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Pruning Investigations: Second Report

BY

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STUDIES IN FRUIT-BUD FORMATION

BY J. R. MAGNESS

INTRODUCTION

Studies carried on at the Oregon Experiment Station in connection with summer pruning of young apple trees and reported in a former publication (1) revealed the fact that under conditions in the station orchard, an early summer heading-back tends greatly to reduce the number of fruit buds formed on the one-year wood. Little influence of the pruning, however, could be detected in the formation of fruit buds on spurs away from the immediate region of the pruning cuts. Not only were buds on spurs not affected, but individual shoots which were not headed-back in these trees seemed to function exactly as though no pruning at all had been given the tree.

From these studies, it appeared that the influence of the pruning was very much localized, and only the buds in close proximity to the pruning cut were affected in any way. At that time, no attempt was made to explain these results, but experiments were planned to throw more light upon the conditions associated with fruit bud formation, and to determine the influence of summer pruning upon these conditions.

OBJECT

Since most of the carbohydrate food material used in the growth of the tree and the development of the buds is synthesised in the leaves, it was planned to determine the influence of the leaf area upon bud development. It is very important, from the pruning standpoint, to know just what the influence of the leaves upon the function of the tree is, since pruning of any kind, whether it be summer or winter, affects the actual or potential leaf area. Summer pruning directly reduces the leaf area, by removing some of the leaves and oftentimes changes the amount of food that is manufactured in those that are left, through changing the amount of light available. Winter pruning reduces the potential area by removing buds that would otherwise open as leaf clusters when growth starts the following spring.

Since summer pruning reduces the leaf area, it was decided to determine whether or not the reduction in leaf area following summer pruning is the principle cause of the influence exerted by the pruning. Further, since the effect of the pruning upon fruit bud formation appears to be very much localized, it was planned to determine whether or not the influence of leaf area through the organic foods manufactured in the leaves, is exerted mainly upon buds in the immediate vicinity of these leaves.

Briefly, the questions to be answered might be summed up as follows:

1. To what extent is fruit-bud formation dependent upon leaf area, through the organic foods manufactured in the leaves?

2. If fruit-bud formation is dependent upon leaf area, to what extent do the leaves in any one portion of the tree nourish the buds of that

(1). Pruning Investigations, Ore. Exp. Sta. Bulletin, No. 139, "The Influence of Summer Pruning Upon Bud Development in the Apple."

portion, and to what extent can the buds draw upon food materials manufactured in leaves on other parts of the trees? Is a bud on a spur dependent upon the leaves on that spur for nourishment? To what extent is a bud on the one-year wood dependent upon the leaf immediately subtending it?

3. What is the influence of leaf area on the development of spurs from axillary leaf buds? Does the leaf area of one year have any influence upon the development of these buds the next year?

METHODS AND MATERIALS

The trees used in this work were six years old, dwarfed on Paradise stock; the same block used in the summer-pruning investigation mentioned above. Most of the varieties are in quite heavy bearing. During the winter preceding the work on these trees, some of them received very severe injury to their trunks. This injury was in the nature of a girdling, the bark being killed all or part way around. In a few instances, this injury was severe enough to kill the trees, while in other cases, the injury was such as seriously to interfere with the normal flow of material through the bark, but not severe enough to kill the trees. Some of the trees upon which work was started in the early summer, later proved to be so severely injured that it was necessary to discard them.

The influence of the leaves upon bud functioning was determined entirely through the removal of leaves, and by comparing the results, thus obtained, with those obtained on check trees which received no defoliation.

Unless otherwise noted, all leaves were removed from June 26 to 28. Fruit-bud differentiation in the trees used first begins about the last of June. Fruit buds on spurs under conditions here are first initiated mainly during July and early August, while those on the one-year wood first show flower parts mainly during August and September. The defoliation, therefore, was given just prior to the beginning of fruit-bud differentiation.

A number of different types of defoliation were practised. They may be outlined as follows:

1. **Bulk Defoliation.** This consisted in removing all the leaves from large portions of the trees. Three varieties, Lady, Monmouth, and Jonathan, were treated. One tree of each variety had all the leaves removed; another had all leaves removed from the spurs, or growths of less than four inches, while leaves on current season growths of more than four inches were left; a third had all leaves removed from growth of the current season of more than four inches length, those on spurs not being removed; a fourth tree was left with no defoliation, to serve as a check.

Trees of other varieties, including Grimes, Ortley, and Glowing Coal had all the leaves removed from half the main scaffold limbs, while the remaining scaffold limbs had no leaves removed. The Ortley tree had all leaves removed from the north half, the Glowing Coal from the south half; one Grimes from the west half, and another from the southwest half. An entirely undefoliated tree in each case served as a check for the variety. The leaves were stripped from the branches, care being taken not to break or tear the buds.

2. **Defoliation as Pruned.** Since it was thought that the influence of summer pruning might be due very largely to the leaves removed through the pruning, it was determined to remove the same amount of leaf area from a number of trees that would be removed by pruning, but to do no actual pruning. Three trees of each of the following varieties were used: Alexander, Fameuse, Yellow Bellflower, Early Harvest, Cox Orange, Waxen, Winesap, and Rhode Island. From one tree of each of these varieties, leaves were removed from the terminal half to two-thirds of the current season's shoots. The defoliation corresponded to a heavy summer heading back. Another tree of each variety had the leaves removed from the terminal one-fourth to one-third portion of the shoot growth, corresponding to a light heading back. The third tree in each case served as a check, receiving no treatment. Leaves developed on the growth made following the defoliation were not removed as they correspond more or less to leaves on secondary growth made following summer pruning, so far as amount and position of elaborated food is concerned.

3. **Thinning by Defoliation.** Two trees of one variety, Babbitt, had all the leaves removed from certain of the current season shoots, no other leaves being removed. A third tree served as a check, no defoliation being given.

4. **Individual Spur Defoliation.** On trees of two varieties, White Pearmain and Keswick, individual spurs were defoliated at various times throughout the summer, and marked with tags bearing the date of their defoliation. Some were defoliated on June 19, June 24, July 3, July 19, and on August 18. A number of the buds from each of the different lots were collected at various times for microscopic examination, but a number were left, and their blossom records were secured the following spring.

5. **Removal of Leaves from Individual Axillary Buds.** Scattered axilliary buds of two Wagener trees were defoliated at intervals during the summer, and the buds marked with tags. Some of these buds were toward the base of the season's growth, though most of them were out toward the terminal portion. Since it was desired that these buds be not injured in any way, the leaves were removed by pinching through the petioles rather than by stripping. Leaves were removed June 28, July 19, and August 18. Care was taken that the leaves removed at successive dates were not from the same shoots, so that there was never more than a very small percentage of the leaf area removed from any one shoot, or from the whole tree.

MICROSCOPIC STUDY OF BUDS

Not only was it planned to study the gross effects of the defoliation upon bud response, but it was intended also to study microscopically the development of the buds, to see what changes were brought about within them. Consequently at the time of defoliation and at intervals of two weeks to a month following until September, collections of buds on spurs and axillary buds from trees treated in different ways were made. Lady and Grimes buds from the bulk defoliated trees, Alexander and Yellow Bellflower buds from those varieties defoliated as pruned, buds from spurs of Keswick and White Pearmain, and axillary buds from Wagener were gathered. In selecting these buds for special study, care was taken that on each date, normally developed buds of the variety were taken for comparison with those of the same variety that had been given the various special treatments. These buds were killed and fixed in the field in corrosive sublimate (Gilson's mixture) imbedded in celloidin, stained in Delafield's Haematoxylin and mounted in Canada Balsam.

THE INFLUENCE OF BULK DEFOLIATION UPON BUD DEVELOPMENT

The respose from bulk defoliation varied somewhat markedly with the variety, but from the average results obtained, it is apparent that fruit-bud formation will generally not occur unless leaves are present in that part of the tree in which the buds are found. Table I shows the results of this type of treatment.

TABLE I. FRUIT-BUD FORMATION FOLLOWING DEFOLIATION TREATMENT

Variety*	Treatment	Spurs	Fruit Buds Formed Axillary	Term	Total
Jonathan	No Defoliation	191	238	30	459
Jonathan	Current Growth Defoliated	8	0	9	17
Jonathan	Spurs Defoliated	10	9	4	104
Jonathan	Entirely Defoliated	0	0	0	0
Monmouth	No Defoliation	73	11	102	186
Monmouth	Current Growth Defoliated	100	0	2	102
Monmouth	Spurs Defoliated	68	5	135	208
Monmouth	Entirely Defoliated	32	2	21	55
Grimes	Half of tree Defoliated				
	(a)—Defoliated Half	0	0	0	0
	(b)—Not Defoliated Half	19	27	50	96
Ortley	Half of tree Defoliated				
Grimes	No Defoliation	120	194	174	488
	(a)—Defoliated Half	0	0	0	0
	(b)—Not Defoliated Half	25	0	12	37
Ortley	No Defoliation	168	0	8	176
Grimes	Half of tree Defoliated				
	(a)—Defoliated Half	0	0	0	0
	(b)—Not Defoliated Half	31	0	25	51
Grimes	No Defoliation	25	1	51	77
Glowing Coal	Half of tree Defoliated (Bad winter injury on trunk)				
	(a)—Defoliated Half	158	35	4	197
	(b)—Not Defoliated Half	277	323	38	638

*No trees of Lady produced blossom buds, so this variety is not included in the table.

From the figures in Table I, it is apparent that there is considerable variation between the response of several varieties. A study of the trees as they occur in the field, however, shows a much greater uniformity than is evident from the figures given, a uniformity that warrants a brief discussion of the several varieties and their response.

1. **Jonathan.** Entire defoliation prevented the formation of any fruit buds in any position. Very few fruit buds were formed, even on spurs, in the tree having leaves removed from the current growth. Examination showed, however, that there were relatively few spurs developed on this tree, and consequently that the defoliation removed most of the leaves from the tree. In the case of the tree given the spur defoliation, most of the spur buds remained as leaf buds, while

buds on one-year wood tended to form flower parts to as great an extent as is normal for the variety. A few spurs formed flower clusters, which were small and very late in opening in the spring. The check tree, receiving no treatment, developed an unusually large number of fruit buds for a tree of its size, being a mass of blossoms when they opened.

