A STUDY OF THE CHARACTERISTICS OF THE PECAN TREE FOR USE IN OBJECTIVE YIELD FORECASTS

by

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Introduction

The inaccuracies found in pecan crop forecasts during past years have led the industry to request that additional studies be made by SRS for the improvement of the pecan forecasts.

These additional studies were begun in 1970 when a pilot research project was set up by the Research and Development Branch (S&RD, SRS) in cooperation with the Mississippi State Statistical Office (SRS). The objectives of the project were (1) to examine different methods of estimating the number of nuts on a pecan tree, and (2) to determine which if any of these methods might be useful in improving early season forecasts of production.

The pecan tree presents one major obstacle which is not found in other fruit and nut studies. The tree is extremely tall; sometimes taller than 100 feet. This is a problem since present objective yield fruit and nut crop models are based on expansion of nut counts on selected sample limbs from the "entire tree" to tree totals. For the pecan crop forecasting model to be based on sample limb expansions would necessitate the assumption that nuts are distributed evenly throughout the tree (higher limbs are inaccessible). To alleviate placing all the weight of a model on this one assumption, other methods of nut counting were developed to study their relationship with final production.

Four types of counts were made during the survey: (a) Counts of nuts from sample limbs less than 30 feet high (CSL), (b) counts of nuts from ground level photography at a distance of 50 feet (CNP), (c) counts of nuts which dropped from the tree between first set and October 1 (CND), and (d) counts of nuts seen through a 15 power spotting scope at 50 feet (CNS).

These counts were collected monthly between June 26 and October 1, 1970. Counts for items two through four were tested for significant correlation with final pecan production. Counts for items one and two were expanded to tree totals and then tested for a significant correlation with final production.

Summary of Major Findings

(1) A significant correlation was found between the count of nuts from a random sample of accessible limbs of approximately equal diameters expanded to tree totals based on the total number of limbs on the tree (ECSL) and pounds of good nuts harvested per tree. The correlation for counts made August 26 (.86) was higher than the correlation observed for June count (.54).

(2) All CNP correlation coefficients were significant at the .05 level. The highest correlations were for adjusted (for interpreter differences) CNP (one side of the tree) expanded to estimated tree totals and pounds of good pecans harvested per tree. The correlations are: July - .98, August - .87, and September - .93 (significant at .01 level).

The remaining two variables CNP and CNP adjusted for interpreter differences are significantly correlated to pounds of good nuts harvested per tree but for each date the correlations are somewhat lower than those listed above.

(3) Counts of nuts made with the 15 power spotting scope were poorly correlated with pounds of good nuts harvested per tree. The lack of correlation may be associated with counting problems such as too powerful of a scope, eye fatigue and wind.

(4) A trend appeared for the four different dates upon which the correlations between CNP (faulty nuts) and pounds of good nuts harvested per tree were computed (.19, .16, .57, .73). The first two collection dates (7/29/70 and 8/13/70) showed no significant correlation. The third date (9/26/70) was significant at the .05 level, and the fourth date (10/1/70) at the .01 level. These early low correlations help explain the lower correlation for ECSL in June as well as showing that early drop counts are of little use in forecasting crop production.

Data Collection

Sample Selection

Four pecan orchards (blocks) near Jackson, Mississippi, were subjectively selected for this study. The primary objectives of the block selections were to observe similar varieties of pecans and have a wide range in ages of trees selected between blocks.

The varieties studied were:

1. Stuart
2. Seedling

The dates of planting for the selected blocks were:

Block A - planted in 1958

Block B - planted in 1935

Block C - planted in 1907

Block D - planted between 1870 and 1890

The sample trees from each block were selected by:

1. Determining the number of rows in the block.
2. Systematically selecting four rows.
3. Counting the number of trees in each row.
4. Selecting five trees in each row and measuring the cross sectional area (CSA) of the trunks.
5. Arraying the 20 trees by trunk CSA and systematically selecting four trees from the array.

Stereo photographs were taken of the selected sample trees from several different angles approximately 50 feet from the base of the tree. Before the stereo photographs were taken, engineering tape was tied to various sized limbs to aid in determining CSA's for selection of sample units--white ribbon on 1.0 CSA limbs (inches), red ribbon on 5.0 CSA limbs (inches), and yellow ribbon on 10.00 CSA limbs (inches).

