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The seventh report in a series on

Efficiency in Fruit Marketing

ECONOMY AND ACCURACY IN ACCOUNTING TO GROWERS FOR FRUIT RECEIVED AT THE PACKING HOUSE

B. C. French and R. G. Bressler

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FOREWORD

This report is the seventh of a series aimed at improved efficiency and lowered costs in the local marketing and packing of deciduous fruits. The present report deals with only one aspect of packing costs--the costs of accounting to growers for fruit received at the packing house. Two commonly used methods of accounting--the separate-lot system and the sampling system--are considered as to their costs and accuracy.

Studies in sample plants indicate that the costs of separate-lot systems vary from \$0.13 to \$1.09 per 1,000 pounds of total plant volume. Improved procedures could result in about a 40-per cent reduction in this cost for the average plant. Sampling systems also show wide variations in cost, depending mainly on the desired degree of accuracy and the size and number of growers. The problems and procedures for efficient sample design are discussed, and the costs of sampling systems are compared with the costs of separate-lot procedures for varying conditions.

These studies were made cooperatively by the Giannini Foundation of Agricultural Economics, California Agricultural Experiment Station, and the Bureau of Agricultural Economics, U. S. Department of Agriculture. They were made under the authority of the Research and Marketing Act of 1946.

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B. C. French^{1/} and R. G. Bressler^{2/}

In the operation of packing and processing plants for many types of fruits and vegetables, field or orchard-run products are received at the plant from a number of growers. To account accurately to the growers for the products received requires determination of the weight or count for each of several important grade and size classifications. Two methods are commonly used to obtain such information: (1) the separate-lot system, where each producer's product is kept separate from all others as it is handled in the plant and (2) the sampling system, where a small portion of each lot is selected and the distribution of the entire lot estimated from the proportions observed in the sample. With the sampling procedure, the fruit of different growers may be comingled in plant operations.

The design of such systems has an important influence on the accuracy of accounting to growers for fruit received. In addition, there are important effects on plant operating costs. The first section of this report discusses accuracy and costs for the separate-lot system. Following sections deal with sampling systems and with the comparative plant costs under the two methods of accounting to growers.

THE SEPARATE-LOT SYSTEM

The essential characteristic of the separate-lot system is that the individual identity of each grower's product must be maintained until it is sorted, graded, sized, and the amount in each size-grade determined. In order to prevent the mixing of products from several growers, each lot is run separately with a delay or break in plant operations at the end of

^{1/} Cooperative Agent of the University of California Experiment Station and the Bureau of Agricultural Economics, U. S. Department of Agriculture.

^{2/} Professor of Agricultural Economics and Agricultural Economist in the Experiment Station and Director of the Giannini Foundation.

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each lot. During this delay period, the amounts of product in each of the several classifications are determined and recorded. In fresh fruit packing houses, the delay also permits the packing of products remaining in the bins or packing belts so that the actual packout can be determined.

Ideally, such a system should provide a very accurate accounting for each grower subject only to such minor errors as result from weighing procedures and the estimates of the tare weight of containers. But a complete separation of lots would usually require relatively long break or delay periods, and this would greatly increase plant operating costs. In order to increase efficiency and reduce costs, various short-cut procedures are commonly used. These serve to reduce the break-for-lot period, but they also introduce opportunities for error. Most of the possibilities for error stem from the fact that short-cut methods usually do not separate each lot completely, and the amount of product in the overlap is obtained by estimate rather than actual measurement. In addition, errors may result from estimating the weight of fruit in some grades--by applying conventional standard weights to the number of boxes where the standards may differ somewhat from actual weights.

In spite of these opportunities for error, practices observed in California fruit packing houses appear to be designed to give reasonable accuracy and to protect the interests and equities of both grower and packing house.

Idle Time With Separate-Lot Systems

The direct cost of a separate-lot system includes the cost of weighing and tallying the amount of fruit in the several grades, but a more important effect is the impact of the plant delays or breaks on over-all output and efficiency. The interruption of the flow of fruit through the plant means that some workers will be completely idle during this period while others are forced to work at lowered rates of activity. The loss of effective working time depends on such factors as the plant volume per hour, the number of dumping units and sorting-packing lines, the average size of lot for individual growers, and the length of the delay or break-for-lot period.

Table 1 summarizes the results of studies of separate-lot systems in a number of plants packing apples and pears or receiving olives for processing. The factors most subject to control or change by the plant manager

each lot. During this delay period, the amount of product in each of the several classifications are determined and recorded. In fresh fruit packing houses, the delay also permits the packing of products remaining in the bins or packing belts so that the actual packing can be determined. Ideally, such a system should provide a very accurate accounting for each grower subject only to such minor errors as result from weighing procedures and the estimates of the tare weight of containers. But a complete separation of lots would usually require relatively long break or delay periods, and this would greatly increase plant operating costs. In order to increase efficiency and reduce costs, various short-cut procedures are commonly used. These serve to reduce the break-for-lot period but they also introduce opportunities for error. Most of the possibilities for error stem from the fact that short-cut methods usually do not separate each lot completely, and the amount of product in the overlay is obtained by estimate rather than actual measurement. In addition, errors may result from estimating the weight of fruit in some grades by applying conventional standard weights to the number of boxes where the standards may differ somewhat from actual weights.

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The direct cost of a separate-lot system includes the cost of weighing and tallying the amount of fruit in the several grades, but a more important effect is the impact of the plant delays or breaks on over-all output and efficiency. The interruption of the flow of fruit through the plant means that some workers will be completely idle during this period while others are forced to work at lowered rates of activity. The loss of effective working time depends on such factors as the plant volume per hour, the number of handling units and sorting-packing lines, the average size of lot for individual growers, and the length of the delay or break-for-lot period. Table I summarizes the results of studies of separate-lot systems in a number of plants packing apples and pears for recieving olives for processing. The factors most subject to control or change by the plant manager

TABLE 1

The Effects of the Separate-Lot System on Effective Working Time
in California Apple, Pear, and Olive Plants

Plant	Volume of fruit			Lots run per line-hour	Break time per lot	Loss of effective working time	
	Per plant-hour	Per line-hour	Per lot			Per hour	Per cent
	1,000 pounds				minutes		
	Apple and pear packing houses						
A	20.4	10.2	10.2	1.0	3.0	3.0	5.0
B	18.0	9.0	-- ^{a/}	--	--	3.4	5.6
L	19.8	9.9	4.3	2.3	3.7	8.6	14.4
M	24.8	24.8	19.8	1.3	3.1	4.0	6.7
N	38.4	12.8	8.5	1.5	11.3	16.9	28.1
R	45.0	15.0	--	--	--	4.7	7.8
S	46.0	15.3	8.1	1.9	0.9	1.8	3.0
T	31.2	31.2	--	--	--	4.2	7.0
U	60.6	30.3	23.3	1.3	2.8	3.6	6.0
	Olive plants						
I	3.1	3.1	2.0	1.5	2.9	4.5	7.5
II	13.3	13.3	4.6	2.9	2.7	7.9	13.2
III	10.0	10.0	1.8	5.4	2.0	10.9	18.2
IV	11.8	11.8	2.8	4.2	3.4	14.2	23.7
V	10.5	10.5	5.3	2.0	2.3	4.6	7.7
VI	7.2	7.2	2.9	2.5	4.2	10.6	17.7
VIII	5.2	5.2	2.8	1.9	4.9	9.1	15.2
IX	12.3	12.3	3.2	3.9	3.6	14.0	23.2

^{a/} Dashes indicate data not available.

TABLE 1

The Effect of the Separator System on Effective Working Time
in California Apple, Pear, and Olive Plants

Plant	Volume of fruit			Lots run per line-hour	Break time per lot minute	Loss of effective working time	
	Per plant-hour	Per line-hour	Per lot			Per hour	Per cent
	1,000 pounds						
Apple and pear packing process							
A	20.4	10.2	10.2	1.0	3.0	3.0	2.9
B	18.0	9.0	9.0	--	--	3.0	2.8
C	19.8	9.9	11.3	2.3	3.3	8.6	11.4
M	21.8	21.8	19.8	1.3	3.3	4.0	6.7
N	38.4	12.8	8.2	1.2	11.2	10.2	28.1
R	12.0	12.0	--	--	--	1.0	7.8
S	16.0	16.2	8.2	1.2	0.2	1.8	3.0
T	31.2	31.2	--	--	--	4.2	7.0
U	60.6	30.3	23.2	1.2	2.8	3.6	6.0
Olive plants							
I	3.2	3.2	2.0	1.2	2.2	1.2	1.2
II	13.2	13.2	4.6	2.2	2.2	7.0	13.0
III	10.0	10.0	1.8	2.4	2.0	10.2	18.2
IV	11.8	11.8	2.8	1.2	3.4	11.2	23.2
V	14.2	10.2	2.2	2.0	2.2	1.6	7.2
VI	7.2	7.2	2.2	2.2	1.2	10.6	17.2
VII	2.2	2.2	2.2	1.2	1.2	2.2	12.2
IX	12.2	12.2	3.2	2.2	3.6	11.0	23.2

-- Dashes indicate data not available.

are the average size of lot and the length of the break period. In apple and pear plants, the average break-for-lot period ranged from less than one minute in Plant S to more than eleven minutes in Plant N. Individual break-for-lot periods ranged even more widely--from less than one-half minute to more than twenty minutes. In the olive plants studied, the break-for-lots averaged from two to five minutes, while breaks for individual lots ranged from one to ten minutes. In both the olive and the apple and pear plants, the average break time was about three minutes.

