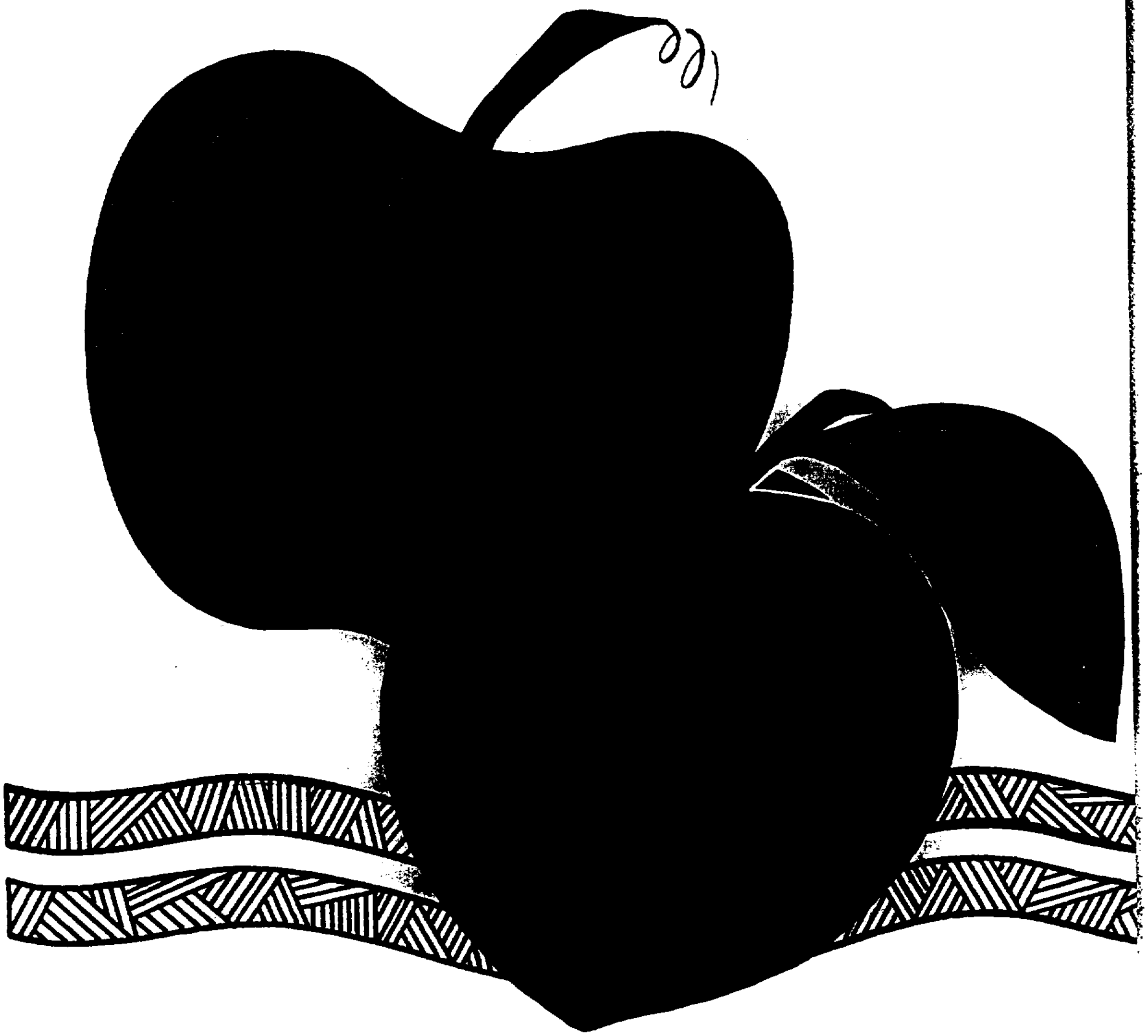
SAMPLING FOR OBJECTIVE YIELDS OF APPLES AND PEACHES



VIRGINIA
1967 - 68

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SUMMARY

Photography can be used as an aid in estimating the number of apples or peaches in an orchard. This study of an apple orchard and a peach orchard in Virginia indicated that, with some training, a team of observers can count the fruit in color slides of a sample of limbs and arrive at a satisfactory estimate. This method is less difficult and less dangerous for the observers than the usual method of counting the actual fruit on the sample limbs, which may be in hard-to-reach parts of the tree.

Sample trees for the study were selected to represent a wide range of trunk sizes (cross-sectional areas). In 1967, the first year of the study, the sample trees were divided into count units of approximately equal size, based on stereo photographs (transparencies). These photographs were taken of the trees in the winter when they were bare. In both years, color slides of the sample limbs were taken in late June or early July, and the fruit was counted both from the slides and on the trees. Counts of apples and peaches from the color slides generally were significantly correlated with the actual number of fruit on the same trees.