2. **Monmouth.** This variety proved to be the least responsive to defoliation of any used in the experiment. The tree which was entirely defoliated developed a number of fruit buds. The buds on this tree, however, were much slower to open in the spring than were those on other trees. Whether these buds were differentiated early, before defoliation, and developed slowly, or whether they were formed late, after the leaves had pushed out again, could not be determined, as no buds of this variety were sectioned.

Quite a large number of spurs in the trees in which the spurs were defoliated formed fruit buds. The fruit-bud formation on the one-year wood was as great in this tree as in the same position on the untreated tree. Removing leaves from the one-year wood almost entirely prevented fruit-bud formation in that position. The untreated tree had a normal crop of bloom.

3. **Grimes.** Two trees of Grimes, of different sizes and with different checks, had all leaves removed from half the tree. In each case, no fruit-bud formation occurred in the defoliated parts, while the buds in the undefoliated halves formed about as many blossom clusters as were formed in half of the check trees. The same is true for Ortley, though in this variety the undefoliated half of the tree was further behind the check in number of fruit buds formed. Plate I, Fig. 1 shows one of the Grimes trees which was half defoliated, at the time of blossoming the next spring.

4. **Glowing Coal.** The response of this tree to the removal of leaves was very interesting. Winter injury had almost girdled the trunk of the tree. The undefoliated half of the tree developed a great number of fruit buds, both on spurs and on one-year wood. The defoliated portion developed quite a large number on spurs, but very few on one-year wood. The buds on the defoliated portion were weak and the flower clusters very small. The clusters in this portion of the tree contained mostly one to five weak blossoms each, while those in the undefoliated portions averaged six to eight. Plate II, Figs. 3 and 4 show representative blossom clusters from the two sides of this same tree.

One hypothesis suggests itself as a possible explanation of the behavior of this tree. It is probable that most of the buds on the spurs on this tree were differentiated before the defoliating was done. Differentiation of fruit buds on spurs normally begins in late June or early July under conditions in this orchard. But it is easily possible that conditions of nutrition caused by the injury, which is supposed to prevent elaborated foods from passing down into the roots, resulted in the initiation of flower parts in the buds at a slightly earlier date. These buds continued to develop to some extent under the conditions of malnutrition caused by removing the leaves, and pushed out as weak blossom clusters the following spring.

INFLUENCE OF REMOVING LEAVES UPON PUSHING OUT INTO GROWTH THE FOLLOWING SPRING

Most varieties showed a very marked relation between leaf area the preceding summer, and growth the following spring. In some cases the defoliated portions of the tree were slightly slower in starting. A short time following the pushing out of the leaves, marked differences could be seen, especially in the trees having one side defoliated. While leaves on the defoliated part were yellow, small and few in number, the foliage in the undefoliated portion was thicker, darker, richer, appearing practically normal.

DEFOLIATION AS PRUNED

The fruit-bud formation for the different varieties and the positions in which they were formed is shown in Table II.

TABLE II. FRUIT-BUD FORMATION FOLLOWING THE REMOVAL OF LEAVES TO THE SAME EXTENT THAT THEY WOULD BE REMOVED IN PRUNING

Variety	Treatment	Fruit Buds Formed Spurs	Axillary	Term	Total
Early Harvest	Heavy removal of leaves	5	0	1	6
Early Harvest	Light removal of leaves	159	26	7	192
Early Harvest	No removal of leaves	41	0	24	65
Cox Orange	Heavy remorval of leaves	315	1	10	326
Cox Orange	Light removal of leaves	266	0	6	272
Cox Orange	No removal of leaves	117	0	3	120
Alexander	Heavy removal of leaves	51	36	25	112
Alexander	Light removal of leaves	23	63	31	117
Alexander	No removal of leaves	5	50	39	94
Fameuse	Heavy removal of leaves	60	0	2	62
Fameuse	Light removal of leaves	37	13	5	55
Fameuse	No removal of leaves	87	31	38	156
Winesap	Heavy removal of leaves	76	2	5	83
Winesap	Light removal of leaves	157	2	4	163
Winesap	No removal of leaves	147	20	23	190
Waxen	Heavy removal of leaves	454	0	12	466
Waxen	Light removal of leaves	664	29	63	756
Waxen	No removal of leaves	218	0	68	286
Rhode Island	Heavy removal of leaves	142	0	19	161
Rhode Island	Light removal of leaves	469	4	88	561
Rhode Island	No removal of leaves	193	0	39	232
Yellow Bellflower	Heavy removal of leaves	175	22	94	291
Yellow Bellflower	Light removal of leaves	142	37	50	229
Yellow Bellflower	No removal of leaves	370	190	53	613

Considerable variation between varieties is shown in Table II, but the average tendency resulting from the treatments can best be determined from a summary of the results, as presented in Table III.

TABLE III. SUMMARY OF TABLE II. EFFECT OF REMOVAL OF LEAVES AS IN SUMMER PRUNING ON FRUIT BUD FORMATION

Type of Treatment.	No.	Buds on spurs. Total.	Per tree.	Axillary. Total.	Per tree.	Terminal. Total.	Per tree
Heavy removal of leaves	8	1311	164	61	8	168	21
Light removal of leaves	8	1921	240	174	22	254	32
No removal of leaves	8	1178	147	291	36	287	36

From Table III it appears that there was a larger average number of blossom clusters to a tree on spurs on those trees from which some leaves were removed from the one-year wood, than on the trees receiving no treatment, thus indicating that there was little, if any, influence of the defoliation on buds on spurs down in the tree. In a number of fruit buds on the one-year wood, however, there was a very marked reduction following defoliation, and especially following the removal of leaves corresponding to a heavy pruning. This was less marked in the case of terminals than in the case of axillary buds, due probably to the fact that the terminals grew out and formed quite a number of leaves soon after defoliation. The total reduction in number of fruit buds formed following a defoliation of varying severity was not far from what would be expected from an equally severe summer pruning.

Plate III, Fig. 5 shows typical shoots of Fameuse that were lightly defoliated, as they pushed out into growth the following spring. The buds in the area from which the leaves were removed were making little growth, while those formed below, from which the leaves were not removed, and those that pushed out following defoliation revealed little influence of the treatment.

The fruit buds formed on the one-year shoots in those trees from which some of the leaves were removed from each shoot were almost invariably found to be either above or below the defoliated portion of the shoot. It was very seldom that a bud from which the subtending leaf had been removed, had developed flower parts.

DEFOLIATION AND PRUNING

The two varieties, Tetofsky and Ortley, trees of which were actually pruned to remove as many leaves as were removed by defoliation, afford a comparison of the influence of summer pruning. The results of this treatment are given in Table IV.

TABLE IV. FRUIT-BUD FORMATION FOLLOWING EQUAL REMOVAL OF LEAVES THROUGH SUMMER PRUNING AND DEFOLIATION

		Fruit Bud Record		
Variety	Treatment	Spurs	Axillary	Term
Tetofsky	Pruned heavily	10	35	8
Tetofsky	Defoliated heavily	14	12	14
Tetofsky	No treatment	24	105	24
Ortley	Pruned heavily	238	0	7
Ortley	Defoliated heavily	150	0	1
Ortley	No treatment	168	0	8

Tetofsky tends to form many fruit buds on one-year wood, while Ortley forms very few. It is seen that in the Tetofsky, the number of buds formed on one-year wood is very greatly reduced both by pruning and by removing leaves. There is little apparent influence of either treatment upon buds on spurs down in the tree.

The question naturally arises in this connection, why does summer pruning tend to prevent fruit-bud formation on the one-year wood? It is probable that the influence is two fold. First, the pruning removes those leaves and buds out toward the terminal of the branch, which would be most likely to form flower parts. If the pruning is late enough in the summer so that no secondary growth is stimulated, the removal of buds most likely to form flower parts naturally reduces the number of blossom clusters formed. If secondary growth is stimulated, through pruning while the tree is still growing vigorously, this growth appears to use up most of the elaborated foods from the leaves, leaving little for bud development. Consequently, there are usually comparatively few fruit buds produced on shoots formed following a summer pruning.

THINNING BY DEFOLIATION

On two trees of one variety, Babbitt, certain of the one-year shoots had all the leaves removed, while others were not defoliated at all. This should correspond to a summer thinning of shoots so far as leaf area removed is concerned. Table V shows the fruit bud formation on the one-year wood of these trees.

TABLE V. FRUIT-BUD FORMATION ON DEFOLIATED AND UNDEFOLIATED ONE-YEAR SHOOTS

	Treatment.	No. of shoots.	Total No. Fruit Buds Formed Axillary.	Term.
Tree 1	Defoliated	24	1	18
	Not defoliated	43	28	40
Tree 2	Defoliated	39	3	29
	Not defoliated	38	52	33

Removing all the leaves almost eliminated fruit-bud formation by axillary buds along the defoliated shoots, those that were formed being near the terminal, from buds and leaves developed following the defoliation. A larger percentage of terminals were formed, due to the fact that a number of leaves formed at the terminal of each shoot following the defoliation. Those shoots that received no defoliation were apparently not influenced by the removal of leaves on adjacent shoots—at least not sufficiently to be noticeable.

Plate III, Fig. 6 shows two shoots in the same tree, the one defoliated and the other not. This photograph was taken as the shoots started into growth the following spring. It shows that the buds from which the leaves were removed are much slower to break into growth than those developed under normal conditions.

INDIVIDUAL SPUR DEFOLIATION

The results of removing leaves from individual spurs of Keswick and White Pearmain are shown in Table VI. These represent only those buds that were allowed to remain on the tree, many others being taken for microscopic study.

TABLE VI. RESULTS ATTENDING INDIVIDUAL SPUR DEFOLIATION.