Size of lot is determined primarily by the particular size and production characteristics of the individual grower. It can be controlled somewhat by plant managers, however, in several ways: (1) scheduling picking and hauling operations from particular orchards so as to result in larger average deliveries at the plant; (2) consolidating several truckloads from a single grower into a single lot at the plant; and (3) discouraging very small growers or by combining the fruit from several small growers into a single lot for plant accounting purposes. The table indicates that average volume per lot ranged from 4,000 to 23,000 pounds for apple and pear plants. Individual lots handled at these plants during the period of study ranged from less than 1,000 to more than 70,000 pounds. Considering all plants, the average size of lot for apples and pears was about 10,000 pounds.

Lots were much smaller in olive plants, averaging only about 3,000 pounds. Individual plants had averages from 2,000 to more than 5,000 pounds during the periods studied. These averages were greatly influenced by a few relatively large cases, however, and many lots were of very small size. Individual lots observed during the study ranged from 400 to 26,000 pounds; 25 per cent of all lots were less than 1,000 pounds and 32 per cent fell between 1,000 and 2,000 pounds.

The table also indicates the effects of the separate-lot system on effective working time. As mentioned above, these effects depend on such factors as the plant volume per hour as well as on average size of lot and the average length of the break-for-lot period.

In apple and pear plants, the loss of time ranged from 3 per cent in Plant S to 28 per cent in Plant N. This extreme variation is due primarily to the difference in the length of the break period--less than one minute for Plant S and more than eleven minutes for Plant N. The 14-per cent loss in Plant L, on the other hand, is primarily the result of unusually low

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average lot size and the consequent increased number of break periods per hour. Plant U has a break time per lot that is about average, but with lots averaging more than 23,000 pounds, the time loss is only 6 per cent.

With relatively smaller lots and typically more break-for-lot periods per hour, the loss in effective working time is typically greater in olive plants than in apple and pear plants. The table indicates that the time loss ranged from 7 per cent in Plant I to 24 per cent in Plant IV. The large losses in Plants IV and IX are due to small lot size relative to plant volume and so to relatively large numbers of breaks per hour. Plant I has the lowest average lot size of all the plants studied, yet, has the lowest time loss. This is due to the very low plant volume per hour and the related small number of lots run per hour.

The effects of size of lot and break time on effective working time are indicated in Figures 1 and 2 for more or less typical plants. The diagrams are based on typical values for plant volume, lot size, and average break time. In individual plants these factors may differ considerably from typical values. In such cases the time loss would differ from that indicated by the diagrams.

With these limitations in mind, the first diagram (Figure 1) indicates how increases in the average break-for-lot period cause corresponding increases in the time loss. In general, each increase of one minute in break time is associated with an increase of 2.5 per cent in the loss of effective working time in apple and pear plants. Because of typically smaller lot sizes, the effect of increased break time is more pronounced in olive plants--each one-minute increase typically results in a 5-per cent loss in effective work time.

Figure 2 shows the general effects of changes in average lot size on effective working time. Since increases in lot size usually mean fewer lots per hour and so less delay time, this diagram indicates that the loss of effective working time becomes smaller and smaller as lot size is increased. In apple and pear plants, lots as small as 2,000 pounds would mean an average loss of nearly 40 per cent in effective working time. With lots of 10,000 pounds (approximately average), the time loss would be reduced to 7.5 per cent while larger lots would bring further reductions, approaching a minimum time loss of 3 per cent. In olive plants, lot sizes of less than 1,000 pounds--and 25 per cent of actual lots fell in this category--would mean time losses of well over 40 per cent in typical plants.

Figure 1. Effect of length of break-for-lot period on utilization of total plant time.

Figure 2. Effect of size of lot on the utilization of plant time.

Even average lots of 3,000 pounds are associated with an average loss of 15 per cent. Very large lots can be handled quite efficiently, however, with average time losses approaching 2 per cent.

Costs of the Separate-Lot System

As explained above, the major impact of the separate-lot system on plant operating costs is in terms of the loss of effective working time and so in the reduced volume of fruit handled per hour by the plant. In most plants, the elimination of the separate-lot system would permit only minor changes in the working forces--grower tally girls for packed fruit could be eliminated in fresh packing houses, and the number of men weighing and handling graded and sized olives could be reduced in some olive plants.

Table 2 summarizes data on plant volumes and estimated direct labor costs for the apple, pear, and olive plants included in the study. This table shows that the elimination of the separate-lot system would result in increases in the potential plant volume per hour, with small increases where the present system results in small reductions in effective working time and large volume increases where present time losses are large. Most of the plants would be able to reduce the direct labor payroll per hour, although these changes would be relatively minor. The combined influence of direct labor reductions and increased volume per hour would be reductions in average direct labor costs (exclusive of packing labor and other piece-rate workers) ranging from \$0.13 to \$1.09 per thousand pounds of apples and pears and from \$0.30 to \$0.80 per thousand pounds of olives. While these costs of the separate-lot system may not seem large, they become significant in terms of the total volume of fruit handled by a plant in any season. Moreover, the range in costs emphasizes that many plants can improve efficiency and reduce costs by adjusting their separate-lot systems in order to minimize the loss in effective working time.

These adjustments may include the installation of automatic counting and weighing devices, better coordination of tallying activities in the various parts of the plant, and improved systems of record keeping. The potential costs of the separate-lot systems in the sample plants with the break period between lots reduced to an average of two minutes are shown in the last column of Table 2. No improvement is indicated for Plants S and III since the break time per lot is already two minutes or less.

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Summary of Results

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These adjustments may include the installation of automatic sorting
and weighing devices, better coordination of sorting activities in the
various parts of the plant, and improved systems of record-keeping. The
potential costs of the separate-for system in the apple plant are shown
from \$0.40 to \$0.30 per thousand pounds of fruit. The improvements shown
in the last column of Table 2. The improvement is indicated for olives
and all other the fruit. The improvement is already the maximum for olives.

TABLE 2

The Effects of the Separate-Lot System on Potential
Plant Volume and on Direct Labor Costs,
California Apple, Pear, and Olive Plants

Plant	Present--with separate lots			Potential--no separate lots			Labor cost per 1,000 pounds for the separate-lot system	
	Plant volume 1,000 pounds per hour	Direct plant payroll per hour	Labor cost per 1,000 pounds	Plant volume 1,000 pounds per hour	Direct plant payroll per hour	Labor cost per 1,000 pounds	Present	Improved: two-minute breaks for lots
	Apple and pear packing houses							
A	20.4	\$ 62.40	\$3.06	21.5	\$ 61.40	\$2.85	\$0.21	\$0.15
B	18.0	73.90	4.11	19.1	72.80	3.81	0.30	-- ^{a/}
L	19.8	82.80	4.18	23.1	81.70	3.54	0.64	0.35
M	24.8	58.70	2.37	26.6	57.70	2.13	0.20	0.13
N	38.4	140.00	3.65	53.4	136.80	2.56	1.09	0.20
R	45.0	119.70	2.66	48.8	117.60	2.41	0.25	--
S	46.0	134.20	2.92	47.4	132.10	2.79	0.13	0.13
T	31.2	103.90	3.33	33.5	102.80	3.07	0.26	--
U	60.6	120.40	1.99	64.5	117.30	1.82	0.17	0.13
	Olive plants							
I	3.1	11.40	3.69	3.4	11.40	3.37	0.32	0.19
II	13.3	24.90	1.87	15.3	23.60	1.55	0.32	0.25
III	10.0	28.70	2.87	12.2	25.30	2.07	0.80	0.80
IV	11.8	21.00	1.78	15.5	19.10	1.23	0.55	0.35
V	10.5	25.20	2.40	11.4	24.00	2.10	0.30	0.28
VI	7.2	17.80	2.50	8.7	16.60	1.91	0.57	0.32
VIII	5.2	17.40	3.35	6.1	16.30	2.67	0.68	0.38
IX	12.3	21.30	1.73	16.0	18.80	1.18	0.55	0.35

^{a/}Dashes indicate data not available.

However, several of the plants show important potential gains in efficiency with the average reduction in cost amounting to about 40 per cent.

The above cost estimates refer only to direct payroll costs and do not include possibilities of cost reduction from the spreading of overhead costs to a larger volume. In order for such reductions in overhead costs to materialize, however, the plant volume per season would have to be increased. While the elimination of the separate-lot system might make such increases possible, the direct effect is in terms of volume per hour. For this reason, overhead costs have not been included in the above calculations.

Finally, it should be noted that these labor cost estimates for the separate-lot systems are useful primarily in making comparisons among plants using this system. They do not mean that a plant could completely eliminate the costs of accounting to producers. Costs with sampling systems will be described in the following section of this report and these costs then compared with the costs for separate-lot systems to determine the particular method most economical under varying conditions.

SAMPLE GRADING SYSTEMS

Sample grading systems are used in many fruit packing houses as a means of accounting to growers for the amounts of their fruit falling in each grade or size classification. In designing such a system, two important items must be considered: (1) the selection of the sample and (2) the size of the sample.

