NEW YORK'S FOOD AND LIFE SCIENCES BULLETIN NO. 9, MARCH 1971

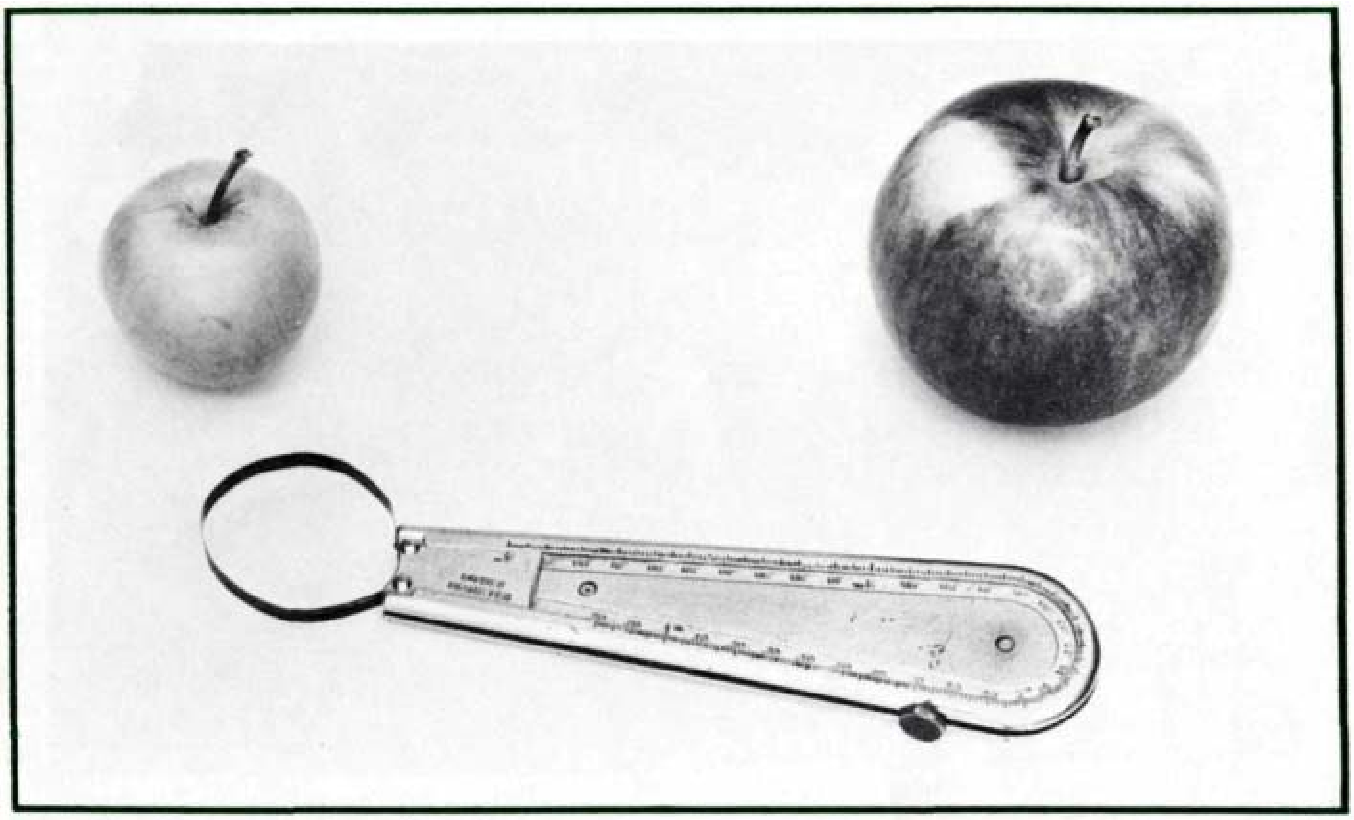
PLANT SCIENCES

POMOLOGY (GENEVA) • NUMBER 1

NEW YORK STATE AGRICULTURAL EXPERIMENT STATION, GENEVA, A DIVISION OF THE NEW YORK STATE COLLEGE OF AGRICULTURE, A STATUTORY COLLEGE OF THE STATE UNIVERSITY, CORNELL UNIVERSITY, ITHACA

