FORECASTING FLORIDA CITRUS PRODUCTION

Methodology & Development

January 1971

FORECASTING FLORIDA CITRUS PRODUCTION

- METHODOLOGY AND DEVELOPMENT -

S. R. Williams
January 1969

Edited and Revised by
Florida Crop and Livestock Reporting Service
January 1971

FOREWORD

The development of objective methodology in citrus forecasting has been gradual with the major breakthroughs occurring in the last two decades. Documentation is somewhat outdated and incomplete. The purpose of this bulletin is to provide a self contained description of the current methodology and history of its development. This bulletin is intended to contain sufficient detail to serve as a record and reference for the Florida Crop and Livestock Reporting Service, and as a technical blueprint for others considering similar endeavor. For the benefit of the reader interested only in general methodology, much of the the technical detail is placed in the appendix.

In the preparation of this bulletin, I am indebted to Joe E. Mullin, Paul N. Messenger, James W. Todd, and Paul E. Shuler, of the Florida Crop and Livestock Reporting Service for providing most of the basic information; to Dr. Bruce W. Kelly, Director of the Agricultural Estimates Division of the Statistical Reporting Service, Washington, D. C.; Dr. Roy Stout, Coca-Cola Co., Atlanta; and Dr. Ray Jessen, University of California at Los Angeles, for permission to include summarizations of relevant publications authored by them. I am also indebted to Drs. Frank Martin and William Mendenhall of the University of Florida and Harold Huddleston, Research and Development Branch of the Statistical Reporting Service in Washington, D. C., for their guidance and assistance.

Editor's Comment: This publication was completed by Mr. Williams in early 1969 but publication was delayed by personnel shortages. The procedures described are, however, still current and relevant. Therefore, in general, only the variables involved and the results of their use in the mathematical models have been brought up to date. Current research will be incorporated in later publications.

TABLE OF CONTENTS

I. INTRODUCTION

Agriculture in Florida is a rapidly growing industry which, in the past few years, has exceeded the billion dollar mark in cash receipts from farm marketings. Citrus, which accounts for nearly a third of Florida's farm income, is the Number One agricultural commodity. Florida produces about 75 percent of the Nation's citrus.

These comparisons give dimension to the Florida citrus industry and emphasize its relative economic importance. The growth of this industry is primarily the result of keen foresight and dynamic leadership by industry management. A prime indication of quality management is the timely realization of the importance of informed decision making. The case in point is their continual stress on obtaining more and better information on both quantity and quality of future citrus production. When this information is in the form of a single, dependably accurate forecast of production, it increases returns to the industry through effective picking, processing and marketing. Florida has been the pioneer in developing a sophisticated objective method of providing quality statistics on prospective citrus production.

Endeavors to obtain accurate information about citrus production in Florida date back more than half a century. Early efforts developed the embryo of an effective methodology for early season forecasting of citrus production. This report offers a description of the methodology and its development.

Past Records

The statistical series on Florida citrus begins in the late nineteenth century when recorded shipments of citrus and County Commissioner estimates of tree population and production were periodically summarized. Official inspection records later improved the series for both production and tree population. Joint efforts of state and industry groups provided a tree census in 1934 and again in 1956. The 1956 census was a significant contribution to the series and also to subsequent production forecasts. This census identified individual groves by mapping and recording variety, age, location and tree numbers. The 1956 census was updated by annual sample surveys from 1960 until 1965 when a complete and detailed census was efficiently obtained with the aid of special aerial photography.

Early Forecasting

Early attempts at forecasting citrus production consisted of various ways of gathering and summarizing subjective evaluations of crop condition. Objective counts and measurements were used in citrus production forecasting as early as 1939. Most of these early systems have become unsatisfactory for present day needs but have paved the way to the relatively sophisticated methodology now being used in Florida.

Present Methodology

Present citrus forecasting considers production to be uniquely defined as a function of four variables: (1) number of bearing trees in the population, (2) average number of fruit per tree, (3) size of fruit at maturity, and (4) natural loss of fruit between original count and maturity (drop).

Tree Numbers

A significant contribution to long range planning and accurate production forecasts is the recently acquired information on the citrus tree population. The data from the 1965 tree census is now updated biennially, using comparative interpretation of aerial photography and a relatively small amount of supporting field work. This current detail on the tree population provides an ideal frame for sample surveys designed to obtain objective information about the other three factors of production. (A frame is a listing of units which are members of the population of interest.)

Fruit per Tree

An unbiased estimate of average number of fruit per tree is calculated from fruit counts on sample limbs randomly selected with known probabilities.

Fruit Size and Drop

Monthly surveys, beginning at the time fruit per tree is estimated, are made to determine (1) fruit growth and size at maturity, and (2) natural loss of fruit or drop. Monthly measurements and counts are projected to harvest size and loss before harvest, assuming normal conditions. These observations are made in groves randomly selected from a segment of the population referred to as the route frame.

Forecast Models

Two types of mathematical models are used to convert survey results into indications of citrus production. (1) The direct expansion estimator uses the functional relationship of the four variables to forecast production. This estimator is based entirely on current data. (2) Relative change estimator adjusts the previous year's production by the ratios of current variables to the previous year's variables.

Utility

This methodology is being used to provide the Florida citrus industry with forecasts of production for major types of citrus with determinable reliability. Also, although cost is a deterrent to the use of these methods for smaller populations, large corporations are employing the objective techniques to forecast production under their control.

II. HIGHLIGHTS OF METHODOLOGY DEVELOPMENT

Records of Production

The chronology for estimates of citrus production dates back to about 1889. At that time, the Report of Commissioner of Agriculture contained an admittedly incomplete summarization of County Commissioner estimates of citrus tree inventories and production in their respective counties. These reports continued through the 1920's. The Atlantic Coast Line Railroad Company tabulated citrus movement out of Florida by all lines of transportation. These reports, along with the Report of Commissioner of Agriculture, were referred to in developing the historic series compiled by the Bureau of Crop Estimates (now Statistical Reporting Service) of the United States Department of Agriculture.

In 1909 the Bureau of Crop Estimates employed a field agent who kept in touch with crop progress and began developing official records of production, utilization and season average price for all citrus and for grapefruit. In 1920 these records were subdivided into separate series for all oranges, all grapefruit, and tangerines. The orange statistical series was further refined beginning in 1933 by separating Valencias from early and midseason varieties, and in 1953 Temples were spun off from the latter classification. Separate estimates of seedless and other varieties of grapefruit were started in 1933 and the seedless type was further subdivided into white and pink fleshed varieties in 1955.

In developing these official production and utilization estimates, the Department referred to the reports of other government agencies and railroad records, as indicated. However, in the mid-1930's, official inspection records became the basis for refining estimates of production and utilization of the crop by types of fruit.

These records of production by type of fruit are essential to accurate forecasts of crop production in advance of harvest.

Records of Citrus Tree Numbers

As indicated above, the Report of the Commissioner of Agriculture provides the earliest history on citrus tree numbers in Florida. These reports were on a county basis with bearing and non-bearing trees usually separated for major kinds of citrus. They provided a measure of the relative importance of individual citrus counties.

Every three to five years, from 1919 to 1941, the Florida State Plant Board issued tabulations of number of trees inspected during one complete cycle covering the State. These related to all trees inspected, extending to such classifications as sour oranges, abandoned groves, and dooryard trees. Both bearing and non-bearing trees were reported separately for each type of citrus. Although these data did include non-commercial trees and did not include variety and age information required for a good sample frame, they did provide valuable background information for the ensuing tree census work.

Brown[1/] noted that some idea of annual plantings could be obtained from the records of nursery stock movement (the State Plant Board formerly required the reporting all of nursery stock sales). It was recognized at the time that these data would not be complete since nursery trees produced by a grower for his own use were not covered. These records have proven inadequate for estimating annual citrus plantings because of the incompleteness and non-enforcement of the law requiring that nursery stock movement be reported. In addition, one cannot distribute nursery stock sales between trees used for replacement in existing groves and those set in new acreage.

In 1934 a marketing agreement was adopted which required the volume sold from each grove to be regulated as indicated by its estimated share of the total forecasted production. Newell[2/] noted that this increased the urgency of more accurate production forecasts and prompted the 1934 tree census.

A complete tree survey was made by the Florida Citrus Control Committee with funds provided by the Florida Emergency Relief Administration. The survey was accomplished in a 3-month period (July-September 1934). Enumerators used personal interview, where possible, to obtain survey data. Absentee ownership made it necessary in many cases to use enumerator counts by variety and prorate ages based upon the personal interview returns. Since no grove mapping was done, it was difficult to check enumerators' work and to maintain the inventory on a current basis. However, the tree census obtained detailed information of number of trees by age and variety needed for an effective sample frame.

For 20 years estimates of Florida citrus tree numbers were based on the 1934 tree census, adjusted by State Plant Board reports of nursery stock movement in subsequent years, and the Census of Agriculture for the years 1940, 1945, 1949 and 1954. These estimates were, at best, rough approximations and lacked detail needed for sampling frames.

[1/] Brown, Arthur C., "Citrus Plantings in Florida," The Citrus Industry, March 1938.

[2/] Newell, S. R., Florida Citrus Tree Survey, USDA Report, July 1935.

In 1954 the need for more complete and current tree census information was discussed by industry and government representatives. Officials of the Florida Crop and Livestock Reporting Service stressed the importance of an accurate census of trees by age and variety in improving forecasts of the Florida citrus crop. Representatives of the State Plant Board stated that a census of this type would cost about $225,000 and could be completed in one season. Florida Citrus Mutual was named as the coordinating agency, the Florida State Department of Agriculture designated as the contracting agency, and the field work was undertaken by the State Plant Board. The financing was a joint effort -- about $75,000 from the State Plant Board with $150,000 coming from Federal-State matching funds and industry organizations.

Because of priority given to work on Spreading Decline and the Mediterranean Fruit Fly emergency, the census work was spread over three seasons instead of the one season intended. In spite of the delay and the 1957 freeze, which rendered much of the census obsolete just 13 days after the summary had been published, this was the most complete and detailed census of Florida citrus trees to that date. The total cost was about one-third of a million dollars.

Preliminary reports by counties contained tree numbers by principal varieties and age classes. These data related to date of survey. The state summary issued on December 1, 1957, contained tree numbers for individual counties by major fruit types. Also, the tree numbers were summarized separately for bearing and non-bearing categories. Individual county data were updated to reflect tree numbers as of late 1956 by making adjustments in individual fruit types from records of nursery tree movement and supplemental information on large acreages set in South Florida.

Detailed records from the 1956 State Citrus Tree Census indentified individual groves by variety, age, location, and tree numbers for those blocks of fruit which had been mapped. Although the Census did not contain complete detail for groves set after the individual county surveys were made, it did provide a fairly satisfactory sampling frame for objective yield surveys conducted during the late 1950's.

The 1956 State Citrus Tree Census was recorded in enough detail to facilitate updating by sample surveys. Methodology for updating tree numbers from a sample was proposed by Kelly[3/] and first applied in 1960 by Stout and Todd[4/]. Although the citrus tree inventory is no longer kept up to date by sampling, the method

---

[3/] Kelly, B. W., How to Keep the Citrus Tree Count Current, unpublished report, August 1957.

[4/] Stout, R. G. and Todd, J. W., A Continuing Survey for Estimating Current Numbers of Florida Citrus Trees, Ag. Econ. Mimeo. Rpt. EC 64-13, June 1964.

proved to be serviceably accurate for estimating total number of trees at the state level. Sample methodology was designed to provide maximum sampling errors (C. V. at $\alpha = 0.05$) for all orange trees of about $15/\sqrt{r}$ for major counties and $4/\sqrt{r}$ for the state total where r is the number of surveys combined for the estimate.

An indication of number of orange trees in the state was calculated from the combined data of three sample surveys. A two percent discrepancy existed between this indication and comparable data from the 1965 Tree Census. Considering the large changes occurring during the twelve years following the 1956 Tree Census, a two percent difference is very nominal and proves the utility of this method where current and complete aerial photography is not available.

The primary sample unit was surveyor section selected systematically by township and range. A rotating twenty percent sample of all citrus and potential citrus sections (land sections) was used each year, so the sections of land containing citrus in 1956 and land having a potential for citrus were completely surveyed in a five year period. Land deemed unsuitable for citrus was sampled at a two percent rate. In the sample of sections for each year, the existence or non-existence of 1956 groves was recorded and trees in all the new groves and a two percent subsample of old groves were completely counted. These data gave an estimate of change in number and size of old groves and an estimate of new (planted since 1956) grove trees by age, type, and county. Estimator, variance, and bias formulas used in updating 1956 tree numbers by county, type and age are covered in Appendix II.

The sample tree survey techniques as applied contained some conceptual flaws. First, the two percent subsample of old groves was used to measure changes in size of groves existing in 1956. It would have been more efficient to have treated grove expansions as new groves and recorded them in the twenty percent sample as such. The two percent subsample should have been used solely for recording changes within the boundaries of groves existing in 1956.

A second serious flaw in the sample tree survey (and this existed in the 1956 tree census) was the assignment of tree age based on tree height or bearing surface. Substantial changes occur during and following a freeze which would continually alter classifications based on these criteria. This type of classification is impractical to keep current in a million-acre population.

Major changes in the citrus population caused by expansion and severe freezes increased variability to the point where the sample being used to update the 1956 census was thought to be unreliable. This was especially true for estimates of tree numbers by type of citrus and age of tree.

Current and accurate knowledge of the citrus tree population is essential for long range planning by citrus interests and for improving accuracy of current forecasts of citrus production. The Florida citrus industry, in recognition of this need, requested the Florida Crop and Livestock Reporting Service to conduct a citrus tree census in 1965 and provided the necessary funds. The detail requested was acreage and tree inventory by major types and varieties, county of location, and date of planting. A subsequent chapter, "Present Methodology for Forecasting", is a description of techniques used to obtain the detailed information desired.

Early Efforts to Forecast Florida Citrus Production

Forecasts of production follow very closely on the heels of the successful establishment of commercial crops. The volume of production, particularly of perishables, influences many decisions made in advance of harvest. Agricultural agents of railroads were among the earliest professional crop forecasters associated with Florida citrus. The responsibility of the railroads to provide transportation for citrus to northern markets stimulated this interest.

Statisticians of the U. S. Department of Agriculture began a form of forecasting around World War I. They relied on their field observations and opinions of informed persons, including railroad agricultural agents, for these predictions. During the 1920's experimental efforts resulted in the development of a system which used grower reports as a basis for crop forecasts.

In 1926, the U. S. Department of Agriculture began a sequence of monthly citrus crop forecasts based primarily on growers' reports which were evaluations of the "condition" of the crop in their locality in terms of "percent of a full crop". Summarized reports of condition were interpreted by graphic regression of historic series of condition reports and production estimates. It should be added that production indicated by this method was often tempered by further subjective interpretation in deciding on the published forecast. Experience with growers' reports of condition have shown that this approach is not reliable, particularly in years of substantial change.

New forecasting techniques were inaugurated by the Florida Citrus Control Committee in 1936.[5] This agency, formed under state law to stabilize prices for citrus, had a vital interest in production estimates as a basis for marketing decisions. Their forecasts in the 1936-37 season were based on subjective evaluations of yield for a selective

[5] Letter from W. W. Hubbell, Florida Citrus Commission, June 24, 1939.

sample of "key groves" which were felt to be representative of varieties and growing conditions in individual counties. Only groves for which there were accurate production records from past seasons were included in the sample. The system is most noteworthy for introducing the first program of sequential growth measurements of fruit on an operational basis. The work was handled by the Florida Citrus Commission in the 1937-38 season.

In 1944 the Growers Administrative Committee inaugurated a series of August "condition reports" obtained from their frame count personnel. This effort to express subjective appraisals in quantitative terms was less than successful as a measure of crop production and was discontinued in 1957.

Frame Count

The Growers Administrative Committee began citrus production forecasts in the fall of 1939 by the "Frame Count and Caliper System."[6] The origin of this system is credited to the California-Arizona Orange and Grapefruit Agency.

The frame count was the first attempt to determine objectively the year to year change in fruit population or, more correctly, fruit density. Counts were made with the aid of a frame two feet square which was positioned at eye level and as near as possible to the outer foliage of the tree. Each fruit within an imaginary tunnel extending from the frame to the center of the tree was counted. Mean counts per frame were used as a measure of fruit population per tree for individual citrus types.

The term "caliper" refers to size measurements made with diameter calipers. Initial size measurements coincided with the frame counts made in August. Average packing house size was calculated and used in the forecast model.

Change in "bearing surface" was recognized in the estimated production by a trend factor to allow for increasing productivity in younger bearing trees.

Forecasts were based on a ratio type estimator. The relative change in number of fruit per frame and average fruit size in the forecast year from the base year were combined with the trend factor to develop an aggregate ratio or index. This multiplied by the base year production provided a forecast.

---

[6] Unpublished report of the Growers Administrative Committee, September 25, 1942.

The "frame count and caliper system" as described was employed by the Growers Administrative Committee and, later, by the Florida Crop and Livestock Reporting Service for over 20 years. The only major change was a shift from systematic selection of sample groves each year to a permanent pre-selected sample. Frame count was discontinued in 1962 after superior techniques were developed.

Grower and Handler Estimates

In the early 1940's the U. S. Department of Agriculture began grower and handler inquiries. These inquiries asked for judgment forecasts of production by types of fruit for groves controlled by the grower or handler. The ratio of forecasted production in the current season to the preceding season's actual production was used to calculate an index. This index was interpreted by regression analysis to develop an indication of crop size.

Theoretically, this approach was an improvement over condition reports as it could reflect, to some extent, changes in bearing surface in existing groves and new groves, and the elimination of old groves. However, grower and handler estimates proved inadequate for early season forecasts, especially when there was substantial change from the previous year's production. General use of the index was discontinued in 1962 but it was used to divide the seedless grapefruit forecast into white and pink varieties until 1968.

The hazards of subjective crop forecasts based on opinions were illustrated in the 1966-67 season when pick-outs exceeded forecasts made by many firms by margins of 30 to 50 percent.

Route Sample and Row Count

It was recognized that early season citrus forecasts need amending as soon as possible during the harvest season. In 1952 sample surveys designed to determine the proportion of groves picked were initiated. The sample used in these surveys consists of rows of citrus fronting on a network of 1,500 miles of roads serpentined through the citrus area. This sample was partitioned into 15 routes, each designed to be traversed in a working day, and rows were indexed as to age and type of fruit. Teams survey the route sample on or about the first day of each month during the harvest season and classify each of about 175,000 rows as either harvested or not harvested, based on visual evaluation. The proportion of rows picked and the volume of that fruit type harvested to the first of any month are the basis of an index of production. These indices are interpreted by regression analysis using actual production. This indication, though biased, provides a reliable basis for revising forecasts when harvest is past mid-point.

The developmental work on this system was provided by Florida Citrus Mutual and the Growers Administrative Committee (GAC). The survey was conducted by GAC until 1961 and is now incorporated in the program of the Florida Crop and Livestock Reporting Service.

Pickout Records

In the early 1950's, the Florida Crop and Livestock Reporting Service instituted a program of collecting the actual production of individual groves to aid in forecasting. It was assumed that year to year changes in the selective sample of groves would be a measure of year to year change in total crop. This effort was abandoned in 1964 after it became evident that such data were reliable only when the harvest season was nearly over.

Trend Toward Objective Yield Surveys

The level of production for citrus in any one season is determined by the interplay of four variables that determine the size of any crop. These are: (1) number of acres or trees, (2) average number of fruit per tree at a specified time, (3) proportion of fruit ultimately harvested (total minus droppage), and (4) average size or weight per fruit at harvest time. Acreage or trees of bearing age are determinable, barring extremely adverse weather or economic factors, well ahead of the forecast season. Growing conditions and cultural practices influence the other factors. Relative importance of these variables on year to year changes in production is depicted by Figure 1, page 14.

Improved Frame Count

Kelly[7] described a technique for improving the frame count method which was later refined by Stout.[8] The concept of tree bearing surface was used. Appendix I shows Kelly's derivation of the formula used to calculate tree bearing surface. Briefly, the tree height, width, and distance from ground to bearing surface were incorporated in the derived equation for the surface of rotation of a parabola. This provided an approximate sampling rate (bearing surface within the frame ÷ total bearing surface of tree), which could be used to expand frame counts to total fruit population per tree.

---

[7] Kelly, B. W., "A Method of Forecasting Citrus Production in the State of Florida," unpublished Ph.D. dissertation submitted to University of Florida, August 1953.

[8] Stout, R. G., "Estimating Citrus Production by Use of Frame Count Survey," Journal of Farm Economics, Vol. XLIV, No. 4, November 1962.

Recent use was made of the frame count method of estimating average fruit per tree in forecasting production of Temples, tangerines, tangelos, and Murcotts from 1962 through 1966. Further research (summarized in Appendix I) pointed out the advisability of replacing the frame count with the limb count method described under "Present Methodology for Forecasting." The change was implemented during the 1967-68 season.

Limb Count

In 1954, R. J. Jessen suggested a method for estimating fruit per tree based upon counts of fruit on sample limbs. The sample limbs were determined by selecting a limb tip within ground reach and following this limb to the point where its cross-sectional area (c.s.a.) was 10 percent of the trunk c.s.a. This sample branch was marked and its fruit counted in successive years.

A modification of the method, which proved much more successful, was soon adopted for use in the "limb count survey" and described in Jessen 9/ and Kelly 10/. This method introduced a random selection of sample limbs at successive stages beginning at the trunk or scaffold. It was based on the relatively high positive correlation between fruit population and limb size as determined by the cross-sectional area at its origin. Selection of limbs with known probabilities permits efficient and unbiased estimation of number of fruit per tree.

In order to put the sample for the limb count survey on a statistically sound basis, the sample frame used for selecting groves and trees was gradually (1963 to 1969) converted from a restricted frame to the total population. The sample groves from the total population were originally systematically drawn with probability proportional to number of trees in the strata and substrata, such that the sample would be self-weighting for location and age of tree. The recent increase in proportion of young trees has led to a shift from a self-weighting sample in favor of an optimum allocation of sample by age strata (effective 1966).

Size and Growth of Fruit

The importance of improving methods to obtain the other components of citrus production was emphasized by Stout 11/. Rate of fruit

---

9/Jessen, R. J., "Determining the Fruit Count on a Tree by Randomized Branch Sampling," Biometrics, Vol. II, No. 1, March 1955, pp. 99-109.

10/Kelly, B. W., "Objective Methods for Forecasting Florida Citrus Production," Estadistica, Journal of the Inter American Statistical Institute, March 1958.

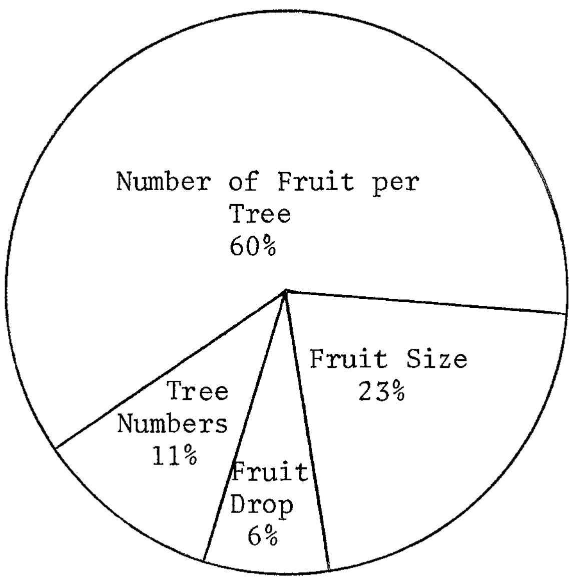
11/Stout, R. G., Size of Fruit and Droppage Rates Influence Total Citrus Production, Agricultural Economics Report No. 62-2, July 1961.

growth was being measured monthly as early as 1951 by calipering the diameter of sample fruit on sample trees at 30-day intervals. In 1954 the diameter calipering of sample fruit was replaced by circumferential measurements which were more suited to large scale surveys demanding precision. Mean fruit sizes were converted to volumes, and then to number of fruit per 90-pound box (85-pound box for grapefruit).

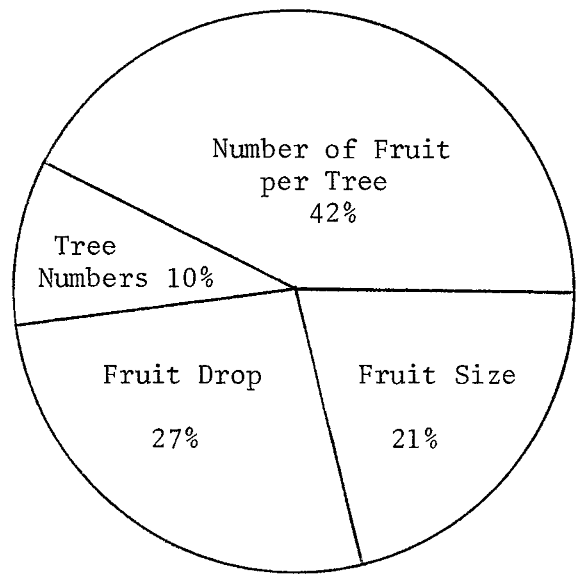
Fruit Loss

Fruit droppage is a factor in establishing an estimate of the amount of fruit to be harvested. From 1956 to 1959, rate of drop was determined by counts of fallen fruit under specified trees. The clearing of vegetative growth to facilitate counting raised the possibility of deferential treatment for the sample trees. Reliability of the monthly counts was also questionable when fruit was small, when temperatures were high or the rainfall was heavy, or when the groves had been cultivated. The lack of accuracy caused this method to be replaced by the present system of comparing monthly counts of fruit remaining on sample limbs. The first of these monthly surveys occurs in August, coinciding with the "limb count" survey.