The study also investigated the relative efficiency of four methods of selecting samples: (1) Multiple stage with probabilities at each stage proportional to size, (2) multiple stage with equal probabilities of selection at each stage, (3) single stage with probabilities proportional to size, and (4) single stage with equal probabilities.

Selecting sample limbs by a single-stage equal probability procedure will result in a sample variance of about the same order of magnitude as the multiple-stage sampling with probabilities proportional to size, unless the correlation between size of the limb and the number of fruit on the limb is extremely high. Therefore, the decision as to which procedure to use would be determined by such factors as feasibility and relative costs.

Stereo transparencies of bare trees can be used as single-stage sample frames for selecting limbs with equal probabilities. A larger scale study should be conducted for the purpose of determining what the cost relationships may be for this type of sampling and to determine whether negative prints of one of the pair of stereo positive transparencies can be used as a sampling frame. (In this study, sketches of individual limbs were drawn from the projected transparencies.)

Additional study over a larger area is needed to determine whether the use of fruit counts from color slides would be feasible in double-sampling.

The proportion of apples counted in late June to those remaining at harvest was relatively constant for the six trees studied (Golden Delicious, 1967). If this proportion is found to remain comparatively stable in different orchards and years, then an estimate of apples on the tree around July 1 could be used to provide a reasonable estimate of apples at harvest.

For the six Golden Delicious trees studied, the linear correlation between size (diameter) of apples in early July and at harvest was quite high. Again, if this relationship holds over different orchards, varieties, and years, measurements in July could be used to provide a relatively precise estimate of size (and weight) at harvest.

SAMPLING FOR OBJECTIVE YIELDS OF APPLES AND PEACHES, Virginia, 1967-68

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INTRODUCTION

Some very limited research on sampling procedures and methods of estimation of apples and of peaches was conducted in Virginia from 1963 through 1965. 1/ This research indicated that:

1. Inexperienced personnel can be trained to accurately count apples on sample limbs. Close supervision would be required in dividing each sample branch into small count-sections, making independent counts of the apples on each subsection by each member of the count team, and correcting any differences in the individual counts.

2. There is a possibility of reducing costs by using auxiliary information such as tree size or counts from photographs in a double-sampling model.

3. The selection of count limbs with "probability proportional to cross-sectional area" as commonly used in citrus sampling 2/ may not be optimum for deciduous fruit.

Additional research was done in 1967 and 1968 in one peach orchard and one apple orchard in Virginia. This study was principally to explore the use of photography as a sampling frame in selecting sample limbs and in estimating the number of fruit per tree. The complete results of this study are reported here.

DATA COLLECTION

Tree Selection

Apples -- **Two** varieties, Golden Delicious and York, in the Freezeland orchards near Linden, Virginia, were used for this study. Within a planting of 110 Golden Delicious apple trees, about 10 years of age, the

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1/ Sturdevant, Tyler R., Research and Development Branch, Standards and Research Division, Statistical Reporting Service, U. S. Department of Agriculture (unpublished report).

2/ Jessen, Raymond J. Determining the Fruit Count on a Tree by Randomized Branch Sampling. Biometrics, March 1955.

cross-sectional area (CSA) of the trunk of every tree of bearing age was measured. These measurements ranged from a low of 7.0 square inches to a high of 31.5 square inches. The large variation in size had resulted at least in part from girdling of a portion of the trees by field mice. Most of the affected trees had been saved by grafting over the girdled area but their growth was still much slower than that of the unaffected trees.

The cross-sectional areas of the trunks were used as a criterion for stratifying the Golden Delicious trees into three strata. Stratum I was composed of 35 trees having a CSA of less than 15.0 square inches. Stratum II included 52 trees having CSA's from 15.0 to 19.5 square inches. Trees with CSA's larger than 19.5 square inches were assigned to stratum III. The trees in each stratum were arrayed by CSA. A systematic sample of three trees was then drawn from each array to insure that the sample trees represented a wide range of CSA values within each stratum. One of the three trees was randomly deleted from the sample at a later time.

A similar procedure was followed in a small-portion (28 trees) of a large planting of older York variety apple trees. Unfortunately, the York trees produced very little fruit in 1967. Therefore, two nearby Stayman variety trees were substituted for the Yorks, principally to provide experience working with the larger trees. Seven more Stayman trees from the same group as the first two trees were added in 1968. The trunk and primary limb cross-sectional areas of these trees were not measured.