On black and white photo enlargements (24x) made from the stereo photography all sections of the tree were identified (figure 1). A section was defined as either path (section) or terminal (section). The intention was that the terminal would be any section whose CSA was between 1.8 and 5.5 square inches at point of origin (point at which section branches from).

This corresponded to a thickness of 1/16 to 3/16 of an inch on the photo enlargements. A path section was a portion of a limb whose CSA at point of origin was greater than 5.5 square inches. The first path section was the trunk. Each branching thereafter defines two or more path sections or path section(s) and terminal(s) (small branches with CSA of less than 1.8 square inches were not considered a branching point but part of the section under consideration). For some blocks the minimum terminal size on the enlargements was increased to 1/8 inch due to the extreme number of terminals present. A path section or sections was assigned the first terminal branching from the path section. Where two terminals branch from the same fork, the path section was assigned to the terminal with the smallest CSA. A "sample unit" was defined as a terminal and any associated path sections.

The sample units were stratified by height within each tree. This was to determine if nut set varied between the strata (heights of limbs on the tree). The three strata were:

1. Stratum A (accessible) - terminal limbs 0-20 feet high. These were limbs that could be reached from a 16 foot ladder.

2. Stratum H (hoist) - limbs 20-50 feet high. The limbs in this region were to be reached by a mechanical hoist.

3. Stratum U (inaccessible) - limbs higher than 50 feet.

Note: A terminal diameter is between 1/16" and 3/16" on a photograph.