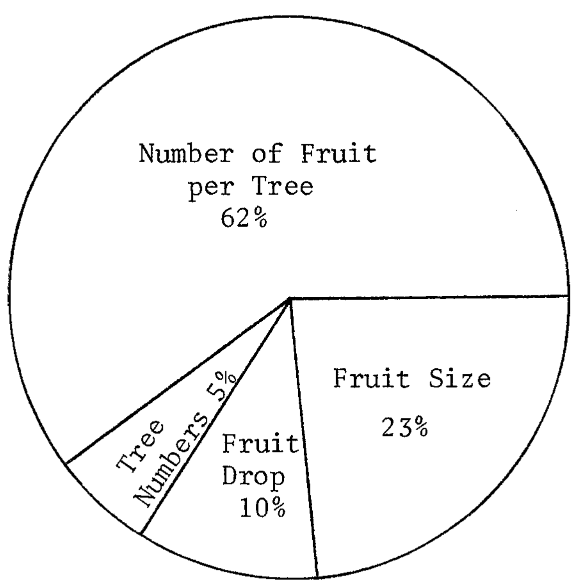
Figure 1: Relative Importance of Factors Affecting Average Annual Change in Florida Citrus Production 1960-61 to 1967-68



Early and Midseason Oranges



Valencia Oranges



Seedless Grapefruit

III. PRESENT METHODOLOGY FOR FORECASTING

Current Tree Inventory

Results of the 1965 census of Florida citrus trees, published in Commercial Citrus Inventory by the Florida Crop and Livestock Reporting Service, climaxed the initial step in a new method of keeping a detailed and current record of all citrus acreage in the state. Aerial photography played a major role in this rapid and efficient method of obtaining a current tree census. The 1956 census and subsequent field work provided accurate basic information for many of the groves in the state.

During November and December of 1965, aerial photography was taken of all citrus areas (about 12,000 square miles) except for minor, isolated areas which were located by subsequent light plane flights. Photography was taken from 15,000 feet with the Wild RC-8 camera, using the Universal Aviogon lens. The photo interpretation was done on rectified positive transparencies (cronoflex) with a scale of 1 inch = 660 feet. Field workers utilized ozalid copies of these enlargements.

The cronoflex enlargements were used to record block (homogeneous planting within a section) boundaries, to planimeter acreage of block, and for overall comparison with existing records. Grove alterations, new groves, and most errors in existing records were readily discernible by this comparison. The blocks for which information was lacking or incomplete were then inspected by field crews. Since many blocks contained more than one age or variety, it was necessary for field crews to use sample counts to estimate proportions of these varieties or ages. Although a follow up study indicated slight bias in total tree inventory and in age classification, it verified the overall level of the census to be subject to only minor errors. Sample methodology and post survey checks are covered in more detail in Appendix III.

The initial complete inventory as of December 1965 was updated in 1967 and again in 1969 by comparative interpretation of new photography and supporting field work.

Estimating Average Number Of Fruit Per Tree

The inventory of trees by type, age, and location is very important in the forecasting of current citrus production by fruit types. It provides a complete and efficient sampling frame of trees for sample surveys designed to estimate the number of fruit per tree. The survey currently used to estimate average number of fruit per tree begins August 1 and continues to September 15. It is referred to as the "Limb Count Survey."

Number of fruit per tree varies considerably due to different ages and locations of the trees. Most citrus trees start bearing about 3 to 4 years after planting. Production increases rapidly for about 10 years, tapers off, and reaches maximum about 25 to 30 years after planting. These tree characteristics and the vital knowledge of tree numbers by age and area allow considerable reduction in estimator variances by using a stratified sample design. Prior knowledge of fruit counts by age of tree was used to construct four strata.

Stratum	Age of Tree -years-
1	4- 9
2	10-14
3	15-24
4	25 and older

The relatively small counts on trees in stratum 1 and the smaller variances of these counts combined with the large influx of young trees into the universe allows increased efficiency by using optimum allocation of sample to age strata. Appendix IV contains additional discussion on use of total frame and optimum allocation of samples.

Since the sample block is too large to be a feasible count unit, variances on complete tree mappings were studied, and it was determined that a 10 to 20 percent limb could be counted and expanded to obtain a fairly efficient estimate of fruit population in the total tree. The sample sizes of number of groves and number of trees per grove were determined from expanded counts made on randomly selected 10 percent limbs. Data were summarized by analysis of variance using a hierarchial classification. Computed variances were used for optimum allocation of sample to age strata.

According to Kelly,[12/] a pilot survey on 50 trees was conducted in 1956, providing estimates of variance components, required sample size, and optimum allocation. His results are presented in Table 1. Subsequent analyses of variance on estimated fruit per tree from the limb count surveys (Appendix IV) indicate the pilot survey to be relatively accurate, especially when considering the small sample used by Dr. Kelly.

The aerial tree census is the source of the sample unit listing of all blocks of each major type of citrus in the state. Again, the block of citrus is not by ownership but rather is defined as being a relatively homogeneous planting with at least 90 percent of the trees being of the same age and citrus type. The block identification, tree numbers and accumulated tree numbers are listed by county and by date of planting within county for each type (a type consists of one or more

---

[12/] Kelly, B. W., "Objective Methods for Forecasting Florida Citrus Production," Estadistica, Journal of the Inter American Statistical Institute, March 1958.

Table 1: Estimated Limb Count Variance Components, 1956

Type of Fruit	Components of Variance[1/] (nested design)				Indicated[2/] Sample Size	Indicated Optimum Trees per Grove
	County	Age	Grove	Tree		
Oranges						
Midseason	0	43	118	360	519	3.5
Late	7	84	162	93	463	1.5
All					499	
Grapefruit						
Seedy	12	0	20	218	294	6.5
Seedless	20	3	69	152	418	3.0
All					370	

[1/] Variance components for number of fruit per tree estimated by limb count method. Variance components rounded to nearest thousand.

[2/] Indicated number of groves required for a maximum of 4 percent sampling error (coefficient of variation of .95 level of confidence), assuming 4 sample trees per sample grove.

similar varieties). The sample blocks for each group of a type of citrus are selected by a random number and appropriate interval increments matched with the cumulative listing of tree numbers.

After the sample groves are selected, a "pivot tree" is chosen in each sample grove. The pivot tree in each case specifies two sample clusters of four trees each; clusters can be rotated to minimize the effects of working in the trees to make fruit counts. The procedure used to designate pivot trees allows the proper proportions of outside trees to be selected (Appendix IV). Due to demise, or to improper age or type, it is sometimes necessary to substitute for a sample tree using a predetermined substitution pattern.

The third and final stage of sampling pertains to selection of a portion of the tree on which the fruit is to be counted. Counts are made on sample limbs selected by the random path technique. When this multiple stage process terminates, the selected limb (branch or group of branches) has a probability of selection proportional to limb cross-sectional area (c.s.a.). The reciprocal of this probability of selection is an efficient method of expanding sample counts to estimated total fruit on tree, due to the close correlation between c.s.a. measurements of limb size and number of fruit. In spite of several points which at first glance might appear to introduce bias, this estimator gives an unbiased estimate of total fruit on tree. Proof of the unbiasedness of the estimator, (x_i/p_i), and derivation of the probability, (p_i), are given in Appendix IV.

Application of the random path selection method is fairly simple. Branches of the primary tree scaffold (first major branching) are measured with a tape which shows c.s.a. inches. The c.s.a. and cumulative c.s.a. inches are recorded for each limb on the field sheet (see Appendix IV) where "limb" is defined as being a branch or grouping of adjacent branches totaling 10 percent or more of the cumulative total c.s.a. at the first scaffold level. A selected number from a random number table determines the individual portion selected. The measuring and random selection process is repeated at the next and succeeding branches until the "10 percent" limb is selected. Subsequent studies corroborate Kelly's 13/ and Jessen's 14/ contention that a limb representing 10 to 20 percent of the tree is the most efficient size for citrus. A logical alternative to the 10 percent sample limb would be two 5 percent limbs. However, smaller limbs appear to have a lower correlation between c.s.a. and fruit count. Sample size and selection within trees is being studied to determine if a change from the single limb is warranted.

The principle involved in the "limb count" is depicted in Figure 2 on page 19. The step-wise procedure includes measurement of the first scaffold c.s.a. to determine that approximately a 19-inch limb (10 percent of 190 square inches) is needed to provide the sample unit. The route toward the sample limb is determined by a random number from 1 to 190 and the cumulated c.s.a. measurements. In the example, the 100-inch limb was the random hit. This limb had a probability of selection of 100/(100 + 90). At the second scaffold the illustrated selection was the 20-inch limb and the 187 fruit on that limb were counted. The probability of selection at the second stage was the first stage probability times the second stage probability given that the first stage selection is known. In the example then, the probability of the 20-inch limb being the sample limb is:

$$\frac{100}{100 + 90} \times \frac{20}{20 + 40 + 50} = \frac{100}{190} \times \frac{20}{110} = \frac{20}{209}$$

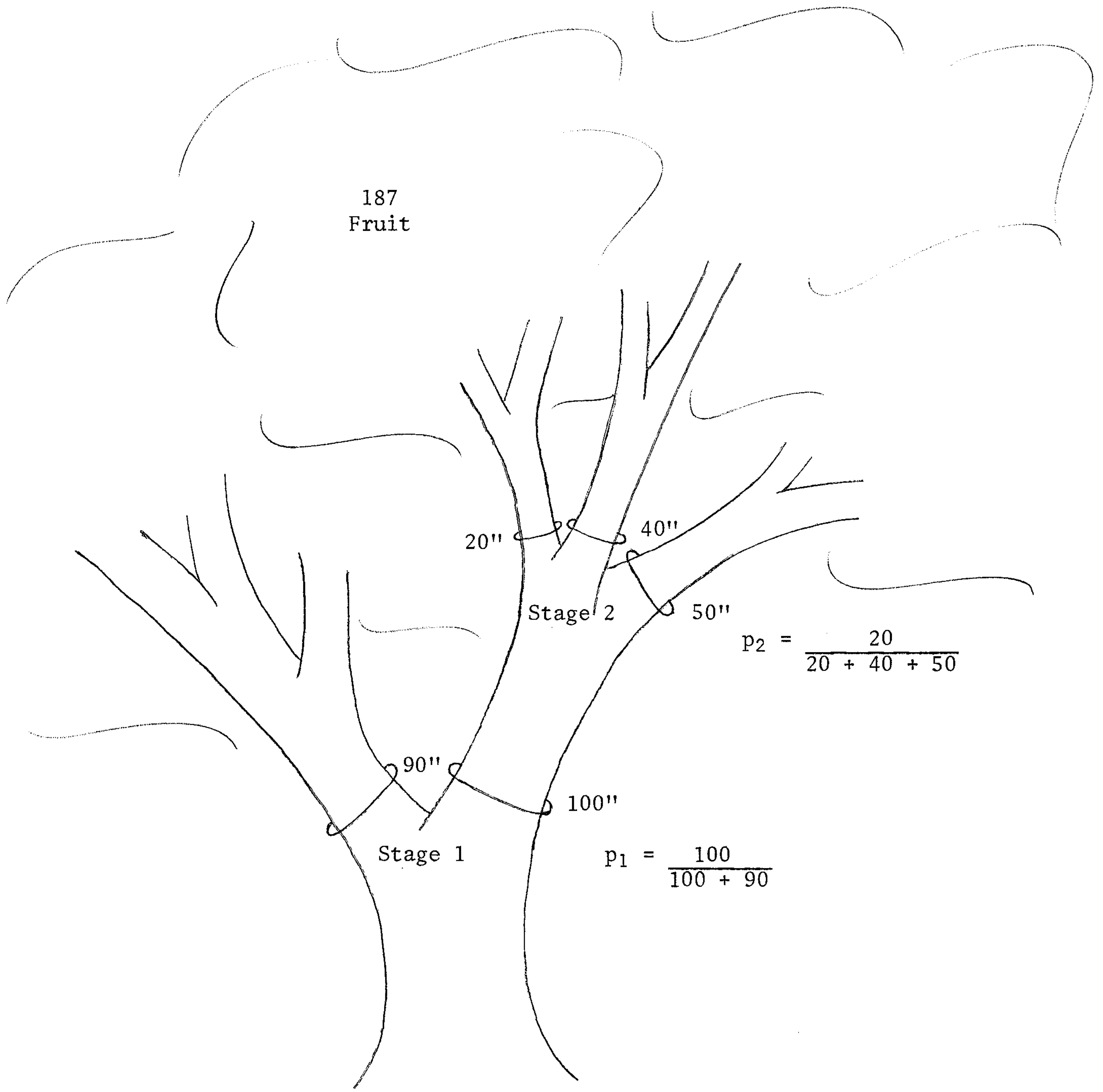
The sample count of 187 is expanded by the reciprocal of the probability to give the estimate of 1954 fruit on the tree (187 x 209/20 ≐ 1954).

Counts of fruit on each "10 percent" limb are made by categories based on the major bloom cycles. Categories are determined by size of fruit at limb count time as shown in Table 2.

13/ Kelly, B. W., "A Method of Forecasting Citrus Production in the State of Florida," unpublished Ph.D. dissertation submitted to University of Florida, August 1953.

14/ Jessen, R. J. "Determining the Fruit Count on a Tree by Randomized Branch Sampling," Biometrics, Vol. II, No. 1, March 1955, 99-109.

Figure 2: Random Limb Selection With Probability Proportional to Cross-Sectional Area



$$p_2 = \frac{20}{20 + 40 + 50}$$

$$p_1 = \frac{100}{100 + 90}$$

Estimated Fruit per Tree

$$\text{Fruit Count} \times \frac{1}{p_1} \times \frac{1}{p_2} = 187 \times \frac{100 + 90}{100} \times \frac{20 + 40 + 50}{20} \doteq 1954$$

Table 2: Fruit Size Classifications Used in Limb Count Surveys

Fruit Type	Diameters of Fruit Size Classifications		
	"Regular" Bloom	"First Late" Bloom	"Second Late" Bloom
	Inches	Inches	Inches
Grapefruit	over 1 1/4"	13/16" - 1 1/4"	less than 13/16"
Oranges1/	over 1"	11/16" - 1"	less than 11/16"
Tangerines	over 11/16"	5/16" - 11/16"	less than 5/16"

1/ Same sizes used for tangelos and Temples.

Many of the trees have branches which, due to dead limbs or major pruning, carry much less bearing surface than indicated by c.s.a. at the scaffolding. Therefore, in the limb selection process, a reduced c.s.a. obtained by measuring branches beyond major prunings is accepted for determining probability of branch selection. Dead limbs are not measured. If this is limited to major reductions it is a worthwhile method of reducing the variance of the estimator.

After the sample limb is selected, it is divided into smaller units for counting purposes. Two separate fruit counts are made, each by a different member of the survey crew. If the two counts do not agree within a specified tolerance, additional counts are made.

A random selection of one of the 10 percent limbs in a 10 percent random subsample of limb count groves is made as a quality check of the original counts. These quality checks indicate the present methodology provides a fairly consistent under-count of about 1 percent.

Forecasting Fruit Drop

A measure of fruit mortality prior to harvest must be introduced into computed crop forecasts because initial estimates of the average number of fruit per tree are established from counts in August and September. Natural loss of fruit, from August until the month in which each type of fruit is considered mature, is measured by a sequence of monthly surveys. Maturity is considered to be reached in predetermined cut-off months which precede the heaviest harvest period. Cut-off months are: December for tangelos and tangerines, January for Early and Mid-season oranges, February for Temples and grapefruit, and April for Late-season oranges.

The sample trees for droppage surveys are drawn from the route frame rather than the limb count frame, since the route frame is readily accessible for monthly observations. This sample frame consists of all bearing commercial groves fronting on a 1,500 mile route which traverses producing areas of the most important counties. This microcosm of the citrus population provides a satisfactory base for sampling drop and other relatively uniform characteristics.

The sample for each variety is stratified into four areas (homogeneous county groupings) and the four age groups previously discussed. The sample size within strata is based on productivity in a base year.

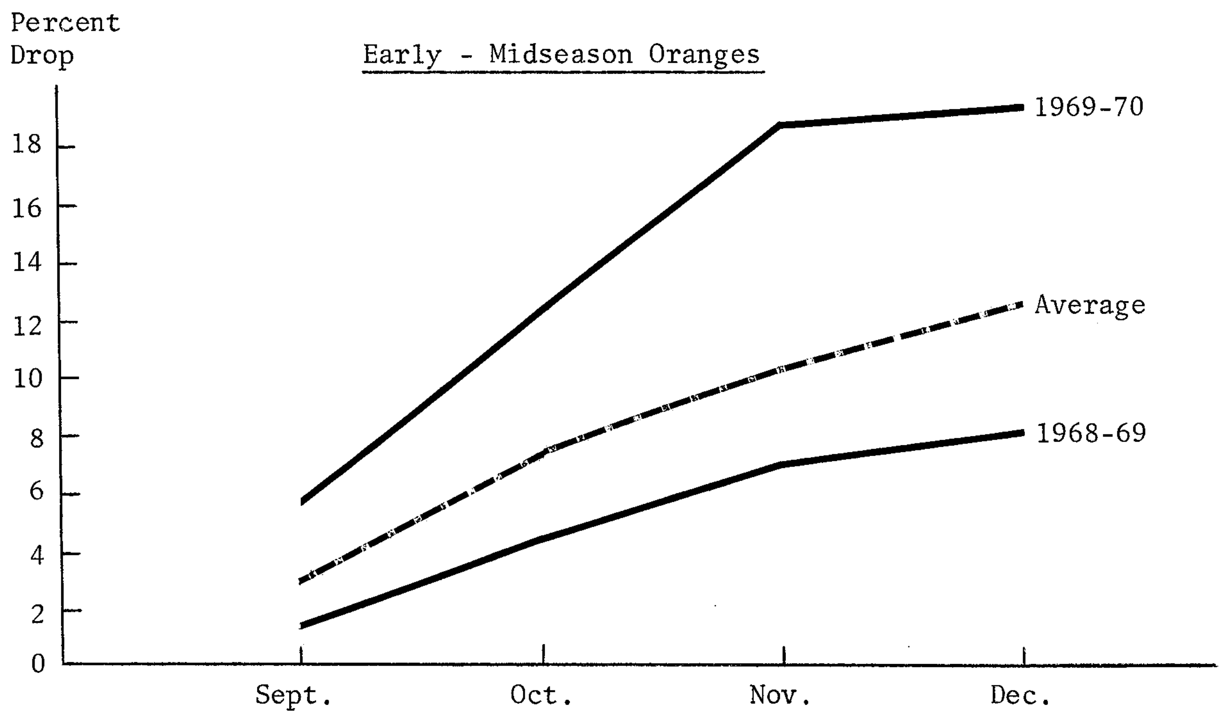
A sample limb approximately two percent of the trunk c.s.a. is selected near shoulder height, on a designated side of the tree. This limb is tagged and all fruit beyond the tag are counted during successive surveys. The monthly counts are entered on the pocket-notebook-size field sheets shown in Appendix IV. These counts are then recorded on IBM punch cards for summarization of identical groves. The differences between the initial survey counts and later survey counts indicate the droppage to the time of the survey. The average drop for each age-area strata is computed and then combined by production weights into the average drop for the state. The sample counts are weighted because groves are selected with probability proportional to production and the "two percent" limb sampling method tends to put a disproportionate part of the sample in older, more productive trees.

The monthly drop rates are adjusted by the estimated proportion of total crop harvested by the survey date. The accumulated fruit drop represents only those groves not yet harvested. The Harvest Adjustment Form shown in Appendix VI is designed to aid in making these adjustments. The adjusted monthly droppage is projected to the cut-off month to estimate seasonal drop rate for use in the forecast models.

As indicated in Appendix VI, the 2,000-tree sample in 1966-67 indicated the proportion of oranges remaining for harvest with a maximum error of three percent at the .95 level of confidence. The sampling errors of the drop survey are expressed as the coefficient of variation for the proportion of fruit remaining to be harvested (1-proportion drop) since this is the error contribution to the production forecast.

Prior to the 1970-71 season, monthly projections of fruit loss expected to occur prior to the cut-off month were made by grapic interpretation of charts similar to those in Figure 3. Although this procedure was satisfactory during years in which loss of fruit was within the normal range, experiences in recent seasons suggested that visual interpretation was not sufficient, particularly when the rate of drop was much higher or lower than usual. Starting in 1970 multiple regression formulas have provided additional means of estimating total fruit loss.

Figure 3: Fruit Drop Curves
Extreme Years and Average of 1963 - 1969 Seasons



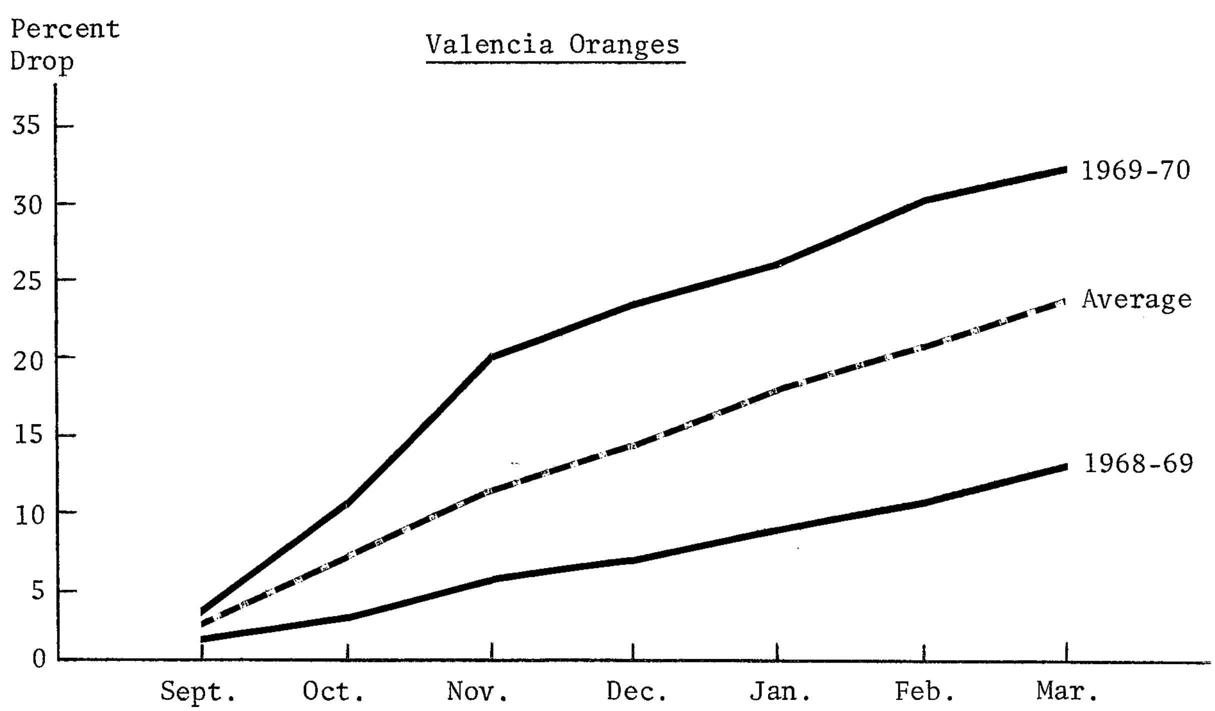
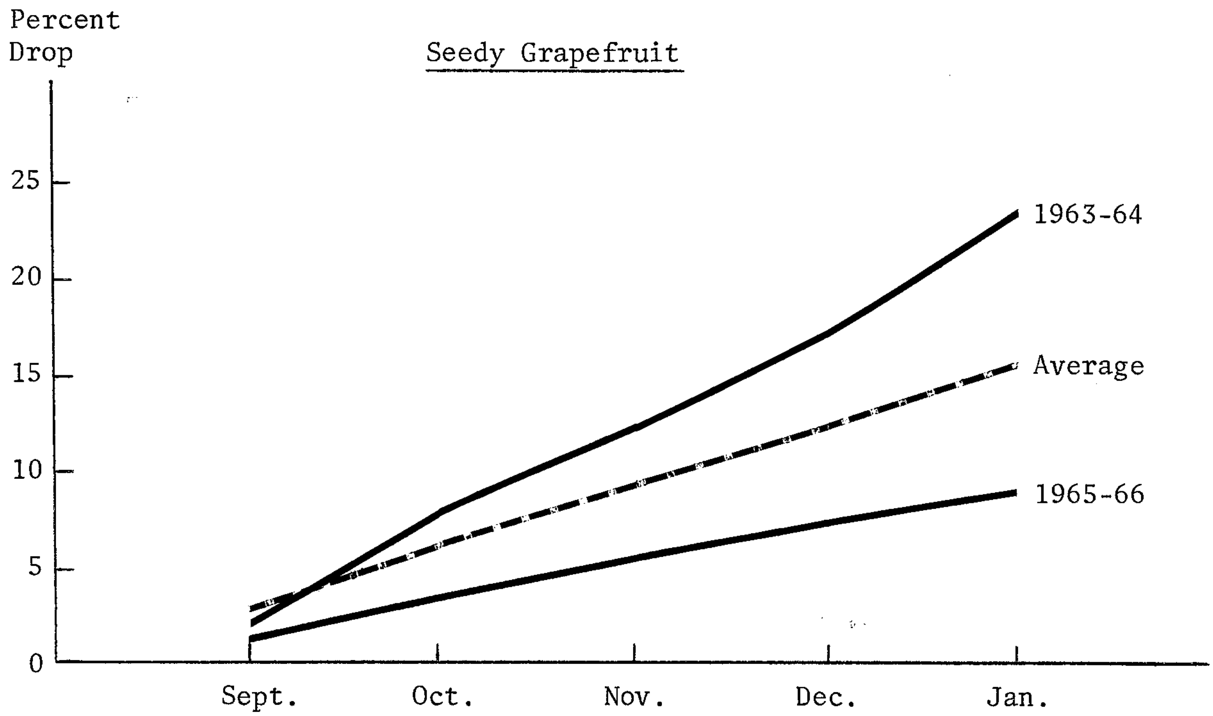