Peaches.-- Peach trees for this study were taken from a block of 194 Redwin variety peaches in the Hill High Orchards at Round Hill, Virginia. Cross-sectional area measurements of the trunks of their trees were used to array and to stratify the trees by the size of the trunk. The 40 smallest trees (CSA less than 14.0 square inches) were placed in stratum I, and 100 intermediate-size trees (CSA from 14.0 to 17.9 square inches) were assigned to stratum II. The remaining 54 trees (CSA of at least 18 square inches) went into stratum III. A systematic sample of three trees was than selected from each stratum. The same trees were used in 1967 and in 1968.

Field Procedures

1967.-- After the "June drop," each primary on each of the selected trees was "mapped," i.e., divided into "path sections" and "terminal branches" (figure 1). As used here, a terminal branch was one which had a CSA of, generally, 0.6 to 2.0 square inches measured at a point 2 or 3 inches above the fork at the base of the terminal. Branches with larger CSA's were classified as terminals if they had no definite forks or divisions which would lead to approximately terminal-size branches. In some cases, for the purpose of reducing costs and variances, smaller branches were classified as terminals rather than comparatively large ones.

A path section was any part of the primary limb which was too large (CSA) to be a terminal and which led to a fork where the branch divided to become two or more terminals and/or additional path sections. That is,

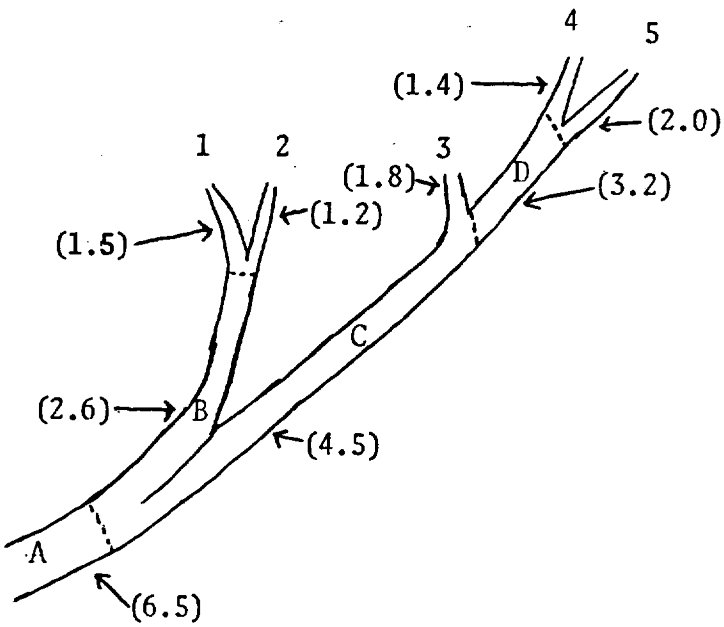

Figure 1.-- Division of a primary limb into path sections and terminals. Path sections are identified by letters (A, B, C, and D), terminals by numbers (1, 2, 3, 4, and 5). The numbers in parentheses represent the CSA's of the individual path sections or terminals.

a path section (a) began at a fork either on the trunk or on a main or secondary limb, (b) normally had a CSA larger than 2.0 square inches, and (c) ended at a fork which divided it into two or more path sections and/or terminals. (Minor divisions which were too small to be terminals were included in the path section). The path sections and terminal branches were further divided into identifiable count sections. Fruit in the count sections were counted independently by two people. Any differences in the counts were reconciled by recounting before leaving the tree.

Each tree was also photographed from two sides. The photographs for one side were taken from a point 22.5 feet from the tree trunk and from the direction which afforded the "best" view of the tree. Photographs of the second side were taken at a point 180 degrees around the tree and also 22.5 feet from the tree trunk. Since the field of view from 22.5 feet using a 35-mm. camera and a 50-mm. lens was not large enough to include the entire side of the tree, jointed aluminum poles were used to divide the tree both vertically and horizontally so that pictures could be taken of each of the four quadrants of each side of the tree.

At harvest, all apples on the selected trees were picked and recounted, by count section, to provide a "true" number of apples produced. This procedure was not used for the peaches.

1968.-- The six Golden Delicious and nine Stayman apple trees and the nine Redwin peach trees were photographed in stereo (Kodachrome II film) during the winter when the trees were bare of leaves. This photography was used to determine whether the stereo transparencies could be used to construct an acceptable sampling frame for use in single-stage sampling. The frame construction consisted of drawing a sketch of each of the primary branches of the tree and dividing the sketch into path sections and terminal limbs in the same manner as in the orchard in 1967, but with an important difference--the decision as to whether a limb was the right size for a terminal was based solely on the apparent size of the limb from the stereo slides.