Variety.	Date.	No. Def.	No. Fruit.	No. Leaf.	% Fruit.
Keswick	June 19	10	2	8	20
Keswick	June 24	16	5	11	31.2
Keswick	July 3	27	5	22	18.5
Keswick	Aug. 18	16	9	7	56.25
White Pearmain	June 19	17	8	9	47.1
White Pearmain	June 24	11	3	8	27.3
White Pearmain	July 3	22	11	11	50
White Pearmain	July 19	32	26	6	81.2

The microscopic study revealed no fruit buds of Keswick initiated before the first week in July, and very few before the middle. It would be safe to conclude, then, that the buds defoliated on or before July 3 were mostly if not entirely leaf, while those defoliated August 18 probably had flower parts formed, if they were going to form them. Grouping all defoliations on or prior to July 3, we find 22.6% of them forming flower parts as compared to 56.2% of those of August 18.

White Pearmain fruit buds are differentiated somewhat earlier than Keswick, many of them showing the beginning of flower parts by the end of June. However, if we make July 3 the division point again, we find 44% of those defoliated on or before that date developed flower parts, while 81.25% of those defoliated July 19 formed fruit buds.

Although the numbers recorded here are rather small, they are sufficient to indicate that there is a marked correlation between the leaf area possessed by a spur and the response of the buds of that spur. This is by no means absolute, and it appears that buds on spurs are less dependent upon the immediately subtending leaves than are buds on the one-year wood. It is also interesting to note that on those defoliated spurs which did develop fruit buds and especially on those which were defoliated early in the summer, the buds were markedly later in opening in the spring. This was apparently due to slow development after differentiation, rather than to a delayed formation of flower parts, for many of the buds not defoliated until late were in this same condition, especially in the White Pearmain. Plate V, Fig. 9 shows a small branch of Keswick, with one spur defoliated June 19, and remaining leaf, another defoliated August 18, showing fruit bud development, and two undefoliated spurs, both with fruit buds opening. In this case, the spur which was defoliated August 18 is about as far advanced as the average undefoliated bud. In Plate IV, Fig. 7 is shown the Keswick tree upon which this work was done.

INDIVIDUAL AXILLARY DEFOLIATION

This work was carried on entirely on Wagener trees, one of which is shown in Plate IV, Fig. 8. Buds defoliated on the different dates were watched closely to see if any differences were discernable from the outward appearance of the buds.

The leaf petioles, from which the blades had been pinched to prevent injury to the bud which might result from stripping, soon became yellow, and dropped off as they would in the fall. There was, consequently, absolutely no mechanical injury to the buds and the result obtained may best be attributed to the leaf area and its relation to food supply.

No results were apparent from an external examination until about the close of the growing season. Then it could be seen that the defoliated buds were slightly smaller than those adjacent buds on the same shoots, which had not been so treated. Under Western Oregon conditions, axillary buds of Wagener increase in size very considerably throughout the winter months. This is especially true if they are axillary fruit buds. Before growth started in the spring, a marked difference could be seen in the size of the defoliated buds, as compared to those that had received no defoliation. They had apparently made little or no growth during the winter, while those about them had increased in size very considerably. Plate V, Figs. 10 and 11 show defoliated and non-defoliated buds as they first began to swell in the spring. Fig. 10 is about natural size, and Fig. 11 is somewhat enlarged. The bud below the tag is in each case the one from which the leaf was removed.

As the buds pushed out in the spring, it became apparent that many of the buds close to those that had been defoliated had formed flower parts, but in no case, out of about 200 under observation, had a bud from below which the leaf had been removed become a fruit bud. Plate VI, Fig. 12 illustrates this condition, showing one shoot, every bud along which had become a fruit bud, with the exception of two that had been defoliated.

As growth continued and axillary leaf buds began to push out and form leaf clusters, some of the defoliated buds pushed out into weak growth, while many others remained entirely dormant, showing no signs of breaking. Plate VI, Figs. 13 and 14, shows two defoliated buds in the midst of growing leaf clusters from other axillary buds. In Fig. 13 the defoliated bud remained entirely dormant, while in Fig. 14 some weak growth pushed out. These photographs are typical of most of the buds defoliated. Some few have made a slightly stronger growth than is indicated in Fig. 14, but all are much weaker than the buds about them.

It is uncertain whether or not the same results would have been obtained with other varieties. Wagener is a variety that tends to develop large, plump axillary leaf buds, and many axillary fruit buds. Spurs also are very readily developed from these buds. It would appear, therefore, that the conditions which would prevent these buds from developing naturally would have to be as severe as for any other variety, and probably more severe than for some whose buds are inclined to develop less vigorously. That can be determined, however, only through trial.

MICROSCOPIC STUDY OF BUDS UNDER DIFFERENT DEFOLIATION TREATMENTS

A careful study of a large number of buds was made to see if anything in their internal structure or development could be discerned which is associated with the very marked influence of removing the leaves. Within a few days following removal of the leaves vegetative development seemed to be stimulated in the buds, especially those that were taken from rather a large defoliated area, as in bulk defoliation. This was especially true of buds on spurs. This growth proceeded much farther in the case of entirely defoliated trees than where even a whole side of a tree, or all the spurs were defoliated. In the case of the whole tree being defoliated, most of the spurs and some of the buds on one-year wood pushed out to the extent of forming a cluster of small leaves. Very few of the defoliated buds broke where leaves were removed from less than half the tree. No difference could be detected between the way these buds started into growth, and the way buds would normally push out following a summer pruning.

Many buds showed a slight activity in the region of the growing point, following the defoliation, but this growth never reached the extent of causing the bud to break. In many of the buds—in fact in most of those taken from trees receiving defoliation to the extent of a pruning or defoliation of individual buds—little influence of the defoliation so far as development or growth is concerned could be detected from a microscopic examination. The last buds taken for sectioning were gathered September 12, and up until that time, little or no external difference could be noted. Buds should be studied throughout the dormant season to make this study complete. An examination of various defoliated and undefoliated buds of September 12 serves to reveal the conditions on that date. Plates VIII and IX, Figs. 17, 20, 23, and 26 show buds that were defoliated June 28, while Figs. 18, 21, 24, and 27 are of buds of the same kind that were not defoliated. Figs. 16, 19, 22, and 25 are of buds of the same varieties taken June 28 and July 3, showing the conditions of these buds at time of defoliation. It will be noted that so far as axillary buds (Figs. 16 to 21) are concerned considerable development has taken place since June 28, but the defoliated buds are not far behind those that received no defoliation up to that date. Buds from spurs (Figs. 22 to 27) do not show much change since June 28, either in the defoliated or undefoliated series. Buds for these plates were selected from those that have no flower parts forming, otherwise the comparison would be of no value.

One very interesting difference that was noted throughout this study was in the number and size of calcium oxalate crystals deposited in the buds. Plates VIII and IX show this difference. Axillary buds taken from near the terminals of shoots (Figs. 16 and 19) show very few such crystals. As the season advances more and more of these crystals are deposited in the tissues of the normal bud. But it was found that in those buds which were defoliated, a very much smaller number were deposited than in the case of normal buds. A comparison of Figs. 17 and 20, and Figs. 18 and 21 illustrates this difference in axillary buds of Wagener and Yellow Bellflower that have been defoliated and those that have not. On buds taken from spurs, relatively more crystals are found from the first. Here again, however, there seems to be a relatively small increase in defoliated spurs as compared to those that received no defoliation. This is shown by a comparison of Figs. 22 and 25, Figs. 23 and 26, and Figs. 24 and 27, the first representing Lady and Grimes at the time the defoliation was done, June 28; the second representing buds from defoliated areas taken September 12; and the third, undefoliated buds of September 12.

The exact conditions under which calcium oxalate crystals are formed in plant tissue is a question more or less unsettled at the present time, but it appears to be associated with the synthesis, transportation and assimilation of various plant foods, especially carbohydrates. Duggar (1) states: "Oxalic acid is of widespread occurrence, and it is most familiar (in the form of calcium oxalate) as the raphides or needle shaped crystals so common in many vegetative organs. The production of acids is usually favored by the abundance of soluble carbohydrates in the tissues." Omar (2) while reaching the conclusion that the formation of calcium oxalate is for the elimination of superfluous calcium and oxalic acid, and not directly connected with physiological processes,

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(1) Duggar, B M. Plant Physiology. p. 262.

(2) Omar, Maxime Theses presentees a la Faculte des Sciences de Faris—Sur le Role de l'oxalate de calcium dans la nutrition des Vegetaux.

found that the crystals are precipitated along the course of the elaborated sap flow. The farther the tissue is removed from the source of the origin of the elaborated food, the fewer crystals are formed.

Since, therefore, it is probable that the formation of these crystals is associated with the soluble carbohydrate supply and assimilation in the plant tissues, the fact that buds with the leaves removed form very few such crystals indicates that the removal of leaves cuts down very much on the food supply available to those buds. This would be expected in the case of the defoliation of a whole tree, but Figs. 16 to 18 show it to be true of buds of certain varieties at least, when only a very few leaves, immediately subtending the buds, are removed.

While no chemical tests to determine food storage in and about the buds have been carried on, the most likely explanation of the whole influence of the leaf area upon the buds seems to lie in the question of supply and storage of carbohydrate food in the bud. If this is true, the response of buds to defoliation indicates that each portion of a tree is quite largely independent of the rest of the tree, and quite dependent upon its own leaves for its supply of elaborated foods. Further than this, it indicates that at least for certain varieties, each bud is quite largely dependent upon the leaf or leaves immediately subtending or about it, and to the same degree, independent of other leaves.

INFLUENCE OF GIRDLING UPON FRUIT-BUD FORMATION

While no direct work to determine the influence of such practices as ringing or girdling of fruit trees was carried on, abundant opportunity for observation of the effect of the winter injury on the trunk was furnished. This injury was mainly to the bark and its influence on the tree would be comparable to an artificial ringing treatment, though more severe than any ringing that would usually be given.

