A STUDY OF THE EFFECT OF CERTAIN FACTORS ON THE SIZE AND COMPOSITION OF APPLES AND THE EFFECT OF FRUITING ON BUD DIFFERENTIATION.

by
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Acknowledgements

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A Study of the Effect of Certain Factors on the Size and Composition of Apples and the Effect of Fruiting on Bud Differentiation.

Introduction

The average mature apple consists of about 85 per cent of water and 15 per cent of dry matter, the latter consisting primarily of organic matter elaborated in the leaves. It is natural to suppose, therefore, that the growth and composition of the fruit would depend largely on the supply of water to the fruit and on the elaborated foods available from the leaves. Obviously a liberal supply of moisture is essential for the proper development of the fruit. However, the role of elaborated foods supplied by the leaves is not so apparent. In this regard, the relationship of leaf area to growth and composition of the fruit appears to be of importance, particularly with reference to the carbohydrate supply to the fruit. The purpose of the investigations reported herein was to obtain definite information relative to the relation of the carbohydrate supply to the growth and composition of the fruit. Another phase of this investigation which is closely associated with carbohydrate supply was the effect of fruiting on bud differentiation.

The supply of carbohydrates available to the fruit depends primarily on two factors, the amount of carbohydrates elaborated per fruit and the transport of the carbohydrates to the fruit.

The amount of barbohydrates elaborated per fruit will depend first upon the leaf area per fruit. The leaf area per fruit may be influenced by certain orchard practices such as thinning, pruning and fertilizing. Pruning usually increases the leaf area per fruit by reducing the number of fruiting spurs and stimulating growth and leaf development in those that remain but it may reduce the leaf area per fruit by increasing the set of fruit per spur. Nitrogen fertilizers also increase the leaf area by increasing vegetative vigor with larger leaves but on the other hand may reduce the leaf area per fruit by increasing the set of fruit. Thinning the fruit is the major influence.

With a given leaf area per fruit the amount of carbohydrates formed will depend on the efficiency of the leaves which in turn may be influenced by such factors as temperature, moisture, amount of chlorophyll, mineral nutrients, the amount of CO_2 in the surrounding atmosphere and the duration and intensity of sunlight. Caldwell (12) has shown an increase in the sugar content of apple juice during seasons of high amounts of sunlight.

Factors that might influence the transport of carbohydrates to the fruit are: The diffusion gradient to the fruit and to other parts of the tree; the distance and direction of the leaves from the fruit and the cross sectional diameter of the conducting tissue at its narrowest point. The seed content of the fruit also seems to have some effect on the accumulation of elaborated foods in the fruit.

Part I of this paper deals with the growth and composition of the fruit in relation to the carbohydrate supply as influenced by the leaf area per apple. Part II presents a study of the transport of the carbohydrates to the fruit as influenced particularly by the distance and direction of the leaves from the fruit. Part III deals with the effect of fruiting on bud differentiation.

I - RELATION OF LEAF AREA TO THE GROWTH AND COMPOSITION OF APPLES.

A preliminary report (27) of part of the material presented in this paper showed that the size of the fruit increased with an increase in leaf area per apple up to a point beyond which further increase in leaf area had little or no effect. Dry weight and sugar concentration also increased with an increase in leaf area. It was found that about 30 leaves were required to produce commercial sized apples with good quality under the conditions of the experiments and with the varieties studied at Arlington Farm, Virginia. Magness (37) and Magness and Overly (39) conducted similar experiments in Washington with both apples and pears and obtained similar results. They found that under Washington conditions the same leaf area produced larger fruit but with a slightly lower sugar concentration than under Virginia conditions.

Material and Methods

The apple trees used in this investigation were located in the variety orchard at the Arlington Experimental Farm, Rosslyn, Virginia. The experiments usually were started in June when the apples were about the size of walnuts or smaller.

Treatments were applied to both ringed and unringed branches. In ringing the branches a strip of bark about one quarter of an inch wide was removed, the cambium was scraped and melted paraffin applied to the wound. Scraping the cambium prevented regeneration of phloem across the ring. This treatment would also prevent the development of new xylem tissue at the ring. There seemed to be more injury to the branches when ringing was done very early in the season, this due perhaps to the reduction in the amount of the new xylem which would probably be more active in the movement of water to the branch. Similarly, the smaller the branch the greater was the injury. For this reason after the first year fairly large branches (at least 2.5 cm. in circumference) were used in order to reduce this injury as much as possible. Larger branches (at least 6 cm. in circumference) were used for the unringed branches. Leaves or fruit were removed from both ringed and unringed branches until the desired number of leaves per fruit was obtained. Small or deformed leaves were stripped off leaving only the medium and large sized ones. All treatments for each variety in most cases were applied to a single tree or to two adjacent trees.

The areas of at least 100 leaves of the sizes used were measured by means of a planimeter and the leaf area per apple was determined from these measurements.

The circumference of the fruit at the widest transverse diameter was determined at the beginning of the experiments and at intervals thereafter until harvest. The volume of the fruit was computed from the circumference measurements assuming the fruit to be a sphere and the increase in volume was obtained by subtracting the volume of each apple at the beginning of the experiment from the volume of the same apple when mature.

The fruit was harvested in the fall. After storing the fruit for a period in order to allow the starch to be changed to sugar, samples were taken and the sugar and acid determinations were made according to the methods described in a previous publication (36). Dry weight determinations were made in 1925 and 1926 by drying 25 gram samples of ground tissue to constant weight at 85° to 90°C. In 1927 direct determinations were made by distilling with toluol according to the method described by Bidwell and Sterling. (10).

Correlation coefficients and probable errors were computed on growth measurements.

Presentation of Results

The results of leaf area studies are divided into two types, in one of which the fruit was grown on ringed branches and in the other the branches were not ringed.

Effect of Ringing:

According to the work done by Curtis (16) (17) (18) Gardner (23) and Mason and Maskell (33), the removal of a ring of bark prevents the translocation of carbohydrates and possibly mineral nutrients in either direction past the ring. Thus fruit grown above the ring would depend entirely upon the leaves above the ring or food stored above the ring; likewise, the food elaborated in leaves above the ring would be confined above the ring, and any excess material would not move out of the branch, as would be the case in unringed branches. Fruit on unringed branches are grown under more normal conditions since they are not necessarily dependent on food elaborated in adjacent leaves but may draw upon food elaborated in leaves on adjacent branches. Also, food elaborated in leaves on the branch may be translocated to other parts of the tree. For these reasons, ringing is necessary to obtain a critical reading of the leaf area required to build the nutrient materials utilized in the development of a fruit. Results obtained on ringed branches, however, are not directly comparable to those on unringed branches.

Effect of Leaf Area on Increase in Size

In Table I are presented the coefficients of correlation between the increase in volume of the fruit and the number of leaves per apple for fruit grown on ringed branches. The correlations are positive and significant in all cases. The correlations are even higher when the fruit grown with the higher leaf areas is not considered. For example, in the case of Ben Davis for 1925 a correlation of +0.743 ±0.028 was obtained when all of the fruit was considered whereas a correlation of +0.933 ±.01 was obtained when only the fruit grown with 5 to 30 leaves was considered, indicating a dropping off in the increase in size with the higher leaf areas. This is brought out more clearly in Figure I in which the increase in volume per 10 day interval is plotted against the leaf area per apple. Figure I shows a rapid increase in volume with an increase in leaf area up to about 40 to 80 square inches per fruit, depending on the variety. Above this range, the fruit continues to increase in volume with an increase in leaf area but the increase is relatively slight.

Table I

Coefficients of correlation between the increase in volume of apples and the number of leaves per apple on ringed branches

Variety	Year	Number of leaves	Correlation
Rome Beauty	1924	1 to 20	+0.975 ±0.002
Ben Davis	1924	4 to 20	+0 .594 ±0.038
Delicious	1924	4 to 20	+ 0.423 ±0.044
Ben Davis	1925	5 to 75	+0.743 ±0.028
Delicious	1925	0 to 75	+0.805 ±0.017
Grimes Golden	1925	0 to 80	+0.829 ±0.009
Ben Davis	1926	5 to 75	+0.696 ±0.033
Ben Davis	1926	0 to 75	+0.760 ±0.031
York Imperial	1926	5 to 75	+0.673 ±0.031
Baldwin	1927	0 to 75	+0.704 ±0.029
Jonathan	1927	0 to 75	+0.800 ±0.029

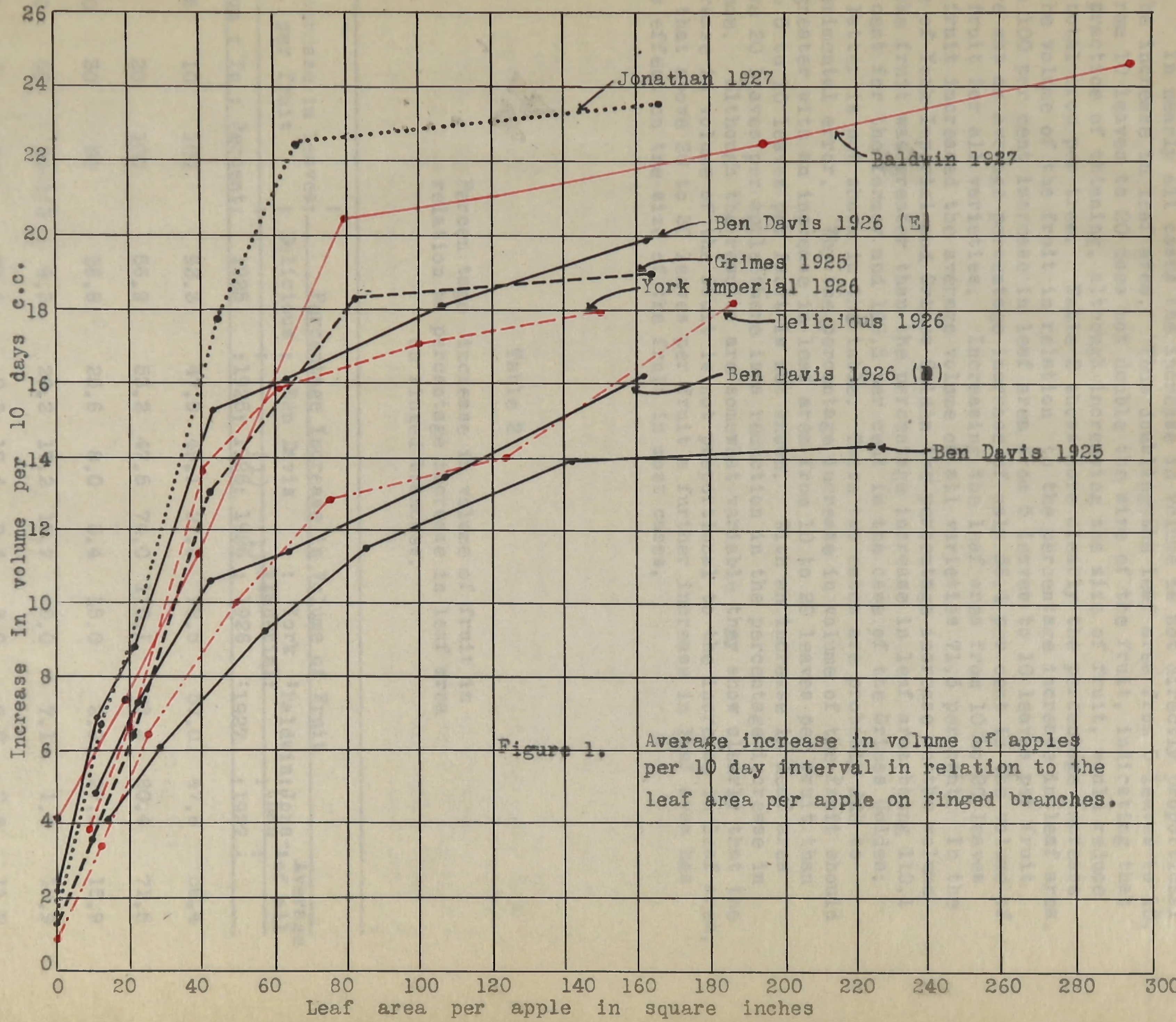

Figure 1. Average increase in volume of apples per 10 day interval in relation to the leaf area per apple on ringed branches.

In nearly all cases the increase in volume is not directly proportional to the increase in leaf area. Thus doubling the leaf area from 5 leaves to 10, or from 10 leaves to 20 does not double the size of the fruit, indicating that the practice of thinning, although increasing the size of fruit, would reduce the total crop per tree. Table 2 shows more clearly the percentage increase in the volume of the fruit in relation to the percentage increase in leaf area. With 100 per cent increase in leaf area from 5 leaves to 10 leaves per fruit there was an average percentage increase of only 56.4 per cent in the volume of the fruit for all varieties. Increasing the leaf area from 10 to 20 leaves per fruit increased the average volume of all varieties 71.5 per cent. In the case of York Imperial and Grimes Golden the percentage increase in the volume of the fruit was greater than the percentage increase in leaf area being 110.1 per cent for the former and 103.5 per cent in the case of the Grimes Golden; the latter is not shown in the table. These two cases are probably due to experimental error. Why the percentage increase in volume of the fruit should be greater with an increase in leaf area from 10 to 20 leaves per fruit than from 5 to 10 leaves per fruit is not known. With an increase in leaf area above 20 leaves per apple there is a reduction in the percentage increase in volume. Although the results are somewhat variable they show clearly that the increase in volume of the fruit is not proportional to the increase in leaf area, and that above 20 to 30 leaves per fruit a further increase in leaf area has less effect on the size of the fruit in most cases.

Table 2

Percen tage increase in volume of fruit in relation to percentage increase in leaf area on ringed branches.

Increase in leaves per fruit			Percentage Increase in Volume of Fruit							
			Delicious	Ben Davis			York Imperial	Baldwin	Jonathan	Average of all
From	To	Percent	1925	1925	1926 (1)	1926 (1)	1926	1927	1927	
5	10	100	93.3	47.9	49.1	27.2	72.5	57.0	47.6	56.4
10	20	100	56.9	53.2	47.5	74.0	110.1	78.2	80.4	71.5
20	30	50	26.8	25.6	8.0	5.4	15.0	2.9	27.5	15.9
30	50	66-2/3	9.3	20.2	17.2	12.7	8.0	7.1	1.7	10.9
50	75	50	29.2	2.8	19.4	9.4	5.0	9.8	2.6	11.2

(1) Treatments applied at different times.

The total average increase in the size of the fruit both on ringed branches and those not ringed is shown in Table 3. The increase in volume per 10 day intervals of fruit on branches that were not ringed is shown in Figure 2. It will be observed that while the tendency for fruit on unringed branches is to increase in size with an increase in leaf area, the increase in size was not nearly as decided or consistent as on ringed branches and in a few cases there was a decrease in size with an increase in leaf area. Fruit on unringed branches with a very small leaf area was usually larger than fruit with the same leaf area on ringed branches, whereas fruit on unringed branches with a large leaf area was usually smaller than the corresponding fruit on ringed branches. In all cases fruit grown on unringed branches from which all of the leaves had been stripped was as large or larger than fruit on ringed branches with 10 leaves per fruit. With the exception of the Delicious variety in 1925, fruit grown on unringed branches with 50 leaves per fruit was as small or smaller than similar fruit grown on ringed branches with 20 leaves per fruit.

The discrepancies between the results obtained on ringed branches and on unringed branches can be explained by the data presented in Part II of this paper in which it is shown that there may be considerable translocation from a branch with a light crop of fruit to one with a heavy crop. There is also a relatively large use of synethesized materials in building trunk and root tissue much of which probably comes from leaves on lightly loaded branches. Thus the fruit grown on unringed branches with few or no leaves per fruit undoubtly drew upon elaborated foods in adjacent branche, while much of the elaborated food in the branches with large leaf area per fruit was translocated to adjacent branches that were more heavily loaded with fruit or to other parts of the tree. This relation is also brought out in Plate I. In this plate the apples from unringed branches are shown directly below apples from ringed branches grown with the same number of leaves.

Table 3

Relation of leaf area per apple to increase in volume of apples.

