segments. This division of the shell is at right angles to the plane of the middle septum. It was found that the area surrounding the sutures becomes lignified nearly the entire length of the nut before lignification begins on that portion of the shell adjacent to the plane of the middle septum. It also was noted that a thin layer of cells is first lignified, and this lignified portion then thickens. The shell continued to increase in length and width until lignification was complete in both years.

Shell Color Markings

In 1963, the color markings were first detected on September 17 as light streaks near the apical end of the shell. The shuck could be slipped off the shell on September 20, and the color markings were then distinct. The streaks were more distinct by September 24 when small brown spots were located over the base of the shell. On October 1, the shuck had begun turning dark. By October 4, the color markings were very distinct, the shell was brown, and the shuck was dehiscing from the nuts.

Data for 1964 show that shell color markings first appeared as streaks on the apical end of the shell on September 22. Development of the markings was the same as in 1963.

Ovule Length and Width

The growth of the ovule was cyclic and could be divided into three periods, Figure 5 and appendix tables 5 and 6. During the first period, the ovule showed a gradual enlargement in

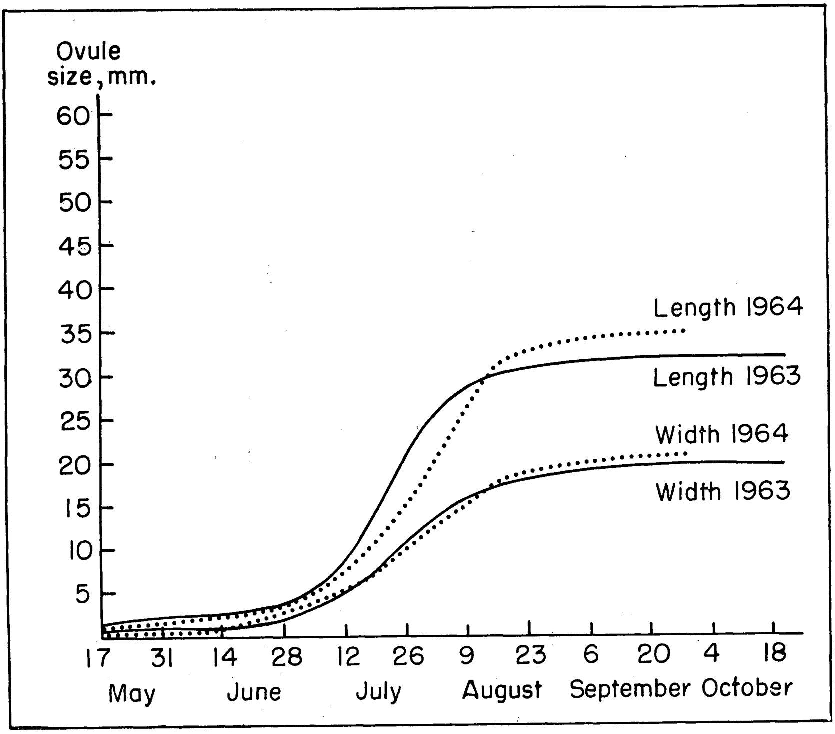

FIG. 5. Length and width of pecan ovules by dates in 1963 and 1964.

length and width – the same in both 1963 and 1964. This period comprised the time from blossoming until July 9 in 1963 and to July 8 in 1964. Ovule length was 21 percent and 16 percent of the final length in 1963 and 1964, respectively, and ovule width was 16 percent and 18 percent of final width, respectively.

The second period was characterized by a rapid increase in ovule length and width. It was during this period that the ovule developed basipetally and filled the shell cavity. For the 1963 season, the second period of growth covered the time from July 9 until August 2. The ovule grew 62 percent and 54 percent of final length and width, respectively, during this time, reaching 83 percent and 71 percent of final length and width, respectively, by August 2.

The second period of growth in 1964 was the 41-day period between July 8 and August 17 when 75 percent and 61 percent of the total increase in length and width, respectively, occurred. By August 17 the ovule was 91 percent of both the final length and width. This period of ovule growth was during the time of most rapid growth of the whole nut.

During the third period, there was a gradual increase in length and width until the ovule had filled the shell cavity and compressed the packing tissue against the shell wall. This period

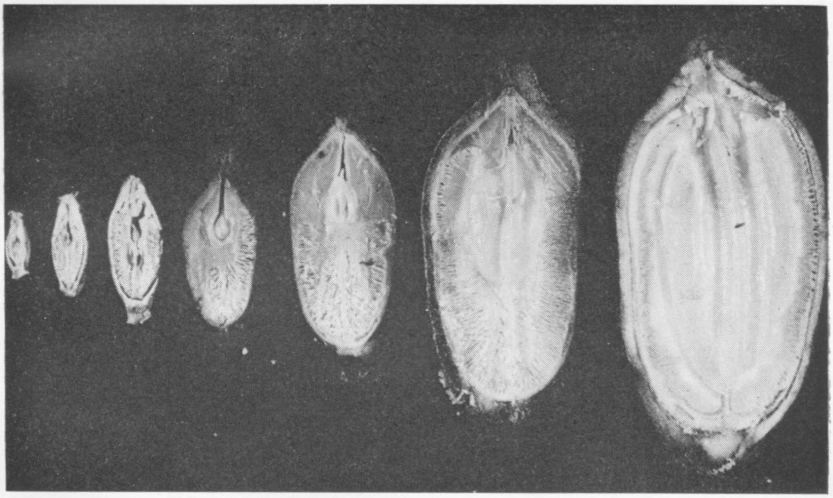

FIG. 6. Pecan nut and ovule development during growing season. Shown are samples collected approximately every 2 weeks from May 21 (left) to August 9 (right).

varied among ovules in the same sample. The ovule reached 100 percent of final length by September 22 in 1963 and by September 14 in 1964 and 100 percent of final width by October 1 in 1963 and by September 22 in 1964.