Invariably, the trees receiving a severe injury to the bark on the trunk produced a very heavy crop of bloom the second spring following the injury. That this was one of the results of the injury, rather than being due to natural development of the trees is indicated by the tree shown in Plate VII, Fig. 15. Note that the lowest branch on this tree, coming out below the injury, has produced no blossoms, while the remainder of the tree, affected by the injury, is a mass of bloom. This same condition was evident in several trees.

Conditions of nutrition in the tree following the winter injury are directly opposite to those brought about by defoliation. The elaborated food from the leaves passes down into the lower part of the tree and some of it into the roots, mainly through the bark. The injury to the bark probably prevents this downward passage and, consequently, there is an accumulation of the organic food held in the top of the tree. Thus the injury results in a very abundant supply of elaborated food from the leaves being held in the top of the tree, while defoliating reduces the supply of such food. The fact that these two treatments have such directly opposite influences upon fruit-bud formation gives added proof to the theory that a relatively abundant supply of such food is one requisite for fruit-bud formation.

PRACTICAL APPLICATION TO THE PRUNING PROBLEM

In connection with pruning, it is equally important to know first the conditions in the tree that are associated with fruit-bud formation and development, and second how various pruning practices, either directly or indirectly, influence these conditions. This is especially true for certain varieties of apples, which are often very difficult to bring into bearing, because of failure to form flower buds. This investigation indicates a number of things that must be considered if the trees are to be brought into and then kept in the best condition for fruiting.

The data indicate that the pruning must be such as will keep a well developed leaf area exposed to the best possible light conditions. Any type of pruning temporarily reduces the leaf area, through the actual removal of leaves, or through removing leaf buds during the dormant season. In the case of trees in low vitality, however, the slight reduction in leaf area immediately following a dormant pruning will often be more than counteracted before the season of fruit-bud formation occurs, by the increased growth following a dormant pruning. Consequently, in old trees, with many old, weak spurs, a dormant pruning may actually increase the number of fruit buds formed for the following year. On young, vigorous trees, however, any type of pruning will usually have a slight tendency to reduce temporarily the number of fruit buds that will form.

The extent of the reduction in leaf area following a pruning varies greatly with the type and amount given. In most varieties of apples, by the time the trees are coming into full bearing, the leaf area is quite closely correlated with the number of spurs present in the tree, due to the relatively large number of spurs as compared to shoots and to the fact that each spur possesses a cluster of several leaves. In general, therefore, it may be said that for young trees those types of pruning which stimulate the number of spurs formed in a tree, tend to increase the leaf area and consequently the tendency to form fruit buds. As trees become older, and possess an abundance of spurs, it often becomes necessary to stimulate vegetative growth through pruning in order to secure the most vigorous and largest leaf area.

Another point to be borne in mind is that there is a close relation between the leaf area in any one particular part of the tree and the development of buds in that part. Consequently, if fruit buds are to be formed to any considerable extent down on the inside of the tree, that portion of the tree must be kept well opened up to the light, for leaves cannot function properly in the absence of a good light supply. While the mere presence of leaves will not always insure fruit buds, their presence is essential if fruit buds are to be formed.

The very marked relationship between the leaf areas of the one-year shoots, and the response of the buds along these shoots indicates that here, also, leaves must be well exposed to the light. It is from these buds that the spurs of future years are developed and unless properly nourished, weak spurs, if any at all, will result. Not only should these shoots be kept thinned out enough to have a good exposure to the light when the spurs are formed, but it is essential that they be not crowded during their first year, if the strongest subsequent development is to be secured. Furthermore, if it is desirable to secure fruit buds on the one-year growth, it is necessary to give these buds a good exposure to the light, even if summer thinning of shoots is necessary. Reducing the leaf area through a moderate thinning will probably have little tendency to inhibit fruit-bud formation on those shoots remaining, since each shoot is largely independent in this regard, and the additional light through less shading will do much to strengthen the buds.

SUMMARY

The study of the relation of fruit-hud and leaf-bud formation and development to leaf area, as shown by the results following the removal of leaves, may be summarized as follows:

1. Fruit-bud initiation will not take place, and fruit buds will not form in most varieties in the absence of a fair amount of leaf area in the tree.

2. Leaf area in one part of the tree will usually not supply food material to the buds in another part to the extent necessary to cause them to become fruit buds. Defoliating one-half of a tree has little influence upon the undefoliated portion, but that part which is defoliated functions as it would if all the leaves had been removed from the whole tree.

3. Food material stored in the tree through the dormant season is apparently stored largely in the tissue adjacent to the leaves in which it was manufactured. This is shown by the fact that the defoliated portion of a tree does not develop as strongly and well during the spring following the treatment, as does the undefoliated portion.

4. Removing the same number of leaves, without any pruning, has practically the same effect upon the fruit-bud formation for the immediate year following that a summer pruning, removing leaves from the same position, would have.

5. Buds on one-year wood, in areas from which the leaves have been removed are slower in starting out into growth, and make a weaker growth the following spring than do other buds on the same shoots not defoliated. This is more noticeable in some varieties than in others.

6. One shoot seems to be very largely independent of other shoots about it so far as fruit-bud formation is concerned. It is apparently largely dependent upon its own leaves for nourishment.

7. Removing leaves from individual spurs tends to prevent the formation of fruit buds upon those spurs, although it does not entirely check the development of flower parts.

8. On those spurs which form fruit buds, notwithstanding defoliation, the blossoms are, on the average, considerably later in opening in the spring.

9. Axillary buds of the Wagener seem to be almost entirely dependent upon the immediate suhtending leaf for the carhohydrate supply with which they are nourished. Removing the subtending leaf entirely prevents fruit-bud formation. Buds so treated either remained entirely dormant during the following growing season or pushed out into very weak growth. Very few of them showed a development approaching normal.

10. Microscopic examination of buds, both defoliated and undefoliated, taken at intervals during the summer, show little influence of the defoliation so far as development is concerned. No buds were studied that were taken later than September 12.

11. There is a very decided decrease in the number of calcium oxalate crystals deposited in the tissues of defoliated as compared to undefoliated buds. This may be indicative of a small supply of soluble carbobydrates and general slow metabolism in the bud tissue.

12. Injury to the bark on the trunk of the tree very greatly stimulated fruit-bud formation. This injury brings about very different conditions of nutrition in the tree from those produced by defoliation, for by preventing the normal flow of elaborated foods to the roots, the supply in the top of the tree is greatly increased by the injury of the bark.

EXPLANATION OF PLATES

Plate I, Fig. 1. Grimes tree—Branches extending to left entirely defoliated July 3, 1916, those to the right receiving no treatment. Photographed May 10, 1917.

Fig. 2. Glowing Coal—Branches to the right entirely defoliated June 28, 1916, those to left receiving no treatment. Photographed May 21, 1917.

Plate II, Fig. 3. Normal blossom clusters from undefoliated portion of Glowing Coal tree, half of which was defoliated June 27, 1916. Photographed May 21, 1917.

Fig. 4. Normal clusters from defoliated portion of same tree.

Plate III, Fig. 5. Shoots of Fameuse tree from which several of the terminal leaves were removed June, 28, 1916. Photographed May 10, 1917. Buds below defoliated area, and those produced following the removal of leaves, breaking into growth.

Fig. 6. Result of thinning by defoliation on Babbitt. Shoots at right entirely defoliated June 28, 1916—shoots at left—no defoliation. Photographed May 10, 1917.

Plate IV, Fig. 7. Keswick tree upon which individual spurs were defoliated.

Fig. 8. One of Wagener trees upon which subtending leaves of individual axillary buds were removed.

Plate V, Fig. 9. Result of spur defoliation on Keswick. One bud, defoliated June 19, remaining leaf, and one defoliated August 18, 1916, opening as a blossom bud. Photographed April 21, 1917.

Fig. 10. Wagener bud, tbe subtending leaf of which was removed July 19, 1916. (Bud below string). Photographed April 16, 1917. Buds beginning to swell.

Fig. 11. Another bud of the same. Photographed April 28. Slightly enlarged.

Plate VI, Fig. 12. Axillary buds of Wagener with leaves removed July 19 and June 28. Photographed May 10, 1917. All buds have developed flower parts except those that were defoliated, which are not breaking.

Fig. 13. Defoliated bud in midst of leaf buds starting into growth. Defoliated bud not breaking. Photographed May 14, 1917.

Fig. 14. Same—Defoliated bud pushing out. Photographed May 14, 1917.

Plate VII, Fig. 15. Glowing Coal with winter injury on trunk above first limb.

Plate VIII, Fig. 16. Axillary Wagener bud, June 28, 1916.

Fig. 17. Axillary Wagener bud, defoliated June 28. Collected Sept. 12, 1916.

Fig. 18. Axillary Wagener bud, Sept. 12, 1916. No defoliation.

Fig. 19. Axillary bud of Yellow Bellflower taken July 3, 1916.

Fig. 20. Axillary bud of Yellow Bellflower taken Sept. 12 from region defoliated June 28, 1916.

Fig. 21. Axillary bud of Yellow Bellflower taken Sept. 12—not defoliated.

Plate IX, Fig. 22. Spur bud of Lady, taken June 28.

Fig. 23. Spur bud of Lady, taken Sept. 12 from tree defoliated June 28.

Fig. 24. Spur bud of Lady, taken Sept. 12. No defoliation.

Fig. 25. Spur bud of Grimes, taken June 28.

Fig. 26. Spur bud of Grimes, taken Sept. 12, from half of tree defoliated June 28.

Fig. 27. Spur bud of Grimes, taken Sept. 12, from undefoliated half of tree.

Plate I, Figs. 1-2.

Plate II, Figs. 3-4.