Variety and date ringed	Leaves per fruit No.	Leaves per fruit Area sq.in.	Volume of apples at start cc	Period of growth (days)	Increase in volume of apples on Ringed branches cc	Increase in volume of apples on Unringed branches cc
Delicious May 8 to June 4, 1925	0	0	13.8	85	5.6 ± 0.5	
	5	12.5	12.7	85	28.3 ± 1.4	
	10	24.9	14.3	85	54.7 ± 1.7	
	20	49.8	13.9	85	85.8 ± 2.4	
	30	74.7	16.1	85	108.8 ± 2.5	
	50	124.5	14.9	85	118.9 ± 4.0	
	75	186.8	17.9	85	153.6 ± 9.4	
	22	55.0	13.7	85		99.4 ± 3.9
	50	124.5	17.5	85		138.3 ± 1.6
Grimes Golden June 17-18 1925	0	0	24.3	68	7.2 ± 0.3	
	5	10.2	23.1	68	25.3 ± 0.7	
	10	20.4	22.4	68	43.1 ± 1.6	
	20	40.8	21.6	68	87.7 ± 1.8	
	40	81.6	22.3	68	124.2 ± 2.8	
	80	163.2	22.3	68	128.4 ± 4.3	
	44	89.8	23.6	68		97.3 ± 1.6
	56	114.2	21.4	68		88.8 ± 1.8
Ben Davis June 3-5 1925	5	14.4	11.8	107	43.4 ± 3.1	
	10	28.7	11.5	107	64.2 ± 2.7	
	20	57.4	12.2	107	98.4 ± 2.6	
	30	86.1	11.5	107	123.6 ± 2.4	
	50	144.0	13.2	107	148.6 ± 3.6	
	75	225.3	12.7	107	152.8 ± 4.5	
	12	34.4	12.7	107		94.0 ± 3.4
	17	48.8	11.2	107		87.2 ± 2.6
	26	74.6	12.7	107		100.0 ± 2.3
	42	120.5	14.0	107		129.8 ± 2.3
Ben Davis May 15-19 1926	5	10.8	1.3	112	54.0 ± 2.2	
	10	21.5	1.0	112	80.5 ± 2.0	
	20	43.0	1.0	112	118.7 ± 4.3	
	30	64.5	.9	112	128.2 ± 4.7	
	50	107.5	.8	112	150.3 ± 6.8	
	75	161.3	1.1	112	179.4 ± 5.4	
	6	12.9	1.1	112		76.8 ± 1.5
	25	53.8	1.2	112		109.4 ± 3.4
	50	107.5	1.0	112		109.2 ± 3.3

Table 3 - (Continued)

Variety and date ringed	Leaves per fruit No.	Leaves per fruit Area sq. in.	Volume of apples at start cc	Period of growth (days)	Increase in volume of apples on Ringed branches cc	Increase in volume of apples on Unringed branches cc
Ben Davis June 24-25 1926	0	0	21.7	76	9.1 ± 0.4	
	5	10.8	22.6	76	52.3 ± 2.3	
	10	21.5	23.9	76	66.5 ± 3.7	
	20	43.0	23.2	76	115.7 ± 3.0	
	30	64.5	23.5	76	122.0 ± 4.9	
	50	107.5	24.9	76	137.5 ± 5.1	
	75	161.3	25.0	76	150.4 ± 6.0	
	0	0	27.8	76		65.5 ± 1.8
	10	21.5	27.5	76		81.5 ± 2.3
	20	43.0	23.9	76		82.5 ± 2.0
	30	64.5	24.5	76		85.0 ± 1.3
	51	109.6	31.4	76		113.0 ± 2.8
York Imperial - May 27 to June 2, 1926	5	10.0	7.7	73	27.6 ± 1.0	
	10	20.1	8.5	73	47.6 ± 1.9	
	20	40.2	10.2	73	100.0 ± 2.4	
	30	60.3	10.1	73	115.0 ± 4.6	
	50	100.5	9.6	73	124.2 ± 3.8	
	75	150.2	9.1	73	130.4 ± 4.6	
	0	0	10.6	73		62.3 ± 2.3
	10	20.1	9.3	73		78.2 ± 1.9
	20	40.2	9.6	73		63.9 ± 1.1
	30	60.3	9.6	73		72.3 ± 1.4
	50	100.5	10.3	73		84.3 ± 1.8
Baldwin June 3-10 1927	0	0	25.2	91	36.4 ± 3.6	
	5	19.7	27.6	91	66.3 ± 3.7	
	10	39.4	27.9	91	104.1 ± 3.5	
	20	78.8	31.9	91	185.5 ± 3.9	
	30	118.2	27.3	91	190.8 ± 5.2	
	50	196.0	24.7	91	204.4 ± 9.0	
	75	294.5	23.3	91	224.4 ± 8.5	
	0	0	28.5	91		121.2 ± 1.9
	8	31.5	22.5	91		128.5 ± 2.5
	51	200.9	39.7	91		176.5 ± 3.4
Jonathan June 20-24 1927	0	0	34.7	64	8.6 ± 0.9	
	5	11.2	35.3	64	42.4 ± 1.5	
	10	22.3	34.6	64	62.6 ± 2.0	
	20	44.6	40.8	64	112.9 ± 3.1	
	30	66.9	43.0	64	143.9 ± 3.9	
	50	111.5	42.4	64	146.4 ± 3.5	
	75	167.3	42.0	64	150.2 ± 3.6	
	0	0	33.4	64		69.5 ± 1.6
	0	0	36.5	64		71.9 ± 1.5
	10	22.3	32.1	64		87.7 ± 2.7
	30	66.9	35.6	64		97.6 ± 2.3
	50	111.5	38.1	64		94.5 ± 2.8

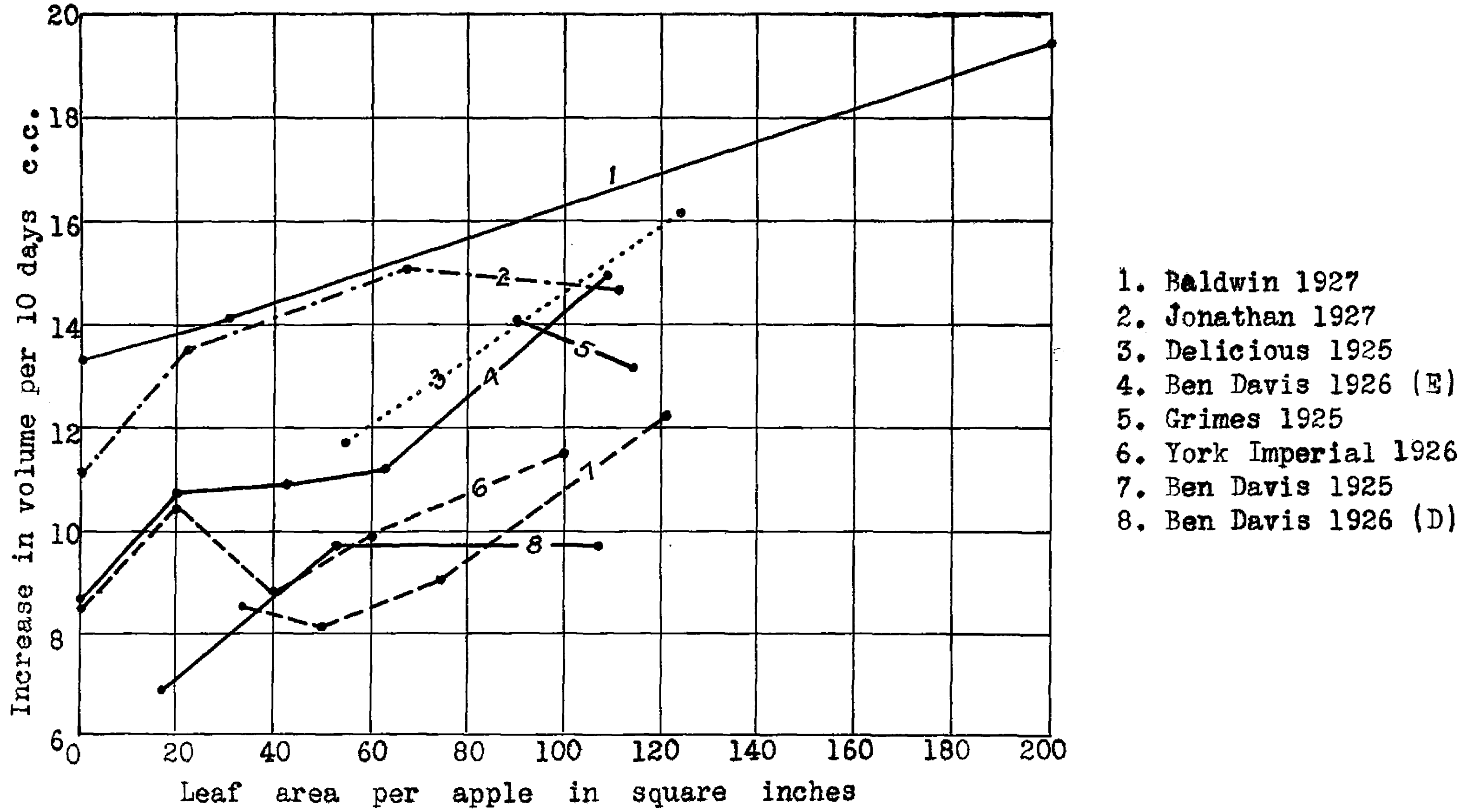

Figure 2. Average increase in volume of apples per 10 day interval in relation to the leaf area per apple on unringed branches.

In figure 3 is shown the increase in the size of the apples on ringed branches per 10 day interval and per 100 square inches of leaf area. There is shown an apparent decrease in the efficiency of a given leaf area with an increase in the leaf area per fruit as 10 apples grown with 10 square inches of leaf area per apple would have 2 to 3 times as great a volume as one apple grown with 100 square inches of leaf area per apple. The size of the fruit, however, is not a true index to the efficiency of the leaves as a greater proportion of the elaborated food probably is used for other purposes such as the growth of wood and buds and storage in the wood and fruit on branches with a large leaf area per fruit. In this connection much greater callus formation at the ring has been observed on branches with a large number of leaves per fruit indicating utilization and storage of elaborated foods at this point. Even so there is probably a reduction in the efficiency of the leaves due to an accumulation of the products of photosynthesis in such branches. Leaves on ringed branches with 50 and 75 leaves per apple were observed to be lighter green than leaves on other parts of the tree and frequently some of these leaves became yellow and dropped prematurely.

Effect of Leaf Area on Chemical Composition.

Table 4 presents the data on the chemical analyses of the fruit both from ringed and unringed branches. The fruit was kept in storage at 40°F. for a period before being sampled so that the starch would be converted to sugar. The sugar analyses would then be at their maximum and more nearly represent the total carbohydrates in the fruit. However, it was not always possible to do the sampling at the proper time so that in some cases the fruit was in storage longer than desirable. With long storage there would be slight changes in the proportion of the various constituents and probably slight reduction in total sugars and acid due to respiration. These changes would not be large and as the sampling was all done at practically the same time for each variety the results are comparable.

With an increase in leaf area per apple there was an increase in the percentage of dry weight and an increase in total sugars for apples on ringed branches (table 4, fig. 4). The increase in total sugars is due principally to an increase in sucrose as the free reducing sugars remained practically constant except for slight increases from 0 to 5 leaves per fruit and in some cases from 5 to 10 leaves per fruit. Above 10 leaves there was no significant change in the reducing sugars. There was usually five to ten times as much sucrose in the apples grown with 50 and 75 leaves as in apples grown with only 5 leaves.

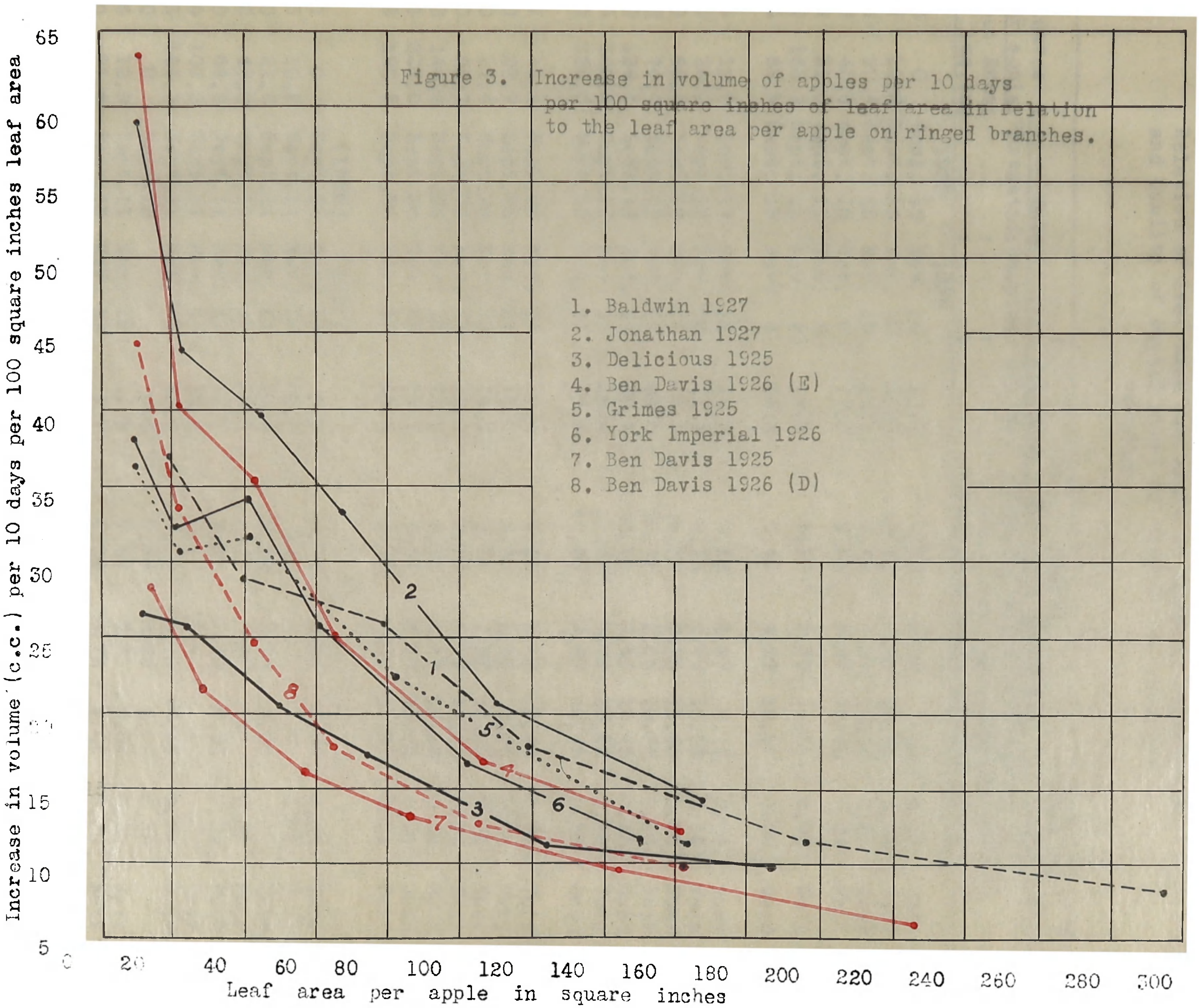

Figure 3. Increase in volume of apples per 10 days per 100 square inches of leaf area in relation to the leaf area per apple on ringed branches.

Table 4

Relation of leaf area per apple to chemical composition and quality of apples grown on ringed and unringed branches.

Variety	Leaves per apple: No.	Leaves per apple: Area: sq.in.	Date: Harvested	Date: Sampled	Per cent dry wt.	Sugars Per cent fresh wt.: Reducing as Dextrose	Sugars Per cent fresh wt.: Sucrose as Dextrose	Sugars Per cent fresh wt.: Total as Dextrose	Acid as malic. Per cent of fresh wt.	Quality
			1925	1925						
Grimes	0	0	Sept. 15	Nov. 10	12.7	7.43	0.37	7.80	0.31	Very poor
Golden	5	10.2	Sept. 15	Nov. 10	15.3	10.05	1.60	11.65	0.32	Very poor
1925	10	20.4	Sept. 15	Nov. 10	16.1	9.88	2.22	12.10	0.29	Poor
	20	40.8	Sept. 15	Nov. 9	17.3	9.53	4.47	13.90	0.34	Fair to good
	40	81.6	Sept. 15	Nov. 5	18.8	8.98	5.37	14.35	0.35	Good
	80	163.2	Sept. 15	Nov. 5						
	√44	89.8	Sept. 15	Nov. 5	16.8	9.43	4.27	13.70	0.30	Good
Delicious	5	12.5	Sept.19	Nov. 12	11.2	7.83	0.27	8.10	0.24	Very poor
1925	10	24.9	Sept.19	Nov. 12	11.9	9.28	0.77	10.05	0.18	Very poor
	20	49.8	Sept.19	Nov. 12	13.3	10.85	0.75	11.60	0.20	Poor
	30	74.7	Sept.19	Nov. 11	15.7	10.43	1.92	12.35	0.20	Fair
	50	124.5	Sept.19	Nov. 11	18.1	10.98	3.47	14.45	0.23	Good
	75	186.8	Sept.19	Nov. 11	19.4	12.23	3.72	15.95	0.25	Very good
	√50	124.5	Sept.19	Nov. 13	15.2	10.38	2.07	12.45	0.23	Good
Ben	5	14.4	Sept.26	Nov. 16	12.6	8.28	1.12	9.40	0.32	Very poor
Davis	10	28.7	Sept.26	Nov. 14	12.7	8.25	1.60	9.85	0.34	Very poor
1925	20	57.4	Sept.26	Nov. 13	14.1	9.18	1.82	11.00	0.31	Poor
	30	86.1	Sept.26	Nov. 13	16.9	9.28	3.12	12.40	0.36	Fair
	50	144.0	Sept.26	Nov. 13	18.1	9.13	4.17	13.30	0.44	Good
	75	225.0	Sept.26	Nov. 13	19.4	9.63	5.52	15.15	0.46	Good
	√42	120.5	Sept.26	Nov. 17	15.4	8.95	2.80	11.75	0.31	Fair
			(1926)	(1927)						
Ben	0	0	Sept.11	Mar. 14	9.2	5.74	0.26	6.00	0.36	Very poor
Davis	5	10.8	Sept.11	Mar. 12	9.0	--	--	--	0.30	Poor
1926	10	21.6	Sept.11	Mar. 11	10.2	7.78	0.78	8.56	--	Poor
	20	43.0	Sept.11	Mar. 11	10.6	--	--	--	0.33	Poor to fair
	30	64.5	Sept.11	Mar. 11	12.9	7.82	2.14	9.96	0.34	Fair
	50	107.5	Sept.11	Mar. 9	12.8	--	--	--	--	Fair to good
	75	161.3	Sept.11	Mar. 9	13.6	7.70	3.18	10.88	0.37	Fair to good
	√0	0	Sept.13		9.8	7.39	0.73	8.12	0.30	
	√6	12.9	Sept.11	Mar. 15	11.1	7.66	0.86	8.52	0.32	Fair
	√10	21.5	Sept.13	Mar. 17	9.7	7.26	0.78	8.04	0.39	Fair
	√20	43.0	Sept.13	Mar. 16	10.8	7.46	1.06	8.52	0.29	Fair
	√25	53.8	Sept.11	Mar. 14	11.0	7.68	0.72	8.40	0.30	Fair
	√30	64.5	Sept.13	Mar. 16	10.0	7.44	0.72	8.16	0.29	Fair
	√50	107.5	Sept.11	Mar. 14	11.6	7.86	1.34	9.20	--	Fair
	√51	109.6	Sept.13	Mar. 21	10.7	7.72	1.20	8.92	0.34	Fair

√On unringed branch.