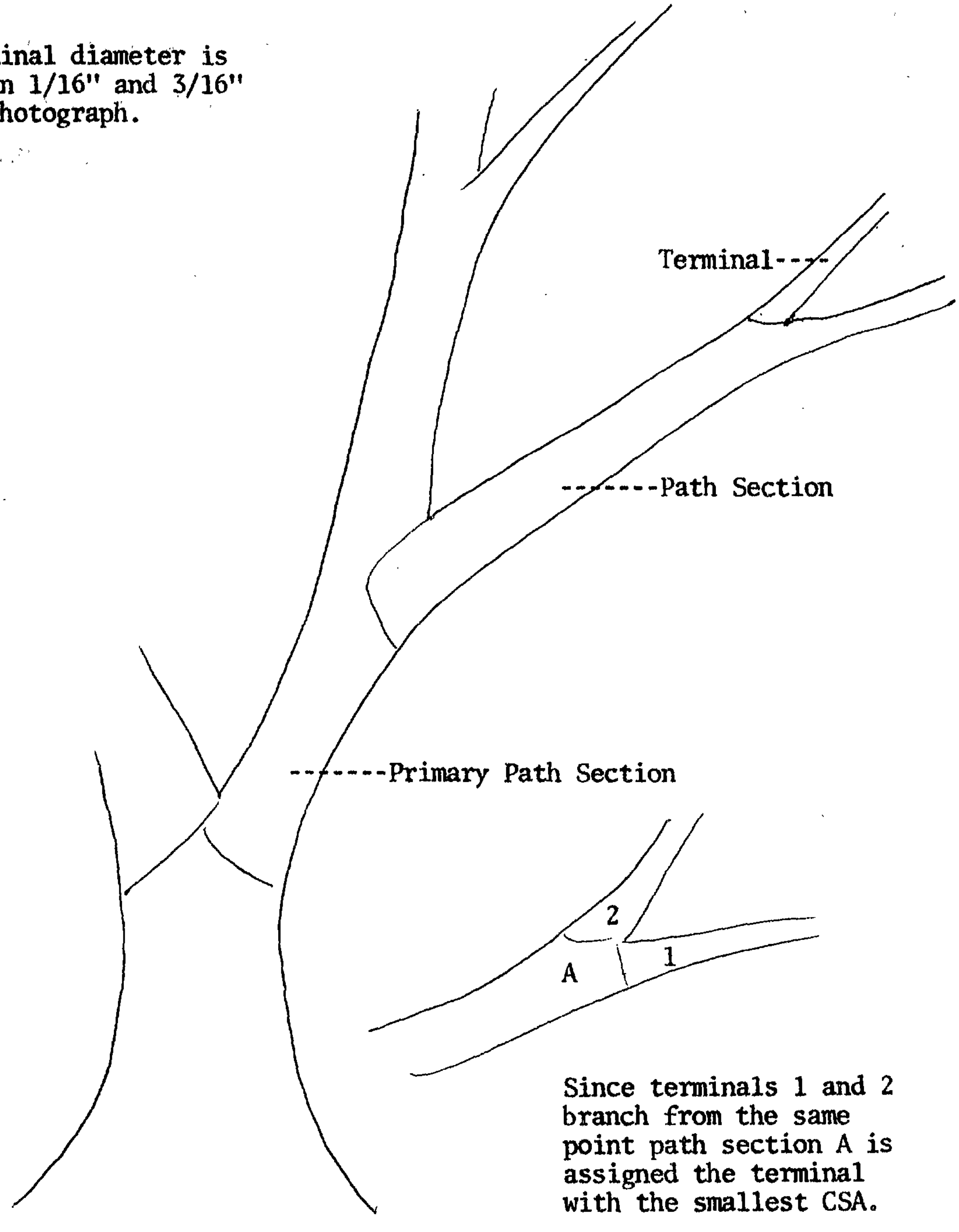


Figure 1.- Mapping of sample trees and assigning of path sections to terminals, Mississippi pecans.

Sample units were selected within strata A and H from the photo enlargements. The number of sample units selected was a function of the total number of terminals in the stratum. Ten percent of the terminals were selected in Stratum A. Twenty percent of the terminals were selected in Stratum H. Stratum U was not sampled. Terminals were selected by simple random sampling, assigning equal probability to each terminal.

Counts on Sample Limbs

All nuts on the selected sample units were to be counted at the end of June and again at the end of August. These counts were made from a mechanical hoist (cherry picker). Unfortunately the hoist enabled the enumerator to obtain a height of only approximately 29 feet so that a number of the sample units in Stratum H could not be counted. Counts of path sections assigned to the sample unit were recorded separately from the counts on terminals.

Drop Counts

During the growing season pecans drop from the tree for various reasons (wind, weevils, moisture content). The nuts that dropped were picked up and counted four times under each tree starting on June 29.

Photography Procedures

For the July 1 and August 1 photography work, eight of the sixteen trees were used. Photographs were taken from two sides of the tree (180° angle) at the compass points indicated on field worksheets. The compass points were chosen by the following procedure. The tree circumference was divided into four points equally spaced. The first point was chosen by randomly selecting a number between 0° and 90°. By adding 90° to the first number, point two was obtained; positions three and four were obtained by adding 180° and 270° to position one, respectively (figure 2).

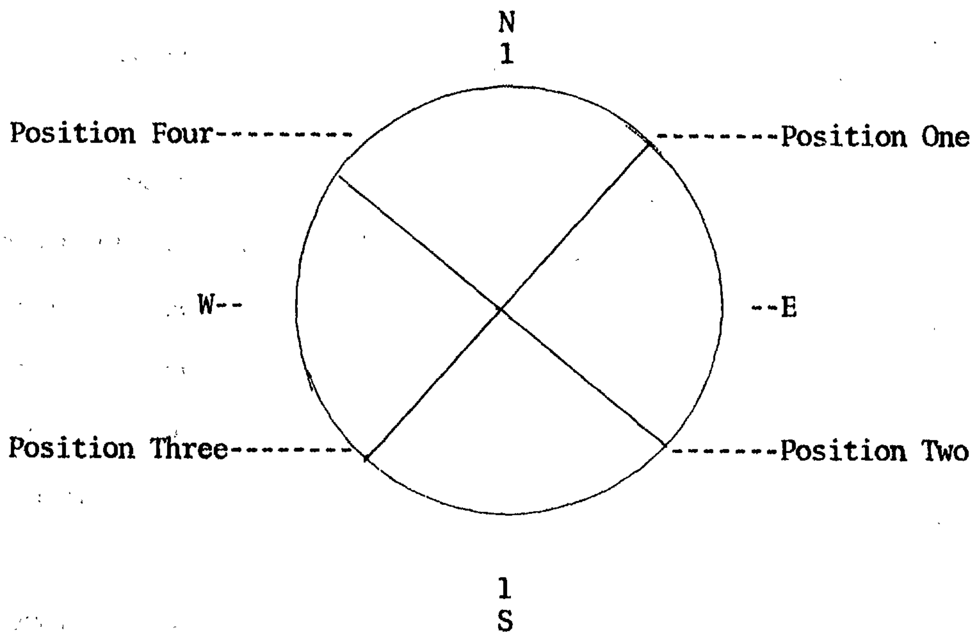


Figure 2.- Example random selection of camera position, Mississippi pecans, 1970.