Sample Selection

Ideally, the sample should be selected at random throughout the entire lot so that the sample will be representative of the actual distribution of grades in the lot. The methods that are commonly used in a number of packing houses may fall a little short of this ideal. In apple and pear plants, for example, the usual procedure is to select several full lugs of fruit at random from each lot, the contents of these boxes serving as a sample. If the fruit in each box is a random representation of all of the fruit in the lot, this procedure will give satisfactory results. However, if, in the picking and field handling operations, fruit of particular grades becomes fairly concentrated in certain boxes, the sample that is obtained may not

be representative. Estimates based on these samples will be free from any consistent bias but will be subject to a wider margin of error than would otherwise be the case.

Representativeness may be improved somewhat by deriving the sample from a part of each of a number of lugs. For example, if 4 per cent of a lot of 100 lugs is to be sampled, the sample may be obtained by taking one-half of the fruit from each of eight randomly selected lugs being certain that the selection is not influenced by size or quality characteristics.

A method used in olive processing plants is to take a handful or scoopful of fruit from each lug as it is received and unloaded, thus, spreading the sample over the entire lot. This practice may give biased results, however, if fruit of particular sizes tend to be sifted out of the hand or scoop during the sampling process. Moreover, this method may conflict with the use of efficient unloading and receiving practices. The magnitude of the possible bias probably will not be large, however, and may be offset to a large extent by the better distribution of the sample throughout the lot.

Mechanical sampling devices which provide convenient and unbiased methods of sampling the entire lot at random are to be preferred. These devices generally consist of shear boards or drops in a conveyor leading from the dumping station, which can be adjusted to collect a sample of the desired size. The shear boards are merely adjustable boards placed on a conveyor belt which "shear off" a portion of the fruit as it passes by, this portion serving as a sample. Since it is difficult to regulate very precisely the size of the sample obtained by this method, the first sample may be divided or "subsampling" to obtain a final sample of the appropriate size. No attempt has yet been made to study the representativeness of samples selected by this method. The method of sampling by drops in a slot conveyor requires more expensive equipment than the shear board method. This device, which has been used primarily in citrus packing houses, is more precise and has been subjected to a considerable amount of statistical testing. It has not yet been used for deciduous fruits but presumably could be adapted for this type of product.^{3/}

^{3/} For additional information, see Roy J. Smith, "Accuracy Improved on Growers' Returns by New Sampling Machine." Fruit and Vegetable Review, vol. 9, no. 10, January, 1949.

...the case.
...may be improved somewhat by deriving the sample
from a part of each of a number of lots. For example, if a lot consists
of 100 units, the sample may be obtained by taking
one-half of the first 20 units, one-half of the next 20 units, and so on.
...the selection is not influenced by size of original quantity.

A method used in some processing plants is to take a sample of
product of fruit from each lot as it is received and enclosed, thus,
ensuring the sample covers the entire lot. This procedure may give biased
results, however, if fruit of particular sizes tend to be sifted out of
the lot or coddled during the sampling process. However, this method
may conflict with the use of efficient unloading and receiving practices,
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Technical sampling devices which provide convenient and unbiased
methods of sampling the entire lot at random are to be preferred. These
devices generally consist of shear boards or drums in a container, from
from the sampling section, which can be adjusted to reflect a sample of the
desired size. The shear boards are usually adjustable boards placed at a
convenient point when "draw off" a portion of the lot as it passes by.
This method serves as a sample, since it is difficult to determine very
precisely the size of the sample obtained by this method, and this sample
may be divided or "subsampled" to obtain a final sample of the appropriate
size. No attempt has been made to store the representativeness of
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testing. It has not yet been used for large quantities of material but
could be adapted for this type of product.

Sample Size

The second important aspect of sample grading, and the one of primary concern in this report, is the size of the sample to be selected. With any sampling system, the estimates of the proportions of the fruit in each grade will be subject to some error because the distribution of grades in the small part of the fruit that is sampled may differ somewhat from the true distribution of grades for all the fruit delivered by the grower. The magnitude of such differences can be reduced, however, by increasing the size of the sample.

The objective in designing a sample grading system is to provide a basis for making accurate payments to growers for their fruit--to limit the possible error in these payments to some specified amount with a small probability of exceeding this limit. The practical sampling procedure to follow depends on the amount of advance information available concerning the total season or pool period deliveries for each grower, the expected proportions of fruit falling in particular grades, and the price for each grade. As knowledge about these conditions increases, sampling systems can be designed that are more efficient in achieving any desired degree of accuracy.

Four cases regarding the amount of advance information may be distinguished: Case I--nothing is known about any of the indicated conditions; Case II--reasonable estimates can be made concerning the expected minimum total quantity of fruit to be delivered by each grower during the season; Case III--advance estimates are available concerning the proportions of fruit falling in particular grade classifications as well as total deliveries; and Case IV--estimates are available concerning the prices of each grade of fruit as well as the proportions and total deliveries. Under Cases I, II, and III, it is necessary to express accuracy in terms of the weight or proportion of fruit in a particular grade rather than in terms of payments. In Case IV, however, accuracy may be expressed directly in terms of total payments or average prices.

Accuracy in Estimating the Proportion of Fruit in Each Grade.--Growers and plant operators will ordinarily be interested in obtaining some degree of accuracy relative to the total quantity of fruit delivered by the grower in a season rather than for a particular lot of fruit. Under the conditions of Case I, however, the best that can be done is to sample so as to obtain

a given amount of accuracy for each lot that is delivered realizing that, if the grower does deliver more fruit, and if additional samples are taken, the over-all accuracy of estimate will be somewhat better than indicated for the particular lot. On the other hand, if past experience plus the personal knowledge of the plant manager and fieldmen permit a reasonably close estimate of minimum deliveries for each grower (Case II), the sampling procedure can be much more efficient.

For either Case I or II, the quantity of fruit to be sampled depends on (1) the desired degree of accuracy and (2) the quantity of fruit in the lot or the expected total quantity of fruit that the producer will deliver during the season.

The accompanying diagram (Figure 3), which may be used for both Cases I and II, indicates how the percentage of fruit to be sampled from each lot changes with the size of lot or total deliveries per season for several designated degrees of accuracy. For Case II, a total sample of the required size could be obtained by taking the entire quantity of one or two of the lots of fruit delivered by a grower as a sample. For adequate representation, however, the sample should be spread throughout all of the grower's lots. Therefore, the total sample is obtained by sampling a percentage of each lot of fruit delivered. It is assumed that each lot sample is a random representation of the total of the fruit in the lot. Accuracy is expressed as a per cent of the total weight or number of fruit of all grades. For example, if the admissible error is to be limited to 1 per cent and the true proportion for the particular grade to which the error limit refers is 50 per cent, the estimated proportion for this grade based on the sample may be expected to fall within 49 and 51 per cent (50 ± 1) in the great majority of the samples.

The basic calculations are made in terms of numbers of individual fruit and are generally applicable to most fruits. Since the quantity of fruit is usually measured in terms of weight, an appropriate ratio must be used to convert to numbers. Gravenstein apples and Bartlett pears for example, average about three fruit per pound of field run produce, while Sevillano olives average from forty to sixty fruit per pound. The lower of the two olive figures should be used in estimating the number of fruit delivered by a grower to be more certain of limiting the error of the desired range.

the overall quantity of salinity will be somewhat better than indicated for the particular lot. On the other hand, it must be kept in mind that the general knowledge of the plant manager and the other people is necessarily subject to a certain amount of minimum deliverable for each lot (Case II), the same

For other cases I or II, the quantity of fruit to be sampled depends on (1) the desired degree of accuracy and (2) the quantity of fruit in the lot or the expected total quantity of fruit that the producer will deliver during the season.

The accompanying diagram (Figure 3), which may be used for cases I and II, indicates how the percentage of fruit to be sampled from each lot changes with the size of lot or total deliverable per season for a given tolerance of accuracy. For Case II, a total deliverable of 100,000 pounds of fruit would be required by setting the entire quantity of fruit in two of the lots of fruit delivered by a producer as a tolerance. For

the lot of the grower's lot, therefore, the total sample is obtained by sampling a percentage of each lot of fruit delivered. It is assumed that each lot sample is a random representation of the total of the fruit in the lot. Accuracy is expressed as a per cent of the total weight of fruit in the lot of all grades. For example, if the accuracy error is to be 1 per cent and the true proportion for the particular grade is 10 per cent, the error limit is 1 per cent, the estimated proportion for each grade based on the sample may be expected to fall within 1 per cent and 11 per cent (99 to 101) of the total quantity of the lot.

The basic relationship is made in terms of number of individual fruit and not necessarily applicable to most fruits. Since the quantity of fruit is usually measured in terms of weight, an appropriate relationship may be used to convert to number; conversely, number and weight may be used. For example, suppose each fruit per pound of fruit per pound. While the relationship allows average from forty to sixty fruit per pound, the limit of the two olive figures should be used in estimating the number of fruit delivered by a grower to be more certain of limiting the error of the relation.

Figure 3. Effect of the desired degree of accuracy and total quantity of fruit per lot or per season on the percent to be sampled from each lot for conditions specified under sampling Cases I and II.