Table 4 (Continued).

Variety	Leaves per apple: No.	Leaves per apple: Area sq.in.	Date: Harvested	Date: Sampled	Per cent Dry wt.	Sugars Per cent fresh wt.: Reducing as Dextrose	Sugars Per cent fresh wt.: Sucrose as Dextrose	Sugars Per cent fresh wt.: Total as Dextrose	Acid as malic. Per cent of fresh wt.	Quality
			(1926)							
York Imperial 1926	5	10.0	Sept.23	Dec.22/26	9.6	7.60	0.52	8.12	0.47	Very poor
	10	20.1	Sept.23	Dec.22/26	10.7	7.94	1.34	9.28	0.48	Poor
	20	40.2	Sept.23	Dec.21/26	11.7	8.40	2.20	10.60	0.46	Fair to gd.
	30	60.3	Sept.23	Dec.20/26	13.8	8.66	4.06	12.72	0.51	Good
	50	100.5	Sept.23	Dec.20/26	14.8	7.94	4.78	12.72	0.49	Good
	75	150.2	Sept.23	Dec.20/26	16.6	8.52	5.88	14.40	0.55	Very Good
	✓ 0	0	Sept.23	Jan.13/27	13.1	8.94	1.09	10.03	0.39	Good to Fr.
	✓10	20.1	Sept.23	Jan.7/27	14.1	8.48	2.68	11.16	0.46	Good to Fr.
	✓20	40.2	Sept.23	Dec.23/26	12.2	8.66	2.22	10.88	0.40	Good to Fr.
	✓30	60.3	Sept.23	Jan.11/27	14.5	9.30	2.58	11.88	0.35	Good to Fr.
	✓50	100.5	Sept.23	Jan. 5/27	14.4	9.10	2.06	11.16	0.40	Good
			(1927)	(1928)						
Jonathan 1927	0	0	Aug.30	Jan.20	13.7	7.1	0.4	7.5	0.58	Very poor
	5	11.2	Aug.30	Jan.19	14.8	9.2	0.4	9.6	0.53	Poor
	10	22.3	Aug.30	Jan.19	16.3	9.6	0.6	10.2	0.56	Fair
	20	44.6	Aug.30	Jan.18	17.7	9.8	1.8	11.6	0.69	Fair to Gd.
	30	66.9	Aug.30	Jan.18	18.6	9.8	3.6	13.4	0.81	Good
	50	111.5	Aug.30	Jan.17	21.7	10.5	4.5	15.0	0.90	Very good
	75	167.3	Aug.30	Jan.16	20.6	9.7	4.1	13.8	0.97	Very good
	✓ 0	0	Aug.30	Jan.24	16.2	9.7	1.0	10.7	0.54	Good to Fr.
	✓10	22.3	Aug.30	Jan.23	17.6	9.8	1.6	11.4	0.65	Good
	✓30	66.9	Aug.30	Jan.21	18.0	10.0	1.6	11.6	0.67	Good
	✓50	111.5	Aug.30	Jan.21	19.0	10.2	1.6	11.8	0.68	Good
Baldwin 1927	0	0	Sept.	Mar.14	12.2	6.8	0.4	7.2	0.42	Very poor
	5	19.7	Sept.	Mar.14	12.4	7.7	0.8	8.5	0.50	Very poor
	10	39.4	Sept.	Mar.14	14.5	8.2	1.9	10.1	0.51	Poor
	20	78.8	Sept.	Mar.13	15.6	7.8	3.6	11.4	0.54	Good
	30	118.2	Sept.	Mar.12	18.1	8.8	4.0	12.8	0.57	Good-V.Gd
	50	196.0	Sept.	Mar.10	18.6	8.6	4.6	13.2	0.59	Good-V.Gd
	75	294.5	Sept.	Mar.10	20.3	9.1	5.9	15.0	0.67	Good-V.Gd
	✓ 0	0	Sept.	Mar.21	14.7	7.8	2.2	10.0	0.55	Fair-good
	✓ 8	31.5	Sept.	Mar.17	15.6	7.8	3.2	11.0	0.57	Good
	✓ 51	200.9	Sept.	Mar.19	15.2	7.9	2.7	10.6	0.71	Good

✓ On unringed branch

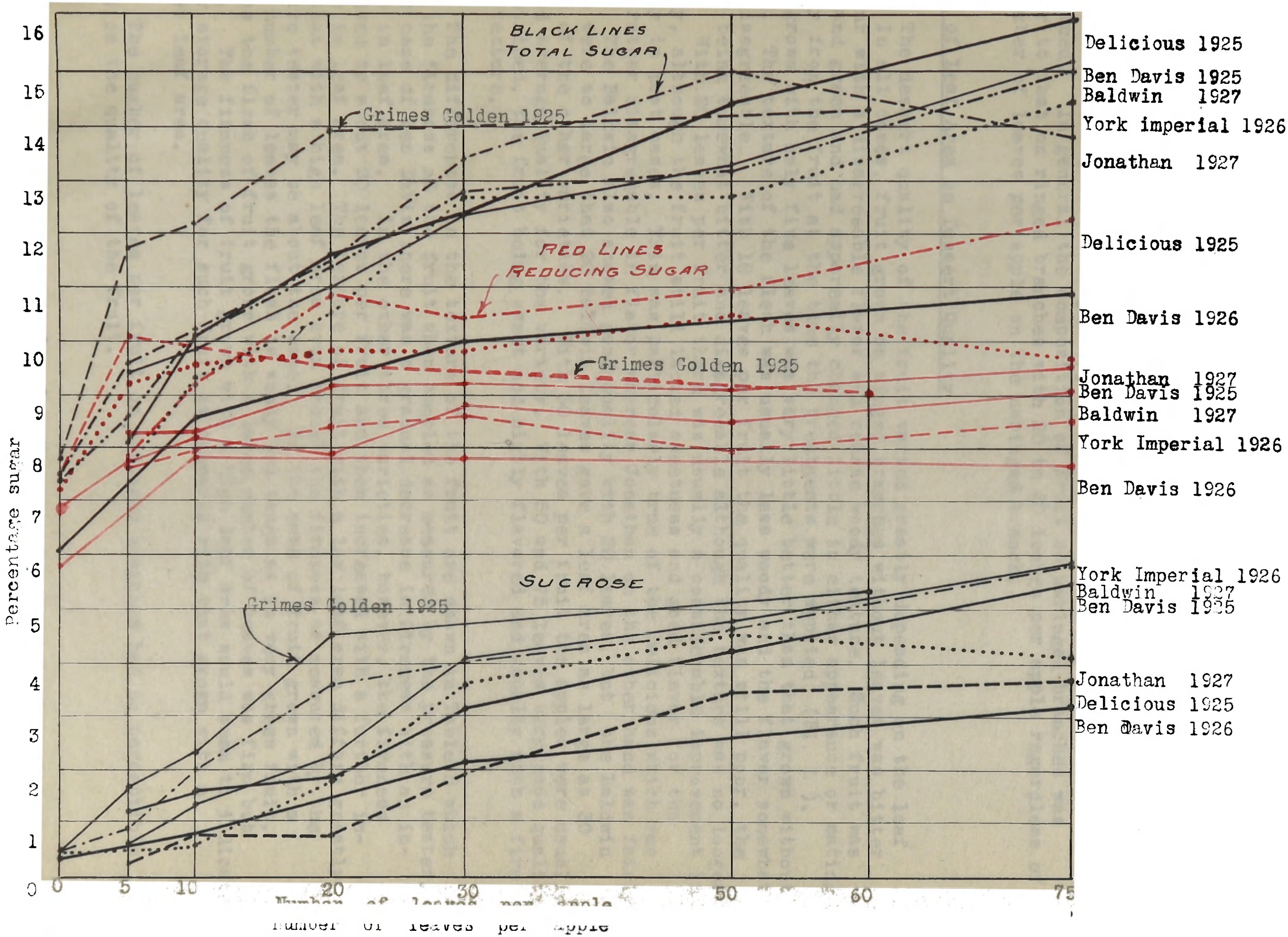

Figure 4. Percentage sugar in apples in relation to the leaf area per apple on ringed branches.

The variation in the results of the acid determinations are not as large or clear cut as were those of the sugar determinations. In general there seemed to be an increase in acidity with high leaf areas. With very low leaf areas, however, there was in some cases an increase in acidity with a decrease in leaf area.

On branches that were not ringed there was no consistent variation associated with the leaf area per apples on the branch in any of the constituents determined. In general the composition of fruit on unringed branches was similar to that on ringed branches with 20 to 30 leaves per apple regardless of the number of leaves per apple on the unringed branch.

Effect of Leaf Area on Dessert Quality

The dessert quality of the fruit varied greatly depending on the leaf area. In all cases, fruit grown on ringed branches without leaves was bitter and sour with a disagreeable flavor and coarse woody texture. Such fruit was small and green and had apparently changed little in either appearance or eating quality from the fruit at the time the treatments were applied (Pl. I). Fruit grown with only five leaves was very little better than that grown without leaves. The texture of the flesh was usually less woody and the flavor somewhat less disagreeable. With 10 leaves per fruit the quality was still poor, the flavor being somewhat bitter and disagreeable although the texture was no longer woody. With 20 leaves per fruit there was usually a considerable improvement in quality, although the fruit still lacked sweetness and good flavor for the variety in most cases. This was particularly true of the Delicious which was still rather disagreeable in flavor whereas Jonathan on the other hand was fairly good. The Baldwin also showed good quality with 20 leaves, but the Baldwin leaves were so large that 20 Baldwin leaves gave a leaf area as large as 30 leaves of the other varieties. With 30 leaves per fruit the apples were usually of good average quality for the variety. With 50 and 75 leaves very good quality was obtained, the fruit being sweet and highly flavored and usually with a firm crisp texture.

The differences in the texture of the fruit are shown in Table 5 which gives the firmness of the fruit when sampled as measured by the pressure tester. In the case of Ben Davis there was a gradual decrease in firmness with an increase in leaf area. In the other three varieties, however, the firmness decreased to about 20 leaves per fruit and then increased with a further increase in leaf area. The texture of fruit with a low leaf area differs greatly from that with a high leaf area even though the firmness as measured by the pressure tester may be about the same. In the case of fruit grown with a small number of leaves the flesh is woody and tough as in very green fruit, whereas the flesh of fruit grown with a large number of leaves was firm but crisp. The firmness of fruit grown with a high leaf area would seem to indicate better storage quality for such fruit as compared with that grown with a smaller leaf area.

The number of leaves per fruit on unringed branches had no perceptible effect on the quality of the fruit.

Table 5

Firmness of apples grown on ringed branches in relation to the number of leaves per fruit.

Leaves per fruit	Pressure test in pounds at date of sampling			
	York Imperial 1926	Ben Davis 1926	Baldwin 1927	Jonathan 1927
0	--	--	12.5	12.1
5	22.8	19.1	10.3	8.0
10	19.8	15.7	10.1	7.7
20	14.0	14.1	10.2	7.1
30	15.3	13.6	11.6	7.7
50	15.3	13;1	12.5	8.5
75	18.2	12.6	14.3	9.0

Color Development in Relation to Leaf Area Per Apple

The importance of an accumulation of carbohydrates in apples for the development of red color has been pointed out in a previous report (38) in which an increase in solid red color with an increase in leaf area has been shown for Delicious. Fletcher (22) found that 20 and 40 leaves for Rome Beauty and York Imperial respectively were necessary on ringed branches for normal color development. He also found increased color and sugar in apples when sugar in the form of "cerelose" was added to the soil. The development of red color in relation to leaf area is shown in Table 6 for apples grown on ringed branches. In general the data show an increase in red color with an increase in leaf area. There was considerable variation, however, and only in the case of Jonathan was there a consistent increase for all leaf areas. In most cases there is a decrease in red color with very large leaf areas which may be due to less exposure to light of such fruit owing to the large leaf area. The reduction in color with the small leaf areas was more marked in appearance than indicated by the table, as the color was usually streaked and a dull brownish red under these conditions. It would seem that at least 20 to 30 leaves per fruit on ringed branches are necessary for normal development of red color in apples. The data indicate that an increase in leaf area above this does not necessarily bring about a further increase in color development, but may result in a decrease due to shading. The data indicate that an accumulation of a certain amount of sugar is necessary for the development of a large amount of bright red color.

Table 6

Percentage of surface of apples with red color in relation to the leaf area per apple on ringed branches.

Leaves per apple	Red Color - Per Cent of Surface					
	Ben Davis 1925	Delicious 1925	York Imperial 1926	Ben Davis 1926	Baldwin 1927	Jonathan 1927
0				0	0	3
5	21		14	22	3	32
10	43	33	39	26	7	38
20	47	38	43	34	41	40
30	55	44	47	22	26	64
50	52	66	49	21	14	66
75	41	47	28	20	18	69

That the ground color is also changed by the amount of leaf area per fruit is indicated by the data presented in Table 7. The ground color of the fruit was determined by comparison with a standard chart as described in a previous publication (36). A ground color of 1 represents a green color corresponding to that found on very immature apples, whereas a ground color of 4 is nearly a full yellow with only a slight tinge of green. Ground colors of 2 and 3 are intermediate. The data in Table 7 show a gradual change toward a yellow color with an increase in leaf area up to 30 leaves per fruit. In most cases there is practically no difference in the ground color of apples grown with 50 and 75 leaves or 40 and 80 leaves in the case of Grimes Golden. As the ground color of apples is an important index to the picking maturity of the fruit these results indicate that apples grown with a large leaf area might be picked earlier than fruit grown with a small leaf area. That the fruit is actually more mature is probable in view of its higher sugar content and excellent dessert quality.

There were no consistent differences in either ground color or red color in fruit grown on branches that were not ringed except that fruit grown on branches from which the leaves were all removed usually showed a higher percentage of red color due to the greater exposure to light. The sugar content of such fruit was usually equal to that of other fruit on unringed branches with a higher leaf area.