Figure 3: Fruit Drop Curves
Extreme Years and Average of 1963 - 1969 Seasons



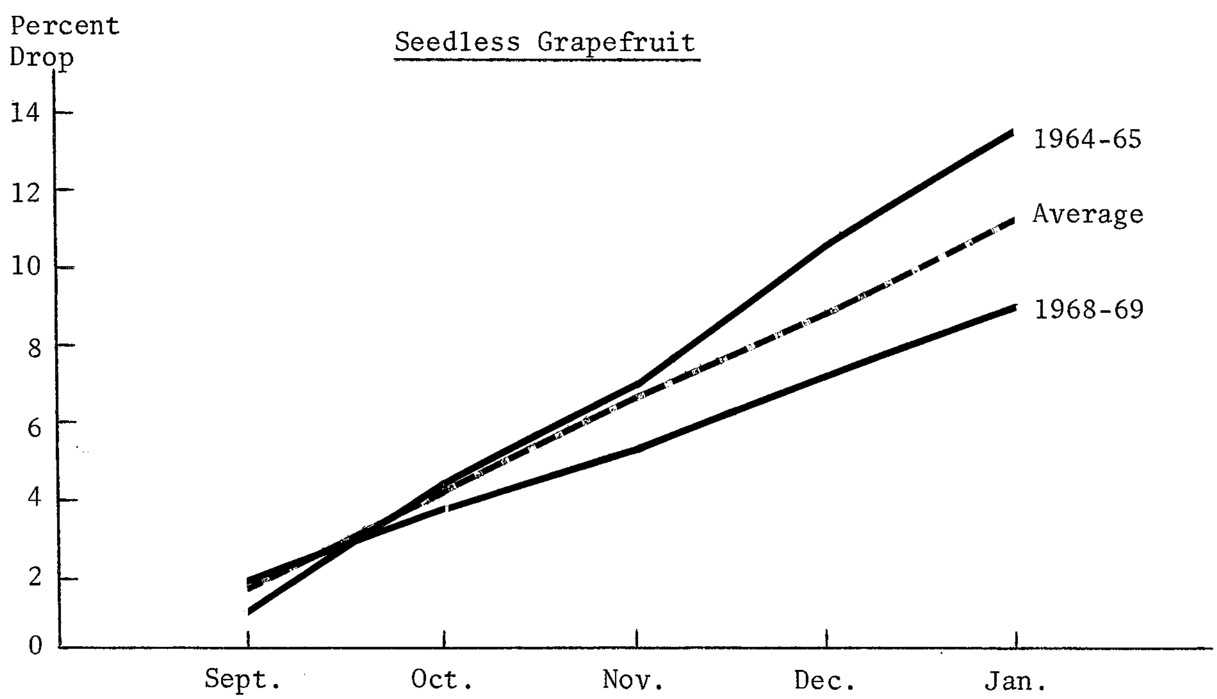
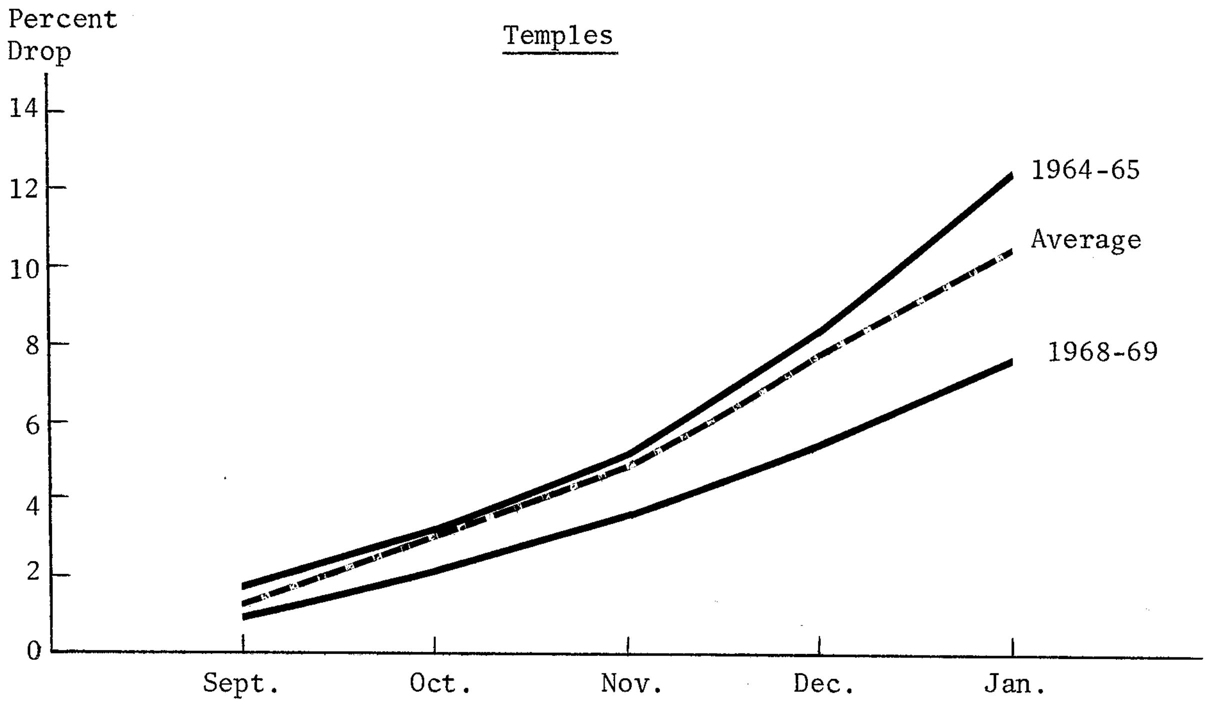


Figure 3: Fruit Drop Curves
Extreme Years and Average of 1963 - 1969 Seasons



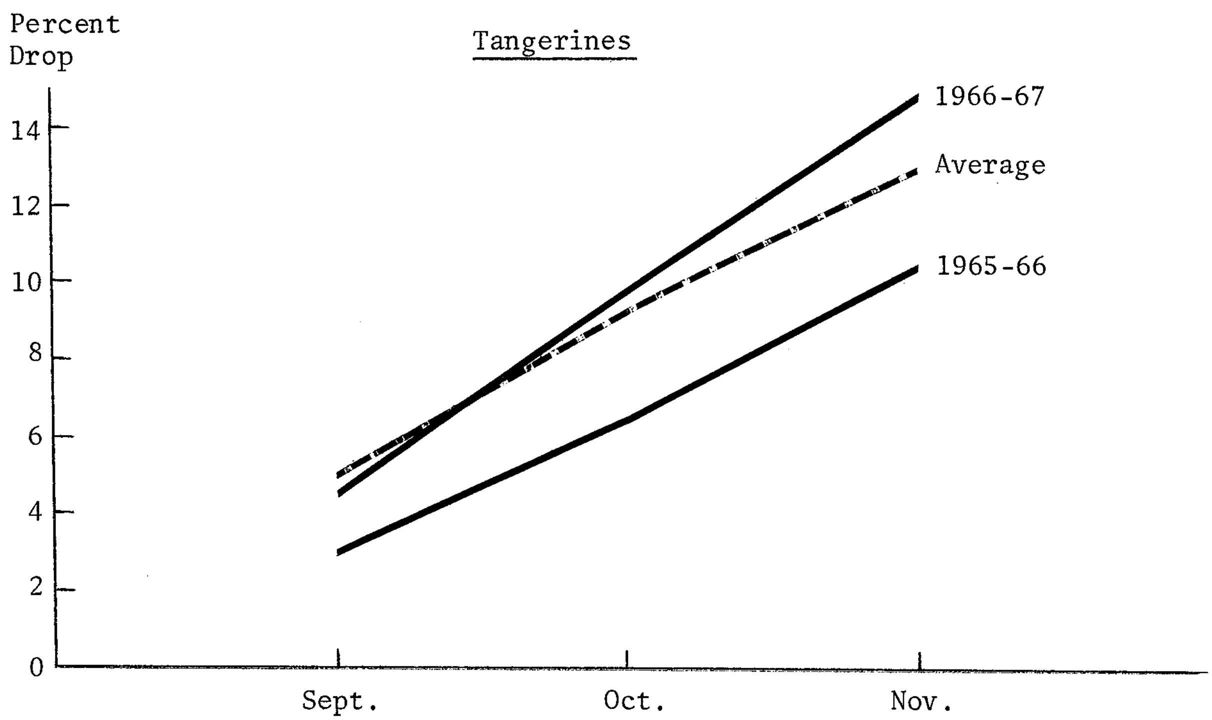
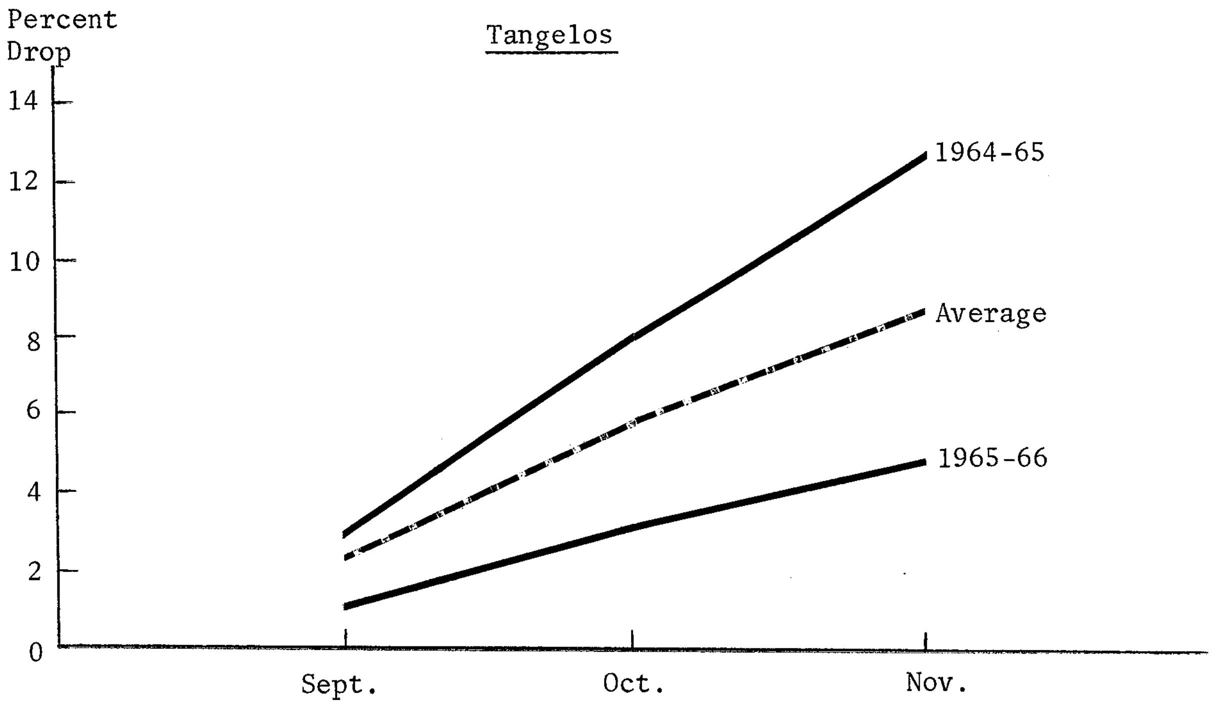


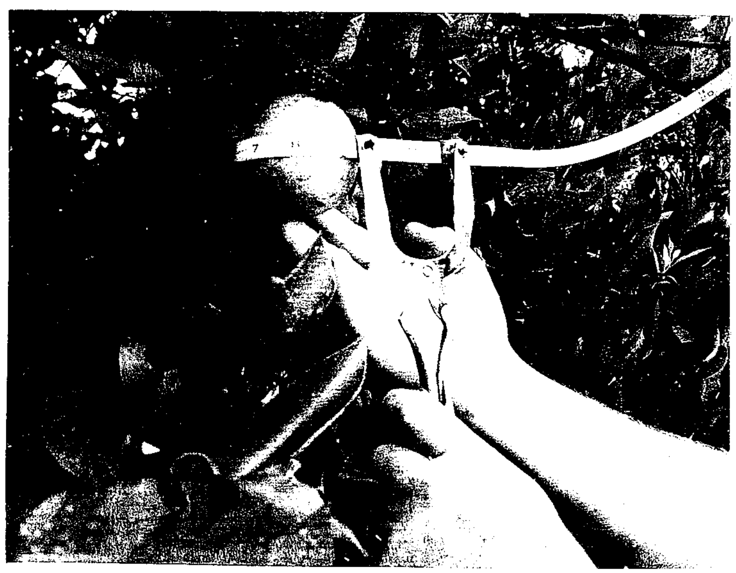
Figure 3: Fruit Drop Curves
Extreme Years and Average of 1963 - 1969 Seasons



Forecasting Average Harvest Size of Fruit

The fruit size survey coincides with the drop survey. Moreover, the same subsample of trees in sample groves drawn from the route frame is used for both sets of monthly observations. In the size survey ten sample fruit per tree are measured from a two-tree cluster per sample grove. Frequency distributions of standard fresh fruit sizes and the estimated average size are obtained each month.

The fruit to be measured are determined by a "random grab" or point on the tree about shoulder height. This point on the tree is tagged and, for each survey, horizontal circumferences are measured on the ten regular bloom fruit nearest the tag. The photograph illustrates the position of measurements and the device used to obtain the circumference.



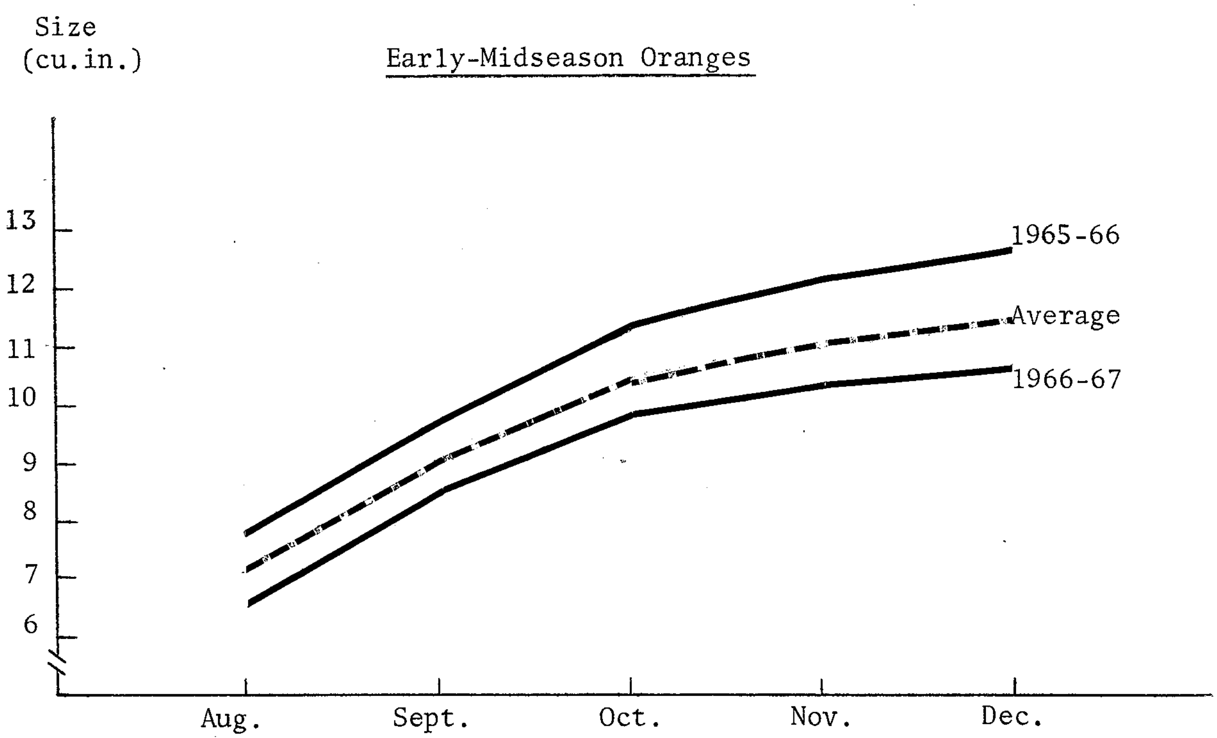
These circumference measurements are entered as a tally on the 240-cell field form shown in Appendix V. Summarization is done in volume which is linearly correlated to weight and, therefore, additive. The weight to volume relationship has coefficient of determination of .96 which is pertinent to a production estimate, since most of the citrus crop is received or purchased on a weight basis.

Figure 4 depicts the growth rates of various citrus types. The dates shown are the month in which surveys were conducted; usually surveys were near third week of each month. The annual growth curves generally parallel each other, thereby allowing these relationships to be a fairly effective tool in forecasting size at maturity. It should be noted that fruit measured on-tree does not reflect harvest size. Early observations are of immature fruit and measurements for forecasts usually cease prior to volume harvest. The size of fruit at maturity is defined as the average size of fruit in groves in a specific month. These cut-off months are the same as in the drop surveys. Prior to the cut-off month, it is necessary to estimate the average size fruit will attain in the cut-off month.

A regression using three variables is used to forecast size at the cut-off month. Estimates of parameters are shown in Appendix V. The three variables are (1) current month's average size in cubic inches, (2) growth during the preceding month and (3) average number of fruit per tree for that type. The multiple regression has provided a sounder indication of final size than a subjective evaluation of the importance of these factors in arriving at a forecast size. In 1967-68 a subsample of fruit on 1,200 sample trees used in size surveys provided a maximum error at the .95 level of confidence of about 1.5 percent on average fruit size for all oranges.

The citrus check data, with which the forecast must be compared, is the number of certified boxes--90-pound boxes for oranges, tangelos and Temples; 95-pound boxes for tangerines; and 85-pound boxes for grapefruit. The forecasted average volume per fruit is converted to number of fruit constituting a box. This number depends upon type of fruit, size of fruit and whether the fruit is sold for the fresh market or is used in processing. The curvilinear relationships are fitted by equations of the form $Y=a + bX = \frac{c}{X}$, where Y is the average number of fruit per box and X is the average size of fruit. Coefficients for the fresh and processed lines are then weighted together by utilization of the crop (previous season's proportion) to provide a basis for converting average volume for each type to "fruit per box" as shown in Appendix V. This method of converting volume to fruit per box also compensates for the deviation from spherical shape in converting circumference to spherical volume.

Figure 4: Fruit Growth Curves
Extreme Years and Average of 1963-1969 Seasons



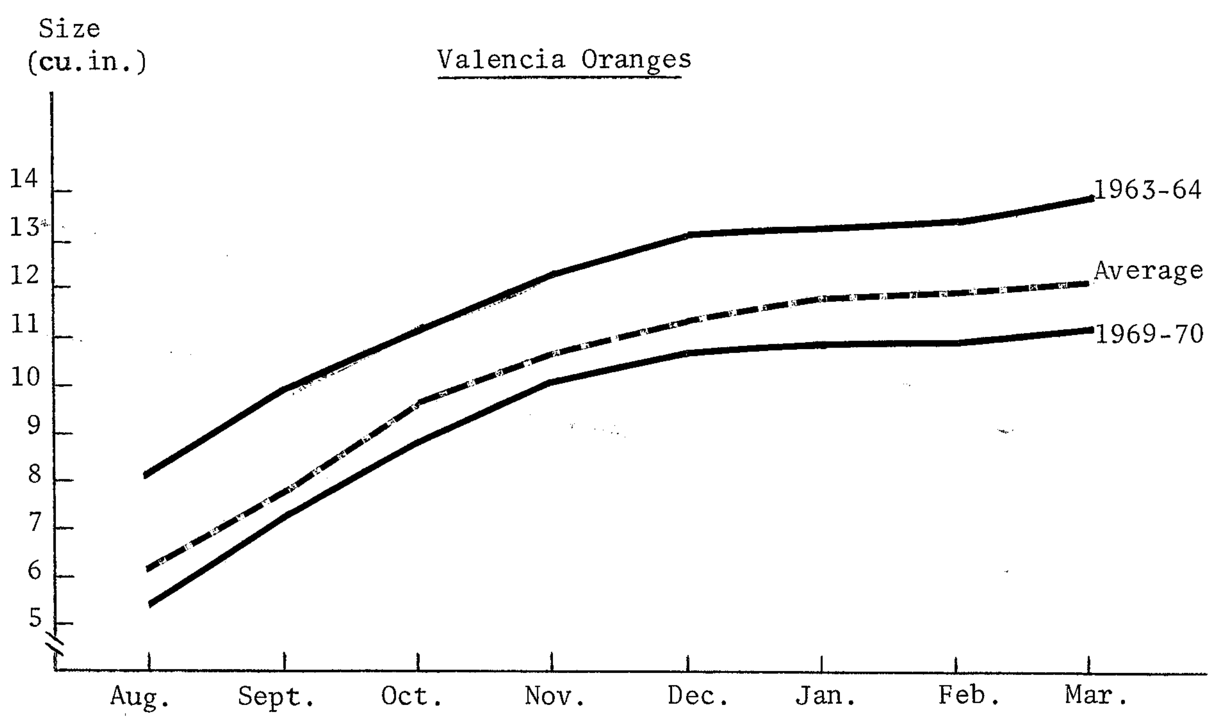
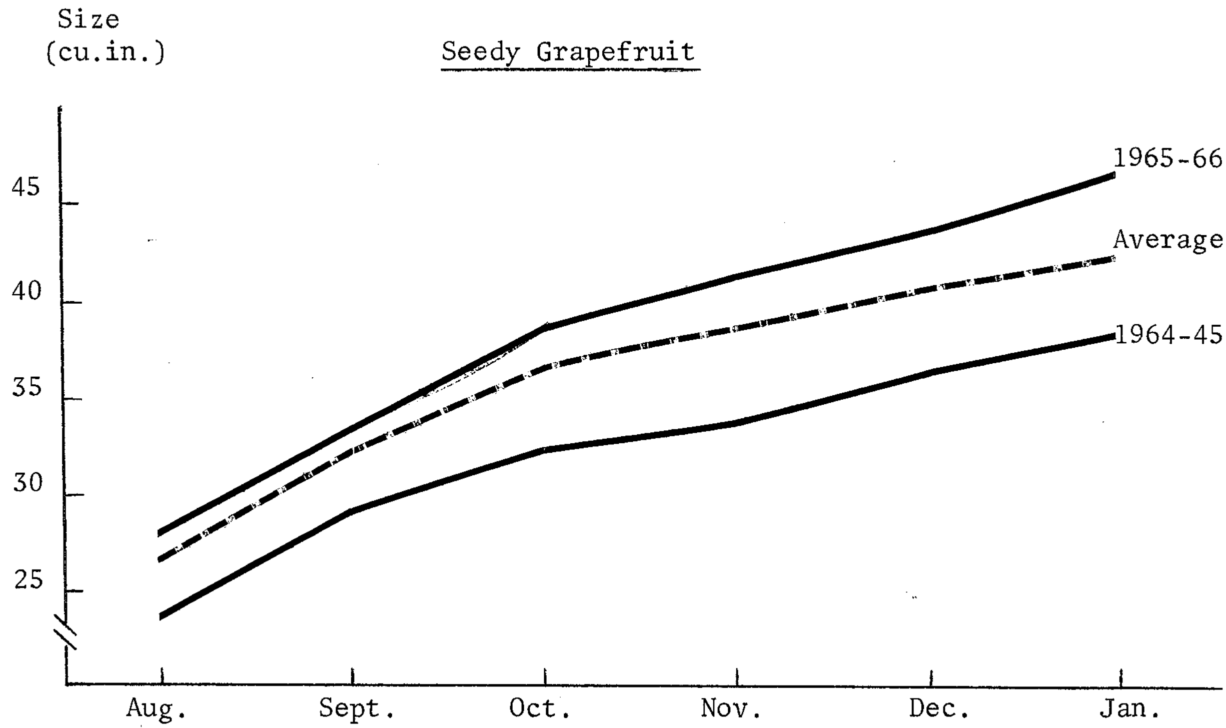