Predicting harvest size of McIntosh apples

by C. G. Forshey



A major factor in establishing the price of apples is the size of the fruit. An accurate estimate of final fruit size in mid-summer would be of inestimable value to the commercial fruit grower. On the basis of such information, cultural practices, such as irrigation and hand fruit thinning could be altered to improve final fruit size. Such an estimate would also provide guidance in the harvesting of the crop and in its disposition.

There is a close relationship between fruit size during the growing season and the size at harvest. This relationship is the basis for harvest size prediction tables for peaches (4), pears (11), and apples (1). In Washington, Batjer, et al (1) found that the harvest size of Delicious and Winesap apples could be accurately predicted as early as 35 days after full bloom. Through the use of their size prediction table, the objective of hand fruit thinning in that area has shifted from the uniform distribution of fruit throughout the tree to the removal of fruits that will be undersize at harvest.

While the results of Batjer, et al (1) indicate that it is possible to accurately predict harvest size of apples during the growing season, it does not necessarily follow that similar results can be obtained with McIntosh in the Northeast. There is, first of all, an important varietal difference with the Mclntosh growing season significantly shorter than that of Delicious and Winesap. Even more important, growing conditions are much more uniform in Washington than in the Northeast, and this difference should be reflected in greater precision in estimating harvest size in Washington. This study was initiated in an effort to determine the applicability of this approach under the growing conditions of the Hudson Valley.

MATERIALS AND METHODS

In the spring of 1965, six Hudson Valley Mc-lntosh apple orchards were selected to provide wide geographic distribution and a variety of soils and sites. In each orchard, four representative trees were chosen for fruit growth measurements. During the course of this study (1965-70), these trees received regular commercial care in accordance with the cultural practices usually followed in these orchards. In each of the 6 years, bloom and fruit set counts were made on 3 randomly-selected branches, of 100-150 blossom clusters each, on each tree. In an effort to eliminate the confusion created by variations in bloom, and to make the counts comparable from year to year, fruit set was expressed as fruits/100 spurs rather than fruits/100 blossom clusters (7). Rainfall was recorded from May through September, and available soil moisture readings were made weekly as described in a previous publication (5). On or about July 1 of each year, 20 fruits were selected at random on each tree and tagged. The diameter of these fruits was determined at that time and at intervals of approximately 10 days thereafter until September 20. This represents a departure from the procedure of Batjer, et al (1), who made all measurements, including the final one, at definite intervals from full bloom. However, the number of days from full bloom to the optimum harvest date is much more variable for Mclntosh in the Hudson Valley than for Delicious in Washington. In this area, Mclntosh apples are harvested over a period of 4 weeks, or more. The average number of days from full bloom to optimum maturity is 136, but this has varied from 124 to 146 (3). In any year, only a fraction of the total crop is harvested at or near the optimum number of days from full bloom. In practical terms, calendar date is more important to a grower with a large volume of Mclntosh to harvest, and, in any year, this harvest is in full swing by the third week in September. It is on this basis that the final measurement date of September 20 was chosen. This closely approaches the long-term average optimum harvest date for the variety in this area (3).

It was not always possible to measure all fruits on the same dates in all years, and, as a result, some conversion by interpolation and extrapolation was necessary to facilitate comparisons between years. After converting all measurements to comparable dates, coefficients of correlation between fruit diameter during the growing season and on September 20 were calculated for each sampling date. Predicted harvest sizes from regression lines were compared with actual harvest sizes, and standard errors of estimate were calculated. For each sampling date, predicted harvest sizes were combined with appropriate standard errors of estimate to form a size prediction table.