Table 7

Ground color of apples on ringed branches in relation to leaf area per apple

Leaves per apple	Ground Color					
	Grimes Golden 1925	Delicious 1925	Ben Davis 1925	York Imperial 1926	Baldwin 1927	Jonathan 1927
0	1.6				1.0	1.7
5	1.9		2.6	2.0	1.4	2.0
10	2.2	2.7	3.0	2.1	1.7	2.2
20	3.3	3.2	3.2	2.0	2.4	2.3
30		3.3	3.3	2.9	2.5	2.8
40	3.8					
50		4.0	3.4	2.8	2.3	3.1
75		4.0	3.6	3.4	2.4	3.1
80	3.7					

Discussion

Varying the leaf area per apple on ringed branches greatly influenced the size and quality of the fruit whereas similar treatment on branches which were not ringed had little or no effect on the fruit. The question arises then as to which of these treatments more nearly represents what would happen if entire trees were treated in a similar manner. When individual branches are treated without ringing there seems to be a translocation of food materials away from or to the branch depending on whether there are more or less leaves per apple on the branch than on the tree as a whole. If an entire tree were treated so that there was a very small leaf area per apple there would be no other source of elaborated food supply to draw upon, except possibly reserve or storage materials that might be present in the branches, trunk and roots, so that under conditions of small leaf area the fruit probably would respond as on ringed branches. Thus Auchter (3) found that when practically all of the leaves dropped in early summer due to cedar rust the fruit ceased to develop and became no larger than walnuts. On the other hand, in case an entire tree were thinned so that there was a very large leaf area per apple there would probably be considerable translocation of elaborated foods away from the fruit to the trunk and roots. In the latter case a large leaf area per fruit on an entire tree would not have as great an effect on the fruit as it would on ringed branches. It probably would have a much greater effect, however, than a similar large leaf area per fruit on an unringed branch, since the roots probably would not draw upon the synthesized foods to the same extent as fruit on adjacent branches with a smaller leaf area. In order to establish these points it would be necessary and very desirable to conduct experiments similar to those reported here using entire trees for each treatment. It seems probable, however, that a somewhat larger leaf area per apple would be necessary on whole trees to produce the same effect on the fruit as is obtained by a given leaf area on ringed branches, since much elaborated food from the leaves must be utilized in growth of roots, trunk and limbs in the normal tree.

It has long been recognized that thinning apples and thus increasing the leaf area per fruit increased the size of the apples. The importance of thinning on quality and color has not been so well recognized. Fruit grown with a small number of leaves was of very poor quality. Of the varieties studied this was particularly true of Delicious and least so of Jonathan.

In publications dealing with thinning it is usually recommended that fruit be thinned to a certain number of inches between fruit. In view of the results given here it would seem more desirable to thin to a given number of leaves or leaf area per fruit. By this it is not meant that the leaves should be counted or measured but that the size of the leaves and their thickness on the branches or trees should be considered. Thus when a tree is bearing heavily and the leaves are small and scattered the fruit should be thinned to a much greater distance apart than on a tree where the leaves are large, vigorous and close together.

From these investigations it would seem that the fruit requires a larger amount of synthesized food for proper development and that there would be little available for vegetative growth and the development of buds unless there is sufficient leaf area to more than supply the major requirements of the fruit. In this connection Chandler & Heinicke (13) found that fruiting reduced the growth of Oldenberg apple trees. This is due in part to the fact that fewer and smaller leaves are produced on fruiting spurs than on nonfruiting spurs. The principal factor responsible for reduced vegetation, however, would seem to be the withdrawal of food materials from the tree into the fruit. Unless thinning were sufficiently severe to materially reduce the total crop there would be little benefit to the tree as the remaining fruit might still use most of the available elaborated materials.

Summary and Conclusions

Apples were grown with varying numbers of leaves per apple both on ringed and unringed branches. Increase in the size of the apples was determined during the growing season. Following harvest the fruit was analyzed for the determination of dry weight, sugars and acid.

On unringed branches the variation in leaf area had no appreciable effect on the composition of the fruit and very little effect on the size. This is thought to be due to the translocation of the food materials to or away from the branches depending on whether the leaf area per apple on the branches was less or greater than on the tree as a whole.

On ringed branches there was an increase in size of fruit with an increase in leaf area up to a point beyond which a further increase in leaf area resulted in little or no further increase in size. This point varies with the variety and probably with other factors such as climatic and soil conditions. With the varieties studied nearly maximum growth was usually obtained with about 30 leaves or 60 to 80 square inches of leaf area per fruit. Increase in size even with low leaf areas was not directly proportional to the increase in leaf area.

The percentage of dry weight and total sugars increased with increased leaf area on ringed branches. The increases in total sugars were due primarily to increases in nonreducing sugars as the free reducing sugars remained practically constant.

Dessert quality in apples was greatly influenced by the leaf area per apple. Good quality was associated with the high concentration of total sugars found in fruit grown with large leaf area. A leaf area insufficient to produce good size did not produce good quality for the variety.

Fruit grown with a small number of leaves was greener and lacked red color, as compared with fruit grown with a sufficient number of leaves to produce good size and quality. Color development seemed to be associated with a fairly high sugar content.

In the case of Ben Davis the firmness of the fruit after storage decreased with an increase in the leaf area per apple. In the case of the York Imperial, Baldwin and Jonathan varieties, there was a decrease in firmness with an increase in leaf area to about 20 leaves per apple. Above 20 leaves per apple there was an increase in firmness of the fruit with a further increase in leaf area.

Plate I. Ben Davis apples (1926) grown with various numbers of leaves per apple.

A.-	75	leaves	per	apple	on	ringed	branch
B.-	50	"	"	"	"	"	"
J-5.-	50	"	"	"	"	unringed	branch
C.-	30	"	"	"	"	ringed	"
J-2.-	30	"	"	"	"	unringed	"
D.-	20	"	"	"	"	ringed	"
J-1.-	20	"	"	"	"	unringed	"
E.-	10	"	"	"	"	ringed	"
J-3.-	10	"	"	"	"	unringed	"
F.-	5	"	"	"	"	ringed	"
H.-	0	"	"	"	"	"	"
J-4.-	0	"	"	"	"	unringed	"

O.- represents the size of the apples at the start of the experiment.


Ben Davis
J-4
J-3
J-1
J-2
J-5
H
F
E
D
C
B
A

II - The Relation of the Distance and Direction of the Fruit from the Leaves to the Size and Composition of Apples.

In the study of the relation of leaf area to the growth of apples (Part 1) it was found that the size of the fruit increased with an increase in leaf area up to 30 to 50 leaves per fruit even though it was often necessary to use leaves at considerable distance from the fruit in order to obtain this number of fully developed leaves. It was considered important therefore to determine to what extent the fruit could draw for elaborated foods upon leaves that were various distances away, and to determine the maximum distance from which foods might be transported to the fruit. The results of such an investigation should have a bearing on fruit bud differentiation and on the practice of thinning. Incidental to this work a study was also made of the increase in size of the fruit in relation to (a) the direction of the leaves from the fruit, (b) the size of the fruit at the start of the season and (c) the seed content of the fruit.

In a preliminary report (27) it was found that apples on ringed branches could apparently draw with equal facility upon elaborated foods from leaves 100 cm. distant as from leaves adjacent to the fruit. Coit (14) has shown that there was no significant difference in the size and sugar content of oranges grown on the ends of twigs that were defoliated for 8 inches back as compared with similar oranges grown on twigs that were not defoliated.

There seems to be no information as to the ability of the fruit to draw upon leaves that are above or below the fruit or that are on separate branches.

Whitehouse (49) has found that the size and shape of apples at the beginning of the season is a fairly accurate index to their size and shape at the end of the season.

A number of investigators including Auchter (3), Morris (40) Asami (1) and others, have found the size of the fruit to be associated to some extent with the number of seeds per fruit.

Material and Methods

The trees used in this investigation were those of the variety orchard at the Arlington Experimental Farm, Rosslyn, Virginia. The experiments were usually started in June when the apples were about the size of walnuts or smaller.

Branches were ringed leaving above the ring one fruit and 20 leaves, the leaves being at varying distances from the fruit. In some cases the leaves were left as close as possible to the fruit (fig. 5-A), in other cases the leaves were left 50 cm or 100 cm or more from the fruit. In some cases the leaves were above the fruit as in Figure 1-B while in other cases the leaves were below the fruit or on separate branches as in Figure 5-C.

In another experiment branches were ringed leaving above the ring 20 leaves and two fruits one of which was far from the leaves while the other was close as shown in Figure 5-D.

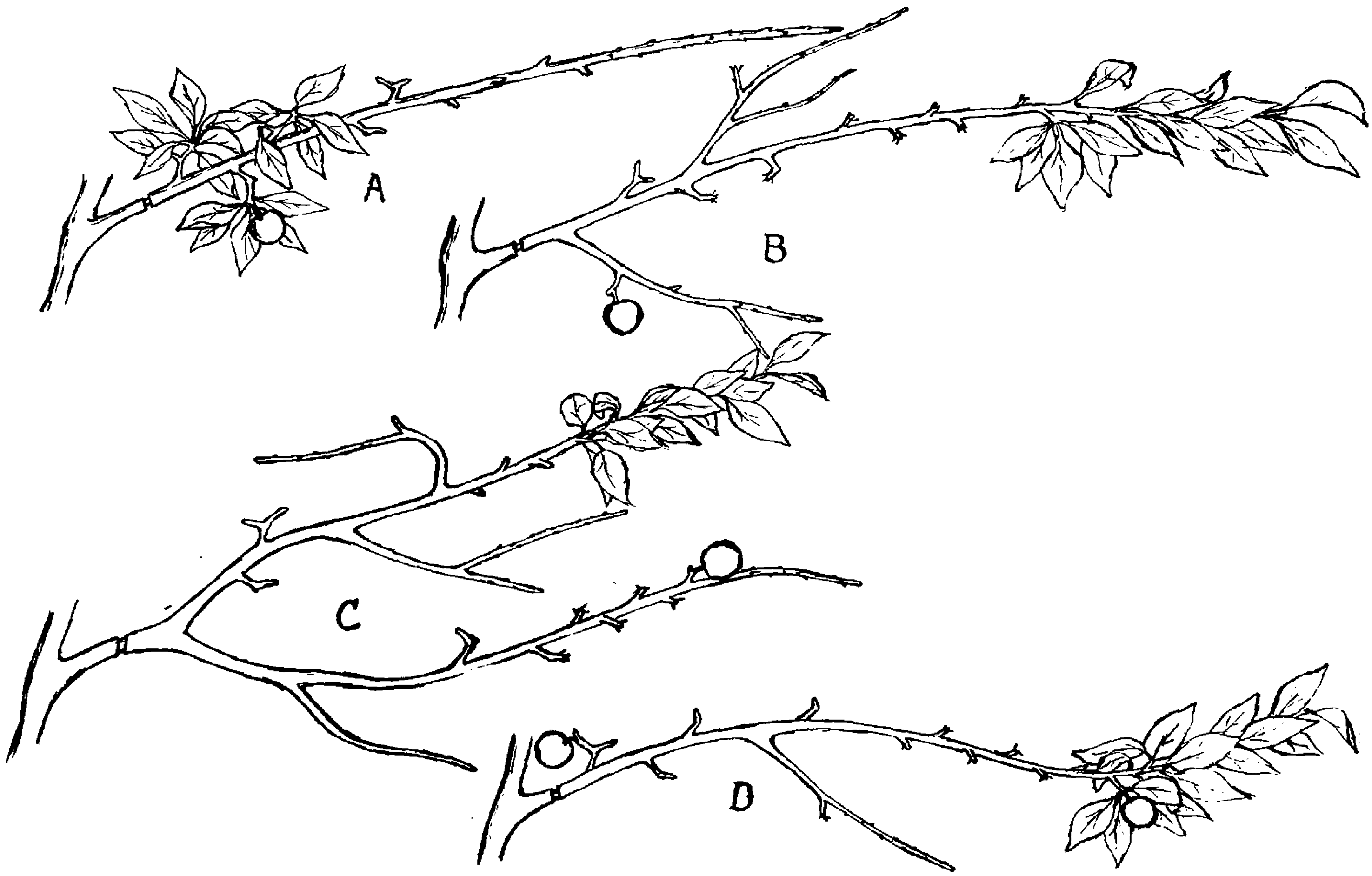

Figure 5. Treatment of ringed branches. A.-Leaves adjacent to apple; B.-leaves distant from apple; C.-leaves distant on separate branch from apple; B.-leaves distant from one apple and adjacent to another.

Another method was to strip the leaves from fairly large branches back to the main limbs to which the branches were attached. On such branches the fruit would be at varying distances from the main limb which would be their nearest source of elaborated food. Circumference measurements of the fruit were taken at the beginning and at the end of the experiments and the volume computed from these ($1/6\pi D^3$).

The fruit from each experiment was harvested in the fall and grouped according to the distance it was from the leaves. After a period in storage samples for sugar and acid determinations were made for each group. Sugar determinations were made as described in a previous publication (36). Acidity was determined by titration with tenth normal Na O H using phenolthalein as an indicator.

Correlation coefficients and probable errors were computed on all growth data.

Presentation of Results

Effect of Leaf Distance on the Growth of the Fruit

The data on the growth of apples on branches that were not ringed but from which all of the leaves had been stripped are presented in Table 8. In the column headed r_{12} are given the correlations between increase in volume and distance to main limb; r_{13} represents the correlation between increase in volume and volume at start; r_{23} represents the correlation between volume at the start and distance to the main limb; while $r_{12.3}$ represents the partial correlation between the increase in volume and distance to main limb with the volume at start constant. A correlation that is four times the probable error is considered significant.

In 1926 one Ben Davis branch was used on which there were 21 apples that were 40 to 150 cm from the main limb and one York Imperial branch on which were 25 apples 40 to 180 cm from the main limb. In neither case was there a significant correlation between the distance from the leaves or main limb and the increase in the volume of the fruit. (Table 8, r_{12}).

In 1927 larger branches were used on which some of the fruits were as much as 300 to 475 cm from the main limb. No correlation was found on the two Jonathan branches between the leaf distance and the increase in the volume of the fruit. On the two Baldwin branches the correlation was significant in both cases, being positive, however, in one and negative in the other.

These apparently conflicting results led to a closer study of the data in an effort to determine the reason why a negative correlation was found in one case and a positive correlation in the other. The correlation between the size of the fruit at the beginning of the experiment and the increase in size was determined to see whether the rate of growth had been changed by stripping the leaves from the branch. The correlation thus obtained (Table 8, r_{13}) were positive and significant in all cases showing that the relative rate of growth of the different apples had not been greatly changed. While these results agree with those of Whitehouse (49), it is surprising to find this relationship maintained even after the removal of all the surrounding leaves.

Table 8. Growth of apples on unringed branches from which all of the leaves were removed as shown by correlations between:
1. increase in the volume of the fruit
2. distance from the fruit to the main limb
3. volume of the fruit at the start of the experiment.
r_{12} indicates correlations between 1 and 2 above.
$r_{12.3}$ " " " 1 " 2 with 3 constant.

Variety	Year	No. of fruit	Distance between apples and main limb cm.	r_{12}	r_{23}	r_{13}	$r_{12.3}$*
Ben Davis	1926	21	40 to 150	$+0.088 \pm 0.15$	$+0.041 \pm 0.15$	$+0.832 \pm 0.05$	$+0.096 \pm 0.15$
York Imperial	1926	25	40 to 180	-0.209 ± 0.13	-0.293 ± 0.12	$+0.840 \pm 0.14$	$+0.071 \pm 0.13$
Baldwin	1927	47	50 to 310	$+0.449 \pm 0.08$	$+0.446 \pm 0.08$	$+0.501 \pm 0.07$	$+0.292 \pm 0.09$
Baldwin	1927	45	170 to 475	-0.714 ± 0.05	-0.315 ± 0.09	$+0.595 \pm 0.07$	-0.690 ± 0.05
Jonathan	1927	55	80 to 280	$+0.202 \pm 0.09$	$+0.499 \pm 0.07$	$+0.780 \pm 0.04$	-0.346 ± 0.08
Jonathan	1927	33	60 to 320	-0.034 ± 0.12	$+0.231 \pm 0.11$	$+0.693 \pm 0.06$	-0.275 ± 0.11

$$^*r_{12.3} = \frac{r_{12} - r_{23} \cdot r_{13}}{\sqrt{1 - r_{23}^2}\sqrt{1 - r_{13}^2}}$$

Since a significant correlation was found between the increase in the size of the fruit and the distance from the main limb without a material change in the relative rate of growth of the fruit, there must have existed a similar correlation between the size of the fruit at the beginning of the experiment and the distance from the main limb. This correlation was computed and shown in Table 8, r_{23}. On the Baldwin branch in which the correlation between the increase in volume and the distance to the main limb was $+0.4495 \pm 0.078$, a correlation of $+0.4460 \pm 0.079$ was found to exist at the beginning of the experiment between the size of the fruit and the distance to the main limb while on the other Baldwin branch correlations of -0.7140 ± 0.049 and -0.3151 ± 0.091, respectfully, obtained. Thus the correlations found on the Baldwin branches between the size and the leaf distance appear to be due to a correlation existing before any treatment was given. Therefore, in order to obtain the true effect of the leaf distance on the growth of the apples it was necessary to compute the partial correlation between the increase in size and distance to the main limb with the size at start constant. This is shown in the column headed $r_{12.3}$.

The corrected results thus obtained show significant negative correlations in the case of one Baldwin branch and one Jonathan branch while on the other four branches the correlations are not significant. On the Baldwin branch on which the fruit was 170 to 475 cm from any leaves a correlation of -0.6902 ± 0.053 was obtained. While this correlation is significant it is somewhat questionable, in view of the fact that a positive correlation of over three times the probable error was obtained on the other Baldwin branch, in which the distance was not nearly so great, and also because of the negative correlation already existing at the beginning of the experiment, which may not have been entirely corrected by the use of the partial correlation.