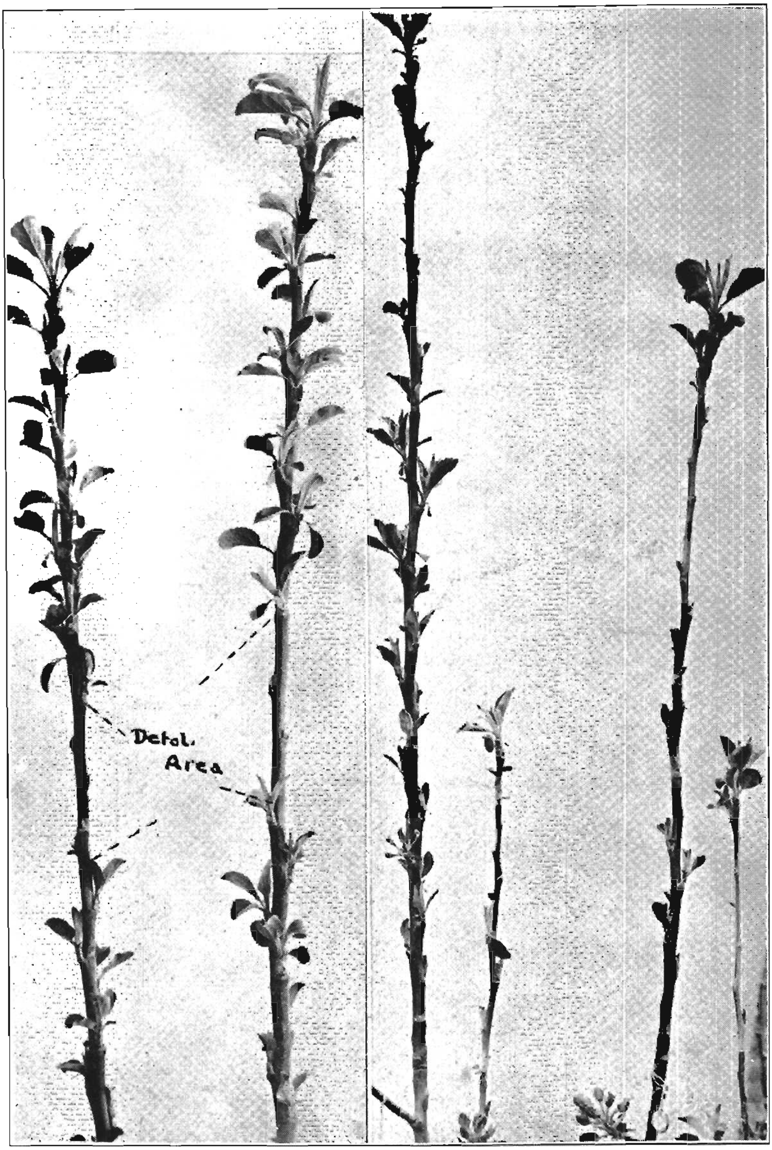

Plate III, Figs. 5-6.

Plate IV, Figs. 7-8.

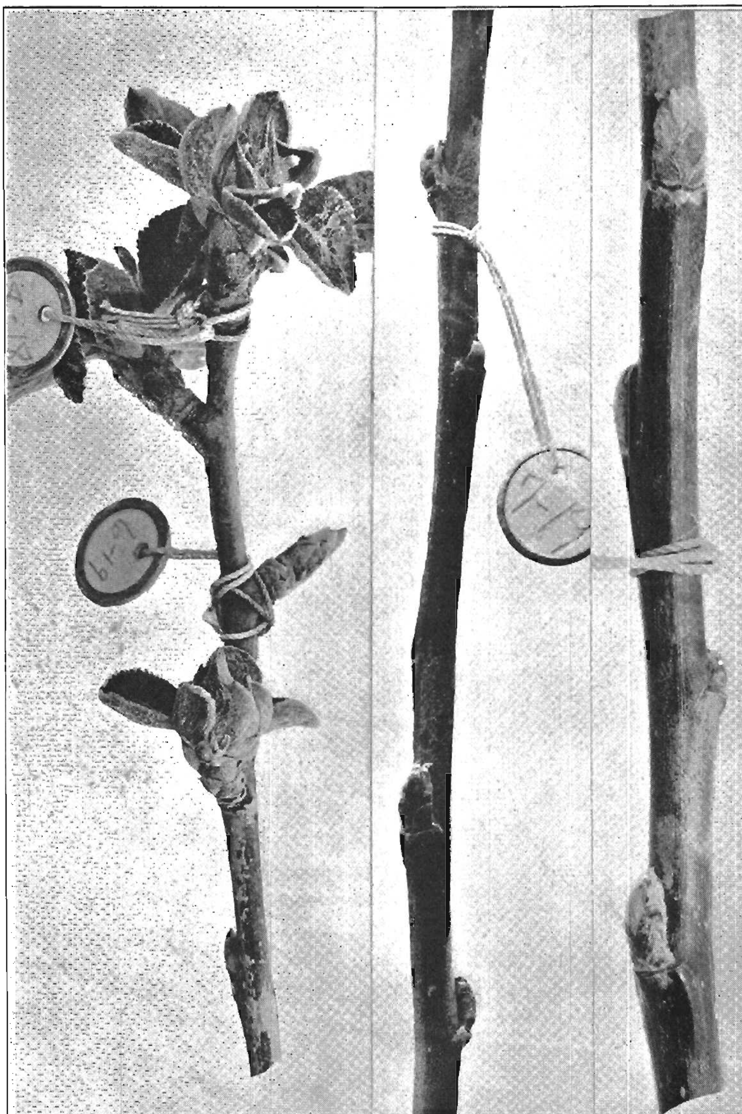

Plate V, Figs. 9-11.

Plate VI, Figs. 12-14.

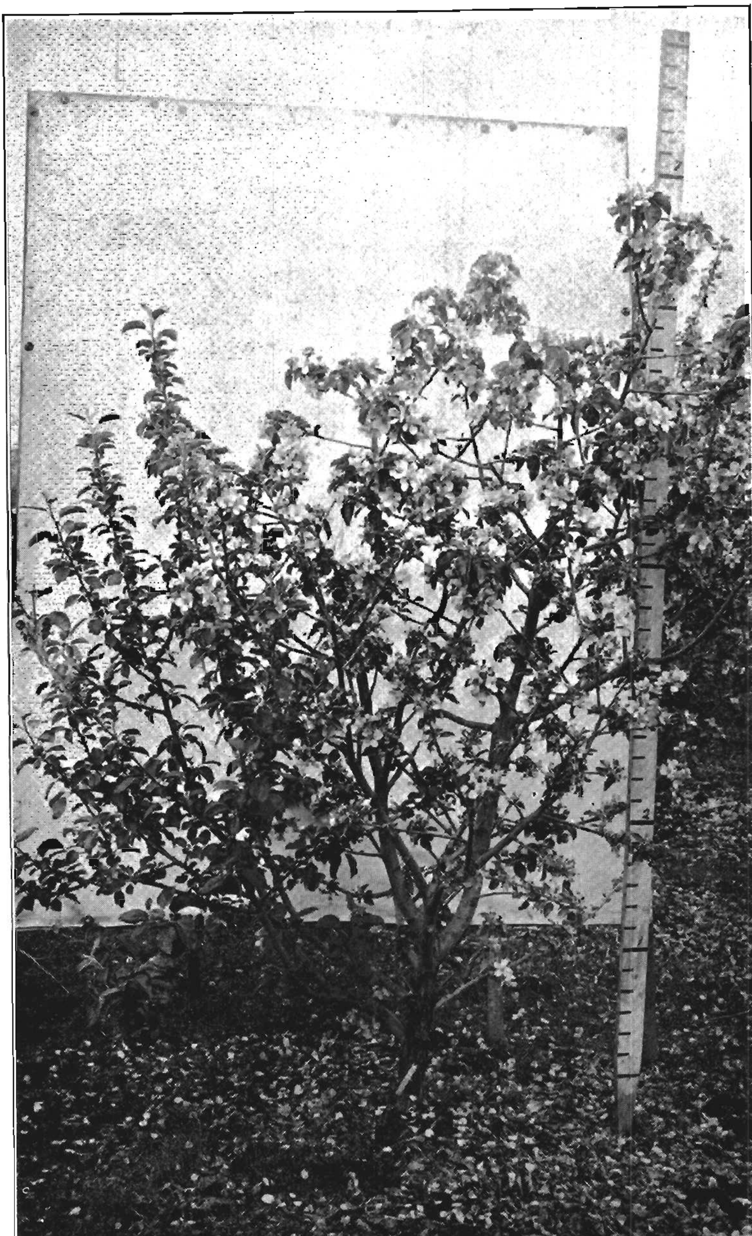

Plate VII, Fig. 15.