The starting position was chosen randomly by selecting a number between one and four. The second camera position was found by rotating the equipment 180° around the trunk. From figure 2, if camera position one was selected, position three was the second camera position. If conditions prohibited photography at either of the designated camera positions an alternate set was used.

The tripod was set 50 feet from the trunk of the tree at each of the selected camera positions and was approximately five feet above the ground.

The distances from the trunk to the edge of canopy and the canopy to the camera were recorded on photo field forms.

Light meter readings were taken near the tree trunk with the meter pointed toward the trunk. This was an attempt to properly expose pecans in the shadows created by leaves. To assure a good depth of field the shutter speed was set so that the F-stop was at least 8.0.

Pictures were taken of a vertical strip running up the center of the tree. Photographs were taken both with a Miranda Sensorex camera using a 135 mm lens and with a Kodak Instamatic camera having 75 mm lens adapter. An aluminum frame divided into eight segments was placed two feet in front of the camera. A segment equaled the viewing area of one exposure. In most instances the full vertical strip of the tree was completely contained within the eight segments.

For the 75 mm Kodak Instamatic there were only four segments in the aluminum frame; i.e., more surface area was covered at 50 feet with each shot. The Kodak Instamatic was used in June, July, and August only.

When shooting in the upper half of the aluminum frame the F-stop was moved up one stop.

Photography for all sixteen trees was taken about September 1 with the following changes in procedure:

(a) Meter readings were taken using the within lens light meter of the Miranda Sensorex camera.

(b) Shutter speed was adjusted more frequently to compensate for high wind.

(c) F-stop set below 8.0 when wind or lighting conditions made it impossible to keep F-stop of 8.0.

(d) Polaroid filter was used.

Photographs about October 1 used light meter readings again taken near the trunk of the tree. Two photographs were taken from the middle segment of the aluminum frame to evaluate different F-stops.

Counts from Photography

Each slide was projected on a screen divided into blocks. A photo interpreter would count the number of pecans in each block and record the count on a form which was a reduced image of the large screen. For one-third of the slides a second counter would recount the pecans for use in computation of adjustment factors.

Counts with Spotting Scope

Counts of nuts made using a 15 power spotting scope were taken at four different times in 1970--June, July, August and September. Two trees were counted in each orchard (block). These counts were taken from the same positions used for making photographs.

The counts were taken of a strip comprising the middle of the tree. Each position (starting with the second) going up the tree trunk was chosen by making a visual marking of some characteristic in the upper visible boundary of the previous position and relocating it in the lower visible boundary of the present position. The total viewing area using the spotting scope was approximately one-third that of photographs. Each viewing area took on the shape of the scope--circular.

During the four month period two counters worked with the CNS. Different combinations of these counters were used during this period. In June, each selected tree was counted from both positions by the two counters; i.e., a total recount was used. In July, to reduce workload, each counter observed opposite sides of the tree; i.e., no recount. In August and September, each man counted one side of the selected trees, and recounted one-fourth of the counts by the other counter to observe counter variations.

Analysis

Drop Counts

The objective of faulty nut collection (drop counts--CND) was to determine whether a significant relationship existed between the number of faulty nuts and pounds of good nuts harvested per tree. The relationship was poor early in the season, but gradually improved as the season advanced (table 1).

Table 1.- Correlation between pounds of good pecans harvested per tree and number of faulty nuts under each sample tree, Mississippi 1970

Date	r	n	P.01	P.05	Average number nuts collected
7/29	.19	16	.623	.497	190.25
8/13	.16	16	.623	.497	130.56
9/26	.57	16	.623	.497	132.75
10/1	.73	16	.623	.497	86.75

The coefficient of correlation is not significant at the .05 level in either late July or early August. The r value is significant at the .05 level in late September and the .01 level in early October. The trend indicates that early drops depend on the individual tree (how much pollination takes place) but as the nut matures factors influencing nut drops are exogenous to the tree; i.e., outside factors (wind, weevil, moisture) have an effect on all trees in a similar manner. This indicates that at some point in the nut maturing process the number of nuts collected under a tree is a function of the number of nuts on the tree. An increased number of faulty nut collections is necessary in order to obtain a better picture of the first year trend.

Count of Nuts on Sample Limbs Expanded to Tree Totals

The pecan trees were originally stratified into three strata, but when actual fieldwork began it was only possible to reach 26 to 29 feet into the tree. This resulted in the use of only two strata, accessible (0-30 feet) and inaccessible (30 feet). The objective was to discover whether a relationship exists between count of nuts on accessible sample limbs expanded to tree totals (ECSL) and actual pounds of good nuts harvested per tree.