In the case of the Jonathan branches the correlations were negative in both cases and significantly so in one case. This would seem to indicate that in the case of Jonathan as well as Baldwin the extreme distance was becoming a limiting factor in the growth of the fruit. In no case, however, was the reduction in size sufficiently marked to be noticeable by simply looking at the fruit on the branch.

The results on unringed branches indicate that apples can if necessary readily draw elaborated foods from leaves that are at considerable distance. With the varieties used no appreciable reduction in size occurred when the leaves were 320 cm distant in the case of Baldwin, about 280 cm in the case of Janathan and at least 180 cm and 150 cm in the case of Ben Davis and York Imperial respectively.

Table 9. Growth of apples on ringed branches with 1 fruit and 20 leaves as shown by correlations between:
1. increase in the volume of the fruit
2. distance from the fruit to the leaves
3. volume of the fruit at the start of the experiment.

Variety	Year	No. of fruit	Distance between apples and leaves cm.	r_{12}	r_{23}	r_{13}	$r_{12.3}$
Grimes Golden	1925	125	0 to 110	+0.519 ± 0.04	+0.129 ± 0.06	+0.131 ± 0.06	+0.511 ± 0.05
Grimes Golden	1926	70	0 to 135	+0.265 ± 0.08	+0.176 ± 0.08	+0.117 ± 0.08	+0.289 ± 0.07
Ben Davis	1926	63	0 to 180	-0.092 ± 0.08	-0.158 ± 0.08	+0.904 ± 0.02	+0.121 ± 0.08
Baldwin	1927	71	0to 200	+0.036 ± 0.11	-0.204 ± 0.08	+0.672 ± 0.06	+0.194 ± 0.08
Jonathan	1927	43	0 to 240	-0.483 ± 0.08	-0.107 ± 0.10	+0.405 ± 0.09	-0.483 ± 0.08
Jonathan	1927	35	0 to 170	-0.038 ± 0.11	+0.054 ± 0.11	+0.318 ± 0.10	-0.058 ± 0.11

The data on the growth of apples on ringed branches with one fruit and 20 leaves at varying distances from the fruit are presented in Table 9. In view of the results obtained on unringed branches it was deemed advisable to compute the partial correlations between the increase in volume and the leaf distance in order to correct for any correlation that might exist at the start of the experiment between the size of the fruit and the leaf distance. This was done although no significant correlation was found (r_{23}) between the size of the fruit at the start and the leaf distance. Neither was there a significant correlation in the case of Grimes Golden between the increase in volume and the volume at the start (r_{13}). Contrary to expectations an apparently significant positive correlation ($r_{12.3}$) was obtained with Grimes Golden in the first year of the experiment (1925). This would indicate that the farther the apples were from the leaves up to 110 cm the larger they would become which seemed obviously incorrect. It was somewhat difficult to find branches on which the fruit could be separated widely from the leaves; consequently, the larger and longer the branch the farther the fruit was likely to be separated from the leaves while small branches were used where the leaves were adjacent to the fruit. The explanation for the positive correlation obtained the first year is probably that the large branches with the more distantly separated fruit and leaves were less injured by the ringing operation than were the small branches. In the later experiments an effort was made to use branches of the same size for the small distances as for the large. The first year's results indicated that at least there was no decrease in the size of the fruit even though there were no leaves within 100 cm of the fruit.

The experiment was repeated in 1926 with Grimes Golden and Ben Davis varieties and in 1927 with Baldwin and Jonathan. Again in 1926 the corrected correlation($r_{12.3}$) for Grimes Golden was positive and practically significant, being 3.9 times the probable error. In this case the correlation was not due to differences in the size of the branches as an effort was made to use branches for the short distances that were as large as those used for the long distances. The circumference of the branch at the ring was measured in each case and the correlation between the circumference of the branches and the increase in the volume of the fruit was $+0.065 \pm 0.119$ showing that the size of the branches had not affected the growth of the fruit.

In the case of Ben Davis and Baldwin the correlations ($r_{12.3}$) were not significant. In the Jonathan variety in which the leaves were in some cases as much as 240 cm from the fruit, a significant negative correlation was obtained. When the branches on which the leaves were more than 170 cm from the fruit were left out the correlation was $r = -0.0587 \pm 0.114$ indicating that the distance was not a limiting factor up to 170 cm.

In general the results on ringed branches indicate that if necessary apples can draw with equal facility upon leaves that are a considerable distance away as from those that are immediately adjacent. With Grimes Golden there was no decrease in the growth of the apples up to 135 cm, with Ben Davis up to 180 cm, with Baldwin up to 200 cm, and with Jonathan up to at least 170 cm.

Although the above results show that an apple will grow as large with 20 leaves that are at considerable distance as an apple with 20 leaves that are immediately adjacent, it was thought that it might not be able to grow as large if two apples were competing for elaborated foods from the same leaves. To determine this point branches were ringed with 20 leaves and 2 apples above the ring, one of which was adjacent to the leaves and the other at a considerable distance from the leaves (fig. 5 D). The data for this experiment are presented in Table 10. In the case of the Jonathan variety there were seven branches treated in this way with the apples that were distant averaging 112.4 cm from the leaves. In the Baldwin variety there were 15 branches treated with the distant apples averaging 109.2 cm from the leaves. At the beginning of the experiment the distant apples averaged slightly larger (2.4 per cent) than those adjacent to the leaves in the case of the Jonathan variety while with the Baldwin variety the distant apples were considerably smaller (12.4 per cent) than those adjacent to the leaves. In both cases the increase in the size of the distant apples was less than that of those adjacent to the leaves being 85.7 per cent as great in the case of Jonathan and 67.2 per cent in the case of Baldwin. Since it was found in the previous experiments that the increase in volume was correlated with the volume at the start of the experiment it would have been expected that the distant Baldwin apples would have increased in volume only 87.6 per cent as much as the apples close to the leaves if they were able to draw with equal facility upon the leaves. Since the distant fruit grew only 67.2 per cent this indicates that while they were able to obtain considerable elaborated foods from the leaves they were not able to get as much as the adjacent fruit. Table 10, column III gives the amount of growth which they made relative to the amount of growth they would have been expected to make from their relative volume at the start of the experiment, and shows that the rate of growth of the distant apples was decreased to 85.4 per cent in the case of Jonathan and 76.7 per cent in the case of Baldwin. Thus the distant apples apparently received 85.4 per cent and 76.7 per cent as much of the elaborated foods as the apples adjacent to the leaves.

Table 10.

Growth of apples on ringed branches in relation to the distance of the fruit from the leaves. Branches with 20 leaves and 2 apples.

Variety	Distance from Leaves	Volume at Start Ave. cc	Volume at Start Relative I	Increase in Volume Ave. cc	Increase in Volume Relative II	$\frac{II}{I}$ .100 III
Jonathan 1927	Adjacent	42.1	100	71.8	100	
	Distant (112 CM)	43.1	102.4	61.5	85.7	85.4
Baldwin	Adjacent	44.4	100	144.0	100	
	Distant (109 cm)	38.9	87.6	96.7	67.2	76.7

Effect of the Direction of the Apples from the Leaves on the Growth of the Fruit.

In the experiment in which branches were ringed leaving above the ring one fruit and 20 leaves at varying distances from the fruit, the leaves were in some cases above the fruit as in Figure 1 B, and in other cases they were below the fruit or on separated branches as in Figure 5 C. In order to determine whether the direction of the fruit from the leaves had any effect on its ability to draw on the elaborated foods the average increase in the size of the fruit in the various positions was determined and is shown in Table 11. Using the growth of the apples with the leaves adjacent as a standard the results show that in no case was there a significant difference in the increase in the volume of the fruit whether the leaves were below the fruit, above the fruit, or on separate branches.

Relation between the Number of Seeds per Apple and Size of Fruit

In the experiments reported in this paper it was found that there was some variation in the increase in the size of the fruit even though it was grown with the same number of leaves. This variation was not correlated with the distance from the leaves but seemed to depend on the size of the fruit at the start of the experiment. In view of the results obtained by Morris (40), Auchter (3), Asami (1), and others, it was thought that the variation in the size of the fruit at the start of the experiment might be due to the number of seed per fruit. At the time of sampling the fruit for chemical analysis the number of seeds per apple was counted and correlated with the size of the fruit at the start of the experiment. The results are presented in Table 12. Slight positive correlations were obtained in the case of York Imperial and Jonathan. In the case of the former, however, the correlation is not significant due to the high probable error. While the number of seeds per apple may be partly responsible for the variation in the size of the Jonathan apples, it apparently had no effect on the growth of the fruit in the other varieties studied.

Table 11

Growth of apples on ringed branches in relation to the relative position of the leaves and fruit.

Variety	Year	Leaves adjacent to fruit		Leaves below fruit		Leaves above fruit		Leaves on separate branch	
		No. of fruit	Increase in Vol. cc	No. of fruit	Increase in Vol. cc	No. of fruit	Increase in Vol. cc	No. of fruit	Increase in Vol. cc
Grimes Golden	1926	14	68.6 ± 2.7	13	72.1 ± 2.7	28	78.6 ± 1.3	15	71.8 ± 2.1
Ben Davis	1926	14	100.7 ± 2.9	7	93.9 ± 2.9	30	97.2 ± 1.8	11	107.0 ± 4.2
Baldwin	1927	11	165.0 ± 2.4	2	170.5	14	167.9 ± 5.5	13	168.1 ± 5.1
Jonathan	1927	10	98.0 ± 1.8			13	99.8 ± 1.8	20	93.2 ± 2.8

Table 12

Correlation between the Number of Seeds and the Volume of Apples at Start of the Experiment.

Variety	Year	Number of fruit	Number of seeds	Correlation between number of seeds and volume of fruit
Ben Davis	1926	57	3 to 10	+0.1112 ± 0.088
York Imperial	1926	52	4 to 10	+0.2983 ± 0.085
Jonathan	1927	259	1 to 10	+0.2290 ± 0.040
Baldwin	1927	186	1 to 7	-0.0016 ± 0.049

Relation between Leaf Distance and the Chemical Composition of the Fruit

Following harvest the apples from each of the different experiments were arbitrarily grouped according to their distance from the leaves and analyses for sugars and acid were made on each group. For the fruit from ringed branches the results are presented in Table 13 and Figure 6, and for the branches that were not ringed but from which all of the leaves had been stripped, in Table 14 and Figure 7.

In no case was there a consistent or significant variation in the acid content. There was practically no variation in the sugar content of the Ben Davis Apples from ringed branches (Table 13). In the case of Jonathan there was a decrease in sucrose and total sugars in the most distant group which was associated with a decrease in the size of the fruit. In the case of Baldwin, however, there was an increase in sucrose and total sugars with an increase in the distance between the fruit and the leaves. Groups "A" and "B" under Baldwin (Table 13) represent apples from ringed branches on which there were 20 leaves and 2 apples, one of which (A) was adjacent to the leaves and the other (B) was distant from the leaves (fig. 5 D). In this case the apples in the B group averaged much smaller than those in the A group and also show a lower sucrose and total sugar content.

There was very little variation in the sugar content of the apples from the branches that were not ringed but from which the leaves had been stripped (Table 14). In general a decrease or increase in total sugar content seems to be associated to some extent with a corresponding decrease or increase in the volume of the fruit on ringed branches (fig. 6) rather than with the distance between the fruit and leaves. Fruit on unringed branches, however, does not seem to show this relation (fig. 7). In all cases the differences are slight.

Table 13

Relation between Leaf Distance and chemical composition of Fruit. Branches ringed with one fruit and twenty leaves above ring.

Variety	Group	Av. leaf distance cm	Av. increase in volume cc	Sugars Per cent of fresh wt. Reducing as dextrose	Sucrose as dextrose	Total as dextrose	Acid as malic Per cent of fresh wt.
Ben Davis 1926	a	10	100.5	7.7	1.8	9.5	0.30
	b	40	112.2	7.9	1.6	9.5	0.28
	c	70	90.7	7.5	1.5	9.0	0.28
	d	90	103.6	7.6	1.8	9.4	0.28
	e	113	94.0	7.5	1.4	8.9	0.28
	f	169	99.8	7.2	2.2	9.4	0.32
Jonathan 1927	a	10	97.7	9.8	2.1	11.9	0.52
	b	86	101.6	10.4	1.8	12.2	0.50
	c	144	97.2	9.7	1.9	11.6	0.57
	d	208	79.4	9.6	1.1	10.7	0.47
Baldwin 1927	a	11	165.2	8.4	3.1	11.5	0.47
	b	80	160.9	8.4	3.6	12.0	0.48
	c	133	167.2	8.2	4.5	12.7	0.52
	A✓	12	144.0	8.2	2.6	10.8	0.45
	B	109	96.7	8.2	1.4	9.6	0.43

✓Branches with 20 leaves and 2 apples. A-adjacent to leaves
B-distant from leaves

Table 14

Relation between leaf distance and chemical composition of fruit. On unringed branches from which all leaves were stripped.

Variety	Branch number	Group	Av. Leaf distance cm	Av. increase in Vol. cc	Sugars Per cent of fresh wt. Reducing	Sucrose	Total	Acid as malic Per cent of fresh wt.
York Imperial 1926	J-5	a	51	63.9	9.0	1.4	10.4	0.38
	do	b	67	57.9	9.0	1.0	10.0	0.38
	do	c	90	64.5	9.1	1.1	10.2	0.39
	do	d	124	56.9	8.9	1.2	10.1	0.40
	do	e	176	54.1	8.6	0.8	9.4	0.43
Ben Davis 1926	J-4	a	57	59.3	7.3	0.6	7.9	---
	do	b	84	64.0	7.4	0.6	8.0	0.31
	do	c	100	69.4	7.4	0.5	7.9	0.29
	do	d	138	57.3	7.5	1.2	8.7	0.29
Jonathan 1927	J-1	a	114	67.0	9.5	1.2	10.7	0.57
	do	b	176	71.3	9.7	1.1	10.8	0.55
	do	c	229	72.0	10.0	1.0	11.0	0.60
	J-2	a	166	70.8	9.7	0.8	10.5	0.51
	do	b	271	71.2	9.7	0.7	10.4	0.48
Baldwin	J-2	a	133	109.8	7.5	1.9	9.4	0.61
	do	b	205	112.6	7.5	1.9	9.4	0.61
	do	c	249	130.8	8.0	1.1	9.1	0.61
	J-5	a	233	140.2	8.0	2.5	10.5	0.52
	do	b	351	124.9	7.6	3.1	10.7	0.47
	do	c	443	107.0	8.1	2.9	11.0	0.48

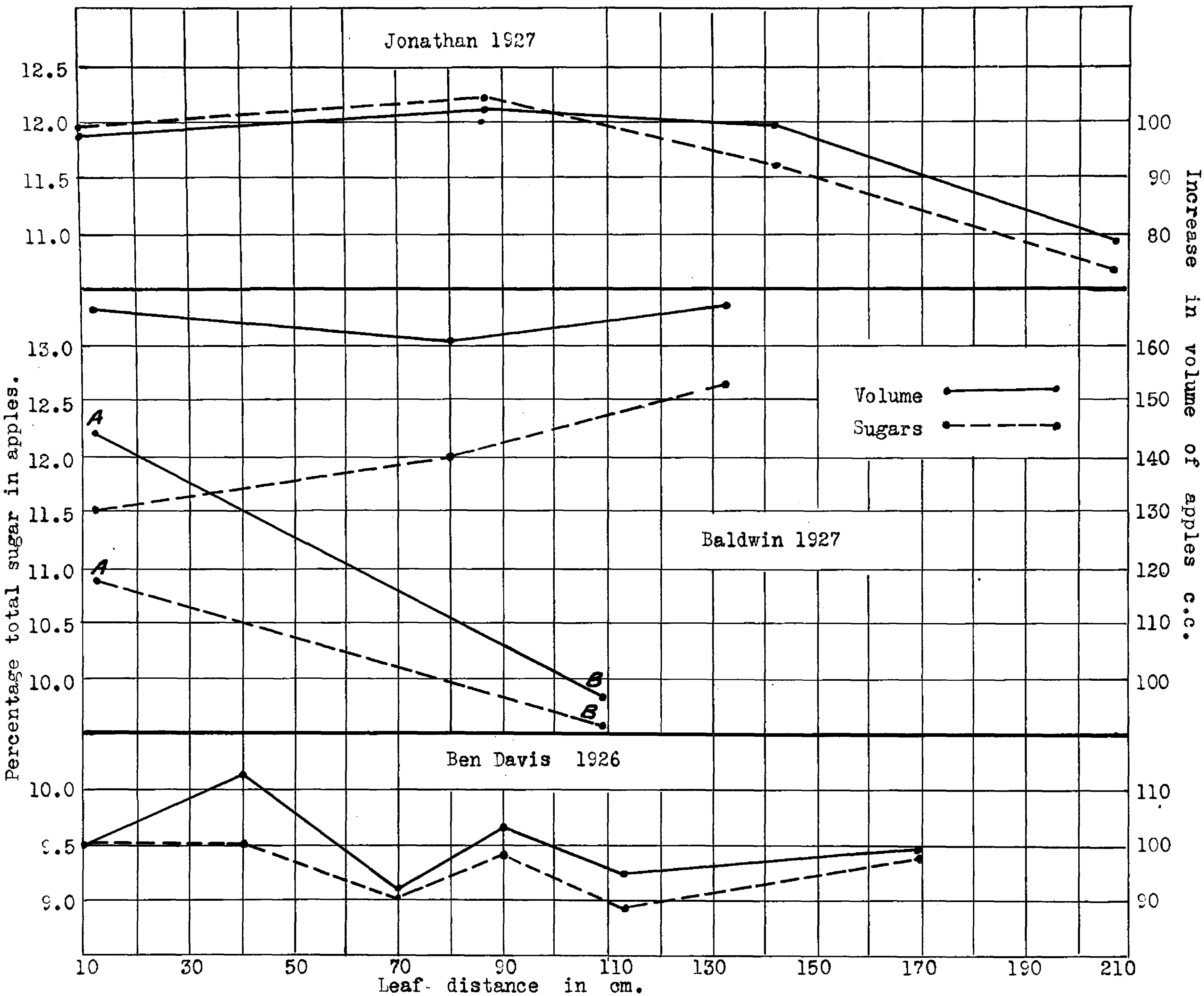

Figure 6. Effect of leaf distance on size and sugar content of apples on ringed branches.