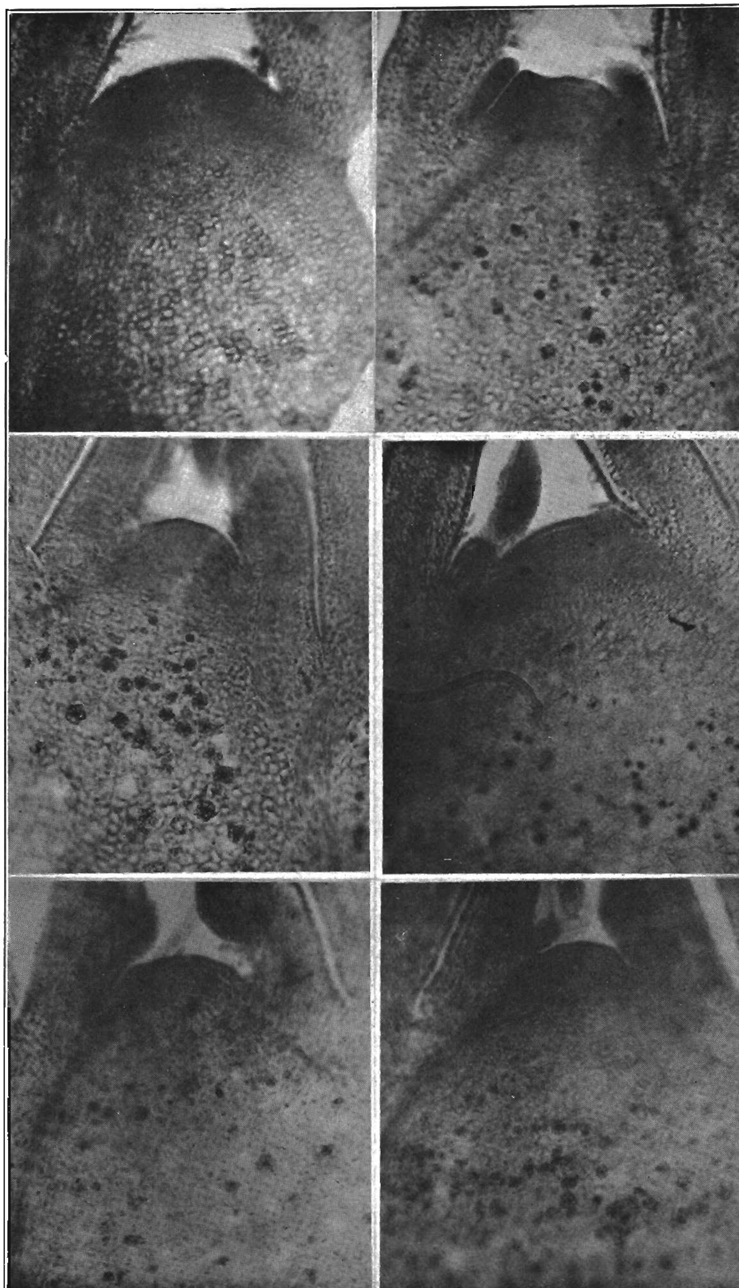

Plate VIII. Figs. 16-21.

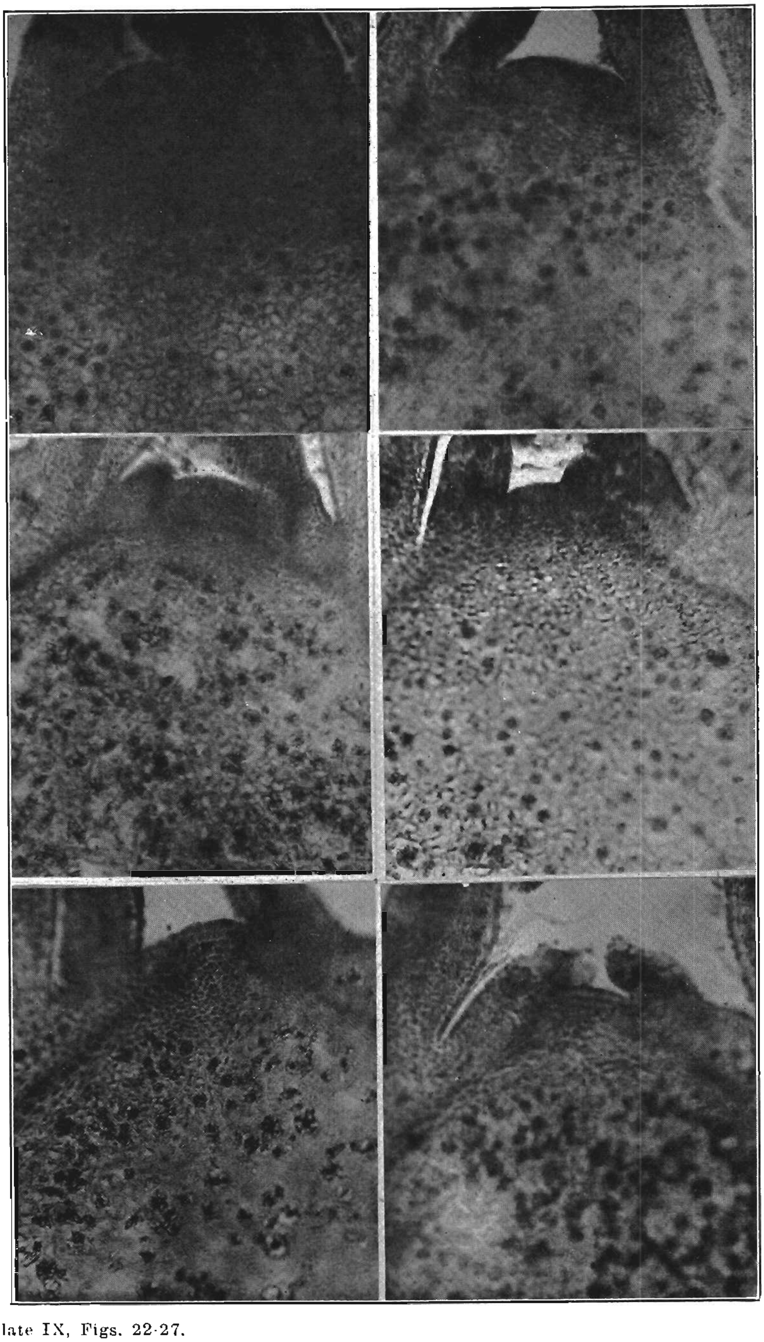

Plate IX, Figs. 22-27.

THE RELATION BETWEEN ANGLE, LENGTH, AND DIAMETER OF SHOOTS AND THE DEVELOPMENT OF SIDE SHOOTS AND FRUIT SPURS FROM LATERAL BUDS

BY A. F. EDMINSTER

INTRODUCTION

Few questions pertaining to the management of fruit trees have received more attention than those dealing with the general subject of mode of training. Fruit growers are very much divided in opinion as to whether, on the average and in the long run, the open-centered tree is inferior or superior to the closed-centered tree—as to whether an upright, an oblique, a horizontal, or a downward direction is to be preferred for the main limbs. There has been less discussion as to the relative merits of the small vertical, oblique, and horizontal limbs—those to which the fruit spurs are directly attached—although it would seem that, at least from certain viewpoints, this is the more important question.

It has been the general impression among the earlier authorities on fruit growing that a horizontal or downward-growing branch is more productive than a vertical or upward-growing branch. This impression evidently was based upon both observations and experiments, but observations and experiments that today would hardly be regarded as sufficient to warrant any hard and fast conclusions.

As early as 1815, John Maher (1) carried on an experiment along this line in an old orchard which he had severely pruned, and in which as a result he had secured a vigorous growth of from three to five feet. He writes: "About the end of June, or a little sooner and later, according to the growth of the branches, I applied oval balls of grafting clay towards their extremity, sufficiently heavy to incline them downwards in a pendulous direction. The sap being thus diverted from its natural mode of ascending and descending, every bud almost became a blossom bud, and in several trees this disposition to produce blossom buds was carried down to the very lowest spurs on the stem and thicker branches. The crop of fruit is not only improved in size and flavour by having so much sun and air, but it is more easily gathered, and suffers much less from the autumnal winds; for branches in this direction are more pliable, and bend more easily to the storm."

In 1833 William Kenrick (2) in speaking of the practice of bending limbs, says: "This appears to be the most simple, easy, and effectual mode of rendering trees productive. When judiciously performed, its effects are extraordinary. The effects appear to be perfectly understood by the Chinese in training their dwarfs. Its effects are also exemplified in the mode of training trees 'en quenouille.' Also on the vine, by which means prodigious crops are produced. Also in the fig, for by this mode Mr. Knight has obtained eight crops in a year. The system is equally

(1) References are given at the end of this article, page 43.

applicable to every species of fruit tree. It consists in bending every limb, or twig, to a position below the horizontal, while it is yet in a vigorously growing state, generally the last of June; with some kinds which have prolonged vegetation, it may perhaps with more advantage be deferred till July, as in the case of the peach. The effect produced in the first instance is a momentary stoppage in their growth; the juices are concentrated and form fruit buds for the production of fruit in the following year. But the growth of all parts of the tree must at the same time be restrained, and if shoots burst forth in other parts of the tree they must be nipped in to a few eyes as soon as they have advanced a few inches."

Cole, in his American Fruit Book, (3) says: "Bending the limbs down, and fastening them in that position, as in quenouille training, retains the sap in them, inducing bearing and improvement in fruit, without injury to the tree. Hence, there is more philosophy than whim in the saying, that the bending down of fruit trees by heavy snow indicates a fruitful season."

An unknown writer (4) in the Horticulturist for 1856 in an article on Pruning of Pear Trees, says: "A shoot ought to be cut clean, just above a bud, which bud must be on the under, or the outside part of the shoot, rarely or never in a vertical position, because it would tend to bring in the construction of the tree more of those vertical or upright shoots, every one of which ought to be carefully cut away, as absorbing, by a natural privilege of its vertical position, all the sap, and destroying the harmony of the tree. It follows that a limb inclined at an angle of 45°, or a lower bend, is more fitted to make spurs, and go over to bearing by the deprivation of superabundant sap." He goes on to state that while bent or inclined shoots make a tree bear, they are injurious to its growth, and unless immediately pruned in a proper manner they "give up at once, and linger or die."

Shirley Hibberd (5) in 1888 states in the Journal of the Royal Horticultural Society that many fruitful trees often acquire a half weeping habit due to the effect of the weight of the fruit pulling down the branches. This reverse position checks growth, and exposes the wood and fruit more completely to the sun and air. The half weeping habit enforced by the law of gravitation "exactly suits its constitution as a fruit producer."

E. A. Bunyard (6) in an article on the physiology of pruning states that the well-known practice of "bending down a branch to make it more fruitful, owes its success to the fact that it would be more difficult for the elaborated sap to flow out of the branch into the stem and thence to the roots."

Sir Thomas A. Knight (7) experimented in training peach twigs at different angles. While he does not report any observations in regard to the production of fruit buds, he states that he found that when the shoots were not of equal luxuriance, by depressing the strongest shoots and elevating the weakest ones, they could both be made to acquire and retain an equal amount of vigor.

It will be noted that some of the authorities cited evidently expect to find increased productiveness associated with drooping or pendulous branches only when they are bent in this direction artificially. On the other hand, others are of the belief that whether branches grow more or less pendulous naturally or are bent down artificially, they are on that account more productive than the upright or oblique ones. Some of those who advise the bending of shoots to make them more fruitful recommend that it be done during the summer. One would infer that some of the others who believe that direction of shoot or branch influences fruitfulness, do not regard time of bending as an important factor.