The estimated number of pecans per tree was obtained by the expansion of nut counts from accessible sample limbs (table 2-3). The expansion procedure followed was:

Let: X_{ij} = count of nuts on jth sample limb in the ith tree.

$\hat{X}_{ij}$ = the estimated number of nuts on the ith tree using the jth sample limb.

$\hat{X}_{i.}$ = the mean of the expansion of nuts to tree total from individual limbs for the ith tree.

E_i = expansion factor for the ith tree. This was the reciprocal of the probability of the jth sample limb occurring in the ith tree. The probability of the jth limb equal $1/N_i$ where N_i = the number of accessible and inaccessible sample limbs for the ith tree.

where $\hat{X}_{ij} = E_i X_{ij}$

and

$$\hat{X}_{i.} = \sum_{j=1}^{n} \hat{X}_{ij}/n_i$$

n_i = number of selected sample limbs in the ith tree.

Table 2.- Harvest data for sample trees, Mississippi pecans, 1970

Block	Tree	Pounds good nuts	Pounds bad nuts in husks	Good nuts per pound	Faulty nuts per pound in husks	Estimated number of good nuts 1/
A	1	21.8	4.9	35	18	763.0
A	2	0.2	0.1	-	-	5.0
A	3	0.3	0.0	-	-	6.0
A	4	7.2	7.2	34	15	244.8
B	1	88.3	9.4	66	61	5827.8
B	2	14.6	8.6	97	71	1416.2
B	3	2.0	2.7	40	25	80.0
B	4	17.0	6.5	65	51	399.5
C	1	12.4	28.2	116	74	503.4
C	2	1.4	8.2	64	53	13.4
C	3	7.8	32.1	48	51	374.4
C	4	8.4	35.9	66	49	554.4
D	1	6.1	2.5	-	-	472.1
D	2	9.6	8.7	-	-	942.4
D	3	2.5	3.7	-	-	218.6
D	4	4.9	6.6	-	-	139.4

1/ Estimated from pounds of good nuts at harvest.

Table 3.- Total nuts counted on accessible sample limbs and estimated number of nuts per tree using CNASL, June, August 1971, Mississippi pecans

Block	Tree	Number of sample limbs	June		August	
			Total CNASL	Estimated number nuts	Total CNASL	Estimated number nuts
A	1	4	138	1104.0	100	800.0
A	2	2	7	17.5	0	0.0
A	3	4	0	0.0	1	8.2
A	4	3	81	702.3	57	494.0
B	1	1/ 5 (4)	382	5118.8	515	8626.2
B	2	4	326	4645.5	192	2736.0
B	3	3	23	328.9	28	401.3
B	4	5	296	3433.6	190	2204.0
C	1	2	92	3496.0	16	608.0
C	2	4	55	825.0	8	120.0
C	3	5	272	4243.2	143	2230.8
C	4	3	No count		84	1932.0
D	1	2	150	4275.0	152	4332.0
D	2	4	333	3496.0	206	2163.0
D	3	5	272	1360.0	No count	
D	4	2	33	528.0	21	32.0

1/ Four sample limbs in August.

Two correlation coefficients were computed each month CSL were made (table 4). One coefficient excluded block D each month because of exogenous factors. Children were observed running through block D picking up nuts under sample trees prior to harvest.

Table 4.- Correlation between pounds of good nuts harvested and ECSL per tree, Mississippi pecans, 1970

Month	r	n	P.01	P.05
June (all blocks)........	1/ .54	15	.641	.541
June (blocks A, B, C)....	1/ .61	12	.708	.576
August (all blocks)......	2/ .86	15	.641	.541
August (blocks A, B, C)...	2/ .94	12	.708	.576

1/ Significant at .05 level (i.e., $r \neq o$).
2/ Significant at .01 level (i.e., $r \neq o$).

Both coefficients were significant at the .05 level in June and at the .01 level in August. What should be noted is the difference in the coefficient of correlation from June to August. The lower correlation for June compared to August can probably be attributed to (1) the pecans not being mature enough to observe and hence obtain an accurate count, or (2) at this early stage trees shed faulty nuts unevenly.

The low correlation between CND early in the season (faulty nuts collected under trees) and pounds of good pecans harvested per tree supports point two. If each tree has a different early shedding pattern then the early CSL will not correlate well to pounds of good nuts harvested.