RESULTS

In the 6 years of this study, the average fruit diameter on September 20 varied from 2.55 to 2.83 inches (Table 1). Generally poor fruit size in 1966 was associated with prolonged periods of deficient soil moisture in all orchards. In 1968, soil moisture deficits were general, but a relatively light

Table 1. Bloom date, fruit set, fruit size, and soil moisture data for six Hudson Valley McIntosh apple orchards for 6 years (1965-70).

Location and Year	Bloom Date[a]	Fruit Set[b]	Fruit Diameter-inches 7/1	9/20	Soil Moisture Deficits Date[c]	Duration[d]
1965						
Milton		16.1	1.52	2.75	7/2	35
Marlboro		19.0	1.50	2.75	6/25	42
New Paltz		28.2	1.60	2.82	7/16	28
Tivoli		16.6	1.57	2.89	6/18	21
Red Hook		24.4	1.36	2.55	7/2	28
LaGrangeville		45.3	1.55	2.88	7/30	35
Average	5/12	24.6	1.52	2.77	7/6	31
1966						
Milton		25.4	1.29	2.46	7/15	56
Marlboro		18.0	1.37	2.68	7/8	49
New Paltz		20.5	1.34	2.67	7/29	42
Tivoli		14.8	1.37	2.63	7/29	42
Red Hook		13.1	1.22	2.27	7/8	63
LaGrangeville		26.5	1.30	2.56	7/15	49
Average	5/20	19.7	1.32	2.55	7/17	50
1967						
Milton		24.9	1.24	2.68	-	0
Marlboro		16.9	1.28	2.80	9/22	0
New Paltz		19.2	1.28	2.96	-	0
Tivoli		29.4	1.29	2.66	8/18	15
Red Hook		14.3	1.21	2.65	9/29	0
LaGrangeville		25.6	1.21	2.70	-	0
Average	5/18	21.6	1.25	2.74	9/13	3
1968						
Milton		15.3	1.54	2.80	8/16	21
Marlboro		4.2	1.61	2.90	7/26	52
New Paltz		10.7	1.54	2.85	8/12	49
Tivoli		9.3	1.59	2.83	7/19	42
Red Hook		16.4	1.49	2.70	8/16	21
LaGrangeville		28.8	1.54	2.84	8/16	35
Average	5/2	14.4	1.55	2.82	8/7	33
1969						
Milton		32.7	1.59	2.85	-	0
Marlboro		20.5	1.50	2.69	6/13-8/29[e]	56
New Paltz		12.6	1.57	2.85	-	0
Tivoli		24.6	1.59	2.73	7/4-8/29[e]	56
Red Hook		15.0	1.62	2.86	7/11-8/29[e]	21
LaGrangeville		38.8	1.60	2.90	-	0
Average	5/11	24.1	1.58	2.83	6/30-8/29	22
1970						
Milton		41.6	1.48	2.68	7/31	21
Marlboro		19.8	1.48	2.69	-	0
New Paltz		21.7	1.51	2.76	7/10	14
Tivoli		22.6	1.54	2.69	8/14	14
Red Hook		33.3	1.51	2.73	-	0
LaGrangeville		45.9	1.62	2.79	8/14	14
Average	5/10	29.0	1.52	2.72	8/2	10

[a]Full bloom in the Milton-Marlboro area.
[b]Fruits per 100 spurs.
[c]Earliest date on which available soil moisture, at a depth of 18 inches, dropped below 25%.
[d]Total number of days between bloom and harvest that available soil moisture, at a depth of 18 inches, was below 25%.
[e]Two periods of deficient soil moisture separated by a period of adequate soil moisture.