OBJECT OF THIS INVESTIGATION

The object of this investigation was to obtain a body of evidence upon the amount and type of growth produced by shoots and branches growing at different angles so that the relation between angle of limb and productiveness can be determined. It is true that the grower can not control to any considerable extent the angle at which shoots naturally develop, without resorting to methods of artificial tying and bending that would be impracticable in a commercial orchard. On the other hand, in the pruning and training of nearly every tree he has a chance to choose between slender and stout, between long and short, and between more or less vertical, oblique, horizontal, and even drooping shoots and branches, from which to develop his framework and smaller fruiting limbs. If limbs or branches possessing certain characteristics of length, thickness or angle are more prone than others to bear fruit, they may be preserved and encouraged. If vertical shoots or limbs are no better and no worse than oblique or horizontal ones, the grower should know about it so that no extra cost need be incurred in their preservation or elimination.

MATERIALS AND METHODS EMPLOYED

The investigation was limited to a study of apple shoots, primarily because of the commercial importance of the apple, and also because of the material available. Four varieties were included in the study—Fameuse, Shiawassee, Wagener, and Yellow Newtown. This list includes varieties with an upright and also a comparatively spreading habit, as well as varieties belonging to quite distinct pomological groups. The Fameuse and Shiawassee trees were about twenty-five years old; the Wagener trees, five years old; the Yellow Newtowns were of both ages. The older trees were moderately vigorous and had been bearing good crops. The young trees were very strong and thrifty and were just coming into bearing. All were growing in comparatively heavy clay soil near Corvallis, Oregon. Data taken from trees of these varieties were recorded during the fall and winter of 1914-15 and included the 1914 performance history of the shoots of 1913. The late (i. e., that of 1912, '13, and '14) performance of the shoots of 1911 and 1912 was also studied to serve as a check upon the performance record of the 1913 shoots.

The angle of each shoot was determined by means of a protractor provided with a spirit level, the angles being read to the closest ten degrees. A vertical line was taken as the standard, shoots growing straight down being recorded as growing at an angle of 0° and shoots growing straight up being recorded as growing at an angle of 180°. The length of each shoot was measured in inches and its diameter in millimeters. Its dormant lateral buds, its fruit spurs and its side shoots were counted, the record of each shoot being kept separate. In all, measurements were taken of nine thousand shoots distributed among the different varieties as follows: Wagener, 1500; Fameuse, 2000; Shiawassee, 2000; Yellow Newtown (old trees), 2000; Yellow Newtown (young trees), 1500. It should be noted that all of the Wagener shoots for which records were made had been headed; while the shoots of the other varieties were unheaded.

The records secured in the orchard were first grouped according to the angle of the shoots, then according to their lengths, and then according to their diameters. From these records, the percent of buds that had remained dormant, the percent that had developed into lateral shoots, and the percent that had developed into fruit spurs for different angles, lengths, and diameters were then determined.

PRESENTATION OF DATA

It is impracticable to present in detail all of the data recorded for each of the 9000 shoots studied. Furthermore, it does not seem necessary to include all of the summary tables that were constructed for purposes of study. Such tables will be included, however, as will present in a condensed form representative portions of evidence upon which conclusions are based.

THE RELATION BETWEEN SHOOT ANGLES AND THEIR LATER PERFORMANCE

The main question under consideration in this investigation has been a study of the relation existing between shoot angles and their later performance: that is, their later production of shoots and of spurs from their lateral buds. The data collected and bearing upon this was assembled in the form of a series of **frequency distribution tables** for the different varieties, showing the percentage of the lateral buds that "broke" and formed either shoots or spurs and the percentage that "broke" and formed spurs at each of the different angles. Thus in Table VII (a typical one of these frequency distribution tables) it is seen at a glance that of the 155 Yellow Newtown shoots growing at an angle of 140°, none of the lateral buds "broke" on two shoots, 15 percent broke on four, 20 percent broke on one, etc. Such frequency distribution tables also constitute **correlation tables** between shoot angles and percent of lateral buds "breaking," for which means, standard deviations and correlation coefficients can be computed and thus accurate measures of the relationship between the two variables obtained.

TABLE VII. CORRELATION TABLE FOR PERCENT OF BUDS BREAKING AND ANGLES OF UNHEADED SHOOTS IN YOUNG YELLOW NEWTOWN

1913 GROWTH

% of buds breaking.	50	60	70	80	90	100	110	120	130	140	150	160	170	180	Freq.
	Shoot Angles														
0		1		2	8	7	4	7	3	2					34
5															
10					1		1								2
15			1	1	3	3	3	7	3	4					25
20				1	3	3	5	1		1		1			15
25				2	2	1		1	1	1					8
30				1	4	2	3	1	1	2			1		15
35				1	4	5	5	6	3	5		4			33
40					2	8	7	15	9	4		1		1	47
45					3	7	14	13	10	9	3	4	1		64
50		1			3	2	8	11	12	8	5	2	1		53
55	1		1		1	8	6	9	8	10	10	7	2		63
60			2		4	4	7	7	15	15	15	7	3		79
65					3	4	9	8	18	31	18	17	6		114
70						4	5	9	17	16	33	35	9	3	131
75						5	4	6	15	20	29	30	10	1	120
80						1	4	3	9	20	22	20	11	4	94
85							2		4	6	14	15	15		56
90								1	2	1	5	11	11		31
95											2	4	5		11
100															
Freq.	1	2	4	8	41	64	87	105	130	155	156	158	75	9	995

Table VIII presents means, standard deviations and correlation coefficients determined from Table VII and also computations made from a number of similar correlation tables constructed from other records that were taken.

TABLE VIII. MEAN, STANDARD DEVIATION, AND CORRELATION COEFFICIENTS DETERMINED FROM TABLE VII, AND OTHER RECORDS

Variety	Number of shoots averaged.	Mean percentage of buds breaking.	Standard deviation in percentage of buds breaking.	Mean angle of shoots.	Standard deviation in angle of shoots.	Correlation coefficient.
Yellow Newtown, young trees; 1913 shoots	995	61.11	21.07	135.68	23.50	.574
Yellow Newtown, old trees; 1913 shoots	690	46.78	22.90	130.19	26.79	.124
Shiawassee, old trees; 1913 shoots	1094	34.23	27.63	117.13	32.57	.079
Fameuse, old trees; 1913 shoots	1098	45.37	29.03	110.89	32.31	.047
Wagener, young trees; 1913 shoots (headed)	872	71.49	15.99	149.32	28.04	.429
Yellow Newtown, young trees; 1912 shoots	300	66.50	17.74	139.40	22.47	.357
Yellow Newtown, old trees; 1912 shoots	634	55.40	17.63	121.18	24.93	.119
Shiawassee, old trees; 1912 shoots	423	31.95	26.89	95.32	35.17	—.004

TABLE VIII. (Continued)

Variety	Number of shoots averaged.	Mean percentage of buds breaking.	Standard deviation in percentage of buds breaking.	Mean angle of shoots.	Standard deviation in angle of shoots.	Correlation coefficient.
Fameuse, old trees; 1912 shoots	394	43.25	27.05	95.81	33.19	.058
Yellow Newtown, old trees; 1911 shoots	541	41.84	24.24	111.61	26.48	.1003
Shiawassee, old trees; 1911 shoots	312	37.69	27.14	82.05	34.88	—.036
Fameuse, old trees; 1911 shoots	250	48.16	25.59	88.04	32.38	—.058

A study of the tables of which No. VII is representative, brings out a number of interesting facts regarding both shoot angles and the percentages of their lateral buds breaking. Turning attention first to the column in Table VIII giving the mean shoot angles, it is noted that for trees of the same age this varies considerably with the variety. The difference of 20° between the 1913 shoots of Fameuse and of Yellow Newtown is not, however, a great one, even though the one variety would be classed as a spreading and the other as an upright grower. The fact that the differences between the older (1911 and 1912) shoots of these same varieties is somewhat greater, in fact nearly 30°, suggests that the shoots of the one variety may be more flexible than those of the other, and consequently bent more readily by the weight of new wood growth and fruits of later years. This would explain the increasingly spreading habit of certain varieties like the Fameuse and Shiawassee. Attention is called to the fact that even an upright variety like Yellow Newtown gradually becomes more spreading, its 1911 shoots averaging 112° in the fall of 1914 as compared with 130° for its 1913 shoots. Attention is also called to the fact that the new shoots on older trees are less upright than new shoots on younger trees of the same variety, the difference in the case of Yellow Newtown amounting to over 5°.

There is likewise considerable variation between varieties in the mean percentage of lateral buds that break. Of the varieties studied, Yellow Newtown had the largest percentage of its lateral buds breaking, and this was true for the growth of successive seasons. There was considerable variation, however, within the variety from season to season, old Yellow Newtown trees showing a smaller percentage of lateral buds breaking certain seasons than Fameuse in other seasons. Though the amount of evidence is limited, it appears that the shoots on young trees are more prone to have their lateral buds break than shoots on older trees of the same variety.

Coming now to the question of relation between shoot angles and the percentage of lateral buds breaking, there seems to be considerable variation between varieties; and an equally great variation within the variety from year to year and between young trees and old trees. Inspection of the correlation tables would indicate that on the average buds on the more vertical shoots are more prone to break than those on the more horizontal shoots. This tendency is especially pronounced in the Yellow Newtown and Wagener, upright growing varieties. This is particularly interesting because the idea has been so frequently expressed in the literature of fruit growing that the oblique or horizontal or even more or less drooping shoots are more productive than the upright ones. It is true that the percent of lateral buds breaking is not necessarily a correct index to fruit production, since it would be possible for the buds on the upright shoots as compared with those on horizontal shoots, to give rise to relatively more branch shoots, and relatively fewer fruit spurs, or to give rise to barren rather than productive fruit spurs. Evidence on this point is furnished in Table IX and Plate X, to which reference will be made later. Unfortunately the correlation coefficients in Table VIII do not furnish an accurate expression of the degree of relationship existing between shoot angles and the percent of their lateral buds breaking. That this statement is true can be told from a close examination of the correlation tables themselves, particularly those for Fameuse and Shiawassee, varieties that are comparatively open spreading growers. Here it is fairly evident that neither the most drooping nor the most upright shoots are the most productive of breaks from lateral buds. Rather it is the oblique shoots that on the average seem to afford the largest percentage of branch shoots and of spurs. This point is brought out still more clearly by curves AAA, MMM, and XXX in Plate X, which were plotted from the means of the columns in some of the correlation tables. In a general way, it may be said that the data indicate that those shoots growing at an angle comparatively close to the mean shoot angle of the variety are most productive of branch shoots and of spurs.