After the June drop, field crews identified the path sections and terminal limbs on the trees as defined on the sketches. The stereo slides were also used by the field crews to help identify corresponding limbs on the trees and on the sketches. After the path sections and terminal limbs had been identified, the fruit on the tree was counted in the same manner as in 1967.

Color photographs (Kodachrome II 35-mm. slides) were taken of both sides of the trees in the same manner as in 1967. The apples on a sample of terminal limbs on the Stayman trees were individually tagged and sized in early July. The sizing operation was repeated in August, and again just before harvest. (One tree had been picked before the final sizing operation). The sizing was done with a standard apple sizer. The average time required for tagging and sizing in July was about 0.8 minute per apple for a two-man crew. In August, when the two-man crew was sizing previously tagged apples, they were able to size about three apples per minute.

Counting Fruit from Color Transparencies

1967.-- The color transparencies were projected on a plain paper background from a 500-watt projector at a distance of about 10 feet. Each slide was examined by two persons in a three-step procedure: (a) The first interpreter marked the location of apples he identified with a small dot on the paper; (b) the second interpreter examined the same slide, using a circle to mark any additional fruit not marked by the first interpreter and an "x" to indicate that he did not concur with a previous dot; (c) the differences were then reconciled by the two interpreters.

The average time required for one person to count one slide was 7 minutes.

1968.-- The color transparencies were projected to about a 27-inch by 36-inch image, on a viewing screen marked off in 3-inch squares. The squares were numbered 1 to 9 vertically and A to M horizontally. The counts of fruit in each square were recorded on a count record sheet which had the same grid pattern and numbering system. Any fruit images which crossed a grid line or one of the aluminum poles were counted in the lower (or right-hand) cell. Only the quarter of one side of a tree which was outlined by the aluminum poles was included in the count for that particular slide.

A total of four persons were used to count fruit on the apple slides. These were selected from a group of seven persons who had been given some training and who then counted a series of test slides. The criterion of selection was consistency in counting the test slides. To reduce the effect of the differences between counters, each person counted one slide from each side of each tree. Each slide was then recounted by a different person and the simple average of the two counts was used in the succeeding analysis.

A different procedure was used in counting the peaches. With a total of three interpreters, only one-half of the slides were counted by two people. The double counting was set up in a randomized incomplete block design so we could estimate the relative amount of over or under-counting by each interpreter, compared with the average of the three. These estimated proportions were then used to adjust all counts for differences in interpreters before they were used in the correlation analysis.

Data obtained from the field counts and from the photo interpretation are summarized in tables 1-3.

ANALYSIS

Alternate Methods of Selecting Terminal Limbs

The complete counts of apples by terminal limbs on each of the six Golden Delicious trees were taken for the purpose of investigating the relative efficiency of different methods of selecting samples. The methods considered were:

(a) Multiple stage with probabilities at each stage proportional to size (MS-PPS).

(b) Multiple stage with equal probabilities of selection at each stage (MS-EPS).

(c) Single stage with probabilities proportional to size (SS-PPS).

(d) Single stage with equal probabilities (SS-EPS).

Most apple trees are pruned so that they have a comparatively short trunk which forks (or divides) into several large primary or "scaffold" branches. (This pattern is also a characteristic of other species of fruit and of many species of nuts). In multiple-stage sampling, the first stage requires that one of the several primaries be selected by some method, e.g., PPS or EPS. If the selected primary is too large to be used as a terminal sampling unit, the sampler must work up the selected primary branch, stopping at every fork where the smallest branch is at least large enough to be a terminal unit and randomly determining by the designated method (EPS or PPS) which branch to select. This procedure would continue until the sampler selected a branch which could be classified as a terminal limb.

For example, assume that the limb in figure 1 had been the selected primary from the first stage of sampling, and that the sampler was to limit his choice of terminal limbs to those which had a cross-sectional area of 1.0 to 2.0 square inches. The CSA at the base of the primary is 6.5 square inches. This is much too large for a terminal, so at least one stage of subsampling would be required. Therefore, the sampler would proceed to the end of path section B, the next stage of sampling would require a random selection of terminal limbs 1 or 2. If the procedure used resulted in selecting path section C, then the third stage of sampling would require a random selection of either path section D or terminal 3. If path section D was selected, then a fourth stage of sampling, a random selection of terminal 4 or terminal 5, would be required.

In contrast, single-stage sampling requires only that a single sample be drawn from a list of all the possible terminal size limbs on the tree. The difficulty lies in identifying all of the possible terminal size limbs.