To illustrate the use of the diagram, suppose that under Case I conditions in which no advance estimates are available, a grower delivers a single lot of fruit consisting of 10,000 pounds of Gravenstein apples or Bartlett pears (30,000 fruit). To be reasonably certain that the error in estimating the proportion of fruit in any grade will be less than 1 per cent of the total weight of fruit in all grades would require a sample of 24.3 per cent of the lot (see point A in the diagram). On the other hand, if minimum total season deliveries for this grower can be estimated in advance (Case II), the per cent to be sampled from each lot can be greatly reduced while still obtaining the desired over-all degree of accuracy. For example, if expected total deliveries were at least 30,000 pounds of apples or pears (90,000 fruit), 1-per cent accuracy could be obtained with a sample of 9.6 per cent of each lot as indicated by point B. For growers with deliveries of at least 100,000 pounds (300,000 fruit), the same accuracy could be obtained with a sample of only 3.1 per cent (see point C). For growers with deliveries above 450,000 fruit, use the scale in the upper right-hand corner of the diagram.

In addition, it is clear that, for any size of delivery, as the limit of admissible error is increased (accuracy reduced), the per cent to be samples from each lot decreases. For example, to limit the admissible error to one-half of 1 per cent for a grower delivering 300,000 fruit would require a sample of 11.4 per cent of each lot, but to limit the error to only 1 per cent would require a sample of only 3.1 per cent of each lot.

It should be emphasized that the limits of admissible error shown in Figure 3 do not represent the amount of error that will occur in each estimate but rather upper limits to the error that will be reached or exceeded only infrequently. The limits of admissible error in Figure 3 are based on the probability of obtaining an error of estimate as large as, or larger than, the amount specified only once out of twenty times. This ratio, though arbitrarily selected, is commonly used in statistical analysis. The great bulk of estimates would be subject to errors considerably less than the limits stated. With an error limit of 1 per cent, for example, the average error would be about four-tenths of 1 per cent. Whatever the limit of admissible error, the actual error can be expected to be approximately one-half that amount in about two-thirds of the cases. Moreover, the error for any grade having a true proportion other than 50 per cent would be somewhat below the amounts discussed above. Thus, these curves

... of fruit consisting of 10,000 pounds of grapes in a year.
... of fruit in all grades would require a sample of
... of the total weight of fruit in all grades would require a sample of
... of the lot (see point A in the diagram). On the other hand,
... minimum total season deliveries for this grower can be estimated in ad-
... (Case II), the per cent to be sampled from each lot can be greatly
... while still obtaining the desired over-all degree of accuracy.
For example, if expected total deliveries were at least 30,000 pounds of
grapes or pears (30,000 fruit), 1-per cent accuracy could be obtained with
a sample of 300 (1 per cent of each lot as indicated by point B, for growers
with deliveries of at least 100,000 pounds (300,000 fruit), the same
accuracy could be obtained with a sample of only 30 (1 per cent (see point C).
For growers with deliveries above 150,000 fruit, use the scale in the upper
right-hand corner of the diagram.

In addition, it is clear that, for any size of delivery, as the limit
of admissible error is increased (accuracy reduced), the per cent to be
sampled from each lot decreases. For example, to limit the admissible
error to one-half of 1 per cent for a grower delivering 300,000 fruit would
require a sample of 150 (1 per cent of each lot), but to limit the error to
only 1 per cent would require a sample of only 30 (1 per cent of each lot).

It should be emphasized that the limits of admissible error shown in
Figure 3 do not represent the amount of error that will occur in each esti-
mate but rather upper limits to the error that will be reached or exceeded
only infrequently. The limits of admissible error in Figure 3 are based
on the assumption of obtaining an error of estimate as large as, or larger
than, the one indicated only once out of twenty times. This ratio,
however, is not a constant. It varies with the size of the delivery and
the degree of accuracy required. The larger the delivery, the smaller the
error for any given degree of accuracy. The smaller the delivery, the larger
the error for any given degree of accuracy. The larger the delivery, the smaller
the error for any given degree of accuracy. The smaller the delivery, the larger
the error for any given degree of accuracy.

do not indicate the typical amount of error in the estimates of the proportions of various grades but upper limits to the expected error that would be exceeded only in relatively rare cases.

If none of the grades approach the proportion of 50 per cent, the procedures outlined for Cases I and II will involve larger samples than actually required to attain the specified degree of accuracy. If there is no way to foretell the approximate values of the proportions in the class or grade containing the largest quantity of fruit, however, these procedures will remain the best available guides.^{4/} On the other hand, if, from past experience and observations of fieldmen, the plant manager can make a reasonable forecast of the proportion in the largest grade for a given grower and of the approximate amount of fruit that the grower will deliver in the season (Case III), more precise and economical procedures are possible.

For Case III conditions, the per cent to be sampled from each lot, as determined in Figure 3 (Cases I and II), may be modified according to the following general rules:^{5/}

(1) If the expected per cent of fruit in the largest grade or class is between 31 and 69 per cent, use Figure 3 without modification.^{6/}

(2) If the expected per cent of fruit in the largest grade or class is between 70 and 79 per cent, or 21 and 30 per cent, multiply the per cent to be sampled as determined in Figure 3 by:

0.9 if the expected deliveries are less than 90,000 fruit per season;

0.85 if the expected deliveries are 90,000 or more fruit per season.

(3) If the expected per cent of fruit in the largest grade or class

^{4/} Proportions should be calculated in terms of numbers of individual fruit. If the average size of fruit is the same for all grades, proportions of weight will be the same as proportions of individual fruit, but if fruit size varies among classes, the weight and numbers proportions will differ. For example, a grade containing very large fruit might contain a high proportion of the total quantity of fruit in terms of weight, but a small proportion in terms of numbers.

^{5/} These rules are simplified for practical application. See the Appendix for more accurate expressions.

^{6/} Use minimum proportions if the expected proportion in the largest grade is greater than 50 per cent; maximum expected proportions if less than 50 per cent. For example, the expected proportion in the largest grade might be at least 70 per cent or not more than 40 per cent.

proportions of various grades but equal rights to the expected per cent of fruit in the largest grade or class.

If none of the grades approach the proportion of 50 per cent, the procedure outlined for Cases I and II will involve taking samples from several grades to obtain the specified degree of accuracy. If there is no way to forestall the approximate values of the proportions in the class

will be the best of all. On the other hand, if, from some experiments and observations of the fruit, the grower can make a reasonable forecast of the proportion in the largest grade for a given season and of the approximate amount of fruit that the grower will deliver to the season (Case III), more precise and economical procedures are

For Case III, consequently, the per cent to be sampled from each lot, as determined in Figure 3 (Cases I and II), may be modified according to the

(1) If the expected per cent of fruit in the largest grade or class is between 51 and 60 per cent, use Figure 3 without modification.

(2) If the expected per cent of fruit in the largest grade or class is between 70 and 79 per cent, or 81 and 90 per cent, multiply the per cent to be sampled as determined in Figure 3 by:

(a) If the expected deliveries are less than 20,000 fruit per season;
(b) If the expected deliveries are 20,000 or more fruit per season.

(3) If the expected per cent of fruit in the largest grade or class is between 91 and 99 per cent, use Figure 3 without modification.

Proportions should be calculated in terms of the expected per cent of fruit in the largest grade or class.

For more accurate estimates, the grower should use the following procedure:

1. Determine the expected per cent of fruit in the largest grade or class for the season.

is 80 per cent and above, or 20 per cent and below, multiply the per cent to be sampled as determined in Figure 3 by:

0.8 if the expected deliveries are less than 90,000 fruit per season;

0.65 if the expected deliveries are 90,000 or more fruit per season.

As indicated previously, the real objective in designing a sample grading system is to provide estimates that will limit the possible error in final payments to growers to some specified amount. While the procedures outlined for Cases I, II, and III achieve this result indirectly, the magnitude of the limit of payment error is influenced by prices. If advance information is available concerning the prices of the various grades of fruit (Case IV), the sampling system may be designed directly in terms of some specified degree of accuracy in the final payments. The calculation of sample size for this case, however, while not difficult, is too complex to present in simple form. Therefore, the procedures outlined for Cases I, II, and III will probably prove most useful for the majority of packing house operators.^{7/}

Sampling Cost

The costs of sample grading include the costs for workers who collect, sort, weigh, tally, and transport the fruit that is sampled and the costs of sample grading equipment.^{8/} The sampling equipment consists of items such as grading tables for apples and pears, sizing-sorting equipment for olives, and scales for weighing the fruit. Mechanical sampling devices for sample selection, used in some plants, are not included here.

Estimates of these costs, based on studies of packing and processing plant operations, are summarized in Table 3. Two levels of equipment cost are indicated for apple and pear plants. For small plants--volume below 20,000 pounds per hour--a small grading table with a capacity for one or two sorters would probably be adequate. Larger plants, or plants with a large volume of fruit sampled, may require a larger table with three or four sorter capacity and with power-driven belts. The equipment for olives would be about the same for plants of nearly all sizes.

^{7/} A simplified mathematical and graphical treatment of the sampling problem for Case IV is given in Appendix A.

^{8/} Since the fruit that is sample graded does not have to be run over the main graders, only part of the sample sorting labor has been treated as a sampling cost.

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plant operations, are summarized in Table 3. Two levels of equipment
are indicated for apple and pear plants. For small plants--volume below
20,000 pounds per hour--a small grading table with a capacity for one or
two sorters would probably be adequate. Larger plants, or plants with a
large volume of fruit sampled, may require a larger table with three or
four sorters. The costs for these plants would be about the same for plants of nearly all sizes.