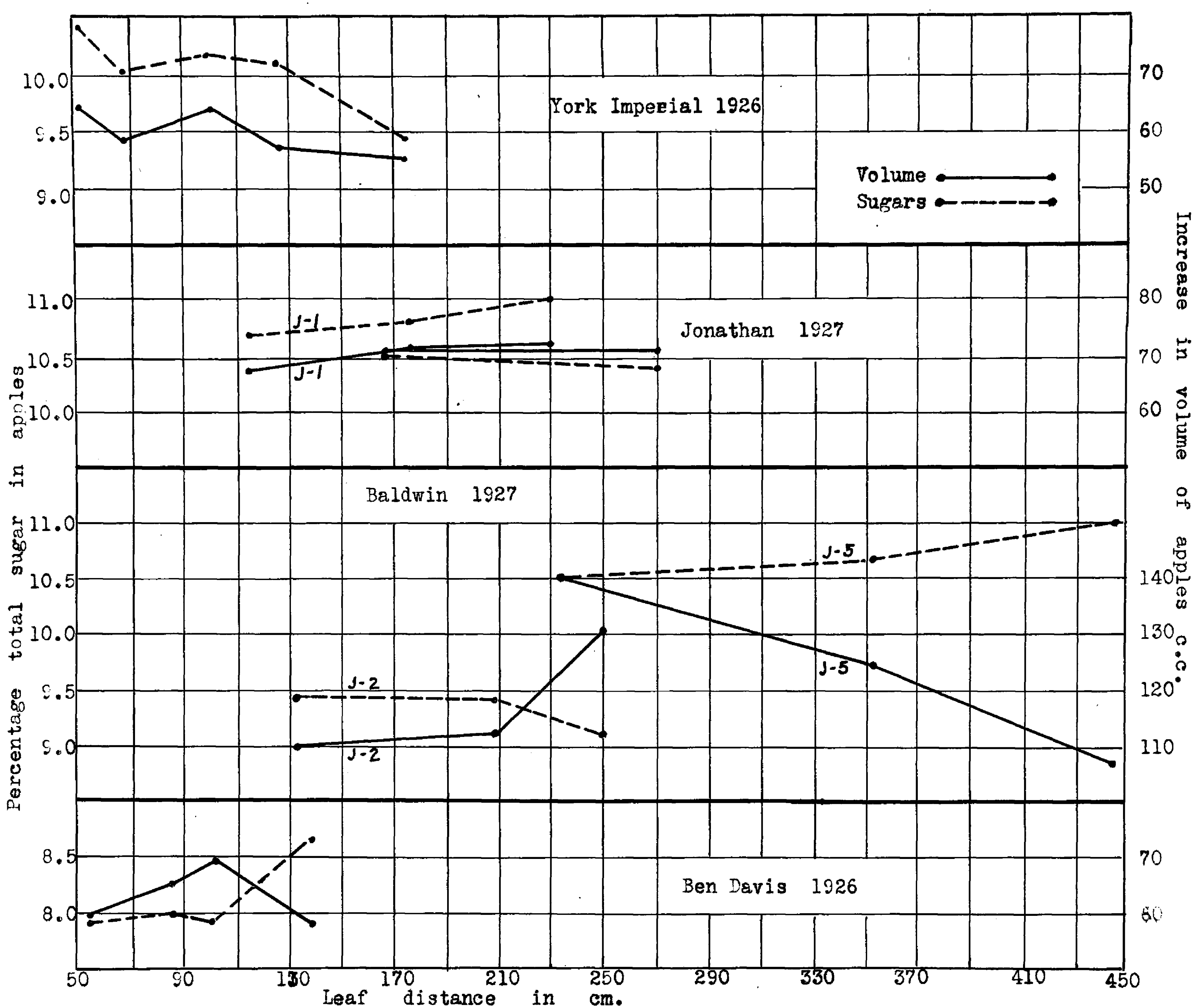

Figure 7. Effect of leaf distance on size and sugar content of apples on ringed branches.

Discussion

The evidence presented seems to indicate that with a limited supply of elaborated foods the fruit may utilize the available material to a greater extent than other parts of the plant. This is brought out by the fact that fruit grown at considerable distance from any leaves became practically as large and was not materially changed in composition of sugar and acid as compared with fruit grown adjacent to leaves. For example fruit on unringed branches from which all of the leaves were removed grew as large, and in most cases larger, than similar fruit on ringed branches with 10 leaves per fruit. Thus in the case of Baldwin in 1927 there were 47 and 45 apples on each of the two branches used (table 8). Since each apple apparently used at least as much food as was elaborated in 10 leaves, the amount of food translocated into each of the branches must have been as much as was elaborated by 470 and 450 leaves, respectively. This amount of food was translocated a distance of 50 to 310 cm in one case and 170 to 475 cm in the other. A further indication that the fruit tends to monopolize the available synthesized foods is that the principal movement seems to be in the direction of the fruit, and may be either upward or downward or from one branch to another, depending on whether the fruit is above the leaves, below the leaves, or on a separate branch. In this connection Murneek (41) has found that vegetative growth in the tomato was inhibited by the development of the fruit and was associated with an accumulation of carbohydrates and nitrogen in the fruit. The accumulation of nitrogen, however, was thought to be the factor responsible for the decreased vegetative growth. Similar results were also found for the apple (42) (43) in which both nitrogen and carbohydrate material accumulated in the fruit to a much greater extent than in any other part of the bearing spur system.

Auchter (4), working with young non-bearing peach and apple trees from one side of which the leaves had been stripped, concluded that the foods manufactured on one side of the tree were used or stored mainly in that side or in the roots directly beneath. The results presented herewith seem to indicate that under certain conditions there may be a cross transfer of elaborated food materials. Thus, if one branch were bearing a very heavy crop and an adjacent branch a very light crop, there would be, to some extent at least, a tendency toward equalization of the food materials.

From defoliation experiments Magness (35), Roberts (46) and Harvey and Murneek (29) have shown that there is considerable individuality in buds and spurs and that they depend largely, if not entirely, upon their own leaves for development and fruit bud formation. On the other hand Hooker and Bradford (31) found with bearing trees that under some conditions there seemed to be no such localization of factors. Since apples require considerably more leaves than are normally present on one spur to supply sufficient material for normal development and since they can apparently utilize material elaborated at some distance for additional foods, it would seem that the presence of fruit would have an effect on the food supply of spurs and buds for some distance from it.

In the experiments reported in this paper there was some variation in the increase in volume of apples that were grown on the same tree and with the same number of leaves. This variation was correlated to a large extent with the size of the fruit at the beginning of the experiment but was not associated with the distance or direction of the fruit from the leaves or with the seed content. Apparently some other factor was operating to cause the variation in the size of fruit upon a single branch or tree. It is suggested that this factor may be the cross sectional diameter of the conducting tissue at its narrowest point, which would probably be the fruit stem or fruit spur. Thus, the central flower or fruit of a cluster usually has a larger, thicker stem than the side flowers or fruit, and such fruit usually grows considerably larger than the side fruit when more than one fruit in a cluster set. Dixon (19) computed the amount of carbohydrates which passed through the stem into the tuber of the potato. He found the average rate of flow if the material were translocated through the bast must have been 50 cm per hour. An even greater rate of movement (88 cm per hour) was found by Mason and Lewin (32) for the yam. This rate of movement is much greater than can be accounted for by simple diffusion. While Mason and Maskell (33) have shown with the cotton plant that the transport of sugars through the phloem may be much more rapid than could be expected from simple diffusion, it seems reasonable to suppose that the size of the conducting tissue to storage organs such as the apple might sometimes be a limiting factor in the growth of the fruit.

The results obtained have a direct bearing on the practice of thinning. They indicate that in thinning each apple does not need to have a sufficient number of leaves close to it for normal growth but may be some distance from the leaves. Thus one branch might be allowed to bear a somewhat heavier crop provided an adjacent branch had a very light crop or no crop. Furthermore, the fruit could be thinned from the outer ends of the branches and be left correspondingly thick farther back on the branches where the weight would be less likely to cause breakage. Such practice, however, would probably result in less color on red varieties due to less exposure to light. Similarly, two apples might be allowed to grow on one spur provided there was sufficient leaf area on other parts of the branch to properly develop them. This practice, however, is also undesirable from the standpoint of color development as well as worm infestation.

Conclusions

Apples can draw upon elaborated foods which are synthesized in leaves at a considerable distance from the fruit. Practically no decrease in the size of the fruit occurred when no leaves were less than 135 cm or about 4½ feet from the fruit in the case of Grimes Golden, 180 cm or about 6 feet in the case of Ben Davis and York Imperial, 200 cm or 6½ feet in the case of Jonathan and over 300 cm or 10 feet in the case of Baldwin as compared with fruit grown with the same number of leaves that were immediately adjacent to the fruit. However, when fruit that is distant from the leaves and fruit that is adjacent to the leaves are competing for elaborated food from the same leaves, the distant fruit does not grow quite as large as that immediately adjacent to the leaves.

Apples may obtain elaborated foods with equal facility from leaves that are above, from leaves that are below, or from leaves on separate branches as from leaves that are adjacent.

The size of the fruit at the end of the season is correlated with the size of the fruit early in the season. This relationship was not affected on branches from which the leaves had been stripped.

In the Ben Davis, York Imperial, Baldwin and Jonathan varieties, the size of the fruit studied was not associated with the seed content, except slightly in the case of Jonathan.

The distance of the leaves from the fruit had no effect on the sugar and acid content of the fruit except in the case of Baldwin apples where the distant fruit was dependent upon the same leaves adjacent to other fruits in which case there was a decrease in sucrose and total sugars corresponding to the decrease in size.

III - Relation of Leaf Area Per Apple to Bud Differentiation.

It has been shown previously that apples require a rather large leaf area of 30 or more leaves per fruit for the development of good size and quality. Since a fruiting spur usually does not have nearly this many leaves, it is necessary for the fruit to draw upon other leaves. This it can do to a considerable degree. It would seem, therefore, that when trees are producing a heavy crop the fruit might utilize nearly all of the material synthesized, not only on the fruit bearing spurs but also on spurs and twigs at considerable distances from them so that a condition of high carbohydrate nitrogen ratio necessary for blossom bud formation would not exist in the spurs. That heavy fruit production inhibits blossom bud formation is well recognized. Theoretically, by thinning the fruit previous to bud differentiation, it should be possible to reduce the carbohydrate consumption by the fruit to such an extent that there would be sufficient accumulation of carbohydrates in the spurs to bring about conditions favorable to blossom-bud differentiation. It is probable, however, that there would be little accumulation of carbohydrates in the spurs until not only the major requirements of the fruit have been met but also the major requirements for the growth of the tree as a whole.

Thompson (47) found an average increase in dry weight for 2 trees each of 5 varieties of 39.7 pounds in growth of leaves, branches, trunk and roots during the ninth year. In a more mature tree this figure would be much larger. On the other hand a 400 pound crop of apples with a dry weight of 15 per cent of the fresh weight would require 60 pounds of dry matter. It seems reasonable to suppose therefore that the dry weight added to the tree in the growth of leaves, shoots and roots and increase in girth of trunk and limbs would equal or exceed the dry weight of a fairly heavy crop of fruit.

Since the work of Kraus and Kraybill with the tomato, considerable attention has been given by horticulturists to the relation of the carbohydrate nitrogen ratio to fruit-bud differentiation in the apple. Analyses of spurs at the time of bud differentiation by various investigators, Hooker (30), Harvey and Murneek (29), Harley (28) and Auchter et al (5) have shown that blossom-bud formation is associated with a relatively high C/N ratio. It also has been shown that factors which reduce the carbohydrate supply, such as heavy fruit production, shading (7) (26) and defoliation (35) (46), inhibit fruit-bud formation.

The time of fruit-bud differentiation varies somewhat with the location and season. In general, however, differentiation has been found to begin during the last week of June and the first two weeks of July as determined by various investigators (11) (21) (24) (25) (48). Axillary buds begin to differentiate about 3 weeks later than spur buds (34). Although the time at which bud differentiation begins has been well established, the literature does not clearly define the period during which differentiation may take place or the time at which maximum differentiation has occurred. Rasmussen (45) has shown for two varieties under Pennsylvania conditions that differentiation began the latter part of July during the two years studied and extended over a period of about 10 to 20 days. While this would seem to indicate a rather short period for blossom-bud formation, it would seem likely that differentiation might occur any time during the summer when conditions were favorable. Normally, however, maximum differentiation probably occurs by the first of August. For maximum results, therefore, any treatment designed to influence blossom-bud formation should begiven sufficiently early to be effective during July although some effect might be expected from later treatments.

That blossom thinning greatly influences blossom-bud formation has been demonstrated by several investigators. Auchter and Schraeder (5) obtained blossom-bud formation on 32 to 37 per cent of the spurs from which the blossoms were removed as compared with 1 per cent of the spurs which matured fruit and 50 per cent of the nonblossoming spurs. This work was done on a Stayman tree which was apparently bearing annually. With a biennially bearing Oldenburg tree Crow (15) was able to get fruit-bud formation in the on year by blossom thinning previous to petal fall but not after the fruit was well set. Drain (20) obtained similar results with Wealthy trees but thinned his blossoms by spraying with chemicals previous to fertilization. Bailey (8) removed the blossoms from 50, 75 and 100 per cent of the spurs of biennially bearing Wealthy, Oldenburg and Yellow Transparent trees. The removal of 100 per cent of the blossoms resulted in fruit-bud formation, whereas 75 and 50 per cent removal had practically no effect.

While blossom thinning has been found to favor fruit-bud formation there has been little evidence that fruit thinning following the June drop, or even previous to that, can effect fruit-bud formation. Beach (9) working with Baldwin, Rhode Island Greening and Hubbardston found no effect of thinning on fruit-bud formation in New York. The time at which the thinning was done was usually between July 1 and July 15 though this was not always stated. The maximum distance to which he thinned was 6 inches and the thinned trees produced only slightly less total crop than the unthinned. It would appear, therefore, that the thinning was done too late and was not sufficiently severe to expect it to have any effect on fruit-bud formation. Gourley (25) states that in Ohio thinning to 12 inches had no effect on alternate bearing. Auchter (2) (3) studied the effect of thinning on several varieties including the Baldwin, York Imperial, Rome Beauty, Ben Davis and Delicious in West Virginia. He thinned at three different periods; just previous to the June drop (about June 15), just after the June drop (about July 1) and in midsummer (Aug. 15). The maximum distance the fruit was thinned was 9 to 10 inches. The thinning in most cases did not materially reduce the total crop per tree nor did it have any effect on fruit-bud formation.

Auchter and Schraeder (5) obtained blossom-bud formation on 5 per cent of the spurs from which the fruit was thinned at the time of the June drop as compared with 1 per cent of the spurs which matured fruits. Auchter and Whitehouse (6) in some unpublished data show that complete removal of the fruit from the entire tree or from half of a tree resulted in blossom-bud differentiation and successive blossoming. Magness and Overly (39) reporting on investigations similar to those presented herein show an increase in blossom bud-formation with an increase in leaf area on ringed branches under Washington conditions.