The procedure used in defining terminal limbs in this study resulted in terminal limb sizes which ranged from 0.62 to 3.26 square inches. Under the assumption that the number of fruit per terminal is positively correlated with the size (CSA) of the terminal, this much variation in terminal size should result in either PPS method of sampling being preferable, in terms of lower sample variances, to either EPS method. This hypothesis agrees with the data summarized in table 4. Where the within-tree coefficient of correlation is quite high, as for the Golden Delicious apples and the Redwin peaches, the PPS methods resulted in significantly lower sample variances than the single-stage EPS method. The multiple-stage EPS method consistently resulted in sample variances which were two to four times larger than the variances from the PPS methods.

When the correlation between terminal CSA and number of fruit is lower, as for the Stayman apples, the sample variances resulting from the single-stage EPS method were at about the same order of magnitude as the PPS methods. However, the multiple-stage EPS procedure still resulted in a much larger sample variance.

In a similar study on Lodel variety cling peaches in California, the EPS single-stage procedure resulted in slightly smaller sample variances than either PPS procedure, even when the correlation between terminal size and number of fruit was significantly large. These results led to the conclusion that single-stage equal probability sampling would be at least as good as PPS methods in terms of sample variances whenever the within-tree correlation between terminal CSA and fruit numbers was not too large. Therefore, the emphasis in 1968 was placed on developing feasible methods of using single-stage equal probability sampling.

Table 1.--Data from six Golden Delicious apple trees, Virginia, June 1967 and June 1968

Stratum and tree number	Total fruit	Trunk CSA	Sum of primary CSA's	Terminals	Fruit counted on photos
	Number	Sq. in.	Sq. in.	Number	Number
June 1967:					
Stratum I					
Tree 1	403	13.5	20.4	19	271
Tree 2	214	7.0	12.5	13	216
Stratum II					
Tree 3	1,658	16.5	25.8	20	840
Tree 4	1,575	19.5	28.1	30	710
Stratum III					
Tree 5	1,901	23.0	37.9	26	783
Tree 6	1,448	20.0	33.2	27	691
Weighted average 1/	1,212.4	1.63	25.4	22.4	597.9
June 1968:					
Stratum I					
Tree 1	602	18.0	30.3	22	214.0
Tree 2	399	12.0	15.8	14	277.5
Stratum II					
Tree 1	758	20.0	28.0	21	404.5
Tree 2	746	24.5	31.8	30	294.0
Stratum III					
Tree 1	1,075	30.0	48.3	31	389.0
Tree 2	1,181	26.5	36.1	34	811.5
Weighted average 1/	855.2	21.2	30.3	24.6	368.8

1/ Stratum weights are: Stratum I, 35 trees; Stratum II, 52 trees; Stratum III, 23 trees.

Table 2.--Data from nine Stayman variety apple trees, Virginia, 1968

Tree number	Total fruit (June)	Terminals	Fruit counted on photos	Average diameter of apples		
				July	August	October
	Number	Number	Number	Inches	Inches	Inches
1..........	1,150	42	455.0	1.79	2.27	2.77
2..........	1,522	54	552.0	1.71	2.21	2.63
3..........	5,394	69	1,099.0	1.45	1.85	2.12
4..........	715	47	257.5	1.37	2.07	----
5..........	2,303	41	1,210.5	1.59	2.02	2.33
6..........	2,109	111	770.0	1.59	2.05	2.45
7..........	1,804	83	376.5	1.59	2.04	2.40
8..........	3,371	87	1,035.0	1.54	1.97	2.31
9..........	5,380	102	2,472.0	1.55	1.95	2.22

Table 3.--Data from nine Redwin peach trees, Virginia, June 1967, and June 1968

Stratum and tree number	Total fruit	Trunk CSA	Sum of primary CSA's	Terminal	Fruit counted on photos
	Number	Sq. in.	Sq. in.	Number	Number
June 1967:					
Stratum I					
Tree 1	370	18.0	21.2	11	210
Tree 2	184	21.0	13.7	8	122
Tree 3	431	13.5	13.1	17	300
Stratum II					
Tree 4	443	22.2	23.1	12	247
Tree 5	250	29.5	16.9	19	155
Tree 6	720	21.4	21.9	17	473
Stratum III					
Tree 1	460	31.0	27.4	14	272
Tree 2	800	39.5	26.4	16	335
Tree 3	401	41.8	33.5	11	138
Weighted average 1/	464.6	26.6	22.0	14.5	262.9
June 1968:					
Stratum I					
Tree 1	347	22.0	22.6	13	45.0
Tree 2	273	22.0	17.1	11	62.4
Tree 3	259	14.0	16.8	11	101.9
Stratum II					
Tree 4	391	23.5	28.2	17	57.2
Tree 5	363	32.0	19.0	15	43.7
Tree 6	361	22.5	24.8	13	64.4
Stratum III					
Tree 7	542	30.5	40.2	12	125.1
Tree 8	391	41.0	35.0	15	131.3
Tree 9	356	44.5	37.5	13	56.7
Weighted average 1/	369.4	28.00	26.6	13.8	71.5

1/ Stratum weights are: Stratum I, 40 trees; Stratum II, 100 trees; Stratum III, 54 trees.