A simplified mathematical and graphical treatment of the sampling
plan for Case IV is given in Appendix A.
It is noted that the sample graded does not have to be the same size
as the lot, only part of the sample sorting table has been treated as a

TABLE 3

Estimated Labor and Equipment Costs for Sample Grading

	Apple and pear plants		Olive plants
	Volume less than 20,000 pounds per hour	Volume more than 20,000 pounds per hour	
Estimated installed cost of sample grading equipment, 1952 <u>a</u> /			
Grading table <u>b</u> /	\$ 50	\$ 650	\$ 700
Bench scales--dial type	560	560	480
	\$610	\$1,110	\$1,180
Estimated annual cost of equipment <u>c</u> /	\$ 70	\$ 160	\$ 160
Typical labor hours per 1,000 pounds of fruit in samples	1.9	1.9	20
Typical labor cost per 1,000 pounds of fruit in samples <u>d</u> /	\$ 2.28	\$ 2.28	\$ 24

a/ Does not include costs of mechanical devices for sample selection.

b/ Table for small apple or pear plants has capacity for two sorters. Table for large plants has powered belts and capacity for four sample sorters. The olive sizing-sorting table has a capacity of about 150 pounds per hour.

c/ Based on a standardized set of annual charges for depreciation, repairs, insurance, interest, and taxes; grading tables, 14.7 per cent; scales, 10 per cent plus \$7.50 per year for repairs and maintenance.

d/ Based on typical average wage of \$1.20 per hour for sample grading labor.

Estimated Labor and Equipment Costs for Sample Collection

Sample Type	Equipment	Personnel	Notes
1. Surface water	Boat, pump, bucket	1 person	Estimated annual cost of equipment: \$1,000
2. Benthic invertebrates	Boat, pump, bucket, dredge	2 persons	Typical labor hours per 1,000 pounds of fruit in samples: 1.5
3. Plankton	Boat, pump, bucket, plankton net	1 person	
4. Sediment	Boat, pump, bucket, corer	1 person	

- Does not include costs of mechanical devices for sample collection.
- Table for 1000 lbs of fruit in samples has been used for two years. Table for 1000 lbs of fruit in samples has been used for two years. Table for 1000 lbs of fruit in samples has been used for two years.
- Station-keeping table has a capacity of about 100 pounds per hour.
- Based on a standardized set of standard charges for transportation, repairs, insurance, interest, and taxes; including about 10 per cent surplus. 10 per cent surplus; interest; and taxes; including about 10 per cent surplus. 10 per cent surplus; interest; and taxes; including about 10 per cent surplus.
- Based on typical average rate of \$1.50 per hour for cost of working labor.

The costs given in Table 3 represent only average annual costs of equipment and the labor cost per 1,000 pounds of fruit in the samples. Total costs of sample grading depend on the quantity or per cent of fruit received that is sample graded which, in turn, depends on the desired degree of accuracy, the total volume handled per season in the packing house, and the distribution of total deliveries among the individual growers. These factors vary from plant to plant so any simple statement of sampling costs is impossible. However, the general nature of these costs and their relation to sampling accuracy may be illustrated with reference to the conditions in a specific plant. Costs for a typical apple or pear packing house and a typical olive processing plant are given in Table 4. In these examples it is assumed that estimates are available concerning expected total deliveries per grower but not concerning expected proportions in the various grades--i.e., Case II conditions exist. The percentages to be sampled are thus read directly from Figure 3.

The size and number of growers are given in columns 1 and 2 of the table where, for simplicity, they have been grouped in several convenient sizes. This is a practical sampling procedure that might be followed in most packing houses. The per cent to be sampled from each lot for each size group was determined from Figure 3 for several levels of accuracy. These figures have been applied to the total quantities of fruit to be sampled for each size group. The columns are then added to indicate the total quantities of fruit that would have to be sampled by this plant in order to obtain various degrees of accuracy. These calculations, which a manager may make for his own plant, indicate a rapidly increasing quantity of fruit sampled--and, thus, an increasing sampling cost--with increases in accuracy, especially for the higher levels of accuracy.

Note that for any level of accuracy a much higher per cent of fruit is sampled for small growers than for those with large total deliveries. In the illustrative pear plant, for example, to limit the admissible error to 1 per cent for all growers requires that 9.6 per cent of each lot be sampled for small producers and only eight-tenths of 1 per cent for the largest producers. On the average, 2.6 per cent of the fruit would be sample graded. While a uniform sample of this size would give the same total sampling cost and approximately the same degree of accuracy (1 per cent) for the average-size grower, the estimates will tend to be less accurate than the desired amount for small producers and relatively more

It is important to note that the accuracy of the results obtained from the use of the above formulae is dependent upon the accuracy of the data used. The data used in the above calculations were obtained from a series of experiments conducted under controlled conditions. The results of these experiments are given in Table I. The data show that the accuracy of the results obtained from the use of the above formulae is high, and that the results are in good agreement with the results obtained from the use of the standard method of analysis.

TABLE 4

The Effect of the Desired Degree of Accuracy on the Volume of Fruit Sampled and the Cost of Sample Grading for Typical Apple, Pear, and Olive Packing Plants

Deliveries per grower per season	Number of growers	Total deliveries per season	Total sample									
			Limit of admissible error--per cent of total weight									
			5.0		3.0		2.0		1.0		0.5	
1,000 pounds ^{a/}		1,000 pounds	per cent	pounds	per cent	pounds	per cent	pounds	per cent	pounds	per cent	pounds
Apple or pear plant												
30	4	120	0.4	480	1.2	1,440	2.6	3,120	9.6	11,520	30.0	36,000
50	8	400	0.3	1,200	0.8	3,200	1.6	6,400	6.0	24,000	20.4	81,600
100	10	1,000	0.2	2,000	0.4	4,000	0.8	8,000	3.1	31,000	11.4	114,000
150	6	900	0.1	900	0.2	1,800	0.5	4,500	2.1	18,900	7.9	71,100
200	5	1,000	0.1	1,000	0.2	2,000	0.4	4,000	1.6	16,000	6.0	60,000
400	2	800	0.1	800	0.1	800	0.2	1,600	0.8	6,400	3.0	24,000
	35	4,220	0.2	6,380	0.3	13,240	0.7	27,620	2.6	107,820	9.2	386,700
Total sampling cost ^{b/}				\$175		\$190		\$223		\$406		\$1,042
Olive plant												
1 ^{c/}	5	5	0.9	45	2.5	125	5.6	280	19.3	965	49.0	2,450
5	7	35	0.2	70	0.6	210	1.1	385	4.7	1,645	16.2	5,670
10	10	100	0.1	100	0.3	300	0.5	500	2.4	2,400	8.9	8,900
20	8	160	0.1	160	0.1	160	0.3	480	1.2	1,920	4.6	7,360
50	5	250	0.1	250	0.1	250	0.1	250	0.5	1,250	1.9	4,750
100	5	500	0.1	500	0.1	500	0.1	500	0.3	1,500	1.0	5,000
200	1	200	0.1	200	0.1	200	0.1	200	0.1	200	0.5	1,000
	41	1,250	0.1	1,325	0.1	1,745	0.2	2,595	0.8	9,880	2.8	35,130
Total sampling cost				\$192		\$202		\$222		\$397		\$1,003

^{a/} Average of three fruit per pound used to calculate number of fruit with which to enter Figure 1.

^{b/} Costs based on larger size sample grading table.

^{c/} Average of 40 Sevillano olives used to calculate the number of fruit with which to enter Figure 1. Field run fruit vary from 40 to 60 per pound. The lower figure is used to be more certain of limiting the possible error to the desired range.

accurate for large producers. From this standpoint, then, differential sampling--varying the per cent sampled according to grower size--is a more equitable procedure.

Following procedures similar to those indicated in Table 4, costs of sample grading have been estimated for a number of plants now using separate-lot systems. These costs are given in Table 5 for several degrees of accuracy. Details as to the season deliveries for each grower were not readily available for every plant. Therefore, the sampling costs have been estimated by using the average volume of deliveries per grower to determine the average per cent of fruit to be included in samples. The cost estimates will be about the same as with the more detailed procedures.

As in the typical plants represented in Table 4, sampling costs per thousand pounds of fruit received increase with increases in the degree of accuracy. The costs also increase with decreases in the average volume of deliveries per grower and, due to the fixed costs for equipment, decrease with increases in the total plant volume per season.

SAMPLING VERSUS SEPARATE-LOT SYSTEMS

The circumstances under which sampling or separate-lot procedures would be more economical as a means of accounting to growers for the amounts of their fruit falling in each grade or size classification cannot be described in any simple form. As has been indicated, the cost of a separate-lot system depends on such factors as the length of break periods between lots, the average size of lot, rates of plant output, and total direct hourly payroll. At the same time, sampling costs are influenced by the desired degree of accuracy, the amount of advance sampling information available, and the distribution of total deliveries among individual growers. The possible sets of conditions for which cost comparisons could be made are innumerable.

The procedures for calculating the costs of separate-lot systems have been indicated in Tables 1 and 2. Costs of the alternative system--sample grading--may be estimated by following the procedures used in Table 4. These calculations may be carried out by a manager for his own plant to ascertain which system is likely to be most economical.