Growth of the ovule at 2-week intervals from May 21 until August 9 during the 1963 season is shown in Figure 6. It can be noted that on July 12 (represented by the fifth nut from the left) the ovule was growing down into the shell cavity. Examination of sections of the ovule at a magnification of 100X showed that the ovule first started growth down into the shell cavity on July 9.

Ovule Fresh and Dry Weight

Fresh weights of ovules were about the same until July 12 in both 1963 and 1964, when there was a sudden increase, Figure 7 and appendix tables 7 and 8. The increase in weight was due primarily to the ovule enlarging into the shell cavity and its vacuole filling with a liquid.

Of the total increase in fresh weight of the ovule 79 percent

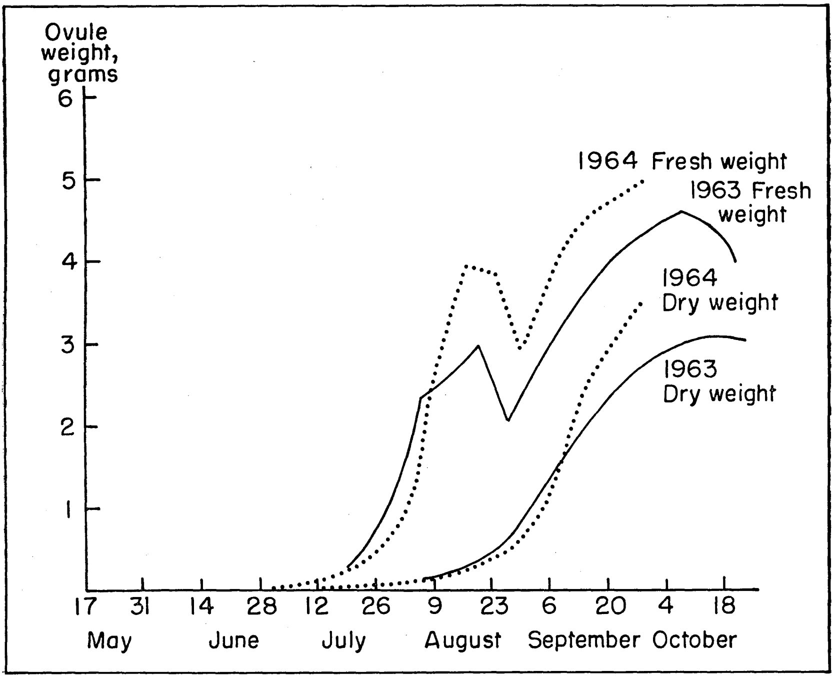

FIG. 7. Fresh and dry weight of pecan ovules by dates in 1963 and 1964.

occurred during the 40-day period from July 12 until August 20 in 1963 and 85 percent during the 36-day period from July 13 until August 17 in 1964. At this time the ovule was turgid and it was nearly impossible to remove the shell without rupturing the ovule wall.

There was a sudden decrease in fresh weight of the ovules on August 20, 1963, and August 24, 1964, Figure 7. This decrease amounted to 23 percent from August 20 until August 29, 1963, and 24 percent from August 17 until August 31, 1964. Reason for this decrease in fresh weight was primarily the disappearance of the liquid contents from the ovule vacuole. At this time, it can be noted in orchards that branches bearing a set of fruit rise.

There was an increase in fresh weight of the ovules starting in 1963 on August 29 and in 1964 on August 31. In 1963 total fresh weight of the ovules increased 65 percent from August 29 until October 8 and in 1964 the increase was 37 percent between August 31 and September 28. This weight increase resulted from the cotyledons moving down into the shell cavity and thickening.

In 1963, there was a decrease of 24 percent in fresh weight from October 8 until October 22, a result of the drying and maturing of the kernel.

Ovule dry weight was 1 percent and 2 percent of the final dry weight on July 26, 1963, and July 27, 1964, respectively. As the ovule moved down into the shell cavity and the cotyledons began growing and moving down into the ovule, there was a corresponding increase in dry weight. In 1963 during the 26-day period from July 26 until August 20, there was an increase of 10 percent in the total dry weight. The 29-day period from July 27 until August 24, 1964, accounted for a 7 percent increase in total dry weight of the ovules.

Ovules began a rapid increase in dry weight on August 20 in 1963 and August 24 in 1964. During the 56-day period from August 17 until October 15 in 1963, there was an increase of 91 percent in dry weight. In 1964 during the 35-day period from August 24 until September 28, there was an increase of 92 percent in dry weight of the ovules. This increase started about the time the cotyledons reached the end of the ovule and began to thicken, continuing as the cotyledons thickened and matured.

In 1963 there was a decrease of 16 percent in dry weight during the 7-day period from October 15 until October 22.

Endosperm and Cotyledon Development

In these studies no differentiation could be made between the nuclei in the embryo sac in the early samples collected in 1963. Neither was the pollen tube found growing down through the stigma or into the embryo sac; therefore, the time of pollination and fertilization was not determined. The first samples prepared for histological study were collected on May 7. On this date the integument had been initiated and had grown up the sides of the nucellus, but it was still bifurcated as shown in Figure 8. The free nucleate endosperm appeared to develop around the margins of the central vacuole until June 21. Cellular endosperm started developing in the chalazal end at this time and progressed downward along the sides of the ovule wall. By July 5 the cellular endosperm was well developed and the free nuclei had disappeared except for a small amount in the micropyle end. On this date the vacuole was large with all material compressed to the sides of the ovule wall. The ovule was filled with a liquid and was turgid.