Figure 4: Fruit Growth Curves
Extreme Years and Average of 1963-1969 Seasons



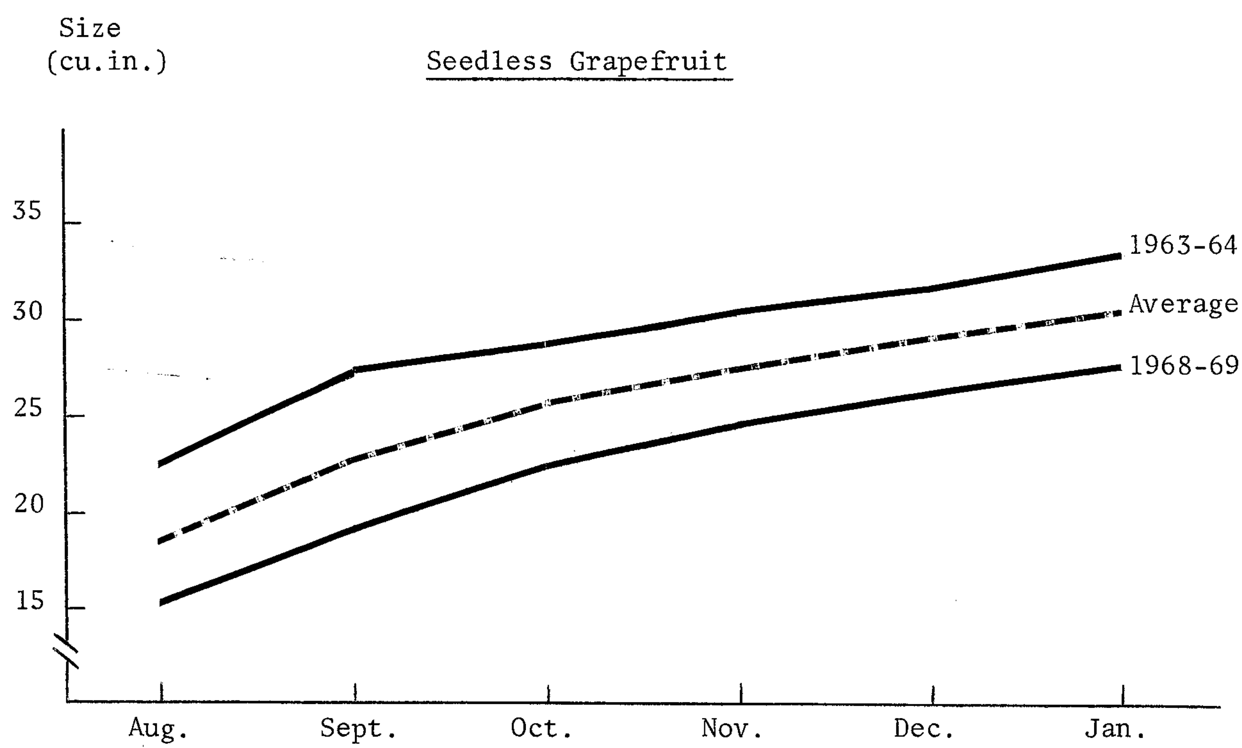
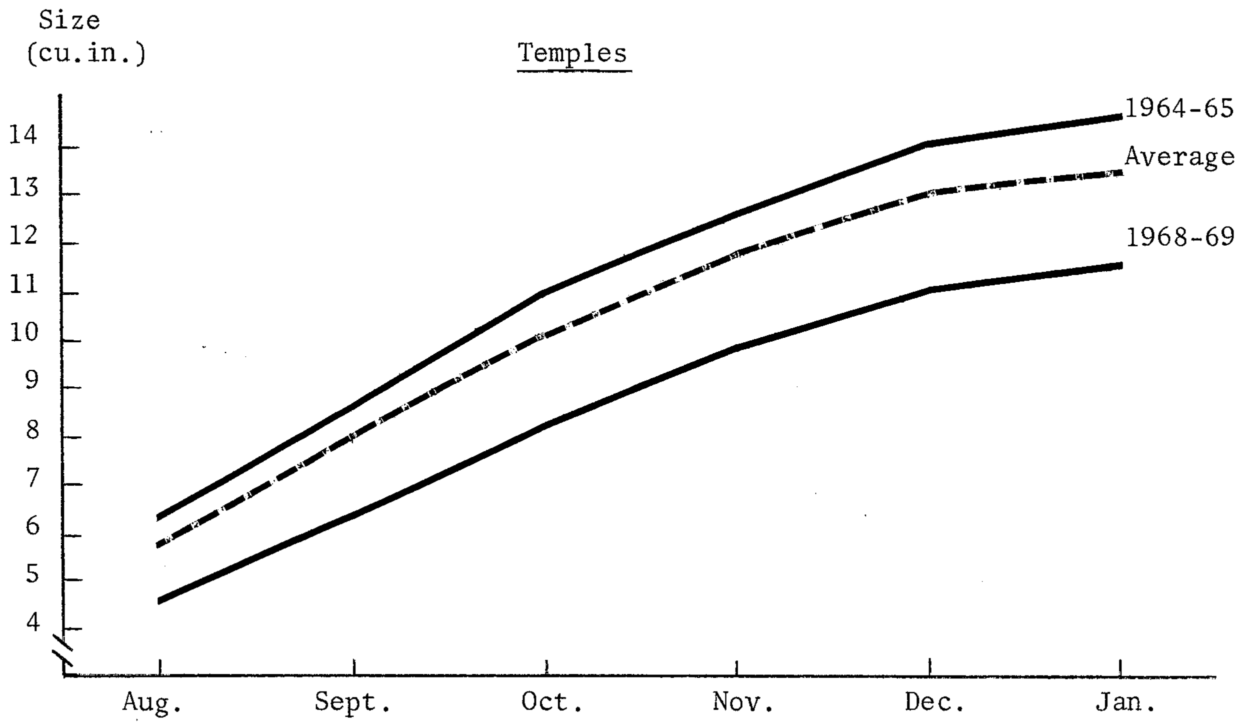


Figure 4: Fruit Growth Curves
Extreme Years and Average of 1963-1969 Seasons



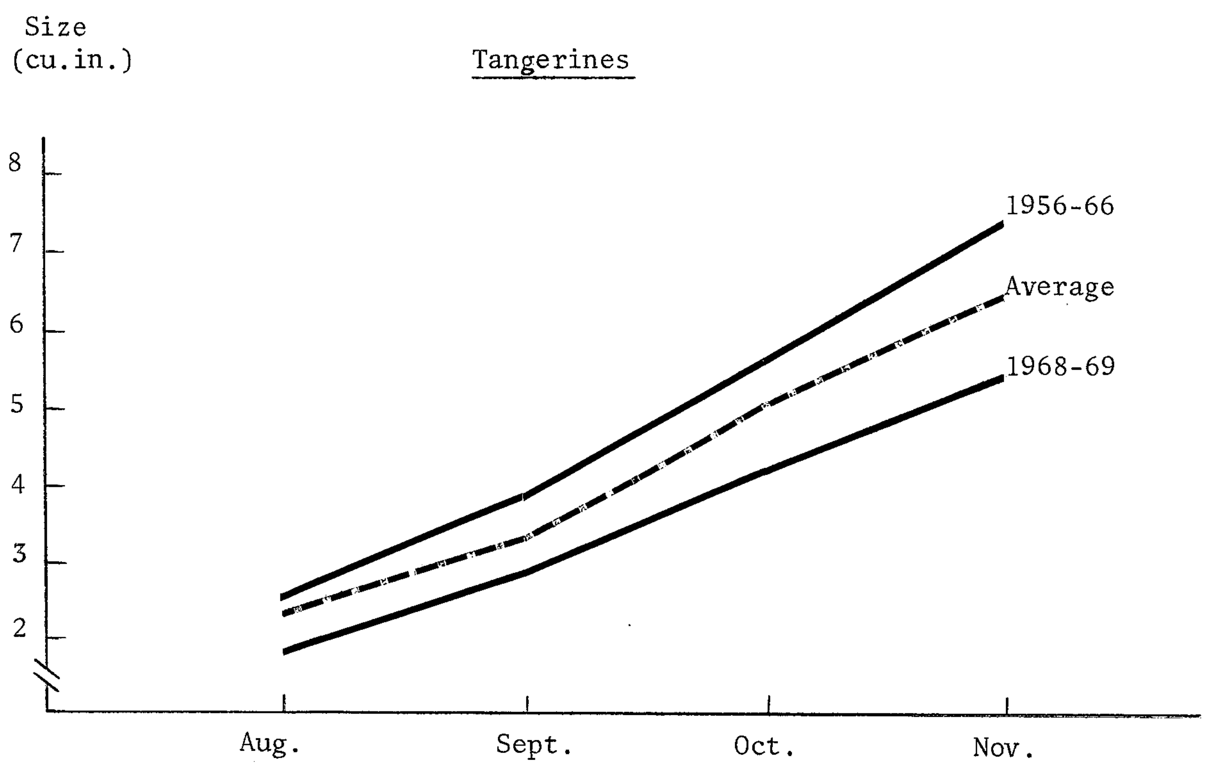
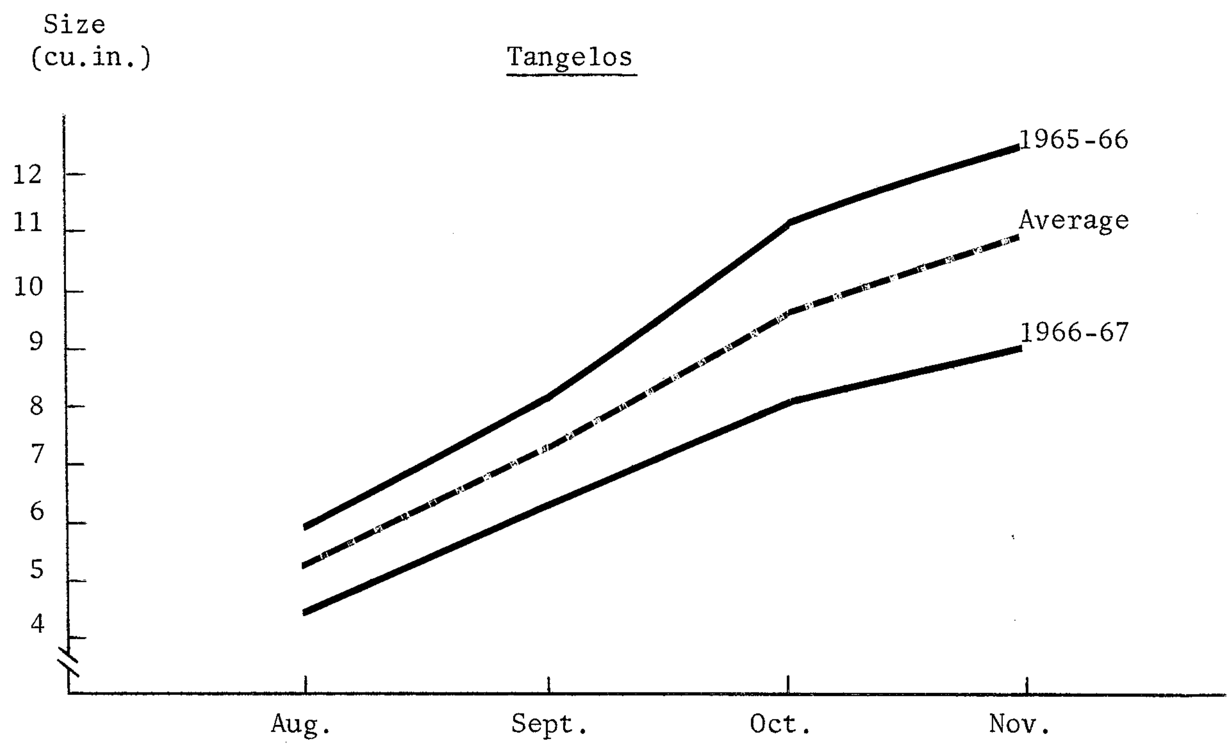


Figure 4: Fruit Growth Curves
Extreme Years and Average of 1963-1969 Seasons



Production Forecasting Models

Two models have been used to combine the four components which determine citrus production. One of the models uses the relative change of components:

$$P_t = \frac{T_t}{T_{t-1}} \times \frac{F_t}{F_{t-1}} \times \frac{H_t}{H_{t-1}} \times \frac{S_{t-1}}{S_t} \times P_{t-1}$$

The other uses a direct expansion estimator: $P_t = \frac{T_t \times F_t \times H_t}{S_t}$

Where:
- P = production
- T = number of bearing trees in the population
- F = average number of fruit per tree in September
- H = forecasted proportion of fruit to be harvested
- S = forecasted harvest size expressed as fruit per box
- t = forecast year
- $t-1$ = previous year

Series of the components of production are shown in Table 3 for the major types of citrus, while Table 4 shows resulting indications and accuracy. As a numerical example, the data for 1965-66 Valencia oranges are shown in the two models:

Relative Change: $P_t = \frac{17{,}496{,}000}{16{,}141{,}000} \times \frac{619}{714} \times \frac{.741}{.711} \times \frac{222}{193} \times 39{,}800{,}000$

$= 1.084 \times .867 \times 1.042 \times 1.150 \times 39{,}800{,}000$

$= 44{,}800{,}000$

Direct Expansion: $P_t = \frac{17{,}496{,}000 \times 619 \times .741}{193} = 41{,}600{,}000$

Until recently, the relative change estimator was the principle means of predicting final production; sufficiently accurate tree numbers were not available for use in the direct expansion estimator.

Variables of the relative change estimator include trees coming into production and trees no longer in production, hence all observations are not strictly matched. The effect of the small number of trees not matched is relatively insignificant as shown in the proof in Appendix VII.

The advent of the biennial tree census caused the direct expansion estimator to become more reliable than the relative change or ratio estimator. For a ratio estimator to be more effective than direct expansion, the year to year correlation for matched observations must be fairly high (correlation coefficient of .5 or larger). The year to year correlations for size and drop are much lower than this, so that with the more reliable tree numbers and no evidence to support a constant bias, the ratio estimator

Table 3: Counts and Measurements Used in Florida Forecast Models for Cut-off Months, 1964-65 to 1969-70

Type	Crop Year	Number of Bearing Trees[1/]			Fruit per Tree[2/]		Fruit per Box[3/]		Fruit Harvested[4/]	
		Revised Tree Numbers[5/]	Forecast Trees: As Used[6/]	Forecast Trees: Adjusted Ratio[7/]	As Used[6/]	Adjusted Ratio[7/]	As Used[6/]	Adjusted Ratio[7/]	As Used[6/]	Adjusted Ratio[7/]
		Millions of Trees			Number		Number		Proportion	
Early & Midseason Oranges	1964-65	15.433	9.929	12.500	969	1104	242	243	.850	.883
	1965-66	17.113	13.325[8/]	14.200	878[9/]	798	203	209	.872	.871
	1966-67	19.336	16.733	19.275	1172	1081	246	246	.907	.907
	1967-68	21.403	21.700	21.406	586	586	210	210	.861	.864
	1968-69	23.339	23.609	23.535	814	814	242	242	.920	.920
	1969-70	25.995	26.087		873		240		.790	
Late Oranges	1964-65	16.141	11.362	14.000	809	883	215	222	.670	.611
	1965-66	17.496	14.315[8/]	16.180	803[9/]	743	193	193	.743	.741
	1966-67	19.132	17.770	18.945	955	880	216	216	.845	.845
	1967-68	20.406	20.502	20.406	570	569	211	211	.716	.714
	1968-69	21.701	21.926	21.853	716	716	221	221	.877	.877
	1969-70	23.409	23.605		801		228		.680	
Temples	1964-65	1.270	1.371		531		190		.840	
	1965-66	1.303	1.120	1.150	835	742	200	200	.912	.904
	1966-67	1.370	1.194		719		206		.912	
	1967-68	1.460	1.470	1.461	674	670	198	196	.881	.880
	1968-69	1.589	1.604	1.601	779	779	237	237	.924	.924
	1969-70	1.830	1.851		786		210		.895	
Seedy Grapefruit	1964-65	1.682	1.763	1.700	516	547	70	70	.800	.840
	1965-66	1.692	1.665[8/]	1.700	488[9/]	490	58	59	.912	.911
	1966-67	1.673	1.665	1.687	740	766	64	74[10/]	.859	.859
	1967-68	1.652	1.715	1.653	540	557	74	74	.852	.852
	1968-69	1.637	1.651	1.648	790	790	82	82	.860	.866
	1969-70	1.645	1.662		527		68		.830	
Seedless Grapefruit	1964-65	3.880	3.756	3.900	640	694	96	96	.840	.885
	1965-66	3.986	3.910[8/]	3.910	664[9/]	671	82	82	.900	.900
	1966-67	4.035	3.960	4.028	804	857	91	96[11/]	.887	.886
	1967-68	4.151	4.217	4.153	585	591	92	92	.879	.878
	1968-69	4.367	4.382	4.375	761	761	102	102	.917	.917
	1969-70	5.102	5.114		568		90		.882	

1/ Bearing trees are those considered to be 4 years old or older.

2/ Numbers of fruit per tree are those used at the time forecasts were made. For 1967-68 through 1969-70, fruit per tree is the weighted average from sample. Not all age groups were included in sample during 1964-65 through 1966-67. Fruit per tree includes all regular bloom and first late bloom fruit present in September.

3/ Number of mature fruit constituting a box, as estimated from on-tree measurements in sample groves. These "harvest" sizes were not available prior to the cut-off months. Forecasts are based upon size projections to these cut-off months.

4/ Estimated proportion of fruit per tree that matured and was harvested. Final proportions were not available until cut-off months. Monthly forecasts are made from projections of survey data. Ratios are adjusted when accurate utilization data becomes available.

5/ Tree numbers are those reported in the biennial censuses or linear interpolations between adjacent census numbers and were obtained as follows:

1964-65, December 1965 Tree Census number of trees planted in 1960 or earlier;

1965-66, December 1965 Tree Census number of trees planted in 1961 or earlier;

1966-67, average of December 1965 and December 1967 census numbers of trees set in 1962 or earlier;

1967-68, December 1967 Tree Census number of trees planted in 1963 or earlier;

1968-69, average of December 1967 and December 1969 census numbers of trees set in 1964 or earlier;

1969-70, December 1969 Tree Census number of trees planted in 1965 or earlier.

6/ Counts and measurements used in Direct Expansion Estimator for the current year. When Relative Change Estimator used different values, these values are shown in footnotes 8 and 9.

7/ Adjusted figures used in Relative Change Estimator for subsequent year, revised by means of more accurate tree numbers. More accurate utilization data changed weighted droppage rate slightly.

8/ Used in Direct Expansion Estimator; in Relative Change Estimator, 12.225 was used for Early-Midseason, 13.715 for Late Oranges, 1.655 for Seedy Grapefruit and 3.815 for Seedless Grapefruit.

9/ Used in Direct Expansion Estimator; in Relative Change Estimator, 1017 was used for Early-Midseason, 909 for Late Oranges, 497 for Seedy Grapefruit and 715 for Seedless Grapefruit.

10/ Weight adjusted to 85-pound box for 90% of production.

11/ Weight adjusted to 85-pound box for 46% of production.

Table 4: Citrus Production by Types.
Forecast Model Estimates in Cut-off Month
Compared to Actual Utilized Production
1964-65 through 1969-70

Crop Year	Production (in Millions of Boxes)			Deviation from Actual			
				Direct Expansion		Relative Change	
	Actual	Direct Expansion	Relative Change	Net	Percent	Net	Percent
Early-Midseason Oranges							
1964-65	42.6	38.9[1]	41.1[2]	-3.7	- 8.7	- 1.5	- 3.5
1965-66	47.0	48.9[3]	44.9	1.9	4.0	- 2.1	- 4.5
1966-67	73.2	72.2	71.9	-1.0	- 1.4	- 1.3	- 1.8
1967-68	51.4	52.1	49.7	0.7	1.4	- 1.7	- 3.3
1968-69	69.7	68.6[4]	68.3[4]	-1.1	- 1.6	- 1.4	- 2.0
1969-70	72.9	75.0	71.8	2.1	2.9	- 1.1	- 1.5
Late Season Oranges							
1964-65	39.8	33.1[5]	34.2[6]	-6.7	-16.8	- 5.6	-14.1
1965-66	48.9	41.6[7]	45.4[8]	-7.3	-14.9	- 3.5	- 7.2
1966-67	66.3	66.4	70.3	0.1	0.2	4.0	6.0
1967-68	49.1	39.7	40.3	-9.4	-19.1	- 8.8	-17.9
1968-69	60.0	58.6[4]	60.5[4]	-1.4	- 2.3	0.5	0.8
1969-70	64.8	56.4	54.3	-8.4	-13.0	-10.5	-16.2
All Round Oranges[9]							
1964-65	82.4	72.0	75.3	-10.4	-12.6	- 7.1	- 8.6
1965-66	95.9	90.5	90.3	-5.4	- 5.6	- 5.6	- 5.8
1966-67	139.5	138.6	142.2	-0.9	- 0.6	2.7	1.9
1967-68	100.5	91.8	90.0	-8.7	- 8.7	-10.5	-10.4
1968-69	129.7	127.2	128.8	-2.5	- 1.9	- 0.9	- 0.7
1969-70	137.7	131.4	126.1	-6.3	- 4.6	-11.6	- 8.4
Temples							
1964-65	3.8	3.2[10]	3.6[10]	-0.6	-15.8	- 0.2	- 5.3
1965-66	4.5	4.1[11]	--	-0.4	- 8.9	--	--
1966-67	5.0	3.8[11]	4.4[11]	-1.2	-24.0	- 0.6	-12.0
1967-68	4.5	4.4	--	-0.1	- 2.2	--	--
1968-69	4.5	4.9	5.0	0.4	8.9	0.5	11.1
1969-70	5.2	6.2	5.7	1.0	19.2	0.5	9.6
Seedy Grapefruit							
1964-65	10.2	10.4	11.9	0.2	2.0	1.7	16.7
1965-66	11.2	12.3	11.4	1.1	9.8	0.2	1.8
1966-67	13.5	16.7	14.4	3.2	23.7	0.9	6.7
1967-68	9.2	10.7	9.6	1.5	16.3	0.4	4.3
1968-69	12.2	13.7	11.8[12]	1.5	12.3	- 0.4	- 3.3
1969-70	9.5	10.7	9.5	1.2	12.6	0.0	0.0

Table 4: (cont'd)

Crop Year	Production (in Millions of Boxes)			Deviation from Actual			
				Direct Expansion		Relative Change	
	Actual	Direct Expansion	Relative Change	Net	Percent	Net	Percent
			Seedless Grapefruit				
1964-65	21.7	21.1	21.0	-0.6	- 2.8	- 0.7	- 3.2
1965-66	23.7	27.6	25.3	3.9	16.5	1.6	6.8
1966-67	30.1	31.1	25.7	1.0	3.3	- 4.4	-14.6
1967-68	23.7	23.5	22.1	-0.2	- 0.8	- 1.6	- 6.8
1968-69	27.7	30.0	30.5	2.3	8.3	2.8	10.1
1969-70	27.9	28.3	26.2	0.4	1.4	- 1.7	- 6.1
			All Grapefruit				
1964-65	31.9	31.5	32.9	-0.4	- 1.3	1.0	3.1
1965-66	34.9	39.9	36.7	5.0	14.3	1.8	5.2
1966-67	43.6	47.8	40.1	4.2	9.6	- 3.5	- 8.0
1967-68	32.9	34.2	31.7	1.3	4.0	- 1.2	- 3.6
1968-69	39.9	43.7	42.3	3.8	9.5	2.4	6.0
1969-70	37.4	39.0	35.7	1.6	4.3	- 1.7	- 4.5

1/ Direct expansion times weight adjustment (1.034) plus 4.0 million boxes for four years' production.

2/ Expansion formula modified to include weight adjustment and add-on of .4 million boxes for one year's production.

3/ Includes weight adjustment of .9767; 50.08 without weight adjustment.

4/ Adjusted for freeze damage, 6%.

5/ Includes 4.0 million boxes added for four years' production.

6/ Includes .35 million boxes added for one year's production.

7/ Includes freeze adjustment of .9551; 43.5 without adjustment.

8/ Additional .35 million boxes and weight adjustment of .9489 due to freeze.

9/ Production figures for All Round Oranges are sums of Early-Midseason and Late Season Oranges.

10/ Based upon Frame Count; .025 million boxes added for one year's production.

11/ Based upon Frame Count.

12/ Adjusted to 13.7 for bias, $\frac{\text{Direct Expansion Base Year}}{\text{Board Production Base Year}} = 1.16$.

is inferior to the direct expansion under present circumstances. This is corroborated by observing the ratio indication when preceded by a relatively large error in the final direct expansion estimate. If previous year's direct expansion is too high, in most cases the current ratio indication will be too low (evidence that the error in the base is either sampling error or a change in bias).

With the present sample sizes, the direct expansion estimator provides an estimate of the all orange production within 6 percent at the .95 confidence level. The coefficient of variation of 7.5 percent for the 1967-68 crop (as calculated in Appendix VII) reflects higher than normal variances. The estimator of variance has a slight upward bias. The error statements pertain to the precision of final survey results and do not reflect errors resulting from predicting size and drop or from non-sampling errors.

Forecasts for oranges made during the late stages of the 1967-68 harvest did not fully reflect the mathematical models. The row count survey (see next section) indicated much higher production than the models and it was given substantial weight in forecasts in April and later months.

Related Surveys

Row Count Survey

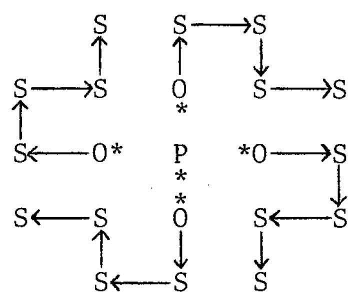
A unique recurring survey used to evaluate objective forecasts after the harvest is well along is called the "row count survey." This survey was discussed in a preceding section, "Early Efforts to Forecast Florida Citrus Production." This indication is currently used to adjust the forecast during the harvest period.