From the investigations heretofore reviewed it would seem that fruit-bud formation is normally associated with an accumulation of carbohydrates in spurs sufficient to give a fairly high carbohydrate nitrogen ratio and that heavy fruit production prevents this. The thinning investigations have shown that reduction of fruiting by blossom thinning may bring about fruit-bud formation but fruit thinning as usually practised does not. From this it has been concluded by some that the critical period for fruit-bud differentiation is at or immediately following blossoming. In most fruit thinning investigations, however, the thinning has been done about the time of the initiation of bud differentiation which may not be time enough for any material carbohydrate accumulation before much of the differentiation was complete. Furthermore, most thinning has not been sufficiently severe to materially reduce the total crop and as it must require as much carbohydrates to produce a given weight of fruit whether the fruits are large or small, it is difficult to see how such thinning could be of much benefit to the carbohydrate accumulation of the tree as a whole.

Material and Method of Procedure

The material used was the same as that reported on in Part I of this paper in which a study was made of the effect of leaf area on the growth and composition of apples. In this work apples were grown on both ringed and unringed branches with varying numbers of leaves per apple on the branches. The treatments usually were made during May and June. In the spring following the year in which the branches were thus treated, the blossom and leaf buds on the spurs of the branches were counted. Spurs which fruited during the year of treatment were tagged in 1926 and 1927, but not in 1925. Spurs that had blossomed but from which the fruit had dropped or had been removed were determined by the fruit scars on the spurs and those which were leaf spurs during the year of treatment were determined by the lack of scars.

Presentation of Results

The data on the bud counts in 1926 following the treatments given in 1925 are presented in Table 15; while those for 1927 following treatment in 1926 are presented in Table 16; and those for 1928 following treatment in 1927 in Table 17. The results on ringed branches are shown graphically in Figure 8; those from unringed branches in Figure 8, also.

In 1925 treatments were applied to three varieties - Grimes Golden, Delicious and Ben Davis. Of these varieties, Grimes Golden and Ben Davis are normally regular annual bearers, whereas Delicious under some conditions tends to alternate. During this year the number of leaves per apple on the unringed branches was the same previous to the date of treatment as after, since neither leaves nor fruit were removed from such branches at the start of the experiment. As the fruiting spurs were not labeled, it was sometimes difficult at the time the bud counts were made to distinguish between those that had fruited and those that had only blossomed in the year previous.

It will be seen from Table 15 and Figure 8 that on ringed branches variations in the leaf area per apple had a decided effect on the formation of blossom-buds. Thus with only 5 or 10 leaves per apple blossom-bud formation was inhibited in all varieties except for one bud in the case of Grimes Golden. With 20 leaves per apple there was blossom-bud formation in all varieties but very slight in the case of Delicious. With 30 or more leaves per fruit there was a rapid increase in blossom-bud formation, amounting to over 90 per cent in the case of Ben Davis with 50 and 75 leaves per fruit and to 60 and 74 per cent, respectively, in the case of Grimes Golden when all of the spurs are considered. With high leaf areas even the spurs that bore fruit the previous season had a high per cent of blossom buds. In the case of Grimes Golden, treatments given as late as June 17 and 18 greatly influenced the blossom-bud formation, preventing it when the leaf area was reduced and greatly increasing it with a high leaf area.

Table 15. Effect of leaf area per apple on blossom bud formation. Bud counts made in 1926 following treatments in 1925. Branches ringed except as noted.

Variety	Date of treatment	Leaves per apple	Leaf spurs of 1925: Leaf buds 1926 No.	Leaf spurs of 1925: Blossom buds 1926 No.	Leaf spurs of 1925: Blossom buds 1926 %	Blossom spurs of 1925: Leaf buds 1926 No.	Blossom spurs of 1925: Blossom buds 1926 No.	Blossom spurs of 1925: Blossom buds 1926 %	Fruit spurs of 1925: Leaf buds 1926 No.	Fruit spurs of 1925: Blossom buds 1926 No.	Fruit spurs of 1925: Blossom buds 1926 %	All spurs of 1925: Leaf buds 1926 No.	All spurs of 1925: Blossom buds 1926 No.	All spurs of 1925: Blossom buds 1926 %
Grimes Golden	June 17 to 18	80	89	288	764	17	75	81.5	24	13	35.1	130	376	74.3
	do.	40	64	131	67.2	22	29	56.9	23	7	23.3	109	167	60.5
	do.	20	64	26	28.9	19	15	44.1	25	0	0	108	41	27.5
	do.	10	51	0	0	12	1	7.7	24	0	0	87	1	1.1
	do.	5	21	0	0	3	0	0	27	0	0	51	0	0
*	do.	56	121	12	9.0	25	2	7.4	21	0	0	167	14	7.7
*	dol	44	192	19	9.0	21	1	4.5	31	0	0	244	20	7.6
Delicious	May 8 to June 2	75	88	327	78.8	7	51	87.9	3	29	90.6	98	407	80.6
	May 9 to June 2	50	87	166	65.6	10	33	76.7	10	21	67.7	107	220	67.3
	do.	30	122	42	25.6	19	4	17.3	28	9	24.3	169	55	24.5
	May 27 to June 2	20	117	5	4.1	29	0	0	43	1	2.3	189	6	3.1
	May 29 to June 2	10	73	0	0	26	0	0	42	0	0	141	0	0
	May 29 to June 3	5	34	0	0	10	0	0	33	0	0	77	0	0
*	June 1	50	245	29	10.6	15	1	6.3	29	0	0	289	30	9.4
*	June 1	22	58	0	0	17	0	0	14	0	0	89	0	0
Ben Davis	June 3	75	6	243	97.6	0	29	100	0	24	100	6	292	98.0
	June 4	50	10	150	93.8	0	7	100	2	27	93.0	12	184	93.9
	June 4	30	26	47	64.4	4	3	42.8	15	9	37.5	45	59	56.7
	June 4	20	56	13	18.8	8	3	27.3	21	1	4.5	85	17	16.7
	June 5	10	39	0	0	1	0	0	22	0	0	62	0	0
	June 5	5	29	0	0	8	0	0	26	0	0	63	0	0
*	June 5	42	127	97	43.3	9	7	43.8	34	5	12.8	170	109	39.1
*	June 5	26	76	5	6.2	32	1	3.0	26	0	0	134	6	4.3
*	June 5	17	13	0	0	12	1	7.7	24	0	0	49	1	2.0
*	June 5	12	6	0	0	1	0	0	11	0	0	18	0	0

* On unringed branches.

Table 16. Effect of leaf area per apple on fruit bud formation.
Bud counts made in 1927 following treatments in 1926.
Branches ringed except as noted.

Variety	Date of treatment	Leaves per apple	Leaf spurs of 1926: Leaf buds 1927 No.	Leaf spurs of 1926: Blossom buds 1927 No.	Leaf spurs of 1926: Blossom buds 1927 %	Blossom spurs of 1926: Leaf buds 1927 No.	Blossom spurs of 1926: Blossom buds 1927 No.	Blossom spurs of 1926: Blossom buds 1927 %	Fruit spurs of 1926: Leaf buds 1927 No.	Fruit spurs of 1926: Blossom buds 1927 No.	Fruit spurs of 1926: Blossom buds 1927 %	All spurs of 1926: Leaf buds 1927 No.	All spurs of 1926: Blossom buds 1927 No.	All spurs of 1926: Blossom buds 1927 %
Ben Davis:	May 15	75	0	109	100	0	72	100	0	10	100	0	191	100
	May 17	50	2	102	98.1	2	39	95.1	1	14	93.3	5	155	96.9
	May 18	30	17	77	81.9	5	20	80.0	5	11	68.7	27	108	80.0
	May 18	20	49	35	41.7	24	10	29.4	14	8	36.4	87	53	37.9
	May 19	10	39	1	2.5	24	1	4.0	20	1	4.8	83	3	3.5
	May 19	5		0	0	16	0	0	15	0	0	38	0	0
	June 24	75	38	40	51.3	9	50	84.7	5	5	50.0	52	95	64.6
	June 24	50	24	17	41.5	7	27	79.4	6	1	14.3	37	45	54.9
	June 25	30	16	14	46.7	15	8	34.8	10	0	0	41	22	34.9
	June 25	20	37	0	0	22	4	15.4	10	0	0	69	4	5.5
	June 25	10	24	0	0	6	0	0	8	0	0	38	0	0
	June 25	5	5	0	0	20	0	0	12	0	0	37	0	0
	* May 19	50	145	9	5.8	102	17	14.3	27	1	3.6	274	27	9.0
	* May 19	25	30	0	0	61	0	0	15	0	0	114	0	0
	* May 19	6	24	0	0	30	0	0	56	0	0	110	0	0
	* June 25	51	39	0	0	39	0	0	13	0	0	91	0	0
	* June 25	30	59	0	0	42	0	0	20	0	0	121	0	0
	* June 25	20	22	0	0	64	0	0	22	0	0	108	0	0
	* June 25	10	26	0	0	9	0	0	24	0	0	59	0	0
	* June 25	0	50	0	0	17	0	0	19	0	0	86	0	0
York Imperial	May 27 to 28	75	47	363	88.5	5	71	93.4	11	6	35.3	63	440	87.5
	May 28	50	92	134	59.3	12	59	83.1	8	5	38.5	112	198	63.9
	May 28 to 29	30	110	28	20.3	50	30	37.5	13	2	13.3	173	60	25.8
	May 29	20	75	0	0	72	0	0	25	0	0	172	0	0
	May 29	10	66	0	0	38	0	0	23	0	0	127	0	0
	" to June 1	5	66	0	0	62	0	0	19	0	0	147	0	0
	* June 3	50		0	0		0	0		0	0		0	0
	* June 3	30		0	0		0	0		0	0		0	0
	* June 3	20 & 10	0	0	0		0	0		0	0		0	0

*On unringed branches

Table 17. Effect of leaf area per apple on fruit bud formation. Bud counts made in 1928 following treatments in 1927. Branches ringed except as noted.

Variety	Date of treatment 1927	Leaves per apple	Leaf spurs of 1927: Leaf buds 1928 No.	Leaf spurs of 1927: Blossom buds 1928 No.	Leaf spurs of 1927: Blossom buds 1928 %	Blossom spurs of 1927: Leaf buds 1928 No.	Blossom spurs of 1927: Blossom buds 1928 No.	Blossom spurs of 1927: Blossom buds 1928 %	Fruit spurs of 1927: Leaf buds 1928 No.	Fruit spurs of 1927: Blossom buds 1928 No.	Fruit spurs of 1927: Blossom buds 1928 %	All spurs of 1927: Leaf buds 1928 No.	All spurs of 1927: Blossom buds 1928 No.	All spurs of 1927: Blossom buds 1928 %
Jonathan	June 20 to 22	75	1	260	99.6	0	190	100	0	20	100	1	470	99.8
	June 21 to 22	50	0	143	100	1	116	99.1	1	20	95.2	2	279	99.7
	June 21 to 22	30	5	75	93.7	7	100	9355	11	15	57.7	23	190	89.2
	June 21 to 22	20	49	27	35.5	31	26	45.6	22	1	4.3	102	54	34.6
	June 22 to 23	10	75	0	0	76	0	0	14	0	0	165	0	0
	June 23 to 24	5	84	0	0	52	0	0	23	0	0	159	0	0
	June 24	0	54	0	0	72	0	0	20	0	0	146	0	0
	* June 25	50	14	22	61.1	16	29	64.4	7	1	12.5	52	37	41.6
	* June 25	30	13	16	55.2	31	18	36.7	16	0	0	60	34	36.2
	* June 25	10	19	0	0	53	1	1.9	13	0	0	85	1	1.2
	* June 24	0	75	0	0	156	0	0	46	0	0	277	0	0
	* June 30	0	131	0	0	110	0	0	25	0	0	266	0	0
Baldwin	June 3 to 8	75	75	126	62.7	42	19	31.1	10	2	16.7	127	147	53.6
	June 3 to 9	50	80	13	14.0	3	1	25.0	7	0	0	90	14	13.5
	June 6 to 9	30	75	26	25.7	2	0	0	8	1	11.1	85	27	24.1
	June 6 to 9	20	124c	3	2.4	23	0	0	26	0	0	173	3	1.7
	June 7 to 9	10	55	0	0	29	0	0	25	0	0	109	0	0
	June 7 to 9	5	29	0	0	15	0	0	24	0	0	67	0	0
	* June 7	**		0	0		0	0		0	0		0	0
	* June 7	50	7	0	0	13	0	0	37	0	0	57	0	0
	* June 7	8	18	0	0	0	0	0	11	0	0	29	0	0
	* June 7	0	27	0	0	0	0	0	40	0	0	67	0	0
	* June 7	0	34	0	0	0	0	0	29	0	0	63	0	0

* On unringed branches ** All of apples removed

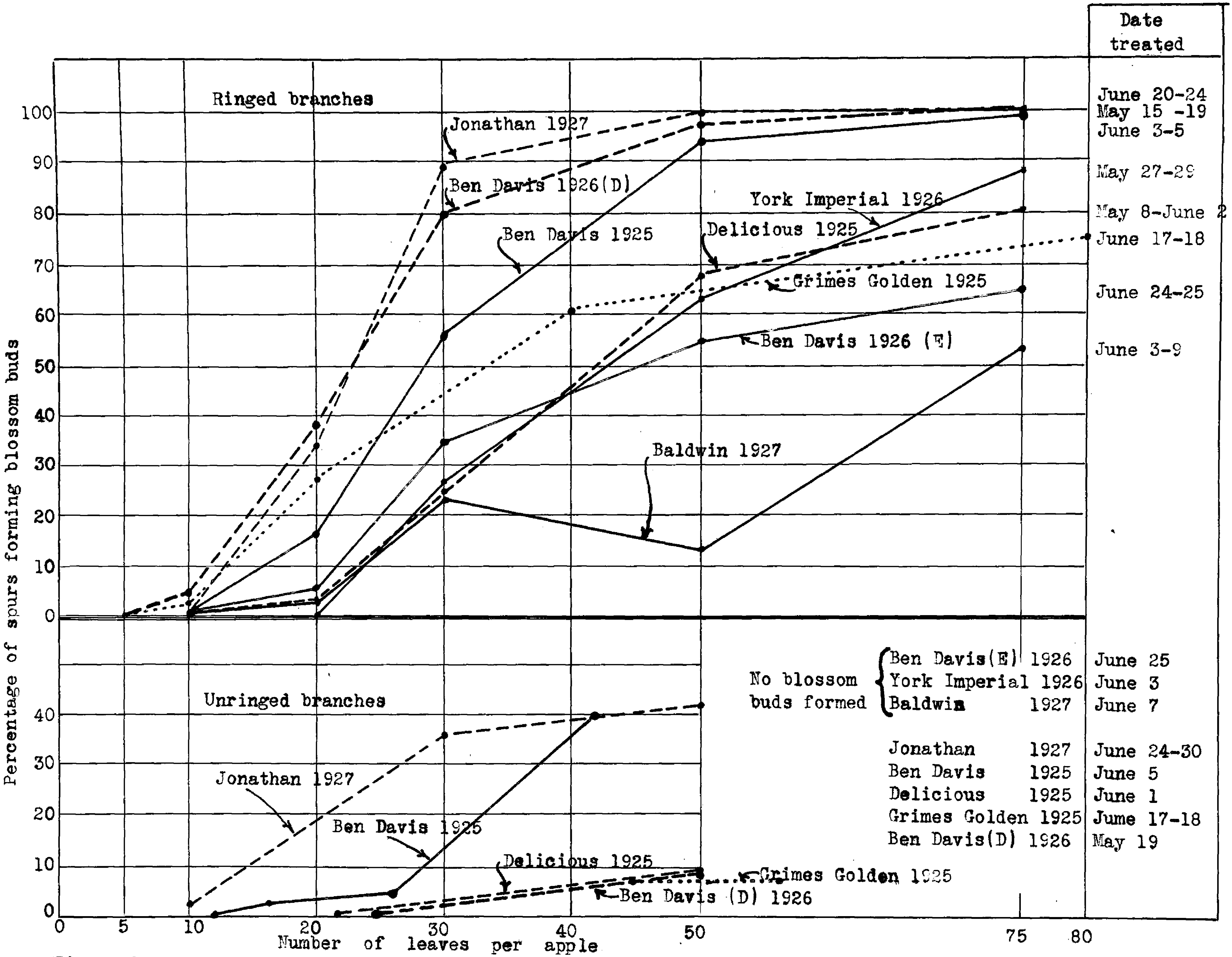

Figure 8. Effect of leaf area per apple on blossom bud formation.

On unringed branches, in the case of Grimes Golden, there was no significant difference in blossom-bud formation between the branch with 44 leaves per fruit and the one with 56 leaves per fruit. In both cases about 7.5 per cent of all spurs formed blossom buds. This represents approximately the performance of the tree as a whole. In the case of Delicious the heavily loaded branch with 22 leave per fruit failed to form blossom buds, while the branch with a light crop (50 leaves per fruit) formed blossom buds on over 9 per cent of its spurs. With Ben Davis there were four unringed branches used. On the heavily loaded branches with 12 and 17 leaves per fruit there were practically no blossom buds formed; with 26 leaves per fruit 4.3 per cent of the spurs produced blossom buds, whereas with 42 leaves 39 per cent of the spurs formed blossom buds.