Development of the embryo was not detected until August 2 when extending cotyledons were noted, Figure 9-A. The cotyledons followed the contour of the ovule wall and grew between the wall and the cellular endosperm as they extended into the

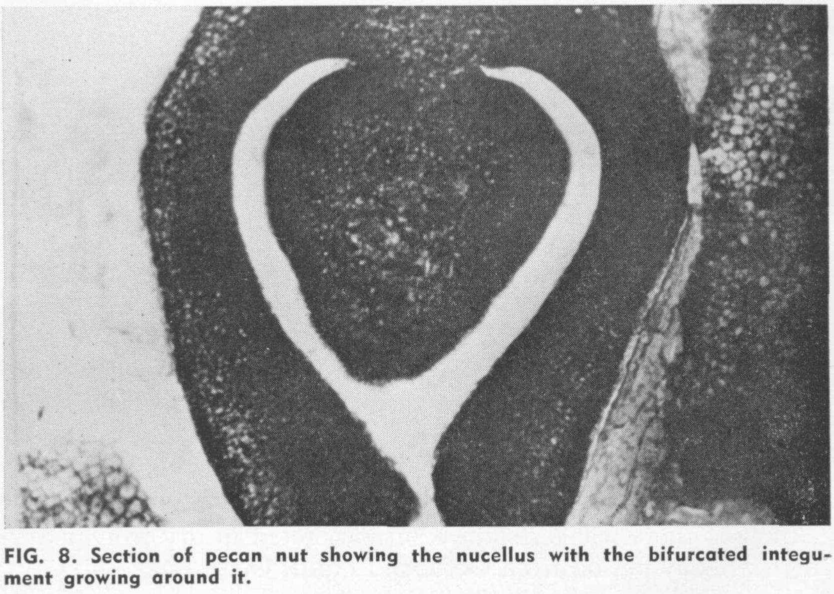

FIG. 8. Section of pecan nut showing the nucellus with the bifurcated integument growing around it.

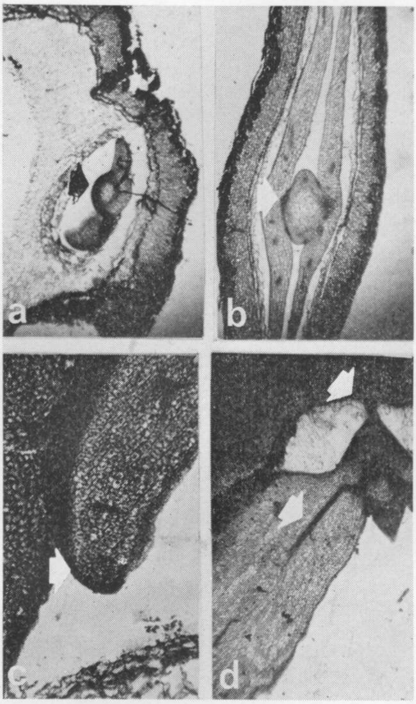

FIG. 9. This magnification shows (a) longitudinal section view of embryo on August 1 showing initial stage of cotyledon growth; (b) cross-sectional view of embryo and cotyledon development on August 6; (c) longitudinal ovule section view showing the terminal portion of the cotyledon; and (d) longitudinal section of the ovule on August 9 showing a well developed vascular system within the cotyledon (bottom arrow).

ovule cavity. The cotyledons were bilobed and perpendicular to the plane of the middle septum with one-half of each cotyledon growing into each cavity of the ovule. By August 6 the cotyledons had extended to the sides of the ovule and were beginning to extend down the ovule wall, Figure 9-B. On August 9, the cotyledons were extending along the ovule wall between the wall and the cellular endosperm as shown in Figure 9-C; the cellular endosperm had started thickening in the micropyle end of the ovule and by August 13 it had formed a thick gelatinous mass within the ovule. This thick mass of endosperm encircles a watery substance, as shown in Figure 10-A.

By August 13, the cotyledons were extended 41 percent of the length of the ovule. They reached the end of the ovule by August and started growing around toward the middle septum, encircling the endosperm and thickening. The cotyledons at this time were 11 cells thick. The cells contained large vacuoles with small nuclei.

During the 40-day period from July 12 until August 20, there was an increase of 97 percent in fresh weight of the ovule. A sudden decrease in fresh weight of the ovules occurred during the period of August 20 to 29, caused by disappearance of the liquid content of the vacuole and the apparent dehydration of the endosperm. By August 27 the liquid had dissipated and the endosperm had coalesced in the center of the vacuole, Figure 10-B. The endosperm was dehydrated to a thin transparent layer