Maturity Survey

Another related survey, which is referred to as the "maturity survey," has proved to be a valuable asset to all segments of the industry. It provides an objective indication of fruit quality which is an influence on the quantity of finished product that will be obtained from a 90-pound box of fruit. In the 1968-69 season the yield of pounds of solids indicated in the maturity and yield test survey was helpful in predicting the low level in processing plant recovery rates experienced that season. The indicated maturity of the fruit has proved useful in plans which require knowledge of date of harvest, and should be useful in improving the forecast models for size and drop of fruit.

Limitation on time and the number of visits required necessitate the use of the route frame as a source of sample groves for the maturity survey. Presently, the survey is run twice monthly from September 1 through February 1 for early-midseason oranges, and from October 1 through mid-May for Valencias. The sample groves are allocated proportional to recent production which causes the maturity data to be approximately self-weighting, as a constant number of fruit is observed in each sample grove. The sample trees are selected the same as for the limb count groves (described in Appendix IV) except the pivot tree is included as a sample tree. The approximate location for obtaining three fruit per tree and substitution pattern for wrong type, vacancies, etc., is predetermined for each of the five trees as follows:

Sample Cluster of Trees



Sample row

Direction of travel ⟶

P = pivot tree; O = one of five sample trees in original cluster; S = substitute; * = point to be sampled

A sample of 15 fruit (3 from each of 5 trees) from each sample grove is tested in a laboratory. The juice is tested for acidity by titration and for specific gravity (Brix) by hydrometer reading. Estimates of percent acid, percent of soluble solids (Brix in juice), soluble solids to acid ratio, pounds of juice per box, and pounds of solids per box are made for individual fruit samples. The form designed for recording test results and computations is shown in Appendix VIII.

When grove operators are using these data to make decisions and comparisons concerning their own operations, area maturity data are generally more pertinent than state levels. For this reason sample sizes were set to give reliability to within 4 percent on solids/acid ratios and to within 2 percent on Brix at the area level for each type of citrus. Sample sizes and corresponding confidence levels are shown in Appendix VIII.

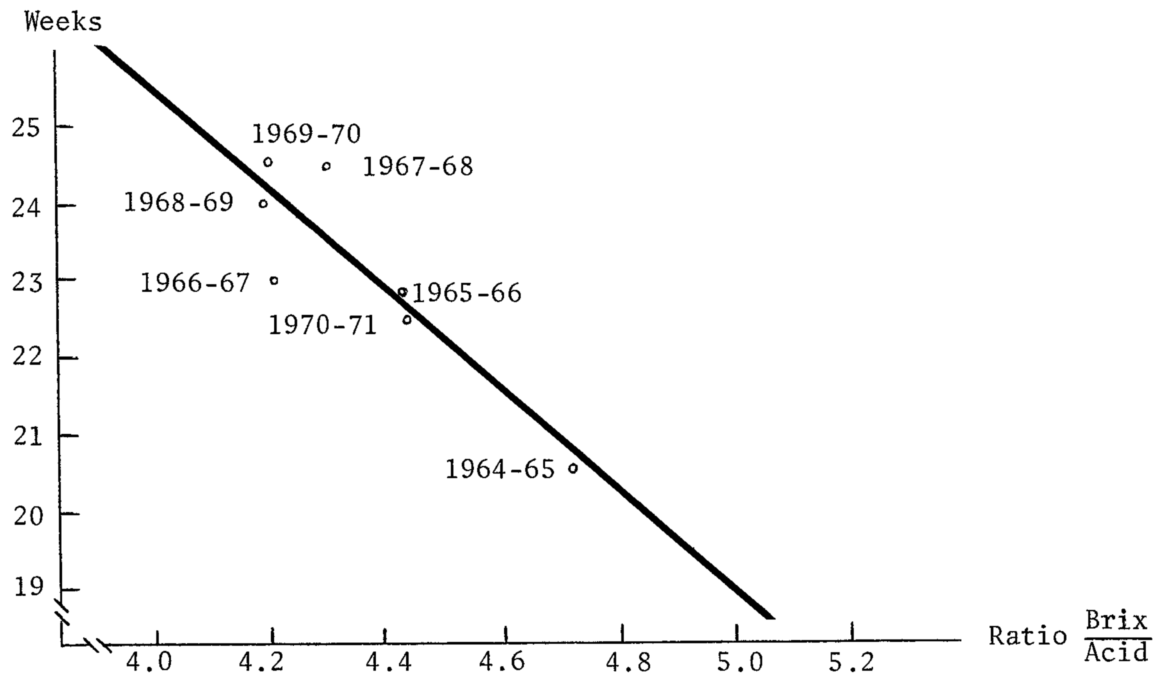
Since the maturity data have occasionally been misinterpreted, it should be stressed that the survey provides indications of maturity and quality of that fruit remaining in the groves, not at the processing plants or packing houses.

The solids/acid ratio may be used to forecast harvest dates. Stout[15] used data collected during a single year to develop a regression for early type oranges. Figure 5 shows the relationships between maturity test results and the number of weeks after October 1 required for Valencia oranges to reach a ratio of 10 to 1. The regression is $\hat{y} = 51.09 - 6.42x$ where y is the weeks after October 1 and x is the three month average of the pounds-solids/acid ratio. The ratio is determined from tests made October 1, November 1 and December 1.

The pounds-solids per box, as published, must be used with caution. Comparisons should be made between years of comparable survey data. Indicated year to year changes in yield levels of immature fruit are highly correlated with finished product recovery rate at processing plants.

Special purpose surveys which relate to citrus forecasts (calamity evaluation, economic abandonment, and individual grove estimation) are briefly discussed in Appendix VIII.

Figure 5: Forecasting Harvest Dates of Valencia Oranges



[15] Stout, R. G.,"Estimating Earliest Harvest Dates and Soluble Solids in Orange Production," unpublished report, October 1961.

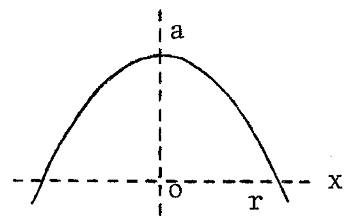
APPENDIX

Historical and Statistical Data Used in Development of Tree Numbers and Production Forecasts

I. IMPROVED FRAME COUNT

Equation for Tree Bearing Surface

The frame count procedure utilizes tree bearing surface to obtain expansion factors. Kelly's[1/] derivation of the equation for bearing surface of a citrus tree assumes that the surface of a tree can be approximated by the surface of revolution for the parabola $y = a - bx^2$ around the vertical axis, as illustrated:



Where S is this surface and a is the height, we have:

$$\begin{aligned} S &= 2\pi \int_0^a x \{1 + (dy/dx)^2\}^{1/2} dy \\ &= 2\pi \int_0^a \{(a-y)/b\}^{1/2} \left[\{1 + (1/4b^2)\}\{b/(a-y)\}\right]^{1/2} dy \\ &= 2\pi \int_0^a \{(a-y)/b + (1/4b^2)\}^{1/2} dy \\ &= (-\pi/6b^2)\ (4ab - 4by + 1)^{3/2} \Big|_0^a \\ &= (\pi/6b^2)\ \{(4ab + 1)^{3/2} - 1\} \end{aligned}$$

If $y = 0$, $x = r$ (where r = tree radius), and $b = a/r^2$ (where a is the height of the tree minus the height of trunk below bearing limbs), the equation becomes:

$$S = \frac{\pi r^4}{6a^2} \left\{ \left(\frac{4a^2}{r^2} + 1 \right)^{3/2} - 1 \right\}$$

Description of the Improved Frame Count Method

This section is a brief description of the improved frame count method operational for specialty citrus crops from 1962 to 1966 (for more detailed information see Stout[2/]). The height and width of the tree bearing surface are obtained by use of a stadiometer.[3/] A frame measuring two

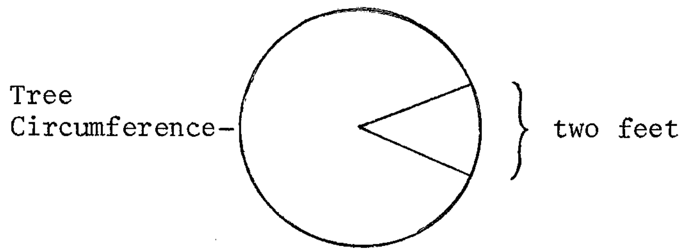
---

[1/] Kelly, B. W., "A Method of Forecasting Citrus Production in the State of Florida," unpublished Ph.D. dissertation submitted to University of Florida, August 1953.

[2/] Stout, R. G. "Estimating Citrus Production by Use of Frame Count Survey," Journal of Farm Economics, Vol. XLIV, No. 4, Nov. 1962.

[3/] Ford, H. W., "A Hand Instrument for Estimating Height and Width of Citrus Trees," Proceedings of the American Society of Horticultural Science, Vol. LXXVI, December 1960, 245.

feet on each side was used to determine the size of the sample unit. The frame was placed against the periphery of the tree and the fruit outlined by an imaginary extension of this frame to the tree trunk were counted. The sample unit was a wedge two feet high and tapering from a maximum width of two feet. The following diagram shows the top view of a tree and sample unit.

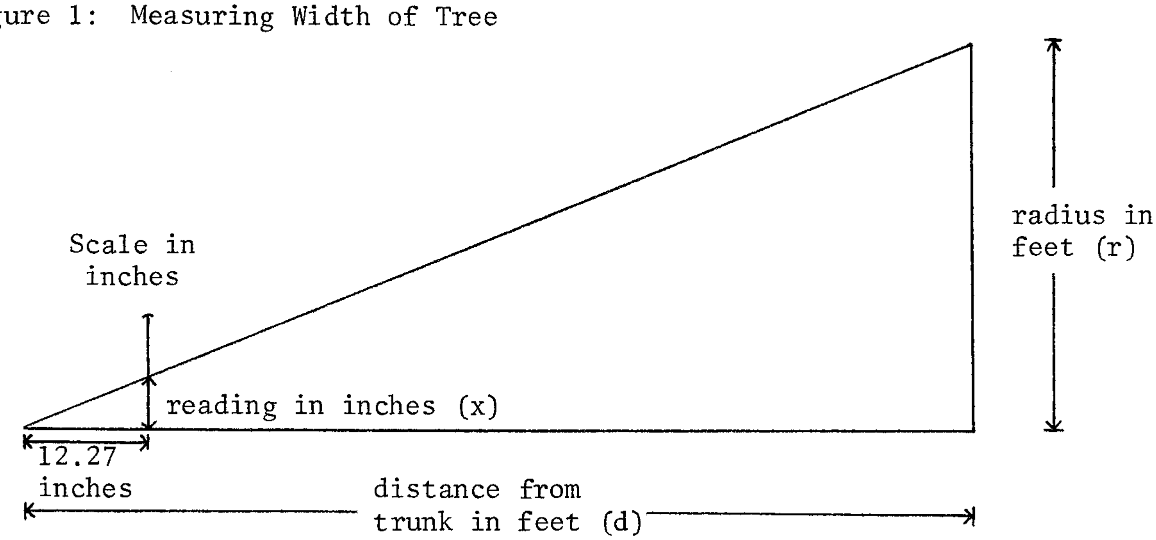


Each sampling unit represents a determinable proportion of the total tree bearing surface. The reciprocal of this proportion is the expansion factor used to estimate total fruit population of the tree from sample counts.

Since desired precision relates to the estimate of fruit per tree, the expanded counts must be used to obtain estimates of variance. The required sample size and optimum sub-sampling rates for a specific type of citrus can be obtained from a nested analysis of variance of the expanded counts.

Some adaptation was required for use of the stadiometer in determining height and width of the citrus tree for use in the frame count method. This adaptation was required due to varying heights of surveyors and distances from which measurements were made. Checks on methodology led to the use of trigonometric adjustments for these variables. Measuring the width of the tree is illustrated in Figure 1.

Figure 1: Measuring Width of Tree

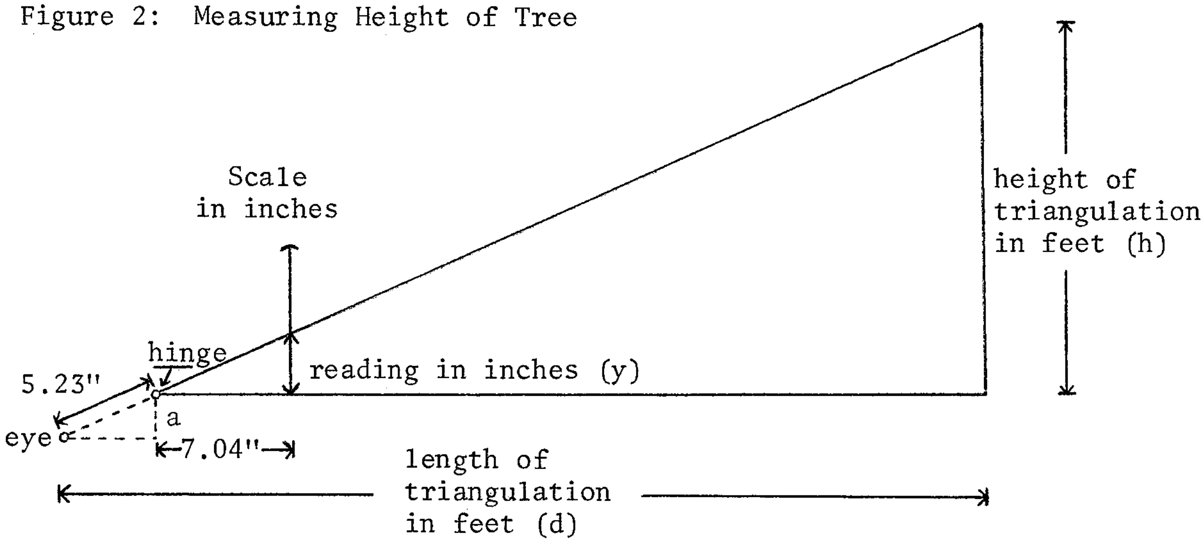


The conversion of the scale reading in inches to tree radius in feet is given by: radius in feet equals reading in inches times feet from tree divided by 12.27 inches. The application of the geometric laws of similar triangles yield these equations:

$$x/12.27 = r/d$$
$$r = (d\ x)\ /\ 12.27 \text{ inches}$$

Height of tree reading must take into account distance from tree, height of surveyor, and the fact that the triangulation is from the hinge, not the eye as is the case in the radius reading. Figure 2 illustrates the triangles involved in measuring tree height.

Figure 2: Measuring Height of Tree



The equations are: $y/7.04 = h/(d-0.4)$

$$h = (yd - 0.4y)/\ 7.04$$

Where "a" is vertical distance from eye to hinge: $a/5.23 = y/\left[y^2+(7.04)^2\right]^{1/2}$

$$a = 5.23\ y/(y^2+ 49.56)^{1/2}$$

so that the overall height of tree (H) equals height of the surveyor's eye plus a plus h.

Comments and Evaluation of the Improved Frame Count Method

In October 1965, an overlapping fruit count survey was done for Valencia limb count sample trees; that is, the frame count and limb count surveys were made on the same trees. Expanded counts were significantly different and indicated a 14 percent downward bias in the improved frame count indication. A survey conducted in February 1967 utilized the limb count to evaluate economic abandonment of tangerines and indicated the frame count estimate had a downward bias of 18 percent.

Research by Stout[4] indicated omission of the tree top and all heights above 10 feet due to an inability to count fruit through the frame may have been a source of downward bias. In his analysis of variance using unexpanded frame counts there was evidence of increased fruit counts at higher heights with probability of .7.

It is also probable that part of the bias of the improved frame count method is due to undercount of fruit in the frame. This would tend to be more serious for counting less mature fruit, fruit in dense foliage, or when the proportion of "inside" fruit is large.

The loss of identity of the sample unit upon removal of the frame prohibits follow-up work such as quality control and damage evaluation surveys.

It should also be noted that a basic assumption in the derivation of the bearing surface formula is that the tree is of parabolic shape. Freeze damage and the increased use of hedging practices cause deviations from the parabolic form. A considerable amount of effort has recently been expended toward determining a better estimator of the bearing surface of a citrus tree. This effort unfortunately has only emphasized the seriousness and difficulty of the problem.

In view of the evidence of a large inconsistent bias and other undesirable properties, some of which have been mentioned, the Florida Crop and Livestock Reporting Service discontinued use of the improved frame count method on specialty fruits in 1967 in favor of the established limb count technique.

---

[4] Stout, R. G., "Estimating Citrus Production by Use of Frame Count Survey", Journal of Farm Economics, Vol. XLIV, No. 4, Nov. 1962.

II. METHODOLOGY OF SAMPLE TREE CENSUS

This is a summary of the procedure utilized by Stout and Todd[5/] as revised for estimating citrus tree populations in Florida. The purpose is to outline estimators which utilize one or more year's data from a rotating sample to update a census of trees.

The annual sample survey was conducted in Florida at a cost of about $85,000. Sample design was developed to yield maximum sampling errors (C.V. at $\alpha = 0.05$) for an estimated number of all orange trees of about $15/\sqrt{r}$ for major counties and $4/\sqrt{r}$ for the state total. Sample error varies by year and by length of time lapsed since the last census.

Data from the basic sample design as discussed in the test can be efficiently utilized in the following equations.

Estimating Number of Trees in Pushed Groves for Each County (Removal of Old Groves)

One sample year: $\hat{S} = 1/f \sum_j s_j$

Combining "r" sample years:

$$\hat{S}_r = \frac{k+r}{fr}\left\{\sum_{j=1}^{n_1} \frac{s_{1j}}{k+1} + \sum_{j=1}^{n_2} \frac{s_{2j}}{k+2} + \cdots + \sum_{j=1}^{n_r} \frac{s_{rj}}{k+r}\right\}$$

$$\hat{S}_r = \frac{k+r}{fr} \sum_{i=1}^{r} \sum_{j=1}^{ni} \frac{s_{ij}}{k+i} \qquad (1)$$

Where f = Sample rate (.2 in this case)

s_{ij} = Number of pushed grove trees in j^{th} section of i^{th} sample year

r = Number of consecutive annual samples being used to update the census; also, $i = 1, \ldots, r$

k = Number of years between census or base and first of sample years in estimator.

5/ Stout, R. G., and Todd, J. W., A Continuing Survey for Estimating Current Numbers of Florida Citrus Trees, Florida Agricultural Experiment Station Agricultural Economics Mimeo, Report EC 64-13, Gainesville, Fla., June, 1964.

$$\text{Var}(\hat{S}) = 1/f^2 \sum_{j=1}^{n} \text{Var}(s)$$

$$= N^2\{\text{Var}(s)/n\} \qquad (2)$$

$$\text{Var}(\hat{S}_r) = \text{Var}\left(\frac{k+r}{fr} \sum_{i=1}^{r} \sum_{j=1}^{n_i} \frac{s_{ij}}{k+i}\right)$$

$$\doteq \frac{N^2}{rn} \text{Var}(s) \qquad (3)$$

Combining r years data in $\hat{S}_r$ and other estimators in this section reduces variance to approximately 1/r times that of the single year estimator.

Bias in $\hat{S}_r$ is small; likely less than 1 percent:

Bias in $\hat{S}_r = E(\hat{S}_r) - \sum_{i=1}^{k+r} t_i$ where t_i is actual number of trees pushed in year i. For example, if k=6 and r = 3,

$$E(\hat{S}_3) = 9/3\ E\left\{\frac{\sum_j s_{1j}}{f(k+1)} + \frac{\sum_j s_{2j}}{f(k+2)} + \frac{\sum_j s_{3j}}{f(k+3)}\right\}$$

$$= 9/3\left(1/7 \sum_{i=1}^{7} t_i + 1/8 \sum_{i=1}^{8} t_i + 1/9 \sum_{i=1}^{9} t_i\right)$$

letting $\bar{t} = \frac{1}{9} \sum_{i=1}^{9} t_i$

$$E(\hat{S}_3) = 3\{1/7\ (9\ \bar{t} - t_9 - t_8) + 1/8\ (9\ \bar{t} - t_9) + \bar{t}\}$$

$$= 1/56\ (216\ \bar{t} - 24\ t_9 - 24\ t_8 + 189\ \bar{t} - 21\ t_9 + 168\ \bar{t})$$

$$= 9\ \bar{t} + 45/56\ (\bar{t} - t_9) + 24/56\ (\bar{t} - t_8)$$

$$\therefore \text{Bias} < 1/2\ (\bar{t} - t_8) + (\bar{t} - t_9)$$

Estimating Trees in New Groves for Each County

One sample year: $\hat{P} = 1/f \sum_{j=1}^{n} x_j$ (4)

Where x_j is tree count in new groves in the "old citrus" and potential citrus section j. State total count of new grove trees in "non-citrus" sections were expanded using reciprocal probability of selection and then prorated to counties based upon results from equation (4).

Combining r sample years:

$$\hat{P}_r = 1/f \left\{ (1/r \sum_{i=1}^{r} \sum_{j=1}^{n} x_{ij}) + \frac{1}{r-1} \sum_{i=2}^{r} \sum_{j=1}^{n} y_{ij} + \cdots + \sum_{j=1}^{n} z_j \right\}$$

Where k is same as in equation (1):

x_{ij} = count of new grove trees to year k+1, in sample year i.

y_{ij} = count of new grove trees planted during year k+2 in sample year i.

z_j = count of new grove trees planted during year k+r in sample year r.

$$\text{Var }(\hat{P}) = \frac{N^2}{n} \text{ Var }(x)$$

$$\text{Var }(\hat{P}_r) \doteq \frac{N^2}{rn} \text{ Var }(x)$$

Estimating Trees in "Old Groves" Still in Production

One sample year: $\hat{Y} = \frac{\sum_j y_j}{\sum_j x_j} (Y_b - \hat{S})$

where Y_b is census (base) tree count for the county, y_j is current count of trees in j^{th} section, x_j is count of trees in j^{th} section in base year for old groves still remaining.

Combining r sample years:

$$\hat{Y}_r = (Y_b - \hat{S}_r)\left\{\frac{\sum_{i=1}^{r}\sum_{j=1}^{n} y_{ij} - \sum_{h=2}^{r}\sum_{i=2}^{r}\sum_{j=1}^{n} v_{hij}}{\sum_{i=1}^{r}\sum_{j=1}^{n} x_{ij}} + \frac{\sum_{j=1}^{n} v_{rrj}}{\sum_{j=1}^{n} x_{rj}} + \cdots + \frac{\sum_{i=2}^{r}\sum_{j=1}^{n} v_{2ij}}{\sum_{i=2}^{r}\sum_{j=1}^{n} x_{ij}}\right\}$$

where v_{hij} = number of trees planted in old groves in sample i, section j, in year h (h = k+1 to k+r).

Equation for variance of product of two independent variables gives:

$$\text{Var }(\hat{Y}) = (Y_b - \hat{S})^2 \text{ Var }(\hat{R}) + \hat{R}^2 \text{ Var }(\hat{S}) + \text{Var }(\hat{R}) \text{ Var }(\hat{s})$$

Where $\text{Var }(\hat{R}) = \hat{R}^2/n \quad \frac{S_{x^2}}{\bar{X}^2} + \frac{S_{y^2}}{\bar{Y}^2} - \frac{2S_{xy}}{\bar{X}\bar{Y}}$, and $\hat{R} = \frac{\Sigma y_i}{\Sigma x_i}$.

Var $(\hat{S})$ is given by equation (2).

Approximate Var $(\hat{Y}_r)$ has the same form but n is replaced with rn, $\hat{S}$ with $\hat{S}_r$, and Var $(\hat{S})$ with Var $(\hat{S}_r)$, as in equation (3).

Estimating Current Tree Inventory for a County

One sample year: $\hat{C} = \hat{Y} + \hat{P}$

Combining r sample years: $\hat{C}_r = \hat{Y}_r + \hat{P}_r$

$\text{Var }(\hat{C}) \doteq \text{Var }(\hat{Y}) + \text{Var }(\hat{P})$

These estimates of total trees in county are additive to state total with variance obtained by summing Var $(\hat{C})$ over all counties.

All variances are calculated as in simple random sampling due to the complexity of variance equations in systematic sampling and because the simple random sampling variances are a good approximation in this case.

III. THE 1965 CENSUS OF CITRUS TREES

Block Determination of Trees by Type and Age

Most of the citrus acreage was mapped into blocks of trees which were essentially of uniform age and type. If it was decided (by ground observation, aerial photo study, or existing records) that more than ninety percent of a block was of uniform age and variety, then it was designated a solid block of that age and type. If, however, it was decided that more than ten percent of the block was vacant, or of mixed age or type, tree counts were made in a sample portion of the block to determine proportions in each classification.

Maximum variances of the binominal probability function were used to determine sampling rate in mixed blocks. The allowable error (at $\alpha = .05$) on proportion estimates ranged from .05 for 40-acre and larger blocks to .12 for blocks of citrus with 10 acres or less. In mixed blocks, a systematic sample of every n^{th} row from random start was selected. All possible tree locations in selected rows were classified as vacant or occupied. Trees were identified as to type and age. The number of trees and commensurate number of rows in the sample were determined by size of block as shown in the following table.

Table 1: Minimum Number of Trees for Specified Block Size

Acres	Number of Trees
10 or less	50
10.1 to 20	75
20.1 to 40	150
over 40	300

Quality Check

Since the 1965 tree census was a test for a considerable amount of new methodology, it was necessary to conduct a quality check. Quality checking is most beneficial when it is done concurrently with the project so that sampling rates and other methodology may be adjusted. With this in mind, the sequential testing method was prescribed, but timeliness of tree census data had precedence and a post census quality check was substituted.