The counting design was the balanced incomplete block model. 1/ This model gives a procedure to correct for interpreter differences. The normal correction procedure was changed to make the correction factor multiplicative instead of additive (table 6).

Let: $T_i' = \frac{U_i - T_i}{U_i}$

Where: T_i = additive treatment constant of the ith interpreter.

T_i' = multiplicative treatment constant for the ith interpreter.

u_i = mean of the photo counts of the ith interpreter.

Thus: $Y_{ijkl}' = T_i' (Y_{ijkl})$

Where: Y_{ijkl}' = adjusted photo count of the lth slide in the kth tree in the jth block for the ith interpreter.

Y_{ijkl} = adjusted photo count of the lth slide kth tree in the jth block for the ith interpreter.

Table 7.- Photo adjustment factors for interpreter differences for the months of July, August, and September, Mississippi pecans, 1970

Month	Counter		
	1	2	3
July	.5417	.6226	3.0667
August	1.2876	.7658	1.0690
September	.7317	.9704	1.7899

1/ Graybill, Franklin A., An Introduction to Linear Statistical Models, McGraw-Hill Book Company, Inc., N.Y., 1961, Vol. I, pp. 308-311.

The coefficient of correlation between adjusted CNP and pounds of good nuts harvested in both July (.93) and August (.84) is significant at the .01 level. The correlation coefficient for September is significant at the .05 level.

The photographs taken of the pecan tree represent varying portions of the tree. In some trees, 40 percent of the tree was photographed. In other trees as little as one percent of the tree was photographed. Consequently, a method was developed so the CNP for each tree could be expanded to represent the entire tree. The basic assumption being made that the pecan tree can take the shape of a sphere.

The factor for converting the area represented by the slide to the total tree was computed as follows:

Let: C1 = camera to canopy distance.

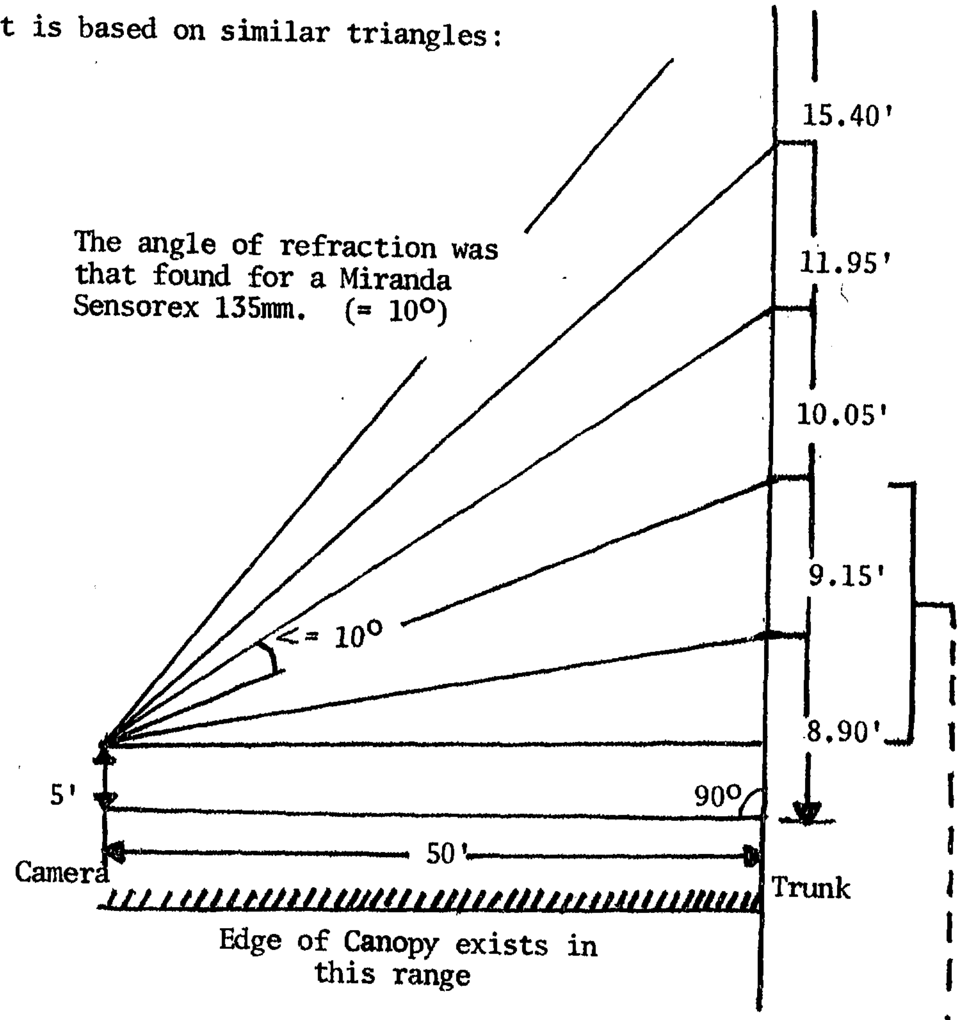
H1 = height at trunk to bottom of designated middle frame.