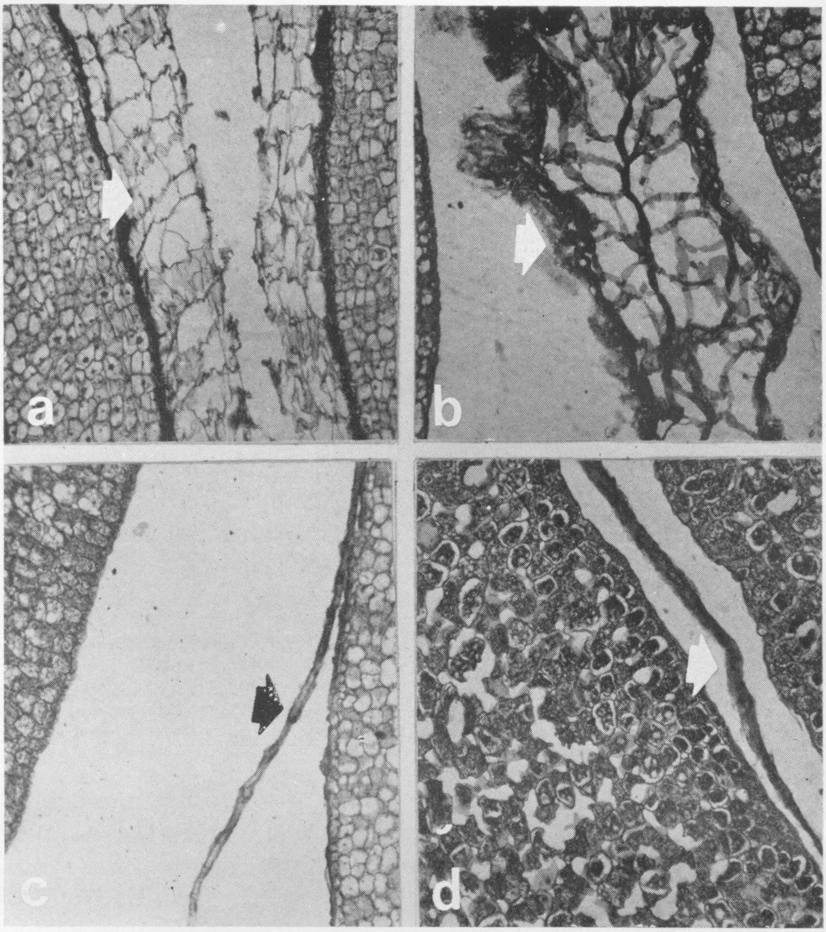

FIG. 10. This magnification shows (a) cellular endosperm encompassed by the cotyledon lobes at time of its most viscous stage on August 20; (b) cellular endosperm on August 27 showing collapsing of cells, dehydration, and folding together of the two sections of endosperm encompassed by the cotyledon lobes; (c) cellular endosperm remnant on August 29 as situated between developing cotyledon lobes; and (d) cellular endosperm remnants on October 4 as situated between well developed cotyledon lobes.

of cells by August 29, Figure 10-C. The thin transparent layer of cells from the cellular endosperm is shown within the folds of the thickened cotyledons on October 4 in Figure 10-D.

Growth of the cotyledons down into the ovule occurred at a later date in 1964 than in 1963. In 1963, the cotyledons had reached the end of the ovule and were thickening by August 16, but on August 17, 1964, their movement down into the ovule could not be detected with the unaided eye. They had extended an average of 15 percent of the length of the ovule on August 24. The nut on the right in Figure 11 was collected on August 17, 1964, and the cotyledons could not be detected moving down into the ovule. The remaining nuts, collected August 24, show the cotyledons moving down at various lengths. By August 31 the cotyledons had extended down the full length of the ovule and had begun thickening. The cellular endosperm was not dehydrated to a thin layer until September 8 in 1964.

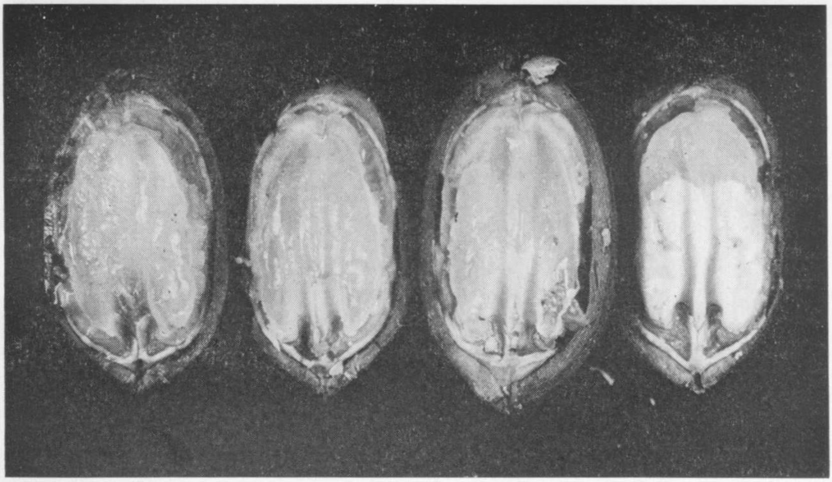

FIG. 11. Varying stages of visible cotyledon development from samples collected August 24 as compared to August 17 sample (left) showing no cotyledon development.

Cotyledon development in 1964 is shown in Figure 12. Cotyledons collected August 31 had reached the end of the ovule and were thickening and growing around next to the middle septum. At this time, the endosperm was a thick mucous mass within the folds of the cotyledons. In the cotyledons collected September 8, the cellular endosperm had been reduced to a thin transparent layer of cells and the cotyledon had thickened considerably since August 31. Average dry weight of the kernels increased 8 percent during the 8 days between August 31 and September 8. Cotyledons collected September 28 had thickened considerably during the 20-day period preceding, with the average dry weight of the kernels increasing 30 percent.

There was 16 percent decrease in dry weight of the kernel from October 15 until October 22.

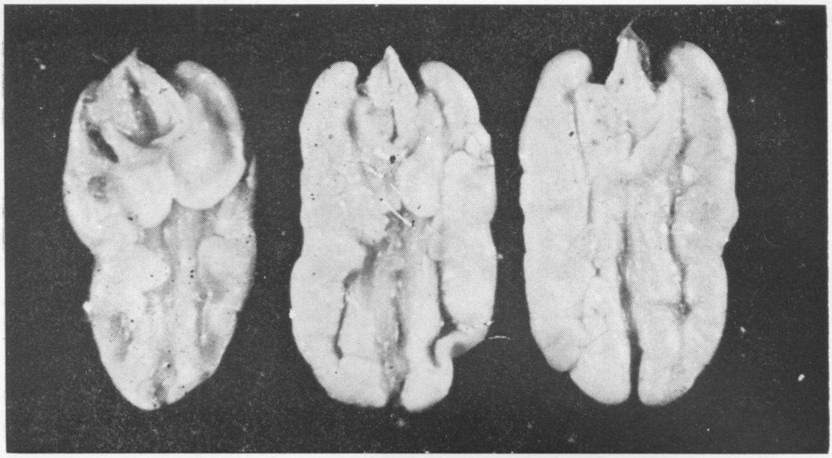

FIG. 12. Cotyledon development on August 31 (left) is compared with more complete development of cotyledon on September 28.

The vascular system was observed to extend from the shuck through the shell and middle septum to the placenta. An elaborate vascular system was noted from the placenta to all parts of the seedcoat and the embryo contained a vascular system, which can be noted in Figure 9-D.