Proposed Methodology for Sequential Testing

The state was divided into nine areas which were judged to be similar in accuracy of records, photographic interpretation, and field work for the census data. Blocks of citrus were to be randomly selected in each area as the work progressed until sufficient information was obtained to reliably accept or reject the quality of work in that area. Tolerance limits were prescribed to determine acceptability of each block. The probability distribution is binominal where "p" is the proportion of blocks that are of unacceptable quality.

It was decided to accept work in an area if it was fairly certain that ninety-five percent or more of the blocks were of acceptable quality. The Hypotheses are:

$$H_o;\ p = .03 \text{ (denote } p_o)$$
$$H_1;\ p = .07 \text{ (denote } p_1)$$

Rejecting H_o when true (α error) would result in some unnecessary work, but is not as serious as accepting H_o when false (β error). Therefore, α error was set at .2 and β error at .1.

Functions of α and β determine whether or not the ratio of probabilities of null and alternate hypotheses is sufficiently different from 1 to make a decision:

$$A = \frac{1 - \beta}{\alpha} \text{ and } B = \frac{\beta}{1 - \alpha}$$

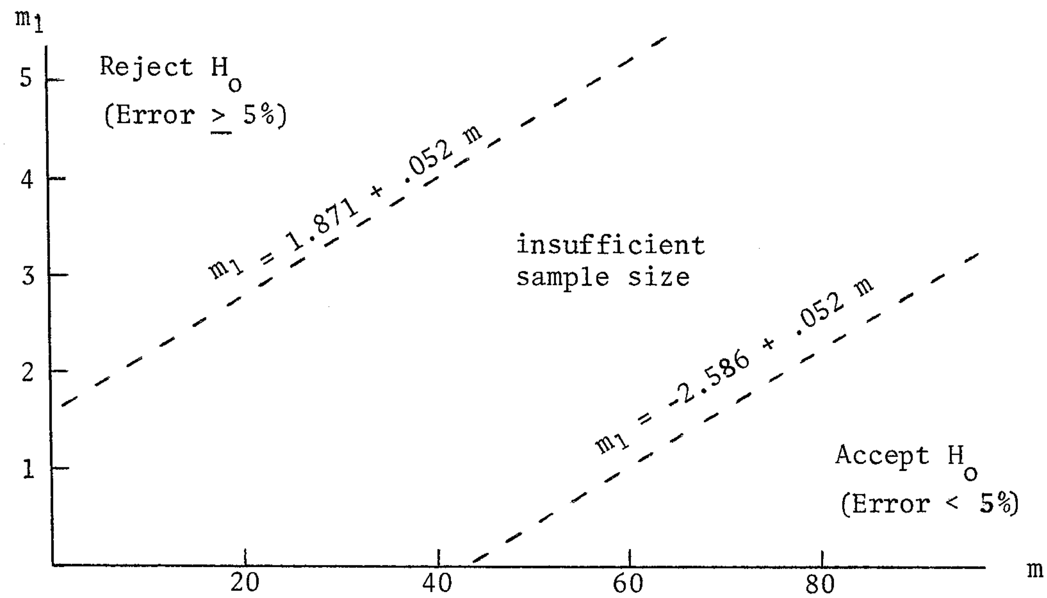
Rejection and acceptance regions can be depicted as linear functions of sample size (m) by:

$$r_m = \frac{\log A}{\log \frac{p_1}{p_o} - \log \frac{1-p_1}{1-p_o}} - m \frac{\log \frac{1 - p_1}{1 - p_o}}{\log \frac{p_1}{p_o} - \log \frac{1 - p_1}{1 - p_o}}$$

$$a_m = \frac{\log B}{\log \frac{p_1}{p_o} - \log \frac{1 - p_1}{1 - p_o}} - m \frac{\log \frac{1 - p_1}{1 - po}}{\log \frac{p_1}{p_o} - \log \frac{1 - p_1}{1 - p_o}}$$

These give critical domains depicted in Figure 3, where m_1 is the number of reject blocks in a sample of m.

Figure 3: Sequential Testing for Quality Checking Tree Census



Fisz has developed formulae[6] to determine sample size for sequential tests. The expected sample size required is given by:

$$E_Q\ (m) \doteq \frac{L\ (Q)\ \log B + \{1 - L\ (Q)\}\ \log A}{\log \left\{ \left(\frac{p_1}{p_o}\right)^p \left(\frac{1 - p_1}{1 - p_o}\right)^{1-p} \right\}}$$

where p is true population proportion.

$L\ (Q) = 1 - \alpha$ if p_o is true,

$L\ (Q) = \beta$ if p_1 is true,

and will range from 60 to 90 blocks of citrus for an area of inference.

[6] Fisz, Marek, Probability Theory and Mathematical Statistics, Third Edition, 1963, pp. 597 and 603.

Quality Check Methodology Used

A random sample of 15 quartersections in each of the nine areas mentioned in the preceding section were observed for quality check. Census and matching quality check data for type and tree age proportions, total inventory, and tree spacings were summarized by area, by enumerator team, and by type of error.

Total number of trees in the census count was indicated by the quality check to have an upward bias of approximately three percent. The primary cause of bias was allowing blocks with less than ten percent vacancies to be classed as solid citrus. Classification by age group indicated about five percent of the trees were classified too old. Classification by type indicated no error in census proportions. Table 2 is a summary of the age group classifications in the tree census and quality check.

Table 2: Quality Check for Tree Census - Age Classes

	Age Group, by Year Set				
	1942 & Older	1943 - 1952	1953 - 1957	1958 - 1962	1963 - 1966
Census Proportion	.30	.15	.10	.21	.24
Quality Check Proportion	.27	.13	.10	.24	.26

The most common problem was failure to sample for classification proportions when minor proportions were greater than the minimum ten percent. Allowing enumerators to subjectively determine whether or not to sample was a mistake. Inaccurate measurement of tree spacing was another frequent problem, caused either by variation of spacing within a block or error in measurement by enumerator. Other problem areas were misclassification of trees by age and errors in planimetering. Type and number of errors are summarized in Table 3.

Table 3: Quality Check for Tree Census - Errors

Type of Error	Age Proportion	Type Proportion	Total Tree Inventory	Total
Existing Record in Error	12	13	7	32
Should Have Been Sampled	154	66	36	256
Definition of Ages	161	---	---	161
Boundary Error	---	---	51	51
Planimeter	---	---	132	132
Sample Bias	73	47	3	123
Definition of Abandoned Block	7	7	8	22
Identification of Types	---	93	---	93
Spacing Measurements	---	---	147	147
Spacing Tolerance	---	---	30	30
Other	6	2	13	21
Total	413	228	427	1068

IV. LIMB COUNT METHODOLOGY AND ANALYSES

Sample Unit Selection

Tree Cluster Selection

To facilitate limb count survey fieldwork, sample trees are selected only from among the first ten trees in a sample row. This restriction allows a border tree a disproportionately high probability of selection. (A border tree is defined as a tree in the first or last row, or the first or last tree in any row in the grove.) As border trees may be subject to environmental effects different from those of inside trees, the procedure to select a random cluster of trees for the limb count survey must insure border trees will not be sampled at too high a rate.

The method of selection is as follows: a random row is selected for a "pivot tree," by means of a random number from 02 to n-1 where n is the number of rows in the grove (this excludes the two border rows from the draw). Then a random number from 01 to 99 is drawn. If the number is 01, the first tree in the randomly selected row is the pivot tree and designates the following two clusters, one a rotation alternate:

Cluster 1	Cluster 2
O	O O
OOPO	OPO

"P" represents the pivot tree and each "O" represents one of the sample trees in the cluster.

If the number 01 was not drawn, a second random number from 02 to 10 will determine which of the trees from 2 to 10 will be the pivot tree, with the following two clusters being formed:

Cluster 1	Cluster 2
O	O O
OPO	P
O	O O

The average block of 30 acres contains about 2400 trees. Assuming a square block, eight percent of the trees are border trees:

$$\frac{(4\sqrt{2400}) - 4}{2400} \cdot (100) = 8.00\%$$

To determine the proportion of border trees which can be expected from the above two patterns, the expected number of border trees (X) in a cluster was calculated, using $E(X) = \sum_i P_i X_i$, where P_i is the probability of occurrence.

If there are 49 trees on each side of a square block, then the expected number of border trees using each of the cluster formations are:

For cluster 1: $E\ (X) \doteq 1\ (\frac{1}{47}) + 1\ (\frac{1}{47}) + 3\ (\frac{1}{100}) + (\frac{1}{9}) = .1837$

$$\text{Percent border trees} = \frac{.1837}{4} \times 100 = 4.6\%$$

For cluster 2: $E\ (X) \doteq 2(\frac{1}{47}) + 2(\frac{1}{47}) + 2(\frac{1}{100}) + 2(\frac{1}{9}) = .3273$

$$\text{Percent border trees} = \frac{.3273}{4} \times 100 = 8.2\%$$

In some areas the planting of citrus trees in beds is increasing. Recent research in lemons indicates a difference in production between inside and outside rows in a bed. These facts may make it advisable to select samples which will be self weighting for border effects within beds.

Derivation of Limb Selection Probability

The probability of selecting a terminal sample limb is the product of individual stage probabilities as determined by limb cross sectional areas (c.s.a.). The process of selecting a sample limb begins at the first major branching of limbs (scaffold). A random number from 1 to A is drawn, where A is the total number of square inches of c.s.a. for all limbs at the scaffold. This random number, matched to a cumulative listing of c.s.a., designates the sample portion or path to the sample limb. Probability of selection equals A_e/A, where A_e is the c.s.a. of the limb selected. The probability of a specific portion (B_e) of the next major branching being selected is determined by the formula for conditional probability: $p(A_eB_e) = p(A_e)\ p(B_e|A_e)$, where $p(A_eB_e)$ is probability of selecting A_e at the scaffold and B_e at the next major branching, and $p(B_e|A_e) = B_e/B$.

If more stages are needed to reach a limb which is approximately ten percent of A, the formula for conditional probability is still applicable:

$$p(A_eB_eC_e) = p(A_e)\ p(B_e|A_e)\ p(C_e|A_eB_e)$$

The following form is a reproduction of the recording sheet used in the groves. The identification, measurements, counts, expansion factors and estimated fruit on sample tree are all recorded on this single sheet.

FLORIDA CROP AND LIVESTOCK REPORTING SERVICE
1222 Woodward Street, Orlando, Florida 32803

LIMB COUNT 1970-71

T ___ R ___ S ___ B ___ Date ___________ Tree Position _____ x _____ (Row) (Tree)

___ ___ ___ ___ Initials ________ Route No. _______________

1	2	3	4	5	6	7	8	9	10	11	12	13	14
TYPE		AREA	COUNTY		AGE GROUP	PLANT DATE		SAMPLE GROVE NUMBER					TREE

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Expansions: Reg. Bloom						First Late Bloom					Second Late Bloom					Reg. Bloom Quality				

FIRST STAGE		SECOND STAGE		THIRD STAGE		FOURTH STAGE	
CSA	CUM CSA	CSA	CUM CSA	CSA	CUM CSA	CSA	CUM CSA
A1	C1	A2	C2	A3	C3	A4	C4

FIFTH STAGE		No. Off ___ Regular Bloom	FRUIT COUNTS: First Late Bloom	FRUIT COUNTS: Second Late Bloom	Quality Check Regular Bloom
CSA	CUM CSA				

FIFTH STAGE (cont.)			
CSA	CUM CSA		
		RANDOM NUMBER DRAW LOCATION FOR FIRST STAGE	Sheet ______ Column ______ Line ______
		Enter Actual Random Number Used for Each Stage in Block Beside Stage Heading	
A5	C5		

HEDGING (√)	1 Side	2 Sides	3 Sides	4 Sides	Topped
Since Jan. 1970					
Prior to 1970					

TIME IN (Tree #1)
TIME OUT (Tree #4)

(Military)

AGE GROUP CODE
1 - 1961 to 1966
2 - 1956 to 1960
3 - 1946 to 1955
4 - before 1946

TYPE CODE
10 - Early Orange
20 - Mid. Orange
30 - Late Orange
40 - Seedy Gft.
51 - White Ss. Gft.
52 - Pink Ss. Gft.
61 - Tangerines
63 - Murcotts
71 - Temples
72 - Tangelos

Bias in Fruit per Tree Estimates

To determine the bias in estimates of fruit per tree based upon Limb Count procedures, it is necessary to establish that $\sum_{i=1}^{n} p_i = 1$, where p_i is the probability of selecting the i^{th} limb of n possible sample limbs. It is assumed, for this proof only, that three stages is the maximum involved for any sample limbs on A (A_e is the portion selected at the scaffold). The proof can be extended to any number of stages.

Sample limb probabilities for all third stage limbs (C) for B_e and A_e are summed. Using the same method of conditional probability as in the previous section, we have:

$$\sum_i \frac{C_i}{C} \cdot \frac{B_e}{B} \cdot \frac{A_e}{A} = \frac{C_1}{C} \cdot \frac{B_e}{B} \cdot \frac{A_e}{A} + \frac{C_2}{C} \cdot \frac{B_e}{B} \cdot \frac{A_e}{A} + \ldots; \text{ since } \sum_i C_i = C,$$

$$= \frac{C}{C} \cdot \frac{B_e}{B} \cdot \frac{A_e}{A}$$

$$= \frac{B_e}{B} \cdot \frac{A_e}{A}$$

Similarly, by summing the second and first stage probabilities for B_e and A_e we get $\sum \frac{B_i}{B} \cdot \frac{A_e}{A} = \frac{A_e}{A}$ and $\sum_i \frac{A_i}{A} = \frac{A}{A} = 1$. The proof is complete.

Since $p_i > 0$ and $\sum_i p_i = 1$, the expected value of estimated fruit per tree may be found by using $\hat{X}_i = \frac{x_i}{p_i}$;

$$E(X) = \sum_i p_i X_i = \sum_i p_i \frac{x_i}{p_i} = X$$

where x_i is count for a sample unit, limb i, and X is total number of fruit on the sample tree. This shows $\hat{X}$ is an unbiased estimate of X, regardless of the c.s.a. assigned to a limb. For this reason, the reduced c.s.a.'s, used for adjustment in situations where c.s.a. is a poor measure of bearing surface, do not introduce any bias. Restricted to major pruning or die-back, adjusted c.s.a. measurements are a practical means of reducing within-tree variation.

Another consideration is the increase in c.s.a. from first scaffold to terminal limbs (approximately thirty percent increase). Although this causes a ten percent limb at the first scaffold to have greater probability of selection than a ten percent limb at subsequent stages, both are selected with known probability so that no bias and very little increase in variance result.

Analysis of Variance

The analysis used a nested classification. Table 4 gives the analysis of variance for four levels. (Notation used follows Cochran[7] quite closely.) Analysis is of the expanded limb count estimates of fruit per tree. Analyses of variance are presented in Tables 5 through 17. Data in Tables 5 through 10 are from samples allocated proportional to tree numbers. Samples for data in Tables 11 through 17 were allocated using Neyman's optimum allocation procedure.

Table 4: Analysis of Variance, Four Stage Subsample

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	Estimated Mean Square
Counties (i)	m-1	$\sum_i \frac{Y^2_{i...}}{n_{i...}} - \frac{Y^2}{n....}$	s^2_b	$\sigma^2_\delta + k_4\sigma^2_\gamma + k_5\sigma^2_\beta + k_6\sigma^2\alpha$
Ages/ Counties (j)	m.-m	$\sum_{ij} \frac{Y^2_{ij..}}{n_{ij..}} - \sum_i \frac{Y^2_{i...}}{n_{i...}}$	s^2_w	$\sigma^2_\delta + k_2\sigma^2_\gamma + k_3\sigma^2_\beta$
Groves/ Age & County (k)	m..-m.	$\sum_{ijk} \frac{Y^2_{ijk.}}{n_{ijk.}} - \sum_{ij} \frac{Y^2_{ij..}}{n_{ij..}}$	s^2_{ww}	$\sigma^2_\delta + k_1\sigma^2_\gamma$
Trees/ Grove, Age, & County (l)	m...-m..	$\sum_{ijkl} \frac{Y^2_{ijkl}}{n_{ijkl}} - \sum_{ijk} \frac{Y^2_{ijk.}}{n_{ijk.}}$	s^2_{www}	σ^2_δ

Notation: m = number of counties

m. = number of age-county totals

m.. = total number of groves

m... = total number of trees

n = number of trees; e.g., $n_{ijk.}$ is the number of trees in the ijk^{th} grove.

$Y_{ijkl} \equiv$ observation from l^{th} tree in k^{th} grove in j^{th} age group in i^{th} county.

---

[7] Cochran, William G., Sampling Techniques, July 1962, pp. 219-231.

Estimated variance of grand mean is: $Var(\bar{Y}) \doteq \frac{s_b^2}{n....}$

The between grove mean square is used to measure variance of the estimated fruit per tree as neither age groups nor counties are sampled.

Variance of fruit per tree is: $Var(\bar{Y}) \doteq \frac{s_{ww}^2}{n....}$

This is based on a self-weighting sample with proportional allocation to age groups in each county. However, when optimum allocation is used, the variance formula should be modified as follows:

$$Var(\bar{Y}) = \Sigma \left\{ \frac{(W_h \; s_{wwh})^2}{n_{h...}} \right\} \qquad (1)$$

Where s_{wwh} is the square root of s_{ww}^2 in the A.O.V. for age h, and W_h are tree weights. Also,

$$C.V._{.05} = \frac{\sqrt{v(\bar{Y})}\,(t_{.05})\; 100}{\bar{Y}}, \text{ where } t_{.05} = 1.96.$$

In addition to coefficients of variability, the following tables include number of trees in sample (n....), average fruit per tree ($\bar{Y}$), and indicated optimum number of sample trees per sample grove (n_{opt}).

$$n_{opt.} = \frac{\sigma_\delta}{\sigma_\gamma} \cdot \frac{\sqrt{C_2}}{\sqrt{C_3}}$$

where σ_δ is the component of variance between trees within groves,

σ_γ is the component of variance between groves,

C_2 is the cost associated with groves, and

C_3 is cost associated with trees. In these calculations, $C_2/C_3 = 4$.

Table 5: Fruit per Tree, Early Oranges

A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1961-62	County	15	83,268,402	5,551,226
	Age/County	22	198,998,176	9,044,917
	Grove/Age	81	195,353,707	2,411,774
	Tree/Grove	357	272,984,510	764,662
1962-63	County	15	98,696,597	6,579,773
	Age/County	31	291,270,842	9,395,834
	Grove/Age	92	264,467,598	2,874,648
	Tree/Grove	417	263,642,447	632,236
1963-64	County	15	63,700,647	4,246,710
	Age/County	32	61,855,919	1,932,997
	Grove/Age	91	181,652,884	1,996,186
	Tree/Grove	417	104,964,603	251,714

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1961-62	476	1,533	9.09	2.73
1962-63	556	1,469	9.58	2.12
1963-64	556	563	20.85	1.52

Table 6: Fruit per Tree, Midseason Oranges
A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1961-62	County	18	24,113,095	1,339,616
	Age/County	30	131,980,412	4,399,347
	Grove/Age	119	197,624,555	1,660,710
	Tree/Grove	500	328,204,366	656,408
1962-63	County	17	108,371,678	6,374,805
	Age/County	34	187,752,106	5,522,121
	Grove/Age	120	270,727,062	2,256,059
	Tree/Grove	516	371,196,113	719,372
1963-64	County	18	94,696,320	5,260,907
	Age/County	33	27,884,462	844,984
	Grove/Age	122	136,699,423	1,120,487
	Tree/Grove	522	180,993,263	346,720

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1961-62	668	934	10.45	3.23
1962-63	688	1,278	8.78	2.74
1963-64	696	434	18.11	2.68

Table 7: Fruit per Tree, Valencia Oranges

A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1961-62	County	18	114,734,493	6,374,138
	Age/County	58	316,666,068	5,459,759
	Grove/Age	247	317,370,610	1,284,901
	Tree/Grove	956	282,959,090	295,982
1962-63	County	18	65,260,098	3,625,561
	Age/County	41	202,424,897	4,937,193
	Grove/Age	273	248,045,395	908,591
	Tree/Grove	999	249,727,896	249,978
1963-64	County	19	175,265,677	9,224,509
	Age/County	41	143,168,542	3,491,916
	Grove/Age	276	294,442,804	1,066,822
	Tree/Grove	1,011	187,276,946	185,289

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1961-62	1,280	1,009	6.15	2.19
1962-63	1,332	911	5.61	2.46
1963-64	1,348	541	10.19	1.83

Table 8: Fruit per Tree, Seedy Grapefruit

A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1961-62	County	18	17,432,423	968,467
	Age/County	9	4,084,563	453,840
	Grove/Age	113	84,916,643	751,474
	Tree/Grove	423	88,371,137	208,915
1962-63	County	17	21,226,460	1,248,615
	Age/County	9	4,990,476	554,497
	Grove/Age	98	45,908,836	468,458
	Tree/Grove	375	61,226,972	163,272
1963-64	County	18	11,198,311	622,128
	Age/County	9	1,792,520	199,169
	Grove/Age	97	36,690,202	378,249
	Tree/Grove	375	30,822,346	82,193

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1961-62	564	567	12.60	2.48
1962-63	500	724	8.29	2.93
1963-64	500	238	22.64	2.11

Table 9: Fruit per Tree, White Seedless Grapefruit
A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1962-63	County	15	41,790,348	2,786,023
	Age/County	16	11,856,887	741,055
	Grove/Age	122	82,558,647	676,710
	Tree/Grove	462	92,343,569	199,878
1963-64	County	15	21,797,615	1,453,174
	Age/County	16	21,549,877	1,346,867
	Grove/Age	122	88,965,191	729,223
	Tree/Grove	462	96,007,814	207,809

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1962-63	616	767	8.47	2.59
1963-64	616	488	13.82	2.53

Table 10: Fruit per Tree, Pink Seedless Grapefruit
A.O.V. from Limb Count Survey

Crop Year	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
1962-63	County	14	20,384,611	1,456,044
	Age/County	23	22,259,543	967,805
	Grove/Age	109	59,871,065	549,276
	Tree/Grove	441	57,871,857	131,229
1963-64	County	14	25,918,315	1,851,308
	Age/County	22	18,991,042	863,229
	Grove/Age	103	48,547,168	471,332
	Tree/Grove	417	60,454,333	144,974

Other Data Summarization

Crop Year	n....	$\bar{Y}$	$C.V._{.05}$	$n_{opt.}$
1962-63	588	638	9.39	2.24
1963-64	568	454	12.43	2.67

Table 11: Fruit per Tree, Early-Midseason Oranges
A.O.V. from Limb Count Survey, 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	Area	3	6,177,706	2,059,235
	County/Area	15	6,083,633	405,576
	Grove/County	80	25,487,415	318,593
	Tree/Grove	297	19,970,087	67,239
Age 2	Area	3	4,809,510	1,603,170
	County/Area	12	6,826,111	568,843
	Grove/County	32	17,668,939	552,154
	Tree/Grove	144	16,592,070	115,223
Age 3	Area	3	24,016,490	8,005,497
	County/Area	14	29,594,610	2,113,901
	Grove/County	60	91,825,610	1,530,427
	Tree/Grove	234	71,750,850	306,628
Age 4	Area	3	58,632,420	19,544,140
	County/Area	19	32,872,300	1,730,121
	Grove/County	177	356,215,600	2,012,518
	Tree/Grove	600	295,178,600	491,964

Other Data Summarization

Age Group	n....	$\bar{Y}_h$
Age 1	396	284
Age 2	192	387
Age 3	312	812
Age 4	800	976

Table 12: Fruit per Tree, Valencia Oranges

A.O.V. from Limb Count Survey, 1967-68

Age Group	Source of Variance	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	Area	3	2,231,981	743,994
	County/Area	18	5,017,319	278,740
	Grove/County	52	8,790,797	169,054
	Tree/Grove	222	8,472,258	38,163
Age 2	Area	3	4,561,019	1,520,340
	County/Area	14	8,282,150	591,582
	Grove/County	35	17,025,010	486,429
	Tree/Grove	159	15,852,861	99,704
Age 3	Area	3	5,893,280	1,964,427
	County/Area	17	15,955,480	938,558
	Grove/County	83	62,235,650	749,827
	Tree/Grove	312	45,485,070	145,785
Age 4	Area	3	33,559,660	11,186,553
	County/Area	20	22,689,220	1,134,461
	Grove/County	166	202,749,620	1,221,383
	Tree/Grove	574	168,879,840	294,216

Other Data Summarization

Age Group	n....	$\bar{Y}_h$
Age 1	296	261
Age 2	212	470
Age 3	416	682
Age 4	764	836

Table 13: Fruit per Tree, Seedy Grapefruit
A.O.V. from Limb Count Survey, 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 4	Area	3	8,651,830	2,883,943
	County/Area	14	9,304,060	664,576
	Grove/County	98	36,189,490	369,281
	Tree/Grove	356	62,675,410	176,055

Other Data Summarization

n.... = 472 $\bar{Y}_h$ = 552

Table 14: Fruit per Tree, Seedless Grapefruit
A.O.V. from Limb Count Survey 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	Area	2	264,141	132,070
	County/Area	2	37,840	18,920
	Grove/County	10	714,031	71,403
	Tree/Grove	45	815,992	18,133
Age 2	Area	2	17,988	8,994
	County/Area	3	57,732	19,244
	Grove/County	13	837,707	64,439
	Tree/Grove	57	2,650,739	46,504
Age 3	Area	3	2,613,350	871,117
	County/Area	11	9,164,750	833,159
	Grove/County	87	48,274,420	554,878
	Tree/Grove	306	46,945,260	153,416
Age 4	Area	3	18,322,810	6,107,603
	County/Area	15	11,980,690	798,713
	Grove/County	150	78,392,840	522,619
	Tree/Grove	515	113,401,760	220,198