Table 4.--Summary of limb sampling procedures, six Golden Delicious apple trees, two Stayman apple trees, and nine Redwin peach trees, Virginia, 1967

Variables	Six Golden Delicious apple trees	Two Stayman apple trees	Nine Redwin peach trees
Total number of terminals	135	92	123
No. of fruit per terminal:			
Average	51.7	21.6	27.9
Standard error	42.0	12.6	
CSA (sq. in.) of terminal limb:			
Average	1.42	1.58	1.58
Standard error	.54	.51	
Within-tree coefficient of correlation (r) between terminal CSA and number of fruit	.65	.39	.71
Sample variances computed by method of sampling:			
Multiple-stage PPS	353,267	338,533	63,779
Multiple-stage EPS	1,851,884	1,486,718	111,511
Single-stage PPS	349,989	317,628	61,600
Single-stage EPS	738,232	330,580	101,459

Use of Double-Sampling Techniques

Disadvantages of using estimators which depend solely on the number of fruit counted on sample limbs include the following:

(1) Counts of fruit on trees (or sample limbs) are fairly expensive in terms of time and often need to be taken in parts of the tree that are hard (and dangerous) to reach.

(2) If a comparatively large sample limb (e.g., "10 percent" of the tree) is used, the area of the tree--and the number of fruit to be counted --becomes so large that considerable undercounting may take place.

(3) If a comparatively small sample limb is used, the within-tree variation makes a substantial contribution to the variance of the estimate. When equal probability sampling is used, it is relatively easy to reduce the contribution of the within-tree variation to the sample estimate by

selecting additional sample limbs. However, in PPS sampling, because the probabilities are not equal and are harder to compute, obtaining an unbiased estimate from more than one sample limb is not an easy task.

A portion of this study is devoted to identifying variables related to fruit production for possible use in double-sampling, and determining ways in which they might be used. Particular characteristics studied were trunk size (CSA), the sum of the CSA's of the primary limbs, the number of terminals per tree, and the number of fruit counted on color transparencies of the tree.

A first requirement for the use of double sampling is that some degree of correlation (r) exists between the information collected from the large and small samples. A second condition is that double sampling is advantageous only if the inequality

$$r^2 > \frac{4 C_1 C_2}{(C_1 + C_2)^2}$$

is satisfied, where C_1 is the per unit cost of gathering auxiliary information, e.g., the X variable in the regression equation, from the large sample of size n, C_2 is the per unit cost of gathering information for the Y statistic from a subsample of size n', and r is the coefficient of correlation between the X and Y characteristics.3/

Looking at tables 4, 5 and 6, we find that the most likely candidate--on the basis of correlation with the number of fruit per tree--is the sum of fruit counted from the projected color transparencies. A second possibility would be the sum of the cross-sectional areas of the primary branches. While the correlation between number of fruit and the sum of the primary CSA's is not as definite as for the photo counts, the lesser cost adds to the attractiveness of the sum of the primary CSA's. The cross-sectional area of the trunk (below the primaries) is both cheaper and less well correlated than the sum of the primary CSA's. On balance, the trunk CSA would be inferior to the sum of the primary CSA's.

If sample limbs are obtained by a single-stage process, then the marginal cost of obtaining the number of terminals is quite small. However, in double-sampling, this information would ordinarily be available only for a small portion of the total sample. The cost of obtaining this information for the remaining trees would be comparatively large. Since the correlation with total fruit is not very good, the number of terminals per tree should not be considered in furture double-sampling schemes.

3/ Hansen, M.H., Hurwitz, W.H., and Madow, W.G. Sample Survey Methods and Theory. John Wiley & Sons, Inc., New York, vol. 1, p. 466, 1953.

Table 5.--Simple weighted correlations and regression coefficients between total fruit in June and indicated independent variables, Virginia apple trees, 1967 and 1968

Independent variable	Year	Coefficient of correlation (r)	Coefficient of regression (b)	Intercept (a)
Six Golden Delicious trees:				
Trunk CSA	1967	*0.886	114.84	-656.02
	1968	.639	57.72	-368.21
Sum of primary CSA's	1967	*.976	52.83	-128.40
Number of terminals	1967	.731	78.37	-546.98
	1968	.715	53.66	-458.59
Sum of photo counts	1967	*.984	2.50	-279.41
	1968	*.942	2.78	-169.00
Nine Stayman apple trees:				
Number of terminals	1968	.489	32.04	374.75
Sum of photo counts	1968	**.814	2.08	733.54