Fresh and Dry Weight of Pecan Nuts

The increase in average fresh and dry weights of a pecan nut corresponds closely with size development of the nut and fresh and dry weight growth of its ovule, Figure 13 and appendix tables 9 and 10. Fresh weight of the pecan samples in 1963 increased at a relatively slow rate until approximately June 21 when it reached 6 percent of the final fresh weight. This was followed by a rapid increase from June 21 until August 20. The nuts did not increase in fresh weight between August 20 and August 27, however, reflecting the decrease in fresh weight of ovules at the time the liquid disappeared from the vacuole of the ovule.

Fresh weight of the nut increased 20 percent from August 27 until October 1, but dropped 17 percent between October 1 and October 22. This October decrease in fresh weight of the nut is due to drying and maturing of the kernel.

In 1964, nut fresh weight increased gradually from the appearance of pistillate flowers until June 25 and then rapidly from June 25 until August 17. A small reduction in fresh weight of the nuts

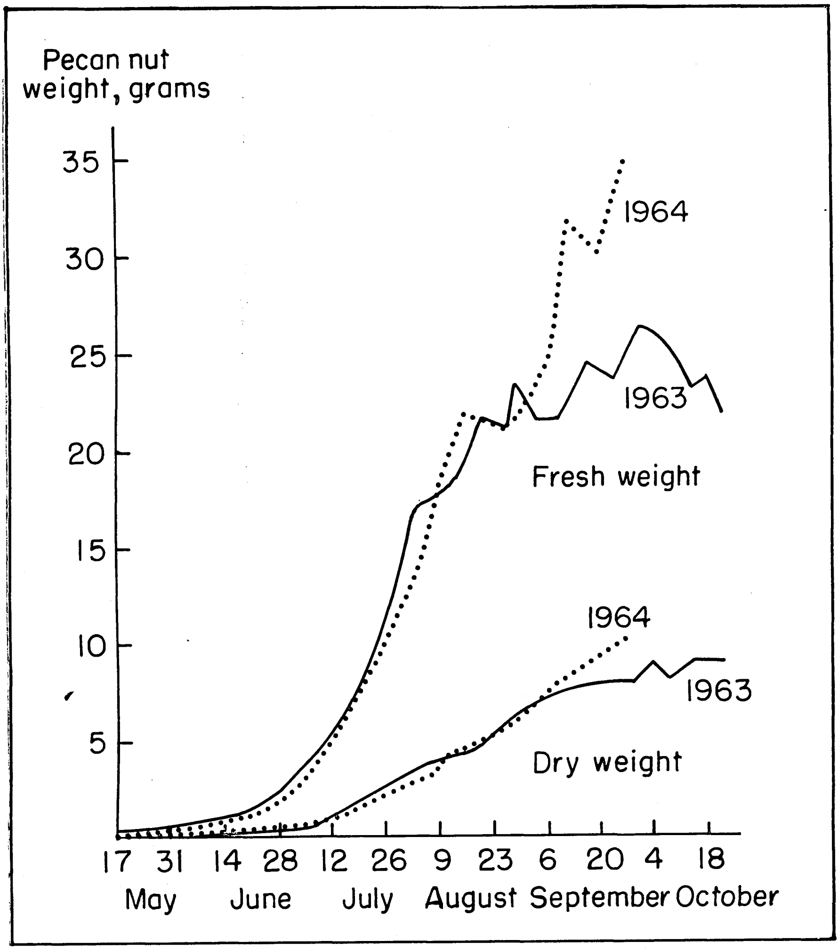

FIG. 13. Increase in fresh and dry weight of pecan nuts in 1963 and 1964.

occurred from August 17 until August 31, reflecting the disappearance of liquid from the vacuole of the ovule. There was a rapid increase in fresh weight from August 31 until September 28, the last harvest date.

Dry weight of the pecan nut increased at a low rate until July 9 in 1963 and July 8 in 1964, at which time it began increasing at a rapid rate. Pecan nuts increased 82 percent of the total dry weight from July 9 to September 6 in 1963 and 93 percent of the total from July 8 to September 28 in 1964, the last sample date. The dry weight increased 21 percent from September 6 until October 15, and then decreased 3 percent from October 15 until October 22 in 1963.

DISCUSSION

This study indicated that morphological and embryological development of the pecan fruit was more logically divisible into three stages rather than two as proposed by Crane and Hardy *(2)* and McKay *(5)*. Crane and Hardy collected their samples when the nuts were mature and postulated that growth and development could be divisible into two periods: (1) the time from blossoming until shell hardening occurred, and (2) from the beginning of shell hardening until separation of the nut from the shuck. They postulated the nut and all its parts grew in size during period one and filling of the nut occurred during period two, but no data were available for this assumption. McKay agreed with the division made by Crane and Hardy, and reported endosperm development occurred during the first period and embryo growth or filling during the second period. The two periods were of approximately the same length.

In this study the first period consisted of the time from appearance of pistillate flowers until approximately the third week in June. Pollination, fertilization, and development of the free nucleate endosperm occurred during this period, accompanied by a slow size increase of the ovule and nut.

The second period of growth and development covered the next 7 weeks, from about the third week in June until approximately the first week in August. Beginning of the second period was marked by the appearance of cellular endosperm in the chalazal end of the ovule on about June 21. Cellular endosperm completely lined the ovule walls by the end of the first week in July. Beginning the third week in June, the nut began increasing rapidly in size. A similar growth spurt, but of much shorter duration, at the time of cytokineses has been reported for peach *(1)*. Thor and Smith's *(9)* data on the green weight of pecan fruits reveal a rapid increase in weight during the middle of June similar to that reported in this work. Therefore, the appearance of cellular endosperm was considered as the beginning of the second period.