H2 = height at trunk to top of designated middle frame.

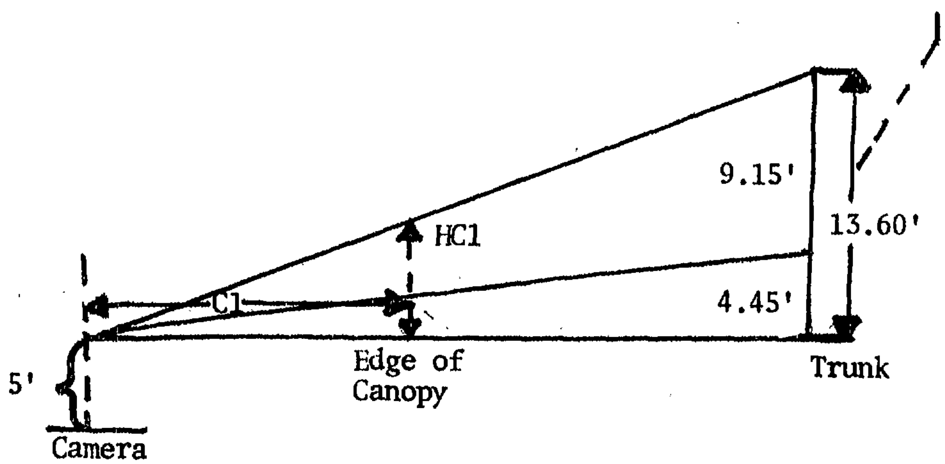
HC1 = height at canopy to bottom of designated middle frame.

HC2 = height at canopy to top of designated middle frame.

The concept is based on similar triangles:



For explanatory purposes the third frame will be considered the middle frame. In cases where an even number of frames are found, the middle frame is the lower of the two middle frames.



Step one: determining HC1

$HC1/C1 = 13.6/50$: C1 known

Step two: determining HC2

HC2 is found in a similar manner moving up one more segment.

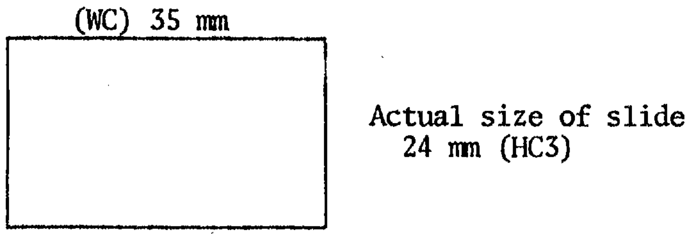
$HC2/C1 = 23.65/50$: C1 known

Step three: determining HC3 the length of the middle frame.

$HC3 = HC2 - HC1$

Step four: determining WC

WC = width of designated middle segment. A 35 mm slide has the dimensions shown below:



By setting up two ratios with WC unknown:

$35/24 = WC/HC3$ and then solving

for: $WC = HC\,(35/24)$

Step five: determining TAMF

AMF = area of designated middle frame.

$AMF = (WC)\,(HC3)$

TAMF = total area of slides for one side of a tree

$TAMF = (N - .5\ (\text{or}\ 1))\ AMF$, the 1 or .5 was subjectively determined by viewing slides, and observing area photographed which is not part of tree.

Where: N = number of slides.

Step six: The surface area of a tree was computed by using the computational formula for a sphere.

Surface Area Sphere (SAS) = $4\pi r^2$

The value used for r is the average of the shortest and longest distances from the edge of canopy to the trunk.

r_1 = radius of short length

r_2 = radius of long length

$r_3 = (r_1 + r_2)/2$

$r_3^2 = r^2$

Step seven: determining expanded photo count for tree

TAMF/SAS = percentage of area photographed

$\sum_{l=1} Y'_{jkml}$ SAS/TAMF = expanded CNP using only photography work on one side of the tree.