*Correlation is different from zero, probability greater than 0.95
**Correlation is different from zero, probability greater than 0.99

Table 6.--Simple weighted correlations and regression coefficients between total fruit in June and indicated independent variables, nine Redwin peach trees, Virginia, 1967 and 1968

Independent variable	Year	Coefficient of correlation (r)	Coefficient of regression (b)	Intercept (a)
Trunk CSA	1967	0.118	2.748	391.53
	1968	.395	3.288	277.33
Sum of primary CSA's	1967	.404	13.653	163.78
	1968	*.761	6.911	185.79
Number of terminals	1967	.256	14.563	253.04
	1968	.362	11.902	205.59
Sum of photo counts	1967	*.879	1.453	82.47
	1968	.455	1.076	292.46

*Correlation is different from zero, probability greater than 0.95

One requirement of any successful use of photo counts should be the careful training and supervision of the interpreters. F-values and variance components computed from the photo counts of fruit from color transparencies taken in 1968 indicate that the interpreters contributed more to the variance of the number of fruit counted per tree than did any of the within-tree sampling patterns (tables 7, 8, and 9).

The values in tables 7-9 also indicate that the randomizing procedure used in selecting the camera locations was effective in that the contribution to the variance from the two locations was quite small. The computed values indicate that while the placement of the vertical and horizontal poles did effectively equalize the two diagonal pairs on one side of a tree, there was still a great deal of variation between the individual quadrants. The difference between quadrants could easily result either from uneven distribution of fruit at different levels on the tree or from irregularly shaped trees.

The variance components in tables 7-9 can also be used to form some very rough approximations as to the optimum number of photos to be taken per tree and of the number of interpreters who should count each photo. Assuming that the between-tree cost of taking photographs is twice as large as the cost of taking a picture and developing the film, and that the cost of interpreting a slide is about the same as the cost of obtaining the slide, we should take pictures of two diagonally opposed quadrants on one side of each tree, and interpret each slide only once.

Table 7.--Analysis of variance and variance components for photo counts of Golden Delicious apples from color transparencies, Virginia, 1967 and 1968

Year and source of variation	Degrees of freedom	Mean square	F	Variance component
1967:				
Between trees	5	6,941.7	25.4	916.3
Between sides of trees	6	276.1	1.12	8.3
Between diagonals	12	245.7	0.55	-109.9
Between quarters	20	447.2	-----	447.2
Total	43	1,122.3	---	---
1968:				
Between trees	5	13,835.7	34.71	839.8
Between sides of trees	6	398.7	1.74	21.1
Between diagonals	12	229.6	.29	-142.9
Between quadrants	24	801.2	4.57	312.9
Between interpreters	48	175.3	-----	175.3
Total	95	1,073.36	---	---

Table 8--Analysis of variance and variance components for photo counts of Stayman apples from color transparencies, Virginia, 1968

Source of variation	Degrees of freedom	Mean square	F	Variance component
Between trees	8	113,953.5	33.32	6,908.3
Between sides of tree	9	3,419.8	2.73	207.6
Between diagonals	18	1,254.7	.17	-1,538.5
Between quadrants	36	7,408.9	3.49	2,642.9
Between interpreters	72	2,123.1	-----	2,123.1
Total	143	9,682.3		

Table 9.--Analysis of variance and variance components for photo counts of Redwin peaches from color transparencies, Virginia, 1967 and 1968

Year and source of variation	Degrees of freedom	Mean square	F	Variance component
1967:				
Between trees	8	1,561.1	10.87	315.3
Between sides of trees	9	142.2	1.44	6.3
Between diagonals	18	98.4	.49	-50.5
Between quarters	36	199.5	-----	199.5
Total	71	320.1	---	---
1968:				
Between trees	8	187.4	2.03	7.9
Between sides of trees	9	92.1	1.96	6.7
Between diagonals	18	47.0	.56	-11.7
Between quarters	36	84.5	3.06	37.9
Between interpreters	36	27.6	-----	27.6
Total	107	67.4	---	---

<u>Sampling for Apple Size and Weight, 1968</u>

Apples on the count limbs of the nine Stayman variety apple trees were measured as described in the section on field procedures on July 10, August 13, and October 4. On the final visit, the apples were also picked, sorted into three size groups, and weighed by size groups. This size and weight information was used to investigate:

(1) The type of relationship (linear, nonlinear) between the size (diameter) and weight of mature Stayman variety apples,

(2) The possibility of predicting the mature size (and weight) from measurements taken relatively early in the season, and

(3) Possible sample allocations for future surveys.