The ovule increased in size until the first week in July, when the ovule lobes began developing basipetally. By the first week in August, the nuts had completed size growth and the lobes of the ovule had completely filled the shell cavity. During development, the ovule was filled with a liquid that exerted pressure on the ovule walls, making the ovule turgid and easily ruptured when removed.

Shell lignification was used to designate the beginning of the third period in this study. This was the same stage of development that McKay *(5)* used to designate the beginning of the second period. The process of lignification began during the last week in July, whereas McKay reported lignification began during the last week in August.

Shell hardening was initiated and completed during the 3-week period beginning the last week in July and ending during the second week in August.

The third period of growth and development was considered to be from the first week in August until the third week in October. This was the period of filling of the nut, or embryo growth and maturity.

The cotyledons started developing basipetally from the embryo between the ovule wall and the cellular endosperm during the first week in August. The cotyledons had reached the end of the ovule by mid-August, and begun thickening and growing around next to the middle septum encircling the cellular endosperm as they grew.

By the beginning of the fourth week in August, the cellular endosperm had formed a thick succulent pad of material that encircled the remaining liquid, which previously had filled the ovule. The liquid substance within the ovule cavity disappeared extremely rapidly during the last week in August and the cellular endosperm was dehydrated to a thin transparent layer. This was reflected by a rapid decrease in ovule fresh weight during this period.

The cotyledons thickened rapidly from the first week in September through the first week in October. At this time the kernel (the embryo plus the integument of the ovule) was filled. The shucks began dehiscing from the nut and there was a decrease in fresh weight of the kernel from the third week in October until harvest.

These findings indicate that initiation of lignification at the shell apex preceded by a few days the enlargement of the embryo just prior to the appearance of cotyledons. Cellular endosperm was most pronounced in the chalazal end of the ovule at the time cotyledon growth began. Progressive development (thickening) of cellular endosperm downward along the ovule wall preceded cotyledon growth. These findings differ somewhat in sequence from those of McKay (5), who reported that maximum shell hardening coincides with maximum endosperm development and the beginning of rapid embryo growth or filling. The results are in accord with McKay's, however, in regard to endosperm actively serving its function during the initial stages of embryo growth rather than during cotyledon thickening as proposed by Finch and Van Horn (3). The endosperm was dehydrated to a thin layer of collapsed cells by the time cotyledon thickening began.

McKay reported the seedcoat has a well developed vascular system composed of a network of bundles extending from the placenta to all parts of the seedcoat. Elaborated food material is translocated to the embryo by absorption from the seedcoat. In this study the vascular system was found to exist in the middle septum and seedcoat. The seedcoat was connected to the middle septum at the placenta as proposed by McKay. He reported that the meristem activity (thickening) of the cotyledon was related to the source of nutrient supply. During the early stage of cotyledon thickening the meristem activity was greater on the inner surface adjacent to the seedcoat. In this study, however, thickening of the cotyledons was found to begin in the area around the embryo. Thickening of the cotyledons proceeded from the apical to the basal end, with the folds thickening last.

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APPENDIX

APPENDIX TABLE 1. SHUCK THICKNESS DURING NUT DEVELOPMENT BY DATES IN 1963

Date		Thickness of shuck	Date		Thickness of shuck
		mm.			*mm.*
May	17	0.33	August	6	2.10
	21	.39		9	2.25
	24	.51		13	2.30
	28	.52		16	2.65
	31	.55		20	3.25
June	4	.54		23	3.15
	7	.56		27	3.45
	11	.61		29	3.70
	14	.70	September	3	3.30
	18	.75		6	3.35
	21	.96		10	3.85
	25	.98		13	3.95
	28	1.00		17	4.21
July	2	1.00		20	4.21
	5	1.08		24	4.00
	9	1.14		27	4.20
	12	1.10	October	1	4.25
	16	1.10		4	4.40
	19	1.70		8	4.30
	26	1.90		15	4.23
	30	1.85		18	4.50
August	2	1.95		22	4.30

APPENDIX TABLE 2. FRESH AND DRY WEIGHT OF PECAN SHUCKS BY DATES IN 1963

Date		Shuck weight		Date		Shuck weight	
		Fresh	Dry			Fresh	Dry
		Grams	*Grams*			*Grams*	*Grams*
May	17	0.522	0.020	August	13	6.520	1.918
	21	.520	.027		16	7.772	2.057
	24	.580	.031		20	9.590	2.234
	31	.640	.060		23	10.195	2.174
June	7	.700	.097		27	10.400	2.254
	14	.870	.173		29	12.050	2.271
	18	.900	.165	September	3	9.814	2.294
	21	.980	.236		6	10.790	2.314
	28	1.260	.302		10	11.163	2.511
July	2	1.380	.334		13	13.408	2.538
	5	1.580	.502		17	13.340	2.341
	9	2.200	.649		20	13.572	2.380
	12	2.224	.764		24	13.930	2.471
	16	2.420	.802		27	11.820	2.623
	19	4.320	1.264	October	1	12.900	2.877
	26	5.160	1.657		4	13.965	2.549
	30	5.470	1.849		8	10.625	2.795
August	2	5.660	1.921		15	12.298	2.613
	6	5.615	1.986		18	12.842	2.805
	9	6.057	1.884		22	11.651	2.752