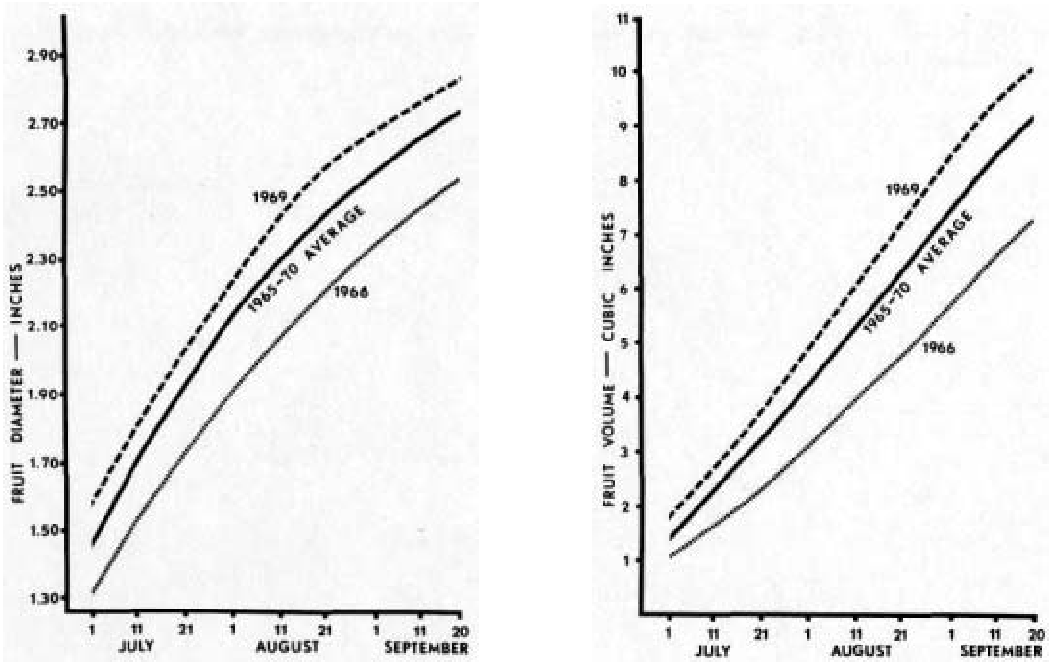


Figure 1.-Fruit growth of Mclntosh apples. (Left: diameter. Right: volume).

fruit set resulted in fruit of above-average size. In 1969, an average fruit set combined with generally favorable soil moisture conditions to produce the largest fruit of the 6-year period. In the other 3 years (1965, 1967, 1970), average fruit diameter on September 20 was near 2.75 inches, and this is generally considered optimum because it provides good size distribution for marketing Mclntosh.

Fruit growth curves were similar to those reported by others (1, 2, 8) for apples (Fig. 1). When growing conditions are at or near optimum, the apple fruit tends to increase in size at a fairly uniform rate, with no periods of sharply accelerated or decelerated growth, and it is this consistent growth that makes possible an accurate estimate of final size several weeks before harvest. That the rate of fruit enlargement is uniform is not readily apparent when fruit size is expressed as diameter because diameter is 1-dimensional and growth is 3-dimensional. When diameter is converted to volume (5), the apple fruit growth curve usually approaches a straight line. In Figure 1, the relationship between date and fruit volume is linear from mid-July to early September. Slightly lower rates of fruit growth in early July and in September are probably due to lower temperatures (8, 9, 10).

Correlation between fruit diameter in July and August and the diameter on September 20 was highly significant for all sampling dates (Table 2). These values increased regularly as the season advanced. However, the coefficient for July 1 (0.631), which is approximately 50 days after full bloom, is lower than the values reported by Batjer,

Table 2. Correlation of diameter of "Mclntosh" apples during July and August with the diameter at harvest.

Date	r
7/1	.631**
7/11	.727**
7/21	.833**
8/1	.872**
8/11	.928**
8/21	.961**
9/1	.977**

**Statistically significant at the 1% level.

et al (1), for 35 days after bloom, and much lower than their values for 55 days after bloom (0.73-0.88). In the present study, a coefficient of correlation of this magnitude was not attained until July 21, or 72 days after the average bloom date of May 10. This illustrates the marked differences in growing conditions between the two areas. On any sampling date, the relationship between size during the growing season and size at harvest was much closer in Washington than in the more variable Northeast.