Following procedures similar to those indicated in Table 1, costs of separate plantings have been estimated for a number of plantings now being made. These costs are given in Table 2 for each of the plantings. Details as to the season of planting for each planting are not readily available for every planting. Therefore, the sampling costs have been estimated by using the average values of deliveries per acre to determine the average cost per acre of fruit in each planting. The cost estimates will be about the same as with the same data.

As in the typical plantings presented in Table 1, sampling costs per acre of fruit received increase with increases in the average value of fruit. The cost of the average value of fruit in the average value of fruit per acre, due to the fixed costs for planting, the cost of the increase in the total plant volume per acre.

The plantings were considered as a means of an attempt to provide a more accurate estimate of the cost of fruit in each planting. As has been indicated, the cost of separate plantings depends on such factors as the length of time between plantings, the average size of lot, rates of plant output, and the average hourly payment. At the same time, sampling costs are indicated by the desired degree of accuracy, the amount of sampling, and the number of plantings. The possible sets of conditions for which cost estimates could be made are innumerable. The procedure for calculating the costs of separate plantings is indicated in Table 2. Costs of the separate plantings may be estimated by using the procedure in Table 2. Some estimates may be made by using a number of plantings to approximate the cost of separate plantings.

TABLE 5

Costs of Sample Grading Systems in Relation to Degree of Accuracy for
California Apple, Pear, and Olive Packing Plants

Plant	Volume per season	Average volume of deliveries per grower		Average cost of sample grading (dollars per 1,000 pounds of fruit received ^{a/})			
				Limit of admissible error for the average-size grower-- per cent of the total weight delivered			
				3.0	2.0	1.0	0.5
	1,000 pounds	1,000 pounds	estimated 1,000 fruit				
Apple and pear packing houses							
A	3,520	90	270	0.06	0.06	0.13	0.33
B	2,331	70	210	0.08	0.09	0.17	0.42
L	4,524	115	345	0.04	0.05	0.10	0.27
M	6,385	320	960	0.03	0.03	0.05	0.11
N	5,695	240	720	0.03	0.04	0.06	0.14
R	9,000	320	960	0.02	0.02	0.04	0.10
S	10,300	115	345	0.02	0.03	0.08	0.25
T	8,125	580	1,740	0.02	0.02	0.03	0.07
U	5,745	190	570	0.03	0.04	0.07	0.17
Olive plants							
I	487	35	1,400	0.35	0.40	0.47	0.95
II	1,713	42	1,680	0.12	0.12	0.21	0.62
III	3,100	18	720	0.08	0.12	0.36	1.25
IV	1,527	26	1,040	0.13	0.15	0.32	0.92
V	2,098	46	1,840	0.10	0.10	0.20	0.56
VI	1,218	14	560	0.18	0.23	0.54	1.67
VIII	824	16	640	0.24	0.29	0.56	1.56
IX	2,409	56	2,240	0.09	0.09	0.16	0.52

^{a/} Costs for apples and pears based on large size sample grading table.

Table showing the results of the analysis of the samples collected from the various sources.

Sample No.	Sample Description		Analysis Results		Remarks
	Location	Depth (m)	Temperature (°C)	Salinity (ppt)	
1	Station A	0-5	15.2	35.0	Surface water
2	Station A	5-10	14.8	35.0	Sub-surface water
3	Station B	0-5	15.5	35.0	Surface water
4	Station B	5-10	14.9	35.0	Sub-surface water
5	Station C	0-5	15.1	35.0	Surface water
6	Station C	5-10	14.7	35.0	Sub-surface water
7	Station D	0-5	15.3	35.0	Surface water
8	Station D	5-10	14.9	35.0	Sub-surface water
9	Station E	0-5	15.4	35.0	Surface water
10	Station E	5-10	14.8	35.0	Sub-surface water

Analysis was conducted using standard methods for temperature and salinity measurements. The results show a consistent pattern of temperature and salinity across the different stations and depths.

Some general conclusions are possible, however, by comparing the costs of separate-lot systems given in Table 2 with the estimated costs of sampling systems given in Table 5 for these same plants. The comparative costs are illustrated by the bars in Figure 4. For each plant, the bar on the left represents the cost of the separate-lot system. The total area of the bar indicates the present cost of the separate-lot system and the darker stippled area represents the estimated cost with standard two-minute average break time between lots. The present break time in Plants S and III was less than or equal to two minutes so no reduction is indicated. Data on costs with two-minute breaks were not available in Plants B, R, and T. The bars on the right represent the estimated cost of a sample grading system in each of these plants. The total area of the bars shows the estimated cost of sampling with an admissible error of one-half of 1 per cent of the total weight of fruit for the average-size grower. The cross-hatched area indicates the cost of sampling with a 1-per cent limit of admissible error.

For apple and pear plants, the estimated cost of the sampling system with a limit of admissible error of 1 per cent for the average grower is, in all cases, less than the cost of separate-lot systems—even where the break period is reduced to two minutes. If it is desired to limit the admissible error to one-half of 1 per cent, the cost of sampling is sharply increased. However, even in this case sampling costs are less than separate-lot costs in five of the nine plants. Thus, for the majority of these plants, the sampling system tends to be the most economical procedure.

The case for sampling is less clear in olive plants. While the costs of the separate-lot system per 1,000 pounds of fruit received are generally higher in these plants than in apple and pear plants, so also are sampling costs. With 1-per cent accuracy, estimated sampling costs are less than present costs of separate-lot systems in seven of the eight olive plants and are less than separate-lot costs with two-minute breaks in five of the eight plants. However, if a limit of admissible error of only one-half of 1 per cent is desired, sampling costs are greater than present separate-lot costs in all but one plant. Thus, with a limit of admissible error of 1 per cent or more, the sampling system has a cost advantage in the majority of the plants. If a higher degree of accuracy is desired, either the present or the improved separate-lot system is generally less costly.

Some general comments are made in Table 2, comparing the costs of separate lot systems with the costs of the integrated system. The comparison of costs are illustrated by the data in Figure 4. For each plant, the cost on the left represents the cost of the separate lot system. The total area of the bar indicates the present cost of the separate lot system and the area on the right indicates the cost of the integrated system. The present break time in Plant 1 and Plant 2 is less than or equal to two minutes so no reduction is indicated. Data on costs with separate break times were not available in Plants 1, 2, and 3. The data on the right represent the estimated cost of a sampling and sorting system for each of these plants. The total area of the bar shows the estimated cost of sampling with an admissible error of one-half of 1 per cent of the total weight of fruit for the average-size grower. The cross-hatched area indicates the cost of sampling with a 1 per cent limit of admissible error.

For Apple and Pear plants, the estimated cost of the sampling system is a limit of admissible error of 1 per cent for the average grower. In all cases, less than the cost of separate lot systems--even when the break time needed is reduced to two minutes. If it is desired to limit the admissible error to one-half of 1 per cent, the cost of sampling is roughly halved. However, even in this case, sampling costs are less than separate lot costs in five of the nine plants. Thus, for the majority of fruit plants, the sampling system tends to be the most economical procedure.

The case for sampling is less clear in olive plants. The estimated cost of the separate lot system for 100 pounds of fruit produced was \$1.00. It is higher in these plants than in apple and pear plants, as also is the present cost of separate lot systems. In terms of the cost of sampling, the present cost of separate lot systems is less than the cost of sampling in five of the eight plants. However, if a limit of admissible error of only one-half of 1 per cent is desired, sampling costs are generally less than separate lot costs in all but one plant. Thus, with a limit of 1 per cent of 1 per cent or more, the sampling system has a cost advantage in the majority of the plants. In a higher degree of accuracy, or a lower limit of admissible error, the present on the improved separate lot system is generally less costly.

Figure 4. Comparative costs of sampling and separate lot systems in California pear, apple, and olive packing or processing plants.

APPENDIX A

The sampling chart for Case I and II sampling conditions and the rules for its use under Case III, presented in the previous pages of this report, should provide a useful guide to packing house operators who are interested in setting up sampling systems or in checking on their present procedures. For some plants, however, a more detailed and comprehensive treatment may be required or desired. This appendix is included for the benefit of those who are interested in more precise formulations of sampling Cases I, II, and III, or in designing a sampling system directly in terms of accuracy of the final payments to producers--Case IV. The procedures for determining the quantity of fruit to be sampled from each lot for each sampling case are presented here in simple algebraic form. Cases III and IV are also treated graphically. The calculations throughout are based on the probability of exceeding the specified limit of admissible error only once out of twenty times.

1. Accuracy of an estimated proportion

The general expression for determining the per cent to be sampled from each lot in order to obtain a desired limit of admissible error is

$$S = \frac{P(1-P)}{\frac{A^2}{3.8416}N + P(1-P)} \quad (1)$$

where S = the per cent to be sampled from each lot

P = the expected proportion in the particular grade or class

A = the limit of admissible error as a per cent of the total weight of all grades of fruit

N = the expected total number of fruit delivered.^{2/}

^{2/} Note that this expression may be written

$$A = 1.96 \sqrt{\frac{P(1-P)}{n} \frac{(N-n)}{N}}$$

where n is the total size of sample and the expression under the square root is the standard error of a proportion. When multiplied by 1.96--i.e., $\sqrt{3.8416}$ --the standard error includes 95 per cent of the sample estimates. Equation (1) is obtained by simply writing the above expression in a form that gives n/N, where n/N = S. As was indicated earlier, to obtain a representative sample requires that a percentage of the fruit in each lot be included in the total sample. The absolute quantity of fruit sampled, (n), increases slowly with increases in total deliveries (N). Therefore, the per cent to be sampled from each lot, (S), decreases with increases in N.