APPENDIX TABLE 3. GROWTH OF PECAN SHELL AND ENCLOSING SHUCK BY DATES IN 1963

Date		Shuck		Shell	
		Length	Width	Length	Width
		mm.	*mm.*	*mm.*	*mm.*
May	17	9.8	3.6	6.2	2.7
	21	11.8	3.8	6.6	2.9
	24	12.9	4.4	7.6	3.2
	28	13.0	4.6	8.6	3.6
	31	16.1	5.8	10.8	4.2
June	4	17.0	7.0	11.1	5.5
	7	17.9	7.3	12.2	6.0
	11	17.6	7.8	12.7	6.3
	14	19.3	8.6	16.6	7.1
	18	21.2	8.9	10.6	7.7
	21	23.3	9.7	19.2	8.2
	25	22.7	9.9	16.6	8.2
	28	25.5	10.9	19.2	10.2
July	2	26.9	12.1	19.8	10.4
	5	31.9	13.2	23.8	12.6
	9	34.3	14.2	25.4	14.0
	12	35.0	15.1	26.6	13.6
	16	39.4	18.2	27.4	14.6
	19	40.9	19.8	32.8	16.4
	26	45.4	23.6	33.6	19.5
	30	47.1	25.2	37.8	21.3
August	2	50.4	27.7	42.1	23.6
	6	50.6	27.4	38.3	23.0
	9	48.4	27.5	37.5	22.2
	13	49.5	28.6	40.1	23.2
	16	48.6	28.4	40.2	23.1
	20	55.4	30.4	40.2	23.2
	23	53.3	30.2	40.1	23.5
	27	49.8	30.6	39.5	23.5
	29	53.9	31.3	39.8	23.8
September	3	49.1	31.4	41.0	23.2
	6	52.3	31.0	40.0	23.5
	10	47.9	31.8	39.9	23.1
	13	52.5	31.0	39.8	23.1
	17	49.5	31.8	39.7	22.8
	20	49.3	32.0	39.8	23.5
	24	49.0	32.5	44.0	24.4
	27	49.9	32.4	42.8	24.4
October	1	47.4	32.7	39.2	23.6
	4	49.6	32.8	41.0	23.8
	8	50.1	33.0	39.8	24.1
	15	50.4	33.3	40.4	24.5
	18	51.2	33.0	38.8	23.8
	22	50.3	33.2	39.4	23.8

Appendix Table 4. Growth of Pecan Shell and Enclosing Shuck by Dates in 1964

Date		Shuck		Shell	
		Length	Width	Length	Width
		mm.	*mm.*	*mm.*	*mm.*
May	22	10.4	3.2	6.5	2.0
	26	11.4	3.4	7.2	2.5
	29	11.4	4.2	7.4	3.0
June	2	12.3	4.4	8.7	3.0
	4	13.6	4.6	9.3	3.4
	11	16.8	5.6	11.4	4.6
	15	18.6	6.8	12.9	5.3
	18	19.2	7.7	13.7	6.3
	22	22.1	9.4	15.8	7.6
	25	23.7	10.4	17.4	8.1
	29	25.7	11.5	20.0	10.0
July	8	31.5	14.6	24.5	12.0
	13	35.8	16.4	26.8	14.1
	20	41.3	19.2	34.1	17.4
	27	41.9	21.6	34.8	18.3
August	3	47.4	24.8	38.7	21.3
	10	47.6	27.0	39.3	21.6
	17	51.0	29.3	43.0	24.0
	24	50.2	28.5	42.2	24.1
	31	47.3	29.1	38.0	22.1
September	8	53.7	31.9	43.3	23.9
	14	57.1	34.1	46.4	24.1
	22	54.8	34.2	43.8	23.8
	28	53.4	35.2	41.9	24.1

APPENDIX TABLE 5. GROWTH OF PECAN OVULES BY DATES IN 1963

Date		Ovule length	Ovule width
		mm.	*mm.*
May	17	1.20	0.60
	21	1.23	.60
	24	1.80	.61
	28	1.86	.60
	31	2.20	.61
June	4	2.20	.62
	7	2.35	.65
	11	2.40	.69
	14	3.00	1.15
	18	3.50	1.50
	21	3.40	1.64
	25	3.40	2.25
	28	4.00	2.20
July	2	4.60	2.10
	5	6.05	3.00
	9	6.70	3.10
	12	8.85	6.00
	16	11.40	6.20
	19	14.90	7.40
	26	20.90	10.80
	30	24.00	12.90
August	2	26.89	14.10
	6	27.50	14.90
	9	27.50	16.10
	13	28.00	15.40
	16	28.00	16.90
	20	30.00	17.40
	23	30.50	17.80
	27	30.40	16.80
	29	30.30	17.90
September	3	31.10	18.80
	6	31.30	19.10
	10	30.30	17.90
	13	31.30	18.80
	17	32.50	18.90
	20	32.00	19.30
	24	31.60	19.10
	27	32.00	19.60
October	1	32.10	20.00
	4	32.40	19.50
	8	33.20	19.80
	15	32.80	20.70
	18	33.00	19.20
	22	31.20	19.70

APPENDIX TABLE 6. GROWTH OF PECAN OVULES IN LENGTH AND WIDTH BY DATES IN 1964

Date		Ovule length	Ovule width
		mm.	*mm.*
May	22	1.15	0.80
	26	1.13	.70
	29	1.10	.70
June	2	1.43	.90
	4	1.60	.85
	11	1.88	.92
	15	2.13	1.07
	18	2.18	1.27
	22	3.00	2.00
	25	3.50	2.10
	29	4.15	2.65
July	8	5.60	3.60
	13	7.70	5.00
	20	12.40	7.10
	27	15.70	12.30
August	3	23.70	12.70
	10	27.70	15.10
	17	31.80	18.10
	24	32.20	18.60
	31	30.40	17.60
September	8	33.90	19.10
	14	36.50	19.40
	22	35.40	21.20
	28	34.30	20.70