Other Data Summarization

Age Group	n....	$\bar{Y}_n$
Age 1	60	202
Age 2	76	364
Age 3	408	616
Age 4	684	676

Table 15: Fruit per Tree, Temples

A.O.V. from Limb Count Survey, 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	County	3	1,147,612	382,537
	Grove/County	5	541,966	108,393
	Tree/Grove	27	710,094	26,300
Age 2	County	0	--------	-------
	Grove/County	5	1,223,966	244,793
	Tree/Grove	18	1,061,436	58,969
Age 3	County	10	17,318,036	1,731,804
	Grove/County	28	20,074,007	716,929
	Tree/Grove	117	20,494,068	175,163
Age 4	County	6	8,533,807	1,422,301
	Grove/County	17	28,274,472	1,663,204
	Tree/Grove	72	20,072,920	278,791

Other Data Summarization

Age Group	n....	$\bar{Y}_h$
Age 1	36	288
Age 2	24	245
Age 3	156	659
Age 4	96	1079

Table 16: Fruit per Tree, Tangerines
A.O.V. from Limb Count Survey 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	County Grove/County Tree/Grove	5 4 10	9,602,904 875,142 3,607,939	1,920,581 218,786 360,794
Age 2	County Grove/County Tree/Grove	5 3 9	15,622,648 3,947,284 18,685,005	3,124,530 1,315,761 2,076,112
Age 3	County Grove/County Tree/Grove	6 6 13	27,280,299 4,522,311 18,306,323	4,546,716 753,718 1,408,179
Age 4	County Grove/County Tree/Grove	15 85 101	251,629,738 805,996,339 542,054,845	16,775,316 9,482,310 5,366,880

Other Data Summarization

Age Group	n....	$\bar{Y}_h$
Age 1	20	636
Age 2	18	1,384
Age 3	26	875
Age 4	202	2,070

Table 17: Fruit per Tree, Tangelos

A.O.V. from Limb Count Survey 1967-68

Age Group	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
Age 1	County	10	29,653,318	2,965,332
	Grove/County	9	591,261	65,696
	Tree/Grove	60	1,450,401	24,173
Age 2	County	8	12,425,082	1,553,135
	Grove/County	4	1,673,723	418,431
	Tree/Grove	39	6,232,918	159,818
Age 3	County	8	35,516,536	4,439,567
	Grove/County	8	75,242,134	9,405,267
	Tree/Grove	51	40,854,618	801,071
Age 4	County	5	11,820,148	2,364,030
	Grove/County	3	12,295,797	4,098,599
	Tree/Grove	27	37,483,531	1,388,279

Other Data Summarization

Age Group	n....	$\bar{Y}_h$
Age 1	80	340
Age 2	52	579
Age 3	68	1,310
Age 4	36	765

Table 18: Sample Size and Optimum Number of Trees per Grove

Type	Crop Year	Sample Trees n....	$\bar{Y}$	C.V.$_{.05}$ 1/	n_{opt}
All Orange	1961-62	2,424	1,091	4.63	2.75
	1962-63	2,576	1,129	4.45	2.40
	1963-64	2,600	517	8.41	1.92
	1966-67 1	3,428	986	4.38	2.58
	1967-68 1	3,396	584	6.14	2.20
All Grapefruit	1961-62	1,660	660	5.98	2.94
	1962-63	1,704	710	5.09	2.57
	1963-64	1,684	402	8.57	2.47
	1966-67 1/	1,816	834	4.56	2.74
	1967-68 1/	1,728	572	5.57	3.57
Temples	1967-68 1/	312	653	13.79	2.03
Tangerines	1967-68 1/	266	1,605	16.65	3.27
Tangelos	1967-68 1/	236	570	18.23	1.52

1/ For 1966-67 and 1967-68, the calculations of coefficients of variation were modified to coincide with the change in sample design. Page 58 gives the formula to calculate C.V.

Pilot Surveys to Estimate Variances

Preliminary statistics, such as estimates of variance, are often obtained by means of pilot surveys. Sample design relies upon estimates of population, mean and variance to determine sample size and expected reliability. The sample size for an effective pilot survey is dependent upon the variance of s^2, which is: Var $(s^2) = 2\sigma^4/(n-1)$.

Using $\hat{\sigma}^4 = (s^2)^2$ and $C.V._{.05} = \frac{2\ S.D.\ (\hat{\theta})\ 100}{\hat{\theta}}$, the approximate

$$C.V._{.05}(s^2) = \frac{2(\sqrt{2/n})\ (s^2)}{s^2}\ (100) \doteq \frac{200\sqrt{2}}{\sqrt{n}}$$

If $C.V._{.05}(s^2) = 10$, then $\sqrt{n} \doteq \frac{200\ \sqrt{2}}{10} = 20\ \sqrt{2}$, and $n = 800$.

Pilot surveys are usually made with limited funds. Concessions are made in the accuracy of the estimates of population values, but these values are only used for the first operational survey. Subsequent sample allocation is determined by the larger sample from this full-scale survey.

Sample Frame and Sample Design for Limb Count

Sample Frame

To facilitate maintaining a representative sample for the limb count survey, a gradual shift was made from the route frame to total population frame or "probability frame". Overlapping checks were made to determine transition effects on survey results. The shift to probability sample frame began in 1963-64 and was completed in 1969-70.

A complete IBM listing of the state's citrus trees provided by the biennial aerial tree census is the probability sample frame. This listing is in order by county, by type of citrus, by date of planting, and finally, by township, range, section, and grove number. To facilitate systematic sampling, which allows a grove to be selected with probability proportional to size, cumulative totals of number of trees are printed adjacent to each grove identification. For each type and age group (sampling rate varies by type and age group) a random start and an interval are used to select sample groves. Field checks are made to insure correct classification of type and age for each sample grove. If misclassification of a grove has occurred, an alternate is selected by taking the grove which would have been selected if the incorrectly classified grove were not in the listing.

Sampling procedure provides a double stratification, tree age and geographic location, which reduces variance of estimated average number of fruit per tree. The sample is self-weighting to the age-type level. Tree numbers are used as weights to combine age group means to overall average of fruit per tree for each type.

Bearing surface has been used as a criterion for age classification but has been discarded in favor of date of planting, as this does not require continual reclassification. Although it is generally necessary to use trunk circumference (above bud union) to establish age, this technique is superior to the bearing surface classification.

Approximate age stratification has been:

Age Group	Age of Tree
I	4 to 9 years
II	10 to 14 years
III	15 to 24 years
IV	over 24 years

These divisions vary slightly from the actual planting dates in each age group for recent surveys as shown in Table 19.

Table 19: Planting Dates Used for Stratification in Limb Count Surveys 1964-65 through 1968-69

Stratum	Crop Year				
	1964-65	1965-66	1966-67	1967-68	1968-69
I	1953-57[1/]	1958-61	1958-62	1959-63	1959-64
II	1949-52	1949-57	1953-57	1954-58	1954-58
III	1939-48	1939-48	1943-52	1944-53	1944-53
IV	1938 & older	1938 & older	1942 & older	1943 & older	1943 & older

[1/] Arbitrary allowance was made for 1958, 1959, and 1960 plantings.

With a significant number of young trees coming into bearing, the commercial harvesting of 3-year-old trees (especially in southern Florida) may become a significant factor, suggesting that three- and even two-year-old trees be included in the limb count sample. However, in tree census fieldwork a high percentage of young trees cannot be identified as a particular type of citrus, so this will increase the number of unidentified citrus trees in the frame and also increase the importance of including these unidentified in the sample.

Updating Stratification

To maintain effective age stratification, some trees should be shifted to older age groups every other year. Age groups have different sampling intervals, therefore sample size for the planting dates being shifted to an older age group will generally need to be adjusted to maintain a constant sampling rate within each age group. To accomplish the adjustment in sampling rate, the sample fraction of the older age group is rewritten as a sum of two fractions, one of which is the sampling rate of the younger age group. The reciprocal of the other fraction should be used as a sampling interval for drawing additional samples (sample intervals become smaller for older trees).

Example: In 1969-70, Age Group I will contain 1959-66 plantings if three-year-old trees are included in sample. The 1959, 1960, and 1961 plantings should be transferred to Age Group II.

Age Group I interval = 1000
Age Group II interval = 250

$$\frac{1}{250} = \frac{4}{1000} = \frac{1}{1000} + \frac{3}{1000}$$

$\frac{1000}{3} = 333$, which is the interval to be used in obtaining additional samples of 1959, 1960, and 1961 plantings.

Sample Size and Allocation

Sample size is determined by $n = \frac{s^2\ t^2}{d^2}$, where s^2 is $\mathrm{Var}(\bar{Y})$ given in equation (1) on page 58.

$$n_h = (ns_h\ N_h/\sqrt{C_h})\ /\ \sum_h (S_h\ N_h/\sqrt{C_h})$$

gives optimum sample size for each age group, using the following cost function: $C = A + \sum_h C_h\ n_h$.

Table 20 shows the costs per grove for each age group. These figures were used to derive the 1967-68 and 1968-69 sample sizes. Sample sizes, tree numbers, sampling intervals, and expected coefficients of variation are presented in Table 21.

Table 20: Limb Count Survey Costs per Grove -- By Age Stratum

Age Stratum	Travel Expense	Travel Wage	Limb Selection	Limb Count	Total C_h
	Dollars	Dollars	Dollars	Dollars	Dollars
I	4.30	7.90	1.70	5.20	19.10
II	3.90	7.20	1.75	6.40	19.25
III	3.50	6.50	1.80	7.60	19.40
IV	3.10	5.80	1.85	8.80	19.55

Table 21: Limb Count Survey -- Sample Size and Reliability

Type	Age Group	Trees in Universe (Thousands)		Sample Interval (Thousands)		Groves in Sample		Coefficient of Var. (α=.05)
		1967	1968	1967	1968	1967	1968	1967
Oranges	1	15,666	19,348	90	90	173	200	
	2	6,337	6,257	65	65	101	99	
	3	6,530	6,345	35	35	182	186	
	4	13,669	13,408	35	35	391	385	
	All	42,202	45,358	--	--	847	870	6.14
Grape-fruit	1	579	738	40	40	16	23	
	2	270	244	13	13	19	20	
	3	1,422	1,362	13	13	108	109	
	4	3,661	3,527	13	13	289	287	
	All	5,932	5,871	--	--	432	439	5.57
Temples	1	298	440	34	17	9	27	
	2	169	164	34	17	6	11	
	3	593	632	18	9	39	74	
	4	410	368	18	9	24	45	
	All	1,470	1,604	--	--	78	157	14.91
Tange-rines	1	236	417	30	16	10	20	
	2	71	74	7	5	9	14	
	3	94	86	7	5	13	18	
	4	672	654	7	5	101	134	
	All	1,073	1,231	--	--	133	186	16.65
Tangelos	1	541	806	27	9	20	88	
	2	145	138	9	3	13	45	
	3	153	157	9	3	17	52	
	4	49	42	9	3	9	19	
	All	888	1,143	--	--	59	204	18.23

Comparison of Optimum and Proportional Allocations

A limb count sample allocated proportional to tree numbers will contain a large portion of groves that produce relatively small amounts of fruit, due to the influx of young trees. Moreover, increased travel costs nearly offset the decrease in counting time for young trees. These facts suggest the use of optimum allocation. Optimum allocation is compared with proportional sampling in the following table.

Table 22: Reliability Comparison for Limb Count Survey-- Optimum vs. Proportional Allocation

Type	Coefficient of Variation (α=.05) 1966-67		Coefficient of Variation (α=.05) 1967-68		Decrease in Error Realized by Optimization
	Opt.	Prop.	Opt.	Prop.	
	Percent	Percent	Percent	Percent	Percent
E-M Oranges	4.86	5.43	9.04	9.27	8
Late Oranges	4.86	5.22	6.53	6.96	7
Seedy Gft.	4.82	4.82	9.93	9.93	--
Seedless Gft.	5.20	5.25	6.22	6.47	3
Temples	--	--	13.79	14.91	8
Tangerines	--	--	16.65	18.66	12
Tangelos	--	--	18.23	27.22	49

This table corroborates the statement by Cochran (p. 86) that optimum allocation may provide little decrease in variance of the estimate, even when optimum departs considerably from proportional allocation. A like reduction in variance could be obtained by increasing sample size twenty percent, at an annual cost of approximately $8,000. Thus, though only a modest improvement is realized, the relatively small amount of additional effort required for summarization is easily justified.

V. FORECASTING SIZE OF FRUIT

Forecasting Model

A multiple regression is used to project current size to estimated size at cut-off month. The model is:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3$$

where X_1 = current size of fruit estimated by combining age-area average volumes per fruit. Numbers of fruit are used for weights (average number of fruit per tree times number of trees for each age-area stratum).

X_2 = estimated average number of fruit per tree for age group 4 (changes in the mean for all age groups is influenced by change in proportion of ages more than by density of fruit).

X_3 = amount (cubic inches) of increase in average volume during previous month.

b = estimate of intercept and regression coefficients.

Table 23: Parameter Estimates Used to Forecast Size, 1967-68

Type of Fruit	Date of Forecast	Parameter Estimates				
		b_0	b_1	b_2	b_3	r
Early-Mid Oranges	Oct. 1	4.3400	.96355	-.001785	- .15912	.95
	Nov. 1	3.8200	.86751	-.001120	- .14572	.98
	Dec. 1	2.3267	.87473	-.000630	.13677	.99
Valencia Oranges	Oct. 1	8.9626	.64348	-.003111	.60936	.82
	Nov. 1	8.3600	.74055	-.003015	- .13986	.83
	Dec. 1	5.5044	.56308	-.000627	1.3860	.92
	Jan. 1	4.3328	.82126	-.001081	- .23311	.87
Seedy Grapefruit	Oct. 1	.33996	1.5055	.001115	-1.1267	.96
	Nov. 1	.42853	1.1090	.004969	- .38749	.96
	Dec. 1	-.91018	1.0355	.005906	- .13453	.97
Seedless Grapefruit	Oct. 1	6.6741	1.3504	-.000338	-1.4092	.99
	Nov. 1	2.2626	1.1904	.002194	- .41980	.99
	Dec. 1	-.6467	1.0589	.002395	.07030	.99

Sample Reliability

Sample design of the fruit size (growth) survey allows the variance of average fruit volumes to be estimated by the grove-level mean square of a nested analysis of variance. The levels of reliability presented in Table 24 were determined by the following formula:

$$C.V._{.05} = \{(s^2_{ww}/n)^{1/2}\ (t_{.05})\ (100)\}/\bar{Y}$$

Inferences for combined types were obtained from weighted means. For example, average size for all grapefruit is obtained by combining seedy (sy) and seedless (ss) grapefruit: $\bar{Y} = W_1\bar{Y}_{sy} + W_2\bar{Y}_{ss}$

with variance of $\bar{Y} = W_1^2\ \mathrm{Var}\ (\bar{Y}_{sy}) + W_2^2\ \mathrm{Var}\ (\bar{Y}_{ss})$.

Table 24: Sample Sizes and Reliability for 1967-68 Size Survey

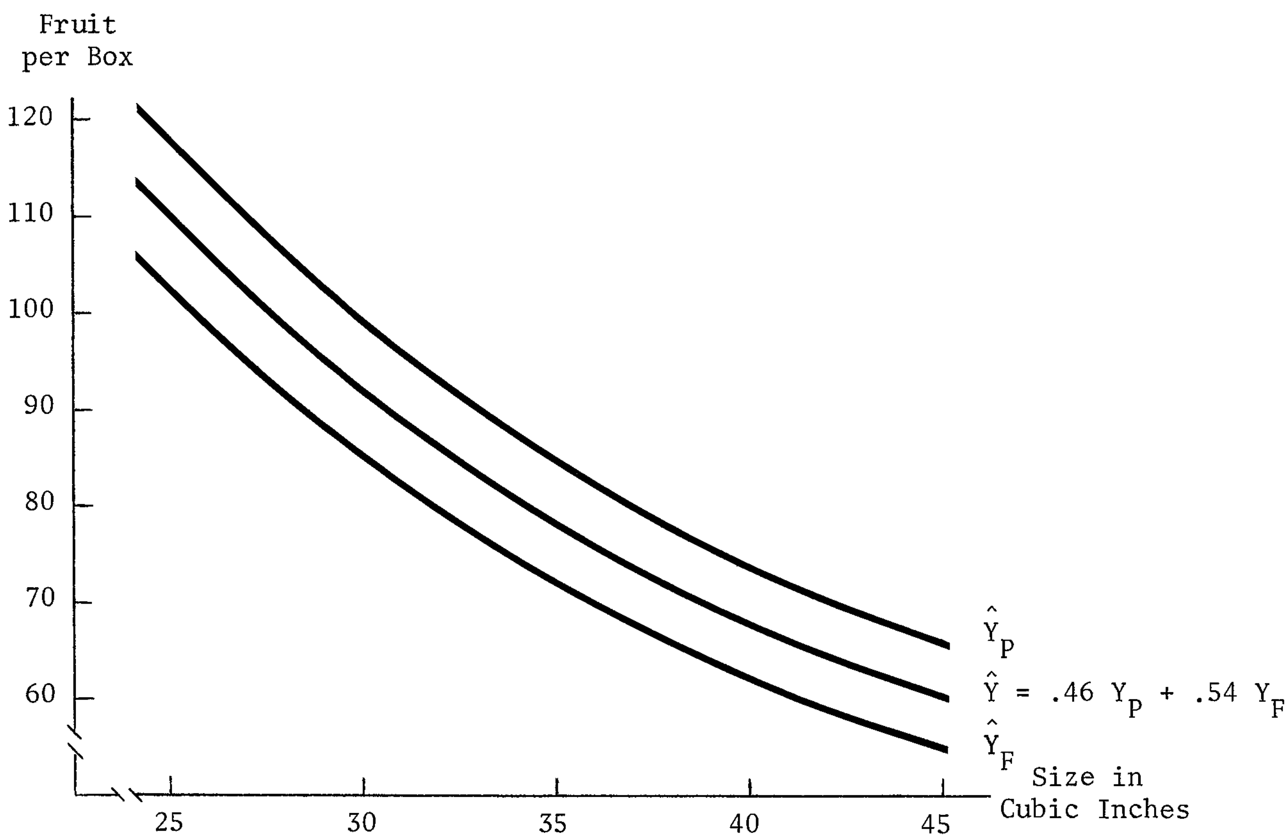
Type of Fruit	Sample Trees n....	Average Size of Fruit ($\bar{Y}$) (cubic inches)	$C.V._{.05}$
Early Oranges	188	12.40	4.5
Mid-Season Oranges	154	12.85	5.0
Early-Mid Oranges	342	12.59	3.3
Valencia Oranges	684	12.10	1.9
All Oranges	1026	12.31	1.4
Seedy Grapefruit	216	43.28	7.7
Seedless Grapefruit	382	30.36	3.9
All Grapefruit	598	33.8	3.6
Temples	100	13.79	6.8
Tangerines	134	6.39	6.1
Tangelos	90	11.10	5.3

It should be noted these statements of precision are for estimates of size of fruit at time of survey and do not reflect any error caused by projecting to harvest date. Since some reference has been made to relative errors calculated by using equations for a simple random sample, a matched comparison is of interest. Calculating simple random sample variance for early oranges gives a biased C.V.(.05) of 1.4, compared to the more realistic 4.5 just given. The 4.5 also reflects a slightly larger than normal variation in size of fruit for the 1967-68 season.

Converting Volume to Fruit per Box - Grapefruit

About 46 percent of the seedless grapefruit crop is normally used in processed products. The processed conversion (Y_p) and the fresh fruit conversion ($\hat{Y}_f$) are combined as shown in Figure 4. Small departures from the normal proportion of processed to fresh do not seriously affect the combined conversion of volume to obtain average number of fruit per box for grapefruit.

Figure 4: Converting Volume to Fruit per Box, Seedless Grapefruit



The general equation for conversion of volume to fruit per box is: $Y = a + bX + c\,\frac{1}{X}$. X is the estimated average size of fruit in cubic inches and Y is the estimated number of fruit in a box. Estimated parameters for selected types of citrus are given in Table 25.

On the following page is a reproduction of the field form used to record circumference measurements. These sizes are entered as tally marks in the appropriate cell. The typed number in each cell is the volume of a sphere corresponding to the indicated circumference. Volumes are tabulated for each tally mark.

Table 25: Parameters for Converting Volume to Fruit per Box

Type of Fruit	Parameter		
	a	b	c
Early-Mid Oranges	53.77	-1.696	2239.5
Valencia Oranges	76.94	-2.450	1992.5
Seedy Grapefruit	8.302	- .2006	3133.2
Seedless Grapefruit	10.840	- .02822	2506.8
Temples	25.608	- .9838	2553.3
Tangerines	54.985	-1.3746	2579.7
Tangelos	18.499	-1.4630	2940.5

FLORIDA CROP AND LIVESTOCK REPORTING SERVICE
1222 Woodward Street
Orlando, Florida 32803

CITRUS GROWTH SURVEY

CIRCUMFERENCE CALIPER MEASUREMENTS

Route______ Area______ Navels ( ) W. Sdy. Gft.( ) Tangerine ( )
Grove______ Co.______ Ear. Org.( ) P. Sdy. Gft.( ) Temple ( )
Mid. Org.( ) W. SS. Gft.( ) Tangelo ( )
Date______ Age Grp.______ Late Org.( ) P. SS. Gft.( ) Murcott ( )

In.	7	8	9	10	11	12	13	14	15	16	17
	0579	0865	1231	1689	2247	2917	3710	4634	5699	6917	8297
1/16	0594	0885	1257	1721	2285	2964	3764	4696	5771	6998	8388
2/16	0610	0906	1283	1753	2324	3010	3818	4759	5843	7080	8481
3/16	0626	0927	1310	1786	2363	3057	3873	4821	5616	7163	8574
4/16	0643	0948	1337	1819	2403	3104	3928	4884	5989	7246	8668

VI. FORECASTING FRUIT DROP

Drop Estimator and Variance

The estimator for determining that proportion of fruit counted in the initial drop survey that still remains for harvest at the time of subsequent surveys is:

$$R = \sum_h W_h \frac{\sum_i Y_{hi}}{\sum_i x_{hi}}$$

The W_h terms sum to 1 and are the same age-area production weights used to combine averages of fruit size. The y_{hi} and x_{hi} are matched observations for current count and original count respectively on limb i in stratum h.

Variance for R is derived as follows:

$$\begin{aligned} \text{Var}\ (\hat{R}) &= \Sigma\ \text{Var} \left\{ W_h \frac{\sum_i y_{hi}}{\sum_i x_{hi}} \right\} \\ &= \Sigma\ W_h^2\ \text{Var} \left\{ \frac{\sum_i y_{hi}}{\sum_i x_{hi}} \right\} \\ &= \sum_h W_h \frac{\hat{R}_h^2}{n_h} \left\{ \frac{s^2{}_{xh}}{\bar{x}_h^2} + \frac{s^2{}_{yh}}{\bar{y}_h^2} - \frac{2s_{xyh}}{\bar{x}_h\ \bar{y}_h} \right\} \end{aligned}$$

Since the observations for each stratum are from a hierarchial sample design, the s^2_{xh}, s^2_{yh} and s_{xyh} terms should come from grove-level mean squares of the nested analyses of variance and covariance for each stratum. For s^2_{xh} and s^2_{yh} this would be the s^2_{ww} shown in Appendix IV, and for s_{xyh} would be:

$$\left\{ \sum_{ijk} \frac{x_{ijk.}y_{ijk.}}{n_{ijk.}} - \sum_{ij} \frac{x_{ij..}y_{ij..}}{n_{ij..}} \right\} \Big/ (m..-m)$$

Combining estimators to higher levels of inference is done in the same manner as fruit size estimators, with the same appropriate variance formulas.

The following sample sizes were used in 1967-68 and provided levels of reliability comparable to recent years.

Table 26: Sample Size and Reliability for Drop Survey Statistics, 1967-68

Type of Citrus	Sample Size n....	Coefficient of Variation for Proportion Remaining for Harvest (α = .05)
Early Oranges	188	4.5
Mid Season Oranges	154	5.6
Early-Mid Oranges	342	3.5
Valencia Oranges	684	4.6
All -- Orange	1,026	2.8
Seedy Grapefruit	216	5.9
Seedless Grapefruit	382	5.8
All -- Grapefruit	598	4.5
Temples	100	5.2
Tangerines	134	3.5
Tangelos	90	1.4

Drop survey data can easily be recorded on a form similar to the one shown, which is used by Florida Crop and Livestock Service.

DROP COUNT SURVEY 1969-70 SEASON

Area ________ Route ______ County ________

Type ________ Grove ______ Age ________

Tree #1		Tree #2
____ x ____ Row Tree	Location of Tree	____ x ____ Row Tree
	Location of Fruit	
Fruit Count	Month of Survey	Fruit Count
	Aug	
	Sept	
	Oct	
	Nov	
	Dec	
	Jan	
	Feb	
	Mar	
	Apr	

Adjustment of Drop for Proportion of Crop Harvested

For any given month citrus production may be divided into two portions, harvested and unharvested as of that date. The "total adjusted drop" for the previous month is an indication of drop for the harvested portion, and current survey drop determines drop to date of unharvested citrus. These two indications are weighted with proportion harvested (W) and proportion unharvested (1-W) to provide a relatively unbiased indication of accumulated drop to date as a percent of total crop.