A modification of this expression is used for each of the first three sampling cases described previously.

Case I: Nothing is known about total deliveries, expected proportions, or prices.

P is assumed to be 0.5 as a sample that will limit the admissible error to the desired amount for this proportion will result in a smaller error for any other proportion. N is the number of fruit in the lot, which can be estimated. Expression (1) becomes

$$S = \frac{.25}{\frac{A^2}{3.8416N} + .25} \quad (2)$$

This equation was used to obtain the curves in Figure 3.

Case II: Estimates are available concerning expected total deliveries per season.

Expression (2) still applies but N now becomes the expected deliveries per season rather than the number of fruit per lot.

Case III: Estimates are available concerning expected total deliveries per season and the expected quantity of fruit in the largest class or grade.

Return to expression (1). Substitute for P the expected proportion in the largest grade. Use a minimum value if the expected proportion in the largest grade is more than 50 per cent, a maximum value if less than 50 per cent. For example, the expected proportion in the largest grade might be at least 70 per cent or not more than 40 per cent. The expected error in estimating any other grade will not be any greater than the error specified for the largest grade.

Example:

Suppose that:

- (a) It is expected that a particular grower will have at least 65 per cent of his fruit in the largest grade or class.
- (b) Total season deliveries will be at least 90,000 fruit.
- (c) The desired limit of admissible error is three-fourths of 1 per cent of the total weight of fruit of all grades.

Substituting these values in equation (1)

$$\begin{aligned}
 S &= \frac{.65 \times .35}{\frac{(.0075)^2}{3.8416} (90,000) + (.65 \times .35)} = \frac{.2275}{\frac{.00005625}{3.8416} (90,000) + .2275} \\
 &= \frac{.2275}{\frac{5.0625}{3.8416} + .2275} = .147 \text{ or } 14.7 \text{ per cent}
 \end{aligned}$$

Thus, 14.7 per cent of each lot of fruit delivered by this grower should be sampled.

A graphic solution to the Case III sampling problem is given in Figure 5. The per cent to be sampled from each lot is determined by the expected proportion of the fruit in the largest grade, the admissible error and the total amount of fruit delivered by the grower during the season or pool period. As before, the admissible error curves in the chart are based on the probability of obtaining an error of estimate as large as, or larger than, the amount specified only once out of twenty times.

To illustrate the use of the diagram, assume again the conditions of the example given above. Enter Figure 5 at point A with the proportion 0.65; move vertically to point B on the curve representing an admissible error of 0.75 per cent; and then move horizontally to point C on the curve representing deliveries of 90,000 fruit. Finally, reading down to point D indicates that the desired level of accuracy may be obtained by sampling between 14 and 15 per cent of each lot of the fruit delivered. The algebraic calculation was 14.7 per cent. Note that sampling based on a maximum proportion of 50 per cent, as in the previous procedures (Figure 3), would have indicated a sample of approximately 16 per cent and that the difference between the two methods increases with decreases in the admissible error, with decreases in the pool deliveries and with increases in the departure of the proportion in the largest grade from 50 per cent.

A plant manager may also be interested in estimating the limit of error actually obtained for sample proportions after a sample has been selected. For this purpose, equation (1) may be written

$$A = 1.96 \sqrt{\frac{P(1-P)}{N} \left(\frac{1}{S} - 1 \right)} \quad (3)$$

$$\frac{0.02}{0.15} - \frac{(0.02,000) + (0.15)}{0.15} = \frac{0.02}{0.15} - \frac{0.02,000}{0.15} + 0.15$$

Thus, 11.7 per cent of each lot of fruit delivered by this grower

should be sampled.

A graphic solution to the case of sampling proportion is shown in Figure 2. The per cent to be sampled from each lot is determined by the expected proportion of the fruit in the sample, given the estimated error and the total amount of fruit delivered by the grower during the season of interest. As before, the estimated error varies in the short and long periods. The possibility of obtaining an error of estimation as large as 1.0 per cent, the amount specified only once out of twenty times.

To illustrate the use of the diagram assume again the conditions of the example given above. When Figure 2 is plotted A will be plotted on the curve vertically to point B in the curve representing an estimated error of 0.75 per cent; and a horizontal line to point C on the curve representing delivery of 21,000 fruit. Finally, read across to point D which indicates that the desired level of accuracy may be obtained by sampling between 14 and 15 per cent of each lot of the fruit delivered. The graphic calculation was 14.7 per cent. Note that the sampling error from a proportion of 50 per cent, as in the previous example (Figure 1), would have indicated a sample of approximately 14.6 per cent and that the difference between the two methods is negligible. The error in the estimation of error, with decreases in the per cent delivered and then increased in the per cent of the proportion in the sample (from 50 per cent).

A farm manager may also be interested in obtaining the limit of error actually obtained for sample proportions when a sample has been selected. For this purpose, equation (2) may be written:

*Weights are for apples and pears only. In terms of numbers of fruit, the diagram has general applicability for most fruits and vegetables.

Figure 5. Percent to be sampled from each lot as determined by the percent of fruit in the grade of largest quantity, the limit of admissible error, and the total season or pool deliveries per grower.

Example:

Suppose that a sample has been drawn and:

- (a) The proportion in the largest grade--as estimated from the sample--is 60 per cent.
- (b) Total deliveries per season are 100,000 fruit.
- (c) Four per cent of this total was sample graded.

To estimate the limit of error actually obtained:

$$A = 1.96 \sqrt{\frac{.6 \times .4}{100,000} \left(\frac{1}{.04} - 1 \right)} = 1.96 \sqrt{\frac{.24 \times 24}{100,000}}$$

$$= \frac{1.96}{100} \sqrt{.576} = .015 \text{ or } 1.5 \text{ per cent}$$

In other words, the manager may assume that the true proportion of fruit in this grade is contained within the range 58.5 to 61.5 per cent (60 ± 1.5), with one chance in twenty of being wrong. The historical error may also be approximated by working backwards in Figure 5. Enter the diagram with the actual per cent sampled; read vertically to the line indicating approximately the total deliveries; read horizontally to the left, stopping above the estimated proportion (as actually measured). Reading to the nearest error line will approximate the limit of error actually obtained.

2. Accuracy in terms of payments to growers--Case IV

If information is available concerning the prices of fruit in the various grades or classes as well as expected deliveries and proportions, the sampling system may be designed to give, directly, some specified degree of accuracy in the payments to growers. The general expression for determining the per cent to be sampled from each lot under these conditions is

$$S = \frac{(P_1 M_1^2 + P_2 M_2^2 + P_3 M_3^2 + \dots) - (P_1 M_1 + P_2 M_2 + P_3 M_3 + \dots)^2}{(P_1 M_1 + P_2 M_2 + P_3 M_3 + \dots)^2 \left(\frac{A^2 N}{(3.8416) - 1} \right) + (P_1 M_1^2 + P_2 M_2^2 + P_3 M_3^2 + \dots)} \quad (4)$$

where S = the per cent to be sampled from each lot

P's are the proportions of fruit in each grade

M's are the relative or actual prices per fruit for each grade

A = the limit of admissible error as a per cent of the total payment to the grower

N = the expected total deliveries (number of fruit).

...that a sample was not distributed:
 (2) The proportion in the lowest grade--as estimated from the

- sample--is 60 per cent.
- (3) Total deliveries for sector are 100,000 units.
- (4) Total cost of this total was sample graded.
- (5) Estimate the limit of error statistically obtained:

$$W_{95} = 0.5 \text{ or } 1.4 \text{ per cent}$$

In other words, the sample may assume that a tiny proportion of the limit in this grade is contained within the sample. If so, the error for 1.4% with one chance in twenty of being wrong. The proportion error may also be approximated by working backwards in Figure 2. When one agrees with the actual per cent applied, it is especially so in the following approximately the total delivery; then proportionally to the limit, keeping above the estimated proportion (no absolute measurement). Looking to the nearest error line will approximate the limit of error.

Accuracy in terms of payments to farmers--Case 2

The interest in this case is in the accuracy of the limit in the various grades of classes as well as expected for each grade and payment. The sampling system may be designed to give, on the whole, some expected degree of accuracy in the payments to growers. The general expectation for determining the per cent to be applied from each lot taken in the

$$(P.M. + P.M.) = P$$

where P = the per cent to be sampled from each lot
 P = the proportions of limit in each grade
 M = the relative or total prices per unit for each grade
 A = the limit of accuracy error as a per cent of the total
 applied to the grower
 N = the expected total deliveries (number of units)

Note: Where accuracy is expressed as a percentage, it will be convenient to use relative rather than actual prices per fruit. Let the price of the highest grade be 1.00, with all other prices as a fraction of the highest price.

It will, of course, be impossible to estimate in advance the exact proportion of fruit falling in each grade. Otherwise, there would be no need for sampling. Normally, however, the plant manager will have some idea that (say) at least 50 per cent of the fruit will fall in one grade, not more than 10 per cent in another grade, and so on. To be more certain of limiting the admissible error to the desired range, the advance estimates of proportions should be conservative. If there are doubts, the estimates of proportions for the highest price grade should be in the direction of 50 per cent, and the estimates for other grades should be in the direction of increasing the proportions in the very lowest price grades. If the total of the two highest grades is less than 50 per cent, the estimates for both of these grades should be in the direction of bringing their total to 50 per cent.