APPENDIX TABLE 7. FRESH AND DRY WEIGHT OF PECAN OVULES BY DATES IN 1963

Date		Ovule fresh weight	Ovule dry weight
		Grams	*Grams*
May	17	----	0.00006
	21	----	.00010
	24	----	.00017
	28	----	.00020
	31	----	.00025
June	4	----	.00030
	7	0.00070	.00038
	11	----	.00040
	14	.00175	.00056
	18	.00240	.00070
	21	.00330	.00080
	25	----	.00090
	28	.00760	.00110
July	2	.01180	.00160
	5	.03130	.00250
	9	.03760	.00330
	12	.08110	.00525
	16	.16360	.01440
	19	.25900	.01890
	26	.91580	.04590
	30	1.23420	.06750
August	2	----	.1030
	6	2.3651	.1203
	9	2.5053	.1398
	13	2.5888	.1854
	16	2.7478	.2713
	20	3.0633	.3242
	23	2.5232	.4206
	27	2.1050	.5417
	29	2.1981	.7794
September	3	2.7054	1.1714
	6	3.1046	1.4264
	10	3.2208	1.6324
	13	3.4645	1.9127
	17	3.9010	2.1540
	20	4.0543	2.4870
	24	3.7807	2.3005
	27	4.0115	2.4938
October	1	4.3056	3.0353
	4	4.0936	2.7163
	8	4.6406	3.2274
	15	4.4145	3.1556
	18	4.5191	3.1983
	22	3.7551	2.8232

Appendix Table 8. Fresh and Dry Weight of Pecan Ovules by Dates in 1964

Date		Ovule fresh weight	Ovule dry weight
		Grams	*Grams*
May	22	----	0.00012
	26	----	.00010
	29	----	.00023
June	2	----	.00017
	4	----	.00017
	11	----	.00024
	15	----	.00026
	18	----	.00037
	22	0.0031	.00060
	25	.0037	.00090
	29	.0060	.00110
July	8	.0199	.00160
	13	.0433	.00410
	20	.1912	.01110
	27	.5500	.03160
August	3	1.1598	.06610
	10	2.8153	.14360
	17	3.9625	.19460
	24	3.8622	.28870
	31	2.8492	.60550
September	8	5.0955	1.43800
	14	4.3584	2.39590
	22	4.8396	2.99370
	28	4.5945	3.49950

APPENDIX TABLE 9. FRESH AND DRY WEIGHT OF PECAN NUTS BY DATES IN 1963

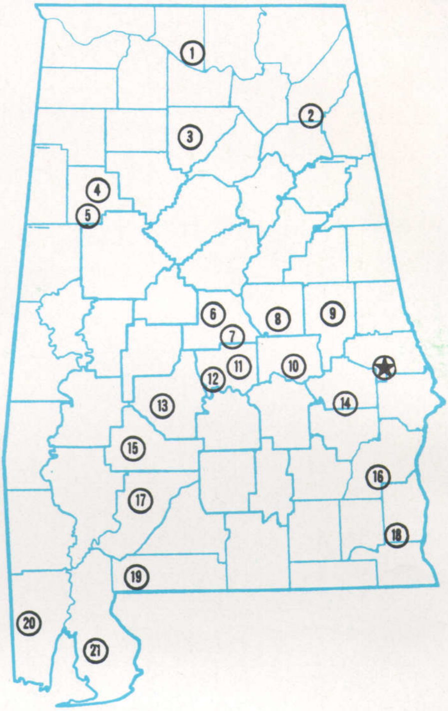
Date		Fresh weight of nuts	Dry weight of nuts
		Grams	*Grams*
May	17	0.1076	0.0320
	21	.1389	.0386
	24	.1813	.0544
	28	.2143	.0592
	31	.2907	.0844
June	4	.3988	.1154
	7	.4740	.1432
	11	.6529	.1890
	14	.7400	.2334
	18	.8974	.2734
	21	1.2330	.2432
	25	1.5205	.3390
	28	2.2021	.3760
July	2	2.3153	.5410
	5	3.5230	.8316
	9	4.3470	.7092
	12	5.6660	1.1910
	16	6.2500	1.3010
	19	8.9530	1.8710
	26	11.5730	2.4110
	30	13.4130	2.5700
August	2	16.7880	3.2720
	6	17.399	3.880
	9	17.634	4.031
	13	18.115	4.031
	16	20.480	4.852
	20	21.640	5.174
	23	21.215	5.584
	27	21.225	----
	29	23.505	6.338
September	3	21.445	6.784
	6	21.445	7.201
	10	21.725	7.015
	13	22.830	7.463
	17	24.555	7.984
	20	24.169	----
	24	23.610	7.897
	27	24.982	7.970
October	1	26.380	8.223
	4	26.315	8.913
	8	25.450	8.075
	13	23.500	8.184
	15	23.180	9.116
	18	23.720	----
	22	21.815	8.829

APPENDIX TABLE 10. FRESH AND DRY WEIGHT OF PECAN NUTS BY DATES IN 1964

Date		Fresh weight of nuts	Dry weight of nuts
		Grams	*Grams*
May	22	0.094	0.0152
	26	.127	.0370
	29	.163	.0494
June	4	.261	.0700
	11	.426	.1174
	15	.575	.1786
	18	.643	.1910
	22	.844	.2698
	25	1.118	.6075
	29	1.553	.4174
July	8	2.935	.6960
	13	4.659	.9846
	20	6.878	1.5642
	27	9.270	2.0866
August	3	13.772	2.7808
	10	18.145	4.1384
	17	21.980	4.7016
	24	20.865	5.0540
	31	21.500	6.1868
September	8	24.170	7.8320
	14	31.550	8.4736
	22	30.995	9.6520
	28	34.620	10.2370

Alabama's Agricultural Experiment Station System
AUBURN UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Thorsby Foundation Seed Stocks Farm, Thorsby.
7. Chilton Area Horticulture Substation, Clanton.
8. Forestry Unit, Coosa County.
9. Piedmont Substation, Camp Hill.
10. Plant Breeding Unit, Tallassee.
11. Forestry Unit, Autauga County.
12. Prattville Experiment Field, Prattville.
13. Black Belt Substation, Marion Junction.
14. Tuskegee Experiment Field, Tuskegee.
15. Lower Coastal Plain Substation, Camden.
16. Forestry Unit, Barbour County.
17. Monroeville Experiment Field, Monroeville.
18. Wiregrass Substation, Headland.
19. Brewton Experiment Field, Brewton.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.