In 1926 two varieties were used, the Ben Davis which is normally regular in bearing but in this case was bearing biennially, and York Imperial which tends to bear alternately and was doing so in this case. One Ben Davis tree was treated between May 15 and 19 and another was treated June 24 and 25. When bud counts were made in 1927 there were no fruit buds on either the York Imperial or the Ben Davis trees except on some of the branches which were treated, as recorded in Table 16.

On the Ben Davis branches which were ringed blossom buds were formed with 20 or more leaves per fruit on the tree that was treated June 24 and 25 and with 10 or more leaves on the tree treated May 15 to 19 (table 16). In all cases the tree treated in May had a higher percentage of blossom buds with the same number of leaves per apple than the one treated in late June. In the case of the tree treated in May all of the spurs formed blossom buds and even some axillary blossom buds were formed when there were 75 leaves per fruit.

No fruit buds were formed on unringed branches except on the branch with 50 leaves per apple on the tree treated in May. The number of leaves per apple on this branch previous to the start of the experiment in May was not determined but it was probably above the average for the tree as a whole.

With York Imperial treated the last of May, 30 leaves per apple were necessary for the formation of blossom buds on ringed branches whereas on unringed branches no blossom buds were formed even with 50 leaves per fruit.

In 1927 two varieties were used, the Jonathan which was bearing regularly, and the Baldwin, which tends to bear alternately and was doing so in this case.

With Jonathan (table 17) on ringed branches 10 or less leaves per apple were not sufficient for blossom-bud formation whereas 20 leaves caused over a third of the spurs to form blossom buds. With 50 or 75 leaves practically all spurs formed blossom buds, and many axillary buds on growth of the of the current season formed flower parts even though the treatments were made as late as June 20 to 24.

On unringed branches practically no blossom buds were formed with 10 or less leaves per fruit, whereas with 30 and 50 leaves 36 and 41 per cent of the spurs formed blossom buds. The latter two branches had 33 and 26 leaves per fruit, respectively, previous to the start of the experiment.

In the case of Baldwin (table 17) on ringed branches practically no blossom-bud formation occurred with 20 or less leaves per apple. Even with 75 leaves per apple only slightly more than 50 per cent of the spurs formed blossom buds. No blossom buds were formed on any of the branches that were not ringed, even though all of the fruit was removed from one of the branches. This branch was over 3 inches in diameter at the base and about 25 feet long, so that it was thought that it would act more or less independently of the rest of the tree.

It is of particular interest to note that in the case of the two varieties, York Imperial and Baldwin, which tend to bear alternately, practically no blossom-bud formation occurred with 20 leaves per fruit on ringed branches whereas with Jonathan, Ben Davis and Grimes Golden, which are normally annual bearers, fairly good blossom-bud formation occurred with 20 leaves. Blossom-bud formation in Delicious, which tends to bear alternately but not to as great an extent as York Imperial and Baldwin, was low with 20 leaves per apple. This would seem to indicate that varieties which tend to bear alternately require a higher leaf area per apple for the development of blossom buds.

While analyses of the spurs were not made the analyses of the fruit should be to some extent an index to the concentration of sugars in the spurs. The concentration of sugars in the spurs would be expected to be proportional to that in the fruit. In this connection it is of interest to note (table 4) that the concentration of total sugars in apples on unringed branches which failed to form blossom buds was lower than the concentration of sugars in fruit on ringed branches which formed blossom buds. In the case of Baldwin, for example, 30 leaves per apple on ringed branches were required to form blossom buds and the fruit had a total sugar concentration of 12.8 per cent; fruit on the unringed branches had a sugar concentration of only 10 to 11 per cent and failed to form blossom buds. Similarly, York Imperial formed blossom buds on ringed branches with 30 leaves per fruit with a total sugar concentration of 12.7 per cent in the fruit; no blossom buds were formed on the unringed branches and the total sugar concentration in the fruit was in all cases less than 12 per cent. In the case of Jonathan, blossom buds were formed on ringed branches with 20 leaves per fruit and a sugar concentration of 11.6 per cent. On the unringed branches, blossom buds were formed to practically the same extent on the two branches in which the fruit had a sugar concentration of 11.6 and 11.8 per cent, but not on the two branches in which the sugar concentration of the fruit was less than 11.6 per cent. A similar relation obtained in the other varieties studied.

Discussion

It is recognized in this work that the results obtained on ringed branches can not be applied directly to the tree as a whole as the physiological responses of ringed branches are affected by the ring. Thus carbohydrates elaborated above the ring must be used or stored there and can not be translocated to other parts of the tree. It is also probable that nitrogen and possibly other mineral nutrients are not translocated past the ring. It is possible therefore that the proper carbohydrate nitrogen ratio for fruit-bud formation may have been brought about on ringed branches by a reduction in nitrogen as well as an abnormal accumulation of carbohydrates. It has been pointed out previously, however, that the tree as a whole probably would respond to a given treatment more nearly like the respomses obtained from ringed branches than from branches that were not ringed, except that a considerably higher leaf area per fruit on the tree as a whole would be required to bring about the same response as obtained by a given leaf area on ringed branches.

It has been recognized that blossom thinning may influence fruit-bud formation but there has been little previous evidence to show that thinning of the fruit later in the season would effect fruit-bud differentiation. Paddock and Charles (44) conclude from shading experiments that fruit buds are differentiated previous to the time indicated by microscopical examination and that treatments following blossoming have no effect on differentiation except on secondary growth. The data presented in this paper conclusively show that treatments even as late as the middle of June if sufficiently severe may inhibit or greatly increase fruit-bud differentiation in the apple.

While on ringed branches 20 to 30 leaves per apple depending on the variety and time of treatment brought about sufficient fruit-bud formation for a fair crop of fruit the following year it would undoubtedly require a much larger number of leaves per fruit on normal trees to have an equal effect. In this connection it is interesting to note that at least 20 to 30 leaves per fruit were necessary to produce apples of reasonably good size and quality.

In most thinning experiments the objective has been to increase the size of the fruit without materially decreasing the total yield of the tree. It is improbable that any benefit can be obtained by the tree from thinning which does not materially reduce the total crop of fruit. In most cases, however, thinning experiments have resulted in more or less reduction in total crop. The maximum distance between fruit has usually been not more than 10 to 12 inches. This probably would not give as many leaves per apple as seem to be necessary for the formation of fruit buds as well as the growth of the fruit of varieties markedly biennial in habit.

It is not claimed from the evidence presented that a biennially bearing tree can be brought into annual bearing by thinning. The evidence strongly indicates, however, that thinning of the fruit may be an important factor in maintaining trees in regular annual bearing. It also indicates that severe thinning to reduce the fruit crop as well as pruning and fertilizing to stimulate growth and leaf area should be resorted to in any effort to change biennial trees into annual bearers. The results further indicate that more severe thinning than is commercially practiced might be profitable if it results in annual bearing as well as superior size and quality of fruit.

Summary and Conclusions

Bud counts were made on both ringed and unringed branches on which fruit was grown with varying numbers of leaves per fruit.

From the evidence presented the following conclusions seem justified:

1. With a low leaf area per fruit most of the synthesized food materials are used by the fruit and no fruit-bud formation takes place.

2. On ringed branches 20 to 30 leaves per fruit depending on the variety, are necessary for fairly good fruit-bud formation

3. Fruit-bud differentiation can be influenced as late as the middle of June and probably later.

General Summary and Conclusions

Apples were grown on both ringed and unringed branches with different leaf areas per apple and with a given leaf area at different distances from the fruit. Growth measurements were made of the fruit during the growing season and the chemical composition was determined following harvest. Bud differentiation was determined on the branches with the different leaf areas per apple.

The data obtained showed that with a low leaf area per fruit most of the material elaborated in the leaves seemed to be utilized in the growth of the fruit. With an increased leaf area a larger proportion of the material is used by other parts of the tree and with a high leaf area per apple on ringed branches there was apparently a reduction in the efficiency of the leaves. The size, dry weight, sugar content, dessert quality and amount of blush color of the apples increased with an increase in leaf area. About 20 to 30 fully developed leaves or 40 to 60 square inches of leaf area per apple, depending on the variety and seasonal conditions, was necessary to supply sufficient synthesized food to develop a good commercial sized apple with good dessert quality. On ringed branches this amount of leaf area was sufficient to bring about blossom-bud formation as well as to develop the fruit.

While the fruit requires a rather large leaf area for full development the leaves need not be close to the fruit but may be at considerable distance away and either above or below the fruit or on adjacent branches without hindering the translocation of the elaborated food to the fruit. The maximum distance that elaborated foods may be translocated to fruit was not determined even though distances of 10 to 15 feet between the fruit and the nearest leaves were used in the experiment. That these distances were becoming limiting factors, however, was indicated by a slight reduction in the size of the apples in the varieties where these distances were used

On ringed branches a low leaf area per apple inhibited blossom-bud formation while a high leaf area per apple caused most of the spurs to form blossom buds. Blossom-bud formation on ringed branches was associated with a relatively high sugar content in the apples on the branch. Bud differentiation on ringed branches was greatly influenced by thinning treatments applied as late as June 25. These results indicate that regularity of bearing in apples might be influenced by thinning the fruit.

Literature Cited

1. Asami, Yoshichi and Chang Chih Hu
1928 Correlation between size of fruit and some characters in the Japanese pear. Jour. Sci. Agr. Soc. (Japan) No. 303. Feb.

2. Auchter, E. C.
1917 Five years investigation in apple thinning. W. Va. Agr. Expr. Sta. Bul. 162.

3. ____________
1920 Some influences of thinning, pollination and fruit spur growth on the yearly performance record of fruit spurs and on the size of fruit produced. Proc. Am. Soc. Hort. Sci. 16: 118-131, 1919.

4. ____________
1923 Is there normally a cross transfer of foods, water and mineral nutrients in woody plants? Md. Agr. Expt. Sta. Bul. 257.

5. ____________ and Schraeder, A. L.
1924 Fruit spur growth and fruit bud production in the apple. Proc. Am. Soc. Hort. Sci. 20: 127-144, 1923.

6. ____________ and Whitehouse, W. E.
1926 Unpublished data. Md. Expt. Sta.

7. ____________, Schraeder, A. L., Lagasse, F. S. and Aldrich, W.W.
1927 The effect of shade on the growth, fruit-bud formation and chemical composition of apple trees. Proc. Am. Soc. Hort. Sci.23: 368-382, 1926.

8. Bailey, J. S.
1929 The effect of apple blossom removal on flower-bud formation. Proc. Am. Soc. Hort. Sci. 25: 198-201, 1928

9. Beach, S. A.
1903 Thinning apples. N.Y. (Geneva) Agr. Expt. Sta. Bul. 239.

10. Bidwell, G. L. and Sterling, W. F.
1925 Preliminary note on the direct determination of moisture. Jour. Ind. & Eng. Chem, 17 (2) 147-149.

11. Bradford, F. C.
1915 The pollination of pomaceous fruits. II. Fruit bud development of the apple. Ore. Agr. Expt. Sta. Bul. 129.

12. Caldwell, J. S.
1928 Chemical composition of apple juices as affected by climatic conditions. Jour. Agr. Res. 36: 289-365.

13. Chandler, W. H. and Heinicke, A. J.
1927 The effect of fruiting on the growth of Oldenburg apple trees. Proc. Am. Soc. Hort. Sci. 23: 36-46, 1926.

14. Coit, I. E.
1918 Effect of adjacent leaf area on the sugar content of oranges. Proc. Am. Soc. Hort. Sci. 14: 92-3, 1917.

15. Crow, J. W.
1921 Biennial fruit bearing in the apple. Proc. Am. Soc. Hort. Sci. 17: 52-54, 1920.

16. Curtis, O. F.
1920 The upward translocation of foods in woody plants. Part I. Am. Jour. Bot. 7: 101-124.

17. ______________
1923 The effect of ringing a stem on the upward transfer of nitrogen and ash constituents. Am. Jour. Bot. 10: 361-382.

18. ______________
1925 Studies on the tissues concerned in the transfer of solutes in plants. The effect on the upward transfer of solutes of cutting the xylem as compared with that of cutting the phloem. Ann. Bot. 39: 573-585.

19. Dixon, H. H.
1922 Transport of carbohydrates in plants. Nature 110: 547-551.

20. Drain, B. D.
1925 Annual crops from biennial bearing apple trees. Proc. Am. Soc. Hort. Sci. 21: 300-2, 1924.

21. Drinkard, A. W.
1911 Fruit bud formation and development. Va. Agr. Expt. Sta. Rept. (1909-10): 159-205.

22. Fletcher, L. A.
1930 A preliminary study of the factors affecting the red color on apples. Proc. Am. Soc. Hort. Sci. 26: 191-196, 1929.

23. Gardner, F. E.
1925 A study of the conductive tissue in shoots of the Bartlett pear and the relation of food movement to dominance of the apical bud. Calif. Expt. Sta. Tech. Paper 20.

24. Goff, E. S.
1901 Investigation of flower buds. Wis. Agr. Expt. Sta. Rept. 18: 304-16.

25. Gourley, J. H.
1915 Studies in fruit bud formation. N. H. Agr. Expt. Sta. Tech. Bul. 9.

26. Gourley, J. H. and Nightingale, G. T.
1921 The effects of shading some horticultural plants.
N. H. Agr. Expt. Sta. Tech. Bul. 18.

27. Haller, M. H. and Magness, J. R.
1926 The relation of leaf area to the growth and composition of apples.
Proc. Am. Soc. Hort. Sci. 22: 189-196, 1925.

28. Harley, C.P.
1926 Normal variation in the chemical composition of fruit spurs and the relation of composition to fruit bud formation.
Proc. Am. Soc. Hort. Sci. 22: 134-146, 1925.

29. Harvey, E. M. and Murneek, A. E.
1921 Relation of Carbohydrates and nitrogen to the behavior of apple spurs
Ore. Agr. Expt. Sta. Bul. 176.

30. Hooker, H. D.
1920 Seasonal changes in the chemical composition of apple spurs.
Mo. Expt. Sta. Res. Bul. 40.

31. __________ and Bradford, F. C.
1921 Localization of factors determining fruit bud formation.
Mo. Agr. Expt. Sta. Res. Bul. 47.

32. Mason, T. G. and Lewin, C.J.
1926 On the rate of carbohydrate transport in the greater yam.
Proc. Roy. Dubl. Soc. 18: 203-5.

33. __________ and Maskell, E. J.
1928 Studies on the transport of carbohydrates in the cotton plant.
Ann. Bot. 42: 571-636., and Ann. Bot. 42: 189-253.

34. Magness, J. R.
1916 The influence of summer pruning on bud development in the apple.
Ore. Agr. Expt. Sta. Bul. 139: 46-77.

35. __________
1917 Studies in fruit bud formation. Ore. Agr. Expt. Sta. Bul. 146.

36. __________, Haller, M. H. and Diehl, H. C.
1926 The ripening, storage and handling of apples.
U. S. D. A. Dept. Bul. 1406.

37. __________
1929 Relation of leaf area to size and quality in apples.
Proc. Am. Soc. Hort. Sci. 25: 285-288. 1928.

38. __________
1929 Observations on color development in apples.
Proc. Am. Soc. Hort. Sci. 25: 289-292, 1928.

39. __________, and Overley, F. L.
1930 Relation of leaf area to size and quality in apples and pears.
Proc. Am. Soc. Hort. Sci. 26: 160-162, 1929.

40. Morris, O. M.
1921 Studies in apple pollenation.
Wash. Agr. Expt. Sta. Bul. 163.

41. Murneek, A. E.
1926 Effects of correlation between vegetative and reproductive functions in the tomato.
Plant Phys. 1:1:3-56.

42. ___________
1926. Is fruiting of the apple an exhaustive process?
Proc. Am. Soc. Hort. Sci. 22: 196-200. 1925.

43. ___________
1928 Nitrogen and carbohydrate distribution in organs of the bearing apple spur.
Mo. Agr. Expt. Sta. Res. Bul. 119.

44. Paddock, W. and Charles, F. G.
1929 The effect of shade upon fruit bud differentiation.
Proc. Am. Soc. Hort. Sci. 25: 195-197, 1928.

45. Rasmussen, E. J.
1930 The period of blossom bud differentiation in the Baldwin and McIntosh apples.
Proc. Am. Soc. Hort. Sci. 26: 255-260, 1929.

46. Roberts, R. H.
1923 Effect of defoliation upon blossom bud formation.
Wis. Agr. Expt. Sta. Res. Bul. 56.

47. Thompson, R. C.
1916 Relation of fruit growing to soil fertility.
Ark. Agr. Expt. Sta. Bul. 123.

48. Tufts, W. P. and Morrow, E. B.
1925 Fruit bud differentiation in decidious fruits.
Calif. Agr. Expt. Sta. Res. Bul. 56.

49. Whitehouse, W. E.
1916 A study of variation in apples during the growing season.
Ore. Agr. Expt. Sta. Bul. 134.

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