The seasonal increase in r values was associated with decreasing errors of estimate of harvest size (Table 3). For all years, the error of estimate declined from ±0.16 inches on July 1 to ±0.06 inches on September 1 (Table 4).

On all sampling dates, the standard error of estimate was greatest for the smallest fruits. This is consistent with other results (1). Fruit size is determined by many factors (seed count, crop

Table 3. Table for predicting harvest size of "McIntosh" apples during July and August.

Diameter (in.) On Sampling Date	7/1	7/11	7/21	Sampling Date 8/1	8/11	8/21	9/1
				Diameter (in.) on September 20			
1.1	2.11±.19						
1.2	2.28±.19						
1.3	2.46±.18	2.15±.18					
1.4	2.66±.16	2.29±.15					
1.5	2.80±.15	2.44±.14	2.13±.15				
1.6	2.97±.15	2.58±.14	2.28±.12				
1.7	3.14±.16	2.73±.13	2.42±.12	2.18±.12			
1.8		2.87±.11	2.56±.11	2.31±.10	2.14±.12		
1.9		3.02±.11	2.70±.10	2.43±.10	2.26±.11	2.13±.11	
2.0		3.16±.12	2.84±.11	2.56±.10	2.39±.09	2.24±.10	2.15±.08
2.1			2.98±.11	2.69±.09	2.50±.08	2.36±.10	2.26±.08
2.2			3.13±.12	2.82±.08	2.62±.07	2.47±.08	2.36±.07
2.3				2.95±.08	2.73±.06	2.58±.06	2.47±.06
2.4				3.08±.09	2.85±.07	2.67±.05	2.58±.06
2.5				3.21±.09	2.97±.07	2.81±.05	2.69±.05
2.6					3.09±.08	2.92±.06	2.79±.05
2.7					3.21±.08	3.03±.06	2.90±.05
2.8						3.14±.07	3.00±.06
2.9							3.11±.06

Table 4. Standard error of estimate of fruit diameter at harvest for different years and sampling dates.

Year	7/1	7/11	7/21	Sampling Date 8/1	8/11	8/21	9/1	All sampling dates combined
				Diameter in Inches				
1965	±.17	±.08	±.07	±.07	±.07	±.05	±.04	±.09
1966	±.13	±.11	±.13	±.12	±.10	±.09	±.08	±.11
1967	±.25	±.22	±.15	±.13	±.07	±.05	±.06	±.14
1968	±.09	±.08	±.05	±.05	±.05	±.04	±.04	±.06
1969	±.15	±.11	±.10	±.09	±.08	±.08	±.06	±.10
1970	±.16	±.13	±.13	±.09	±.08	±.04	±.04	±.10
All years combined	±.16	±.13	±.11	±.10	±.08	±.06	±.06	

Table 5. Accuracy in predicting harvest diameter of "McIntosh" apples.

Sampling date	1/4"	Per cent within 1/8"	1/16"
7/1	88.3	53.2	30.0
7/11	94.6	68.9	34.7
7/21	99.2	79.0	40.5
8/1	99.5	91.0	43.8
8/11	100.0	92.0	54.6
8/21	100.0	96.0	63.8
9/1	100.0	97.0	70.0

load, soil moisture supply, tree vigor, spur vigor, position, etc.), and their interactions produce fruits with a wide range in potential harvest size. These differences in potential are apparent relatively early in the season and are the basis for the old adage "once a small apple, always a small apple." The greater variability in growth rate of the smaller apples suggests that they are affected more by unfavorable growing conditions, such as moisture stress, than the larger fruits.