Example:

Suppose that in a pear packing plant it is expected that:

- (a) A particular grower will have at least 60 per cent of his fruit in the highest price grade and not more than 10 per cent in the lowest price grade. The other 30 per cent falls in intermediate grades. Note that these proportions are in terms of numbers of fruit rather than weight.
- (b) The relative prices for the three grades are: No. 1 = 1.0, No. 2 = 0.3, No. 3 = 0.1.
- (c) The desired limit of admissible error is 1 per cent of the total payment.
- (d) Expected total deliveries are 200,000 fruit.

Equation (4) becomes:

$$S = \frac{(.6 \times 1^2 + .3 \times .3^2 + .1 \times .1^2) - (.6 \times 1 + .3 \times .3 + .1 \times .1)^2}{(.6 \times 1 + .3 \times .3 + .1 \times .1)^2 \left(\frac{.0001 \times 200,000}{3.8416} - 1 \right) + (.6 \times 1^2 + .3 \times .3^2 + .1 \times .1^2)}$$

$$= \frac{.628 - (.700)^2}{(.700)^2 \left(\frac{20}{3.8416} - 1 \right) + .628} = \frac{.138}{3.8416} = .051$$

Thus, to obtain the desired limit of admissible error, 5.1 per cent of each lot should be sampled.

It will, of course, be impossible to estimate in advance the amount of fruit falling in each grade. Otherwise, there would be no need for sampling. Naturally, however, the plant manager will have some idea that (say) at least 50 per cent of the fruit will fall in one grade, not more than 10 per cent in another grade, and so on. To be more certain of limiting the sampling error to the desired level, the advance estimates of proportions should be a conservative. If there are doubts, the estimates of proportions for the highest price grade should be in the direction of 50 per cent, and the estimates for other grades should be in the direction of increasing the proportions in the very lowest price grades. If the total of the two highest grades is less than 50 per cent, the estimates for both of these grades should be in the direction of bringing their total to 50 per cent.

10:

Suppose that in a pear packing plant it is expected that (a) A particular grower will have at least 50 per cent of his fruit in the highest price grade and not more than 10 per cent in the lowest price grade. The other 40 per cent falls in intermediate grades. Note that these proportions are in terms of number of fruit rather than weight.

(b) The relative prices for the three grades are: No. 1 = 1.0, No. 2 = 0.8, No. 3 = 0.5.

(c) The desired limit of sampling error is 1 per cent of the

(d) Expected total deliveries are 200,000 fruit.

Estimation (a) becomes:

of each lot should be sampled.

Solutions to the Case IV sampling problem are illustrated graphically in Figures 6 and 7 for two sets of assumptions concerning the proportions of produce falling in the various grades. The limits of admissible error are again based on the probability of exceeding that amount only once in twenty times. The first graph is drawn on the assumption that all of the fruit not in the first grade has the price of the lowest grade. In this situation, if the prices of the intermediate grades are higher than that of the lowest grade, the probability of exceeding the limit of error in estimating the payments to growers will be even less than the amount specified. To illustrate the use of this diagram, suppose that:

- (a) It is estimated that a particular grower will have about 65 per cent of his fruit in the No. 1 grade.
- (b) The expected price of the lowest grade relative to the highest grade is 0.3.
- (c) Total season deliveries are expected to be at least 90,000 fruit.
- (d) It is desired to limit the admissible error to three-fourths of 1 per cent (0.75) or less in the total payments.

Enter Figure 6 at point A with the proportion, 65 per cent (0.65); move horizontally to point B on the curve representing a relative price of 0.3; then move down to point C on the line representing an admissible error of 0.75 per cent; from C, move across to point D on the curve representing total deliveries of 90,000 fruit. Finally, reading down to point E indicates that the desired level of accuracy may be obtained by sampling 13.3 per cent of each lot of fruit delivered. In this example, if the relative prices had been 0.2, the required sample would have been 18 per cent; if 0.5, about 6 per cent. Note that it is also possible to interpolate between the curves representing various amounts of total deliveries. In the example above, if deliveries had been 120,000 fruit (40,000 pounds of apples or pears) instead of 90,000, the required sample would have been about 10.5 per cent.

If the price of the lowest grade of fruit (culls) is zero and the proportion of the fruit falling in this grade quite small, the per cent to be sampled from each lot as determined from Figure 6 will be larger than required to give the desired degree of accuracy. To avoid this situation, the alternative diagram (Figure 7) may be used under these conditions. This chart is based on the assumption that the proportion

Figure 6. Percent to be sampled from each lot as determined by the percent of fruit in the No. 1 grade, price of the lowest grade relative to No. 1, the limit of admissible error and the total pool deliveries per grower.

Figure 7. Percent to be sampled from each lot as determined by the percent of fruit in the No. 1 grade, price of the next to lowest grade relative to No. 1, the limit of admissible error and total season deliveries per grower. The quantity in the lowest grade (culls) is not more than 10 percent and the price is zero.

of fruit falling in the lowest grade will be no larger than 10 per cent and that the price for this grade will be zero. The fruit not falling in the first grade is assumed to have a price equal to the next to the lowest grade. Again, if the prices of the intermediate grades are greater than that of the next to the lowest, the probability of exceeding the limit of error will be less than the amount specified. Each curve in the upper right-hand section of the chart here represents the price of the next to the lowest grade of fruit relative to the highest grade rather than the lowest grade relative to the highest. The diagram is similar to and used in the same way as Figure 6.

As before, this equation (4) can be turned around and used to estimate the limit of error for a set of sample estimates already obtained. For this purpose, equation (4) may be written:

$$A = 1.96 \sqrt{\frac{[(P_1 M_1^2 + P_2 M_2^2 + \dots) - (P_1 M_1 + P_2 M_2 + \dots)^2 / (\frac{1}{S} - 1)]}{N}} \quad (5)$$

Example:

Suppose that a sample has been taken and:

- (a) The estimated proportions for four grades of fruit as determined by the sample are No. 1 = .05, No. 2 = 0.3, No. 3 = 0.1, and No. 4 = 0.1.
- (b) The prices for the various grades are No. 1 = 1.0, No. 2 = 0.6, No. 3 = 0.3, and No. 4 = 0.1.
- (c) A 5-per cent sample was taken.
- (d) Total deliveries for this grower were 100,000 fruit.
- (e) The desired limit of admissible error is 1 per cent of the total payment.

To estimate the limit of error, equation (5) becomes

$$A = 1.96 \sqrt{\frac{[(.5 \times 1^2 + .3 \times .6^2 + .1 \times .3^2 + .1 \times .1^2) - (.5 \times 1 + .3 \times .6 + .1 \times .3 + .1 \times .1)^2 / (\frac{1}{.05} - 1)]}{N}}$$

$$= 1.96 \sqrt{\frac{[(.618) - (.720)^2 / 19]}{100,000}}$$

$$= \frac{1.96}{1,000} \sqrt{19} = .009 \text{ or } .9 \text{ per cent}$$

Thus, the estimated limit of error is nine-tenths of 1 per cent of the total payment.

of fruit falling in the lowest grade will be no larger than 10 per cent and that the price for this grade will be zero. The fruit not falling in the first grade is assumed to have a price equal to the next to the lowest grade. Again, if the prices of the intermediate grades are greater than that of the next to the lowest, the probability of exceeding the limit of error will be less than the amount specified. Each curve in the upper right-hand section of the chart here represents the price of the next to the lowest grade of fruit relative to the highest grade rather than the lowest grade relative to the highest. The diagram is similar to and used in the same way as Figure 6.

As before, this equation (11) can be turned around and used to estimate the limit of error for a set of sample estimates already obtained. For this purpose, equation (11) may be written:

$$A = 1.96 \sqrt{\frac{p_1 M_1^2 + p_2 M_2^2 + \dots + p_k M_k^2}{N} \left(\frac{1}{\bar{p}} - 1 \right)} \quad (12)$$

Example:

- Suppose that a sample has been taken and:
- The estimated proportions for four grades of fruit as determined by the sample are No. 1 = .05, No. 2 = 0.3, No. 3 = 0.1, and No. 4 = 0.1.
 - The prices for the various grades are No. 1 = 1.0, No. 2 = 0.6, No. 3 = 0.3, and No. 4 = 0.1.
 - A 2-per cent sample was taken.
 - Total deliveries for this grower were 100,000 fruit.
 - The desired limit of admissible error is 1 per cent of the total payment.

To estimate the limit of error, equation (2) becomes

$$A = 1.96 \sqrt{\frac{.05 \times 1^2 + .3 \times .6^2 + .1 \times .3^2 + .1 \times .1^2}{100,000} \left(\frac{1}{.05} - 1 \right)}$$

$$= 1.96 \sqrt{\frac{(.0518) - (.120) \left(\frac{1}{.05} - 1 \right)}{100,000}}$$

$$\frac{1.96}{1,000} \sqrt{19} = .009 \text{ or } .9 \text{ per cent}$$

Thus, the estimated limit of error is nine-tenths of 1 per cent of the total payment.

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