An estimate of the proportion of total crop already harvested (W) is provided by disposition tables of the Growers Administrative Committee. When actual certified production is available, the preliminary adjusted drop is multiplied by the ratio of estimated production to actual production, $\frac{\hat{P}}{P}$, to correct errors caused by using estimated production. An example of the use of a harvest adjustment form follows:

Fruit Drop Adjusted for Harvest

1966-67 Season Type Seedless Grapefruit

Date	Unadjusted Drop to Date (D)	Proportion Unharvested (1-W)	Adjusted Drop for Previous Month (D_a)	Proportion Harvested (W)	Adjusted Drop $D(1-W)+D_aW$
	Percent		Percent		Percent
Oct. 1	1.83	1.000		.000	1.83
Nov. 1	4.44	.960	1.83	.040	4.33
Dec. 1	7.46	.850	4.33	.150	6.99
Jan. 1	9.70	.769	6.99	.231	9.07
Feb. 1	12.48	.672	9.07	.328	11.26

VII: FORECASTING PRODUCTION

Sample Sizes

The following tables provide a historic series of sample sizes for major citrus surveys.

Table 27: Sample Size for Limb Count Survey

Type of Fruit	Crop Year			
	1965-66	1966-67	1967-68	1968-69
	Groves	Groves	Groves	Groves
Unidentified Oranges	0	0	0	15
Early Oranges	204	231	223	226
Midseason Oranges	213	221	202	206
Late Oranges	375	405	422	438
Seedy Grapefruit	116	114	125	127
White Seedless Grapefruit	181	187	180	185
Pink Seedless Grapefruit	146	154	127	127
Temples[1/]	147[2/]	162[2/]	78	157
Tangelos[1/]	85[2/]	110[2/]	59	203
Tangerines[1/]	149[2/]	159[2/]	133[2/]	186[2/]
Murcotts[1/]	37[2/]	65[2/]	95	0
Total	1653	1808	1644	1870

[1/] Frame count used in 1965-66 and 1966-67.

[2/] Number of sample groves consisting of two trees per grove; all other samples consist of four trees per grove.

Table 28: Sample Size[1/] for Fruit Size and Drop Surveys

Type of Fruit	Crop Year			
	1965-66	1966-67	1967-68	1968-69
	Groves	Groves	Groves	Groves
Navels	0	0	0	49
Early Oranges	106	120	94	94
Midseason Oranges	114	122	77	77
Late Oranges	367	387	342	342
Seedy Grapefruit	78	81	108	108
White Seedless Grapefruit	114	117	107	107
Pink Seedless Grapefruit	109	110	84	84
Temples	55	54	50	50
Tangelos	30	32	45	44
Tangerines	51	51	67	67
Murcotts	18	25	40	41
Total	1042	1099	1014	1063

[1/] Two trees per sample grove, ten fruit per tree.

Table 29: Sample Size for Row Count Survey

Type of Fruit	Crop Year 1965-66	1966-67	1967-68	1968-69
	Rows	Rows	Rows	Rows
Early Oranges	21,894	25,486	27,144	27,450
Midseason Oranges	31,133	34,389	35,501	34,869
Late Oranges	56,610	61,865	65,361	65,681
Seedy Grapefruit	5,412	6,279	7,801	7,927
White Seedless Grapefruit	5,159	5,821	7,199	7,287
Pink Seedless Grapefruit	3,591	3,944	4,975	4,950
Unidentified Grapefruit	12,083	14,273	10,454	10,058
Temple	4,798	5,090	5,336	5,269
Tangerine	5,173	5,882	6,025	6,115
Tangelo	1,458	1,682	2,148	2,147
Murcott	498	848	1,010	1,044
Total	147,809	165,677	162,954	172,797

Table 30: Sample Size[1] for Maturity Survey

Type of Fruit	Crop Year 1965-66	1966-67	1967-68	1968-69
	Groves	Groves	Groves	Groves
Early Oranges	50	49	72	72
Midseason Oranges	50	51	56	56
Late Oranges	50	50	100	100
Seedy Grapefruit	0	25	25	25
White Seedless Grapefruit	60	60	60	60
Pink Seedless Grapefruit	50	50	50	50
Total	260	285	363	363

[1] Five trees per sample grove, three fruit per tree.

Survey Costs

Cost is an important factor in evaluating existing surveys and designing similar surveys. Although some of the costs in the following summaries are estimates, figures are based on actual expenditures and should provide a good approximation for those considering the implementation of such methodology. Expenses related to size and dispersion of sample (such as preliminary fieldwork) are not included, so these summaries are conservative estimates of total costs.

Table 31: Total Survey Costs of the 1967 Aerial Tree Survey

Photography[1]	Photo Check and Recording	Field Check		Data Processing		Total
		Jeep	Wages	Machine	Wages	
$ 24,342	$ 43,549	$8,000	$37,904	$1,050	$1,000	$115,845

[1] Includes field ozalids and record cronaflexes at $.63 and $13.00 each respectively.

Table 32: Costs for Objective Yield and Related Surveys, 1967-68

Survey	Unit of Cost	Cost Classification					Total
		Field				Office	
		Wages		Mileage	Per Diem	Supplies, Clerical & ADP	
		Within Grove	Between Groves				
Limb Count[1]	Sample Grove	$ 9.43	$ 6.29	$ 4.87	$ 1.02	$ 1.62	$ 23.23
Size & Drop[2]	Sample Grove	.84	1.25	.45	.27	.82	3.63
Maturity[3]	Sample Grove	.23	1.30	.47	.10	.21	2.31
Row Count[4]	Survey	620.00	110.00	200.00	35.00	100.00	1065.00

[1] Costs are based upon a five-man crew consisting of four fieldmen plus a supervisor.

[2] Treated as one survey as both types of observations are made on the same sample trees. Surveys conducted each month. Information usually collected by a two-man crew.

[3] Survey conducted twice each month.

[4] Cost per month.

Variance of Direct Expansion Estimator of Production

The direct expansion model is $\hat{P}_t = T_t F_t H_t / S_t$, where the notation is as defined in the text (pg. 32). Derivation of the variance for this estimator is as follows: $\text{Var}\ (P_t) = T_t\ \text{Var}(F_t H_t / S_t)$.

$F_t \times (H_t/S_t)$ is the product of 2 independent variables, therefore

$$\mathrm{Var}(\hat{P}_t) = T^2\left\{F_t\ \mathrm{Var}(H_t/S_t) + (H_t/S_t)^2\ \mathrm{Var}(F_t) + \mathrm{Var}(H_t/S_t)\ \mathrm{Var}(F_t)\right\}$$

The size and drop surveys provide matched observations so that this is a valid ratio estimator where covariance between size and drop is relatively small. Thus, assuming the $\mathrm{Cov}(H_t, S_t)$ to be zero, there is a small upward bias in the following expression.

$\mathrm{Var}(H_t/S_t) \leq (H_t/S_t)^2\ \{\mathrm{Var}(H_t)/H_t^2 + \mathrm{Var}(S_t)/S_t^2\}$, so that:

$$\mathrm{Var}(\hat{P}_t) \leq \frac{T_t^2 H_t^2}{S_t^2}\left\{\frac{F_t^2\ \mathrm{Var}(H_t)}{H_t^2} + \frac{F_t^2\ \mathrm{Var}(S_t)}{S_t^2} + \mathrm{Var}(F_t) + \frac{\mathrm{Var}(H_t)\mathrm{Var}(F_t)}{H_t^2} + \frac{\mathrm{Var}(S_t)\mathrm{Var}(F_t)}{S_t^2}\right\}$$

Using dominant terms,

$$\mathrm{Var}(\hat{P}_t) \doteq \frac{T_t^2 H_t^2}{S_t^2}\left\{\frac{F^2\mathrm{Var}(H_t)}{H_t^2} + \frac{F_t^2\mathrm{Var}(S_t)}{S_t^2} + \mathrm{Var}(F_t)\right\}$$

Table 33 shows coefficients of variation for the 1967-68 season. These coefficients are slightly larger than normal.

Table 33: Relative Error for Direct Expansion Estimator - 1967-68 Season

Type of Fruit	Coefficient of Variation (α = .05)
Early Oranges	14.0
Mid-season Oranges	16.3
Valencia Oranges	8.4
All Oranges	7.5
Seedy Grapefruit	14.0
Seedless Grapefruit	9.2
All Grapefruit	7.7
Temples	8.1
Tangerines	18.2
Tangelos	18.8

Production for all oranges or all grapefruit is obtained by adding production of component types. Since the production estimators are additive their variances are also additive. For example, the variation for all grapefruit is: $\mathrm{Var}(\hat{P}_{gft}) = \mathrm{Var}(\hat{P}_{ss}) + \mathrm{Var}(\hat{P}_{sy})$. The symbols P_{ss} and P_{sy} denote production of seedless grapefruit and seedy grapefruit, respectively.

$F_t \times (H_t/S_t)$ is the product of 2 independent variables, therefore

$$\mathrm{Var}(\hat{P}_t) = T^2\left\{F_t \mathrm{Var}(H_t/S_t) + (H_t/S_t)^2 \mathrm{Var}(F_t) + \mathrm{Var}(H_t/S_t)\mathrm{Var}(F_t)\right\}$$

The size and drop surveys provide matched observations so that this is a valid ratio estimator where covariance between size and drop is relatively small. Thus, assuming the $\mathrm{Cov}(H_t, S_t)$ to be zero, there is a small upward bias in the following expression.

$\mathrm{Var}(H_t/S_t) \leq (H_t/S_t)^2 \{\mathrm{Var}(H_t)/H_t^2 + \mathrm{Var}(S_t)/S_t^2\}$, so that:

$$\mathrm{Var}(\hat{P}_t) \leq \frac{T_t^2 H_t^2}{S_t^2}\left\{\frac{F_t^2 \mathrm{Var}(H_t)}{H_t^2} + \frac{F_t^2 \mathrm{Var}(S_t)}{S_t^2} + \mathrm{Var}(F_t) + \frac{\mathrm{Var}(H_t)\mathrm{Var}(F_t)}{H_t^2} + \frac{\mathrm{Var}(S_t)\mathrm{Var}(F_t)}{S_t^2}\right\}$$

Using dominant terms,

$$\mathrm{Var}(\hat{P}_t) \doteq \frac{T_t^2 H_t^2}{S_t^2}\left\{\frac{F^2 \mathrm{Var}(H_t)}{H_t^2} + \frac{F_t^2 \mathrm{Var}(S_t)}{S_t^2} + \mathrm{Var}(F_t)\right\}$$

Table 33 shows coefficients of variation for the 1967-68 season. These coefficients are slightly larger than normal.

Table 33: Relative Error for Direct Expansion Estimator - 1967-68 Season

Type of Fruit	Coefficient of Variation (α = .05)
Early Oranges	14.0
Mid-season Oranges	16.3
Valencia Oranges	8.4
All Oranges	7.5
Seedy Grapefruit	14.0
Seedless Grapefruit	9.2
All Grapefruit	7.7
Temples	8.1
Tangerines	18.2
Tangelos	18.8

Production for all oranges or all grapefruit is obtained by adding production of component types. Since the production estimators are additive their variances are also additive. For example, the variation for all grapefruit is: $\mathrm{Var}(\hat{P}_{gft}) = \mathrm{Var}(\hat{P}_{ss}) + \mathrm{Var}(\hat{P}_{sy})$. The symbols P_{ss} and P_{sy} denote production of seedless grapefruit and seedy grapefruit, respectively.

Ratio Estimator of Production

The ratio estimator usually requires successive observations on the same sample unit. Following is proof that allowing current year variables of the relative change estimator to include trees coming into production that year is preferable to using matched observations plus an "add-on".

Notation is similar to that on page 32, (except that T_2 and F_2 exclude trees coming into production initially in year 2, 1 is previous year, and 2 is current year). Let t be the number of trees and f be the average number of fruit per tree for those trees new to the producing universe. Average fruit per tree for bearing trees including t is a weighted average, so the proposed relative change estimator is:

$$\hat{P}_2 = \frac{(T_2 + t)}{T_1} \cdot \frac{(F_2T_2 + ft)}{F_1(T_2 + t)} \cdot \frac{H_2S_1}{H_1S_2} \cdot P_1 \qquad (1)$$

$$= \frac{(F_2T_2 + ft)}{F_1\,T_1} \cdot \frac{H_2S_1}{H_1S_2} \cdot P_1$$

$$= \frac{F_2T_2}{F_1T_1} \cdot \frac{H_2S_1}{H_1S_2} \cdot P_1 + \frac{ft}{F_1T_1} \cdot \frac{H_2S_1}{H_1S_2} \cdot P_1$$

If last year's direct expansion estimator is approximately equal to last year's actual production (if $T_1F_1H_1/S_1 \doteq P_1$), then

$$\hat{P}_2 = \frac{F_2T_2}{F_1T_1} \cdot \frac{H_2S_1}{H_1S_2} \cdot P_1 + \frac{ftH_2}{S_2} \qquad (2)$$

which is the ratio estimator with an add-on for young trees coming into production. If the above assumption does not hold or there is a constant bias, then equation (1) is superior as it adjusts the new tree estimate for bias indicated in the previous year direct expansion.

VIII: RELATED SURVEYS

Maturity and Juice Yield

Fruit for the maturity survey is obtained from sample groves in the route frame. (See text for discussion on purpose and methodology used to obtain sample of fruit from sample trees.) Usually a sample of three fruit from each of five trees are used for laboratory tests. Tests are made on a composite sample.

Below is a form similar to the one used to record test results and calculations for each sample of fruit.

MATURITY TEST

Route	Grove	Brix Hydrometer Reading		Temperature Correction		Total Soluble Solids
			+		=	

Date						Type		Var.		Ar.	Age	Plant Date		Sample Grove			Root Stock
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Mo.		Day		Yr.													

Wt. Fruit (1)				Wt. Juice (2)				Acid (3)			Total Sol. Solids (4)			
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Pounds				Pounds				Percent			Percent			

Solids/Acid Ratio (5)				Juice Ratio (6)				Solids Ratio (7)			
34	35	36	37	38	39	40	41	42	43	44	45
(4) ÷ (3)				(2) ÷ (1)				(4) x (6)			

A pilot survey was conducted in the 1961-62 season. Table 34 gives the analysis of variance and sample size required to detect specified differences with 95 percent confidence.

Table 34: Orange Maturity A.O.V. - 1961-62 Season

Source	d.f.	Mean Square			Variance Component		
		Brix	Pounds Juice	Pounds Solids	Brix	Pounds Juice	Pounds Solids
Between Routes	1	.00	135.1	.86	0	12.3	.06
Between Groves	18	.86	11.6	.24	.40	3.3	.09
Between Trees	20	.05	5.0	.06	.05	5.0	.06
Arithmetic Mean		8.39	53.56	4.21			
Indicated n for $C.V._{.05}=2\%$		117	39	131			
Indicated n for $C.V._{.05}=3\%$		52	17	58			

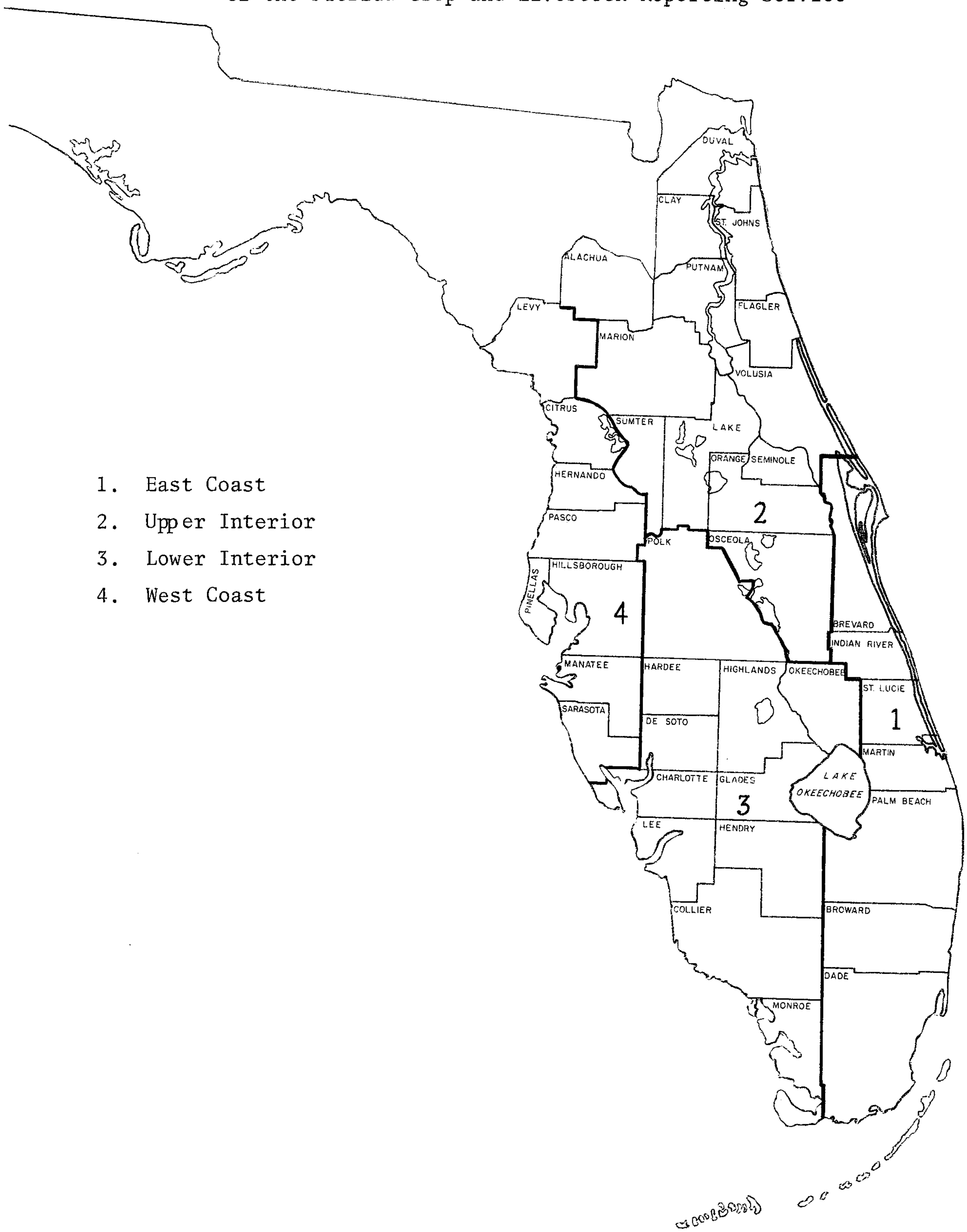
The pounds of soluble solids is an important consideration for fruit to be processed. Survey data on pounds solids from the 1966-67 season had the following levels of accuracy:

Table 35: Accuracy of Estimated Pounds Solids, 1966-67 Season

Area[1]	Early Oranges			Midseason Oranges		
	$C.V._{.05}$	Bias[2]	"Maximum Error"	$C.V._{.05}$	Bias[2]	"Maximum Error"
	percent	percent	percent	percent	percent	percent
Area 2	3.2	.6	3.8	4.4	.6	5.0
Area 3	2.7	.6	3.3	4.2	.6	4.8
State	2.3	.6	2.9	2.6	.6	3.2

[1] Areas are delineated in Figure 5 on following page.
[2] Due to omission of 5- to 9-year old trees during the 1966-67 maturity survey.

Figure 5: Major Citrus Producing Areas as Designated for Citrus Reports of the Florida Crop and Livestock Reporting Service



1. East Coast
2. Upper Interior
3. Lower Interior
4. West Coast

As mentioned in the section on interpretation of the pounds-solids indication, these data should be compared to previous year's data to obtain an estimate of change. Therefore, the variance of R is needed:

$$\text{Var }(\hat{R}) = \frac{\hat{R}^2}{n^2}\left\{\frac{S_{y^2}}{y^2} + \frac{S_{x^2}}{x^2} - \frac{2S_{xy}}{xy}\right\} \doteq .0002$$

This provides about the same accuracy as indicated by the "maximum error" in the actual level of pounds-solids (in grove), due to the low correlation between years for tests of fruit from identical trees (r = .26).

As mentioned, the maturity inferences at the area level are pertinent to individual producers making comparisons and decisions concerning their own operations. Beginning with the 1967-68 maturity survey, sample sizes were increased to give $C.V._{.05} \doteq 3\%$ at the area level as indicated below.

Table 3: Relative Errors for Indicated Area Sample Sizes, 1967-68

Indication	Area	Early - Mid[1]		Valencia[1]	
		n_h	$C.V._{.05}$	n_h	$C.V._{.05}$
Ratio, $\frac{\text{Brix}}{\text{Acid}}$	2	56	3.3	30	3.4
	3 & 4	63	4.0	61	2.7
Brix	2	56	1.8	30	2.2
	3 & 4	63	1.4	61	1.2
Pounds-Solids per Box	2	56	3.7	30	3.8
	3 & 4	63	4.5	61	3.0

[1] Total number of samples in the state were 128 Early-Mid Season groves and 100 Valencia groves.

Special Purpose Surveys

Calamity Surveys

Unusual occurrences, such as freezes or hurricanes, require an evaluation of crop loss. When mature fruit is damaged, there is no appreciable loss because salvaging is begun immediately. However, a freeze can necessitate placing an embargo on fresh fruit shipments from some areas, in which case the fruit is generally utilized in processed products. To provide timely and reliable information on location and severity of freeze damage, the Florida Crop and Livestock Reporting Service again utilizes its route frame. At dawn following a night of freezing temperatures, crews begin cutting small samples of fruit in a systematic sampling of the route frame (every nth grove by type). A tentative evaluation of the situation is available by noon of the same day. If the freeze is severe, a follow-up damage survey is conducted two weeks later. Damage is determined by cutting individual fruit to depths of 1/4 inch, 1/2 inch, and to the center. The deepest penetration of cell deterioration is recorded. This information is summarized by area to estimate the proportion of fruit in each category: no damage, 1/4 inch, 1/2 inch, and center damage (major or minor). This information on the extent of fruit damage is published for the major citrus areas. Information on tree damage is also recorded and disseminated.

A freeze has several effects on immature fruit: (1) reduced rate of fruit growth, (2) accelerated fruit drop, and (3) fruit cell deterioration (juice loss). Size, drop, and maturity surveys usually provide reliable means of adjusting production forecasts. In the event of severe freeze or hurricane, however, the relative error of the drop survey may justify a recount on a subsample of the limb count survey, using comparison of identical limbs to determine amount of fruit drop.

Economic Abandonment Surveys

When harvesting costs are high and marketing returns marginal, some of the crop is not harvested, resulting in economic abandonment. This causes a difference between physiological and certified production. Knowledge of that proportion of a crop which was not harvested is used in evaluation and improvement of production estimators. The economic abandonment survey is based on fruit counts from a subsample of identical limbs from the limb count sample.

SELECTED BIBLIOGRAPHY

Bulletins

Newell, S. R. Florida Citrus Tree Survey. U.S.D.A. Report, July 1935.

Stout, R. G. Size and Fruit Droppage Rates Influence Total Citrus Production. Florida Agricultural Experiment Stations Agricultural Economics Mimeo, Report 62-2, July 1961.

Stout, R. G. Specific Gravity as a Means of Estimating Juice Yields of Freeze Damaged Valencia Oranges. University of Florida Agricultural Experiment Stations Circular S-150, Gainesville, March 1964.

Stout, R. G., and Todd, J. W. A Continuing Survey for Estimating Current Numbers of Florida Citrus Trees. Florida Agricultural Experiment Stations Agricultural Economics Mimeo, Report EC 64-13, Gainesville, June 1964.

Articles and Periodicals

Brown, Arthur. "Citrus Plantings in Florida," The Citrus Industry. Winter Haven: Lake Region Publishing Corp., March 1938.

Commercial Citrus Inventory. Edited by J. E. Mullin. Orlando: Florida Crop and Livestock Reporting Service, December 1965.

Ford, H. W. "A Hand Instrument for Estimating Height and Width of Citrus Trees," Proceedings of the American Society of Horticultural Science, LXXVI, December 1960.

Jessen, R. J. "Determining the Fruit Count on a Tree by Randomized Branch Sampling," Biometrics, II, March 1955.

Kelly, B. W. "Objective Methods of Forecasting Florida Citrus Production," Estadistica, Journal of the Inter-American Statistical Institute, March 1958.

Stout, R. G. "Estimating Citrus Production by Use of Frame Count Survey," Journal of Farm Economics, XLIV, November 1962.

Books

Cochran, William. Sampling Techniques. New York: John Wiley & Sons, Inc., July 1962.

Fisz, Marek. Probability Theory and Mathematical Statistics. New York: John Wiley & Sons, Inc., 1963.

Unpublished Material

Kelly, B. W. "A Method of Forecasting Citrus Production in the State of Florida." Unpublished Ph.D. dissertation, University of Florida, August 1953.

Kelly, B. W. "How to Keep the Citrus Tree Count Current." Unpublished report to Florida Crop and Livestock Reporting Service, Orlando, August, 1957.

Stout, R. B. "Estimating Earliest Harvest Dates and Soluble Solids in Orange Production." Unpublished report to Florida Crop and Livestock Reporting Service, Orlando, October 1961.