It was possible to predict harvest size more

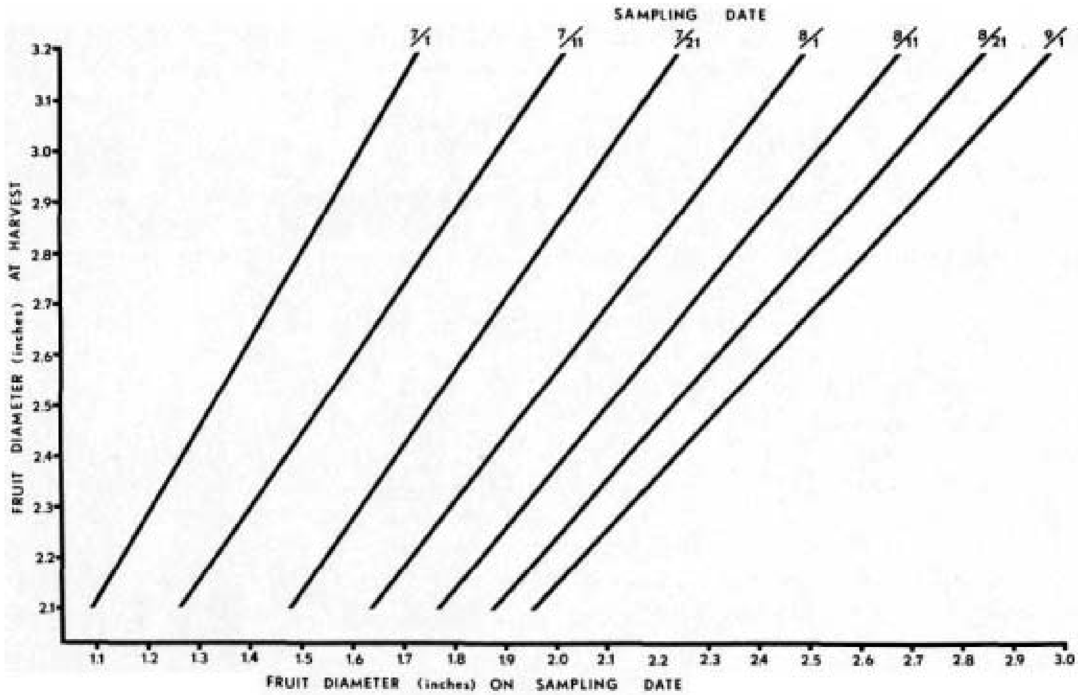


Figure 2.-Regression of Mclntosh fruit diameter at harvest on diameter in July and August.

accurately in some years than in others (Table 4). In 1967, the standard error of estimate was more than double that of 1968. Bloom was late in 1967, and there were no soil moisture deficits of significance throughout the entire growing season. The fruits were the smallest on July 1 of all the years included in this study, but they attained average size by harvest. As a result, fruit size was underestimated early in the season. However, the standard error of estimate declined sharply as the season progressed and was actually less than the mean value for all years on August 11. In contrast, in a year with prolonged soil moisture deficits (1966), fruit size was overestimated early in the season, and the standard error of estimate declined very little as the season progressed. On July 1, the standard error of estimate was next to lowest, but by August 11, it was the highest for all years and remained highest for the later sampling dates.

When the accuracy in predicting harvest size is expressed as the per cent within definite linear limits (Table 5), the results follow the trends established by the coefficients of correlation (Table 2) and the standard errors of estimate (Tables 3 and 4). As the season progressed, the accuracy of the predictions increased. By August 1, more than 90 per cent of the predictions were within 1/8 inch and nearly half were within 1/16 inch. If the important point is count cartons (100's, 120's, 140's), the harvest size of more than 90 per cent of the crop could be predicted within 1 box size on August 1.

While the accurate prediction of the harvest size of an individual fruit is very desirable, size distribution data can be equally important to a Hudson Valley fruit grower. In this case, the emphasis is not as much on altering the final size as on estimating the potential value of the crop and planning its disposition. The most important statistic in this respect is the proportion of the crop that will be under size, or less than 2 1/2 inches in diameter at harvest. Such size distribution data can be obtained by collecting random samples of fruit, estimating the harvest size of each, and calculating the per cent that will be undersize.