Where: Y'_{jkml} represents adjusted photo count of the lth slide in the mth side of the kth tree in the jth block.

The correlation between expanded CNP and pounds of pecans harvested per tree was very good. The three months July, August, and September had correlations of .98, .87, and .93, respectively. All three are significant at the .01 level.

Given a significant relationship exists between nuts counted from photographs and pounds of good nuts harvested per tree it is necessary to look at the workload. The questions raised were:

(a) Is it necessary to photograph both sides of the tree?

(b) Is it necessary to photograph several trees in each block?

A nested analysis of variance was used to check for significant differences between blocks, between trees and between angles (sides of a tree) (tables 8-10).

Table 8.- Nested analysis of variance, CNP, Mississippi pecans, July 1970

Source of variation	DF	Sum of squares	Mean square	F	F.01	F.05
Between blocks...	2	119.036	59.5182	1.98	8.02	4.26
Between trees....	3	90.189	30.0629	5.09	29.50	9.28
Between angles...	3	17.707	5.9025	0.13	4.51	2.92
Slides...........	30	1406.695	46.8898			
Total.......	38	1633.628	42.9902			

Table 9.- Nested analysis of variance, CNP, Mississippi pecans, August 1970

Source of variation	DF	Sum of squares	Mean square	F	F.01	F.05
Between blocks...	2	860.877	430.439	0.33	8.02	4.26
Between trees....	9	11676.858	1297.429	3.91	5.35	3.18
Between angles...	9	2985.170	331.686	1 [illegible]	2.62	1.98
Slides...........	92	16007.260	173.992			
Total.......	112	31530.164	281.519			

Table 10.- Nested analysis of variance, CNP, Mississippi pecans, September 1970

Source of variation	DF	Sum of squares	Mean square	F	F.01	F.05
Between blocks...	3	464.090	154.697	0.45	7.59	4.07
Between trees....	8	2740.651	342.581	9.31	6.89	3.73
Between angles...	7	257.598	36.800	0.72	2.82	2.10
Slides...........	99	5047.958	50.989			
Total.......	117	8510.293	72.738			

The results indicate no significant difference between block or angles (sides of tree) at the .01 level. With so few degrees of freedom, additional evidence is needed to reach any final conclusions. With no significant difference between angles, the cost of photo work would be reduced by taking photographs of one side of the tree but at least one more year of research is necessary. Similarly, the number of blocks required would be small if further studies based on widely scattered blocks would confirm these results.

Counts of Nuts on Individual Sample Trees Through a Spotting Scope

Counts of nuts made from a spotting scope (CNS) were made on four different dates approximately one month apart. Table 11 shows the correlation coefficients between scope counts for the sum of the two strips in each tree and pounds of good nuts harvested per tree. However, it should be kept in mind that the strip did not bear any definite relationship to the tree size. Therefore, the two variables being correlated do not represent pairs of observations from the same kind of sampling unit which results in biased estimates of the correlation coefficients.

Table 11.- Correlation between pounds of good pecans harvested in sample trees and number of pecans counted through a spotting scope per tree, Mississippi 1970

Month	r	n	P.01	P.05	Average number nuts per tree
June.........	.56	8	.834	.707	66.4
July.........	.68	8	.834	.707	49.8
August.......	.33	8	.834	.707	71.6
September....	.32	8	.834	.707	68.8

The correlation coefficients are not significant at the .05 level for any of the dates counted. Several factors may have contributed to the low correlation.

1. Scop too powerful, too small a surface area covered.
2. Insufficient data to make adjustments found in photography section.
3. Length of time counting. Wind blowing will co[illegible]tly change picture.
4. Eye strain causing inaccurate counts.
5. Biased estimates of the correlation coefficients.

Each of these points will be considered in future research. If the problems described above can be alleviated one should find CNS results similar to CNP. Instead of counting in an office from slides, the count takes place in the field--the eye being our camera.

Concluding Remarks

The results of this years research are very encouraging for the individual orchards observed. The correlation coefficient for characteristics studied (except scope counts) were satisfactory in at least one stage of their use. If these results hold in the same orchards next year, a new group of problems must then be faced in setting up an accurate forecasting model. Among the problems are: (1) What is the effect of geographical location on the model parameters? (2) What is the effect of varying management techniques used by different operators? (3) What is the effect of different improved varieties on these techniques? (4) What is the number of noncultivated seedling trees harvested each year?