Under the assumption that the density of an apple is independent of its size, then the volume of an apple (approximately a cubic function of the radius) would be directly related to its weight. We then need to determine whether the diameter, a linear function of the radius, provides a satisfactory approximation over the range of probable values. To this end, the mean diameters of apples in each of the 57 groups weighed were transformed to quadratic and cubic functions of the radius and correlations with the mean weight computed for each function. It would appear from the computed correlations that very little would be gained by using a cubic function of the radius rather than the diameter on estimating the weight of apples.

Function of mean diameter	Coefficient of correlation with mean weight
Linear	0.943
Quadratic	.950
Cubic	.954

Correlations between average size of apples from the 24 sample limbs measured on July 10, August 13, and October 4 and shown in table 10 were quite high (approximately 0.95). This indicates that it should be possible to estimate the harvest size of apples from measurements taken in early July. Density of fruit (number of fruit per unit CSA) was correlated negatively with size. This correlation was significant at 5 percent level of probability. The multiple cofficient of correlation based on both density and July fruit size, was significantly higher than an simple correlation with only the July fruit size (table 11).

Any inferences about possible sample allocation for estimating apple size or weight are necessarily restricted by the limitations of the data. However, the variance components computed from these nine trees suggust that only one or possibly two sample limbs be selected from each sample tree and that from five to 20 apples on each limb be sized. (In determining an average weight of mature apples, it probably would be more efficient to pick and weigh <u>all</u> the apples on the sample limb(s).)

Table 10.--Apple size data, Stayman variety apples, Virginia, 1968

Item	Mean	Standard deviation	Correlation with size at harvest
Size at harvest (Sept.).......	2.46	0.23	---
Size in July.................	1.61	.12	**0.95
Size in August...............	2.07	.16	** .96
Terminal size (CSA)...........	1.52	.92	.08
Fruit per terminal............	27.46	28.20	-.34
Fruit/CSA.....................	21.98	20.05	*-.50

* Correlations having absolute values larger than 0.40, 22 degrees of of freedom, would occur by chance less than 5 percent of the time in repeated sampling.

** Correlations having absolute values larger than 0.51, 22 degrees of freedom, would occur by chance less than 1 percent of the time in repeated sampling.

Table 11.--Coefficient of correlation and parameters of regression estimators for estimating fruit size, Stayman apples, Virginia, 1968

Independent variable	Correlations	Parameters		
		a	b	c
Size, July 10.................	0.959	-0.340	1.736	-----
Size, August 13...............	.957	-.379	1.370	-----
Size, July 10, plus density...	.984	-.073	1.607	-.003

Proportion of Apples Remaining Harvest, 1967

The proportion of apples remaining on the six Golden Delicious trees and on the one Stayman tree at harvest to those counted in June ranged from 0.908 to 0.967. The average proportion was 0.945. The standard deviation of the observed proportions for these seven trees was 0.022. The June count for the second Stayman tree apparently was not complete as more (3.1 percent) apples were picked from this tree at harvest than were counted in June.

Weight of Mature Apples

1967.-- The mature apples from the six Golden Delicious trees averaged 0.256 pound in weight. The within-tree standard deviation of Golden Delicious apple weights was 0.0186 pound. The between-tree standard deviation was 0.434 pound. Comparable figures for the two Stayman trees were: mean, 0.315 pound; standard deviation within trees, 0.0206 pound; and standard deviation between trees, 0.0339 pound.

1968.-- Mature apples from eight Stayman trees averaged 0.224 pound in weight. The between-tree and within-tree components of variance are given in table 12.

Table 12.--Components of variance for size and weight of apples from nine Stayman variety trees, Virginia, 1968

Source of variation	Component of variance	
	Diameter	Weight
	Inches	Pounds
Between trees	0.00763	0.00275
Between limbs	.00577	.00073
Within limbs (apples)	.01804	.00112

RECOMMENDATIONS

Several of the techniques examined in this study should be tested further over a broader data base, which should include trees of different varieties and ages and under different managements. It could be secured by sampling orchards in some commercial apple area. The size of such a project would of necessity be limited by the available resources but should probably include trees from at least 20 to 30 different orchards.

Such testing would be directed specifically at determining:

(1) The operational feasibility and economic practicality of these techniques, and

(2) obtaining information on costs and variance components which would be needed in designing an operational program.

Particular items which should be tested are:

(1) The use of stereo photographs of bare trees in selecting sample limbs.

(2) The use of fruit counts from photographs, or of tree size, as auxiliary information in a double-sampling estimation model, and

(3) using measurements of immature apples to predict final size and weight.

Since the field work on such a test would need to be closely supervised and largely carried out by SRS personnel, a logical place for such a test would be the commercial apple area near northern Virginia.