DISCUSSION

In the 6 years of this study, growing conditions differed significantly from year to year. This period included years of very early (1968), average (1965, 1969, 1970), and very late bloom (1966, 1967). Fruit set was very heavy in one year (1970) and very light in another (1968). A year of drought (1966) was followed by a very wet year. In addition to differences between years, there were also important differences between orchards. In 4 of the 6 years, the Red Hook orchard produced the smallest fruit. Soil moisture was a chronic problem in the Tivoli orchard. The LaGrangeville orchard consistently carried heavy crops, and fruit set in the Marlboro orchard was just as consistently below average. In spite of these differences between years and between orchards, the rate of growth of an individual fruit in any one year was consistent enough to permit mid-summer estimation of fruit size at harvest. Final fruit size could not be accurately estimated as early in the season as is possible with Delicious in Washington, but an estimate of acceptable precision could be made by August 1. In Washington, early estimates of final size are desirable because potential size is the basis for hand fruit thinning, and the earliest thinning is the most effective (1). Since hand thinning is not a common practice with Mclntosh, accurate early-season estimates of harvest size are less important. On the other hand, the most serious soil moisture deficits in the Hudson Valley usually develop in August. A July 21 or August 1 estimate of harvest fruit size would be early enough in most years to provide the necessary guidance for maximum benefits from supplemental irrigation. If the predicted size in late July indicated a high percentage of undersize fruits, further losses in fruit size should be prevented by the maintenance of optimum soil moisture levels for the remainder of the season. Conversely, a soil moisture deficit of limited duration might actually improve fruit size distribution if an August 1 prediction indicated a substantial percentage of the fruits would be 3 inches, or larger in diameter at harvest. In this situation, which might occur in light crop years, irrigation would be both unnecessary and undesirable.

In the harvesting, storage, and sale of Mclntosh apples, fruit color is of primary importance. If acceptable color is assumed, then the factor next in importance is fruit size. Advance information on fruit size and size distribution can be useful in planning the order in which different orchards are harvested and in the disposition of the fruit after it is picked. Estimates on August 1 or later are completely satisfactory for this purpose. Through the use of such estimates, the orchards that will have the most desirable fruit size can be determined in advance. Where a high percentage of small fruits is indicated, the returns may be small, and rigid cost control is highly desirable. Such fruit should be sold at harvest and, if possible, should be sold orchard-run. With fruit of satisfactory size distribution, the cost of packing is easily absorbed, and such fruit can be packed for immediate sale or stored and packed later. Those orchards with the best size distribution can be scheduled for late storage, and those with a substantial percentage of oversize fruits, which do not store as well, can be stored for shorter periods.

Small differences in fruit size early in the season become large differences late in the season; therefore, accurate estimates of harvest size demand precise determination of the diameter of the developing fruits. The most practical device for rapid and accurate fruit diameter measurements is the size thinning gage described by Batjer, et al (1). In the use of this gage, a flexible metal tape is placed snugly around the apple, and the diameter is indicated in one-hundredths of an inch.

In order to estimate harvest size accurately and consistently, a standardized sampling procedure must be followed. It is axiomatic that the estimate will be no better than the sample on which it is based. In this study, 20 fruits were selected at random from each of 4 representative trees. However, the objective was not to characterize all the fruits on the tree, but rather to obtain a wide range in fruit sizes. Meaningful size distribution data require a more intensive sampling procedure. On the basis of a systematic sampling study (6) and comparisons of sample sizes, the following routine sampling procedure is suggested. Fruit size measurements should be made on four trees that are representative of the orchard. On each tree, 3 branch segments, bearing approximately 20 fruits each, should be selected at random, and all of the apples on these branch parts should be measured. This approach of measuring *all* of the fruits in a given area reduces the possibility of selection and bias. Where conditions differ markedly, one four-tree sample may not be descriptive of the entire orchard, and additional samples may be required from areas that differ significantly in soil depth or texture, tree vigor, or crop load.

The observed differences between years and between locations are worthy of consideration in the interpretation of fruit size estimates. Differences between locations would seem to be unimportant because harvest size could be estimated with about the same precision in all six orchards. The range in standard error of estimate, for all years and all sampling dates, was from ±0.09 inches in the Milton orchard to ±0.12 inches in the New Paltz orchard. While this indicates that the prediction table can be used with confidence throughout the Hudson Valley, it does not mean that these data are directly applicable in other Mclntosh producing areas. The average length of growing season for Mclntosh varies from 136 days in the Hudson Valley, through 131 days in the Lake Ontario region, to 117 days in Monmouth, Maine (3). Such differences in length of growing season could easily be associated with differences in growth rate of sufficient magnitude to seriously limit the usefulness of the prediction table in other areas.

In contrast to the differences between locations, differences between years were of greater significance, and they provide valuable guidance in the use of the size prediction table. In years in which bloom is late, estimates made early in July are likely to be inaccurate. Prolonged soil moisture deficits also reduce the accuracy of the estimate, and a greater allowance for error should be made in periods of drought. With a light crop, fruit size may be underestimated. The opposite effects of a light crop and a period of soil moisture deficiency may nullify each other and result in fruit of average, and accurately predictable size. In all probability, the greatest possible extremes were not recorded in the 6 years of this study, and, in any given year, greater errors in estimating harvest size are possible. However, the prediction table should provide reasonably accurate estimates of harvest fruit size in most years, and this is information that the progressive fruit grower can use to advantage.

LITERATURE CITED

1. Batjer, L. P., H. D. Billingsley, M. N. Westwood, and B. L. Rogers. 1957. Predicting harvest size of apples at different times during the growing season. Proc. Amer. Soc. Hort. Sci. 70: 46-57.
2. Blanpied, G. D. 1966. Changes in the weight, volume and specific gravity of developing apple fruits. Proc. Amer. Soc. Hort. Sci. 88: 33-37.
3. Blanpied, G. D. and Shaul Ben-David. 1970. A New York study of "Mclntosh" apple optimum harvest dates. J. Amer. Soc. Hort. Sci. 95(2): 151-154.
4. Davis, L. D. and Marie M. Davis. 1948. Size in canning peaches. The relation between the diameter of cling peaches early in the season and at harvest. Proc. Amer. Soc. Hort. Sci. 51: 225-230.
5. Forshey, C. G. and B. A. Dominick, Jr. 1965. Irrigation of apples in the Hudson Valley. N. Y. State Agr. Exp. Sta. Bull. 809: 1-30.
6. Lapido, Olasupo Oyetoro. 1966. A sampling procedure for studying apple yield. M.Sc. Thesis, Cornell University.
7. McKee, M. Wayne, C. G. Forshey, and M. B. Hoffman. 1966. Effects of chemical thinning on repeat bloom of Mclntosh apple trees. Proc. Amer. Soc. Hort. Sci. 88: 25-32.
8. Tukey, H. B. and O. J. Young. 1942. Gross morphology and histology of developing fruit of the apple. Bot. Gaz. 104: 3-25. 9. Tukey, L. D. 1956. Some effects of night temperatures on the growth of Mclntosh apples, I. Proc. Amer. Soc. Hort. Sci. 68: 32-43.
10. Tukey, L. D. 1960. Some effects of night temperature on the growth of Mclntosh apples, II. Proc. Amer. Soc. Hort. Sci. 75: 39-46.
11. Williams, Max W., H. D. Billingsley, and L. P. Batjer. 1969. Early season harvest size prediction of "Bartlett" pears. J. Amer. Soc. Hort. Sci. 94(6): 596-598.

Editor's Note

This is a new series that replaces the former Research Circular series published by the New York State Agricultural Experiment Station at Geneva. It results from an intensive study made by a special committee, which recommended that all existing publication series be streamlined and modernized to better answer today's needs of both scientific and general audiences. It was thought important to identify each publication with its appropriate subject matter discipline, such as Biological Sciences, Food Sciences, or Plant Sciences, as well as with a departmental designation.