TABLE IX. AVERAGE BRANCHES FOR THE GIVEN ANGLES IN YOUNG YELLOW NEWTOWN—1913 GROWTH.

1	2	3	4	5	6	7	8	9	10
50	1	9.00	3.7	9.0	4.0	0	5.0	55.6	55.6
60	2	5.50	4.8	6.5	4.5	0	2.0	30.8	30.8
70	4	7.75	4.6	9.0	4.5	0	4.5	50.0	50.0
80	8	8.25	3.8	10.9	8.5	.25	2.1	21.7	19.5
90	41	8.08	3.8	9.5	6.3	.05	3.2	33.8	33.3
100	64	11.90	4.4	12.7	6.7	.10	5.9	47.4	46.7
110	87	15.05	4.8	15.8	7.4	.22	8.1	52.9	51.5
120	105	15.14	4.7	15.4	7.4	.14	7.8	51.9	50.9
130	130	19.16	5.4	18.9	7.3	.31	11.2	61.2	59.2
140	155	24.17	6.3	23.3	8.2	.62	14.5	64.7	62.0
150	156	29.06	7.4	27.5	7.6	1.00	18.8	71.9	68.6
160	158	32.63	8.2	29.8	8.0	2.11	19.8	73.6	66.5
170	75	33.90	8.6	31.9	6.6	3.17	22.2	79.4	69.5
180	9	31.65	8.9	29.0	7.4	3.78	17.8	74.3	61.3

KEY TO TABLE SHOWING AVERAGE BRANCHES FOR THE GIVEN ANGLES

1. Angles of average shoots.
2. Number of shoots represented in the average.
3. Length of average shoot in inches.
4. Diameter of average shoot in millimeters.
5. Total number of buds for each average shoot.
6. Dormant buds.

7. Buds having developed into branches.
8. Fruit spurs.
9. Percent of buds breaking.
10. Percent of buds forming fruit spurs.

It is not considered necessary to present all the evidence collected on the relation of shoot angle to development of spurs. Table IX and the broken lines in Plate X give in very condensed form a portion of the data on this point. A comparison of the last two columns in Table IX and of the solid and broken lines in Plate X indicates clearly that practically the same relation exists between shoot angle and percent of fruit spurs formed as between shoot angle and percent of lateral buds breaking. It is true that all of the lateral buds that break do not develop into fruit spurs but the percentage is comparatively high and the curves representing the percentage of buds that break and percentage that form fruit spurs are nearly parallel. It is worthy of note, however, that the curves more closely parallel each other at the lower angles than at the higher ones; but even though this is the case, the curve showing percentage of buds that form fruit spurs rises higher at the higher angles (i. e., for the more upright shoots) than the curve for the percentage of buds that break rises at the lower angles. Thus there is unmistakable evidence that the more upright shoots—or more accurately the shoots more nearly the mean shoot angle for the variety—are the most productive of fruit spurs. Shoots of our ordinary varieties that grow naturally more or less downward not only possess no superiority over more upright shoots in the same trees on account of their direction, but on the average they are distinctly inferior to them.

THE RELATION BETWEEN SHOOT LENGTHS AND THEIR LATER PERFORMANCE

In order to determine whether or not the length of a shoot has any influence upon the development of its lateral buds, the data collected for a study of shoot angles was rearranged so that a direct comparison of shoots of different lengths might be made. As some relation had been found between shoot angles and the development of their lateral buds, it was thought best to examine separately the shoots of each angle, thus avoiding any possible error due to grouping together shoots differently influenced by that factor. In order to deal with as large numbers as possible and yet secure enough different lengths for purposes of comparison, the shoots of each angle were divided into two to six arbitrary sub-groups based upon length, and averages were then determined for each of these sub-groups. In the case of the Wagener and young Yellow Newtown trees, whose shoots were comparatively long, groups were made to include shoots from 0″-8″, 8″-16″, 16″-24″, etc.; while in the case of the Shiawassee and Fameuse, whose shoots were comparatively short, the groups were made to include shoots 0″-4″, 4″-8″, 8″-12″, etc.

Table X for 1913 shoots of young Yellow Newtown trees presents in condensed form the evidence on this question furnished by that variety. Plate XI presents curves constructed from the figures in this same table. On account of the space they would require, corresponding tables and curves for the other varieties are not included.

TABLE X. INCREASE IN THE PERCENT OF BUDS BREAKING AND OF BUDS FORMING FRUIT SPURS, WITH AN INCREASE IN THE LENGTH OF SHOOTS. YOUNG YELLOW NEWTOWN —1913 GROWTH.

1	2	3	4	5	6	7	8	9	10	11
80°										
	0-8 "	3.84	3.5	6.0	5.5	0	.5	8.3	8.3	4
	8-16"	12.65	4.1	15.8	11.5	.5	3.8	27.0	23.8	4
90°										
	0-8 "	5.43	3.4	6.9	5.3	.1	1.5	23.4	22.8	23
	8-16"	10.31	4.0	11.2	6.4	.1	4.7	42.5	41.8	12
	16-24"	18.19	5.4	21.8	13.0	0	8.8	40.2	40.2	4
100°										
	0-8 "	4.81	3.3	6.5	4.9	0	1.6	24.0	24.0	20
	8-16"	11.75	4.2	12.3	6.1	.1	6.1	50.7	49.5	28
	16-24"	19.15	5.6	20.0	9.6	0	10.4	51.9	51.9	13
	24-32"	26.96	8.0	26.7	11.7	.7	14.3	56.2	53.8	3
110°										
	0-8 "	5.83	3.3	7.2	5.3	0	1.9	25.5	25.5	19
	8-16"	11.68	4.0	12.8	6.3	.1	6.4	50.6	49.7	28
	16-24"	20.20	5.6	20.6	9.3	.1	11.2	55.0	54.2	31
	24-32"	27.05	6.9	26.3	8.4	1.1	16.8	68.1	63.9	10
120°										
	0-8 "	5.57	3.2	7.0	5.1	0	1.9	26.1	26.1	22
	8-16"	10.82	3.7	11.1	5.1	.2	5.8	53.8	52.4	32
	16-24"	19.61	5.4	20.0	10.0	.1	9.9	49.8	49.1	34
	24-32"	27.0	6.7	25.3	9.5	.2	15.5	62.6	61.1	13
	32-40"	33.27	7.2	31.	10.	0	21	67.7	67.7	1
130°										
	0-8 "	5.93	3.2	7.3	4.8	0	2.5	34.5	34.5	16
	8-16"	12.77	4.2	12.9	4.8	.2	7.9	62.8	60.9	32
	16-24"	20.6	5.6	21.0	8.5	.3	12.2	59.6	58.1	43
	24-32"	26.95	6.9	25.3	9.1	.5	15.7	64.2	62.2	34
	32-40"	33.29	7.3	26.5	8.0	1.5	17	68.6	63.5	6
140°										
	0-8 "	5.08	2.9	6.9	4.6	0	2.3	32.8	32.8	8
	8-16"	10.43	3.7	10.7	4.9	.1	5.7	53.9	53.4	18
	16-24"	20.51	5.5	21.0	9.2	.3	11.5	56.2	54.7	28
	24-32"	28.08	7.2	26.8	8.9	5.5	17.3	66.8	64.7	74
	32-40"	34.16	7.8	30.8	9.0	1.7	20.1	70.7	65.2	23
	40-up"	40.88	9.3	36.5	8.5	3.0	25.0	76.7	68.5	2
150°										
	0-8 "	4.75	3.6	6.0	2.0	0	4.0	66.7	66.7	3
	8-16"	12.31	4.5	12.4	5.1	.3	7.0	59.1	56.4	12
	16-24"	23.58	6.2	22.2	6.1	.5	14.6	68.9	66.4	11
	24-32"	28.80	7.3	27.4	7.9	.7	18.8	71.2	68.5	68
	32-40"	34.77	8.5	31.7	8.2	1.3	22.2	74.2	70.2	56
	40-up"	43.66	9.7	38.0	10.0	2.7	25.3	73.7	66.7	3
160°										
	0-8 "	6.0	3.0	6	4	0	2	33.3	33.3	1
	8-16"	10.31	3.3	10.1	5.1	.1	4.9	49.4	48.2	8
	16-24"	20.31	6.6	20.2	8.5	.3	11.4	57.7	56.3	11
	24-32"	28.44	7.1	27.3	8.4	1.0	17.9	69.1	65.6	32
	32-40"	35.67	8.9	32.9	8.0	2.4	22.5	77.2	68.0	91
	40-up"	41.46	10.6	37.4	7.1	5.3	25.0	81.2	67.0	15

TABLE X—*Continued*

1	2	3	4	5	6	7	8	9	10	11
170°										
	0-8 "	7.0	2.7	7.0	4.5	0	2.5	35.7	35.7	2
	8-16"	11.67	3.6	10.3	3.7	0	6.6	64.5	64.5	3
	16-24"	20.69	5.6	10.0	7.0	.5	12.5	65.0	62.5	2
	24-32"	29.86	7.4	29.4	6.8	1.5	21.0	76.8	71.6	17
	32-40"	36.60	9.4	34.1	6.5	3.4	24.2	80.8	71.0	39
	40-up"	43.15	11.0	40.3	7.5	6.5	26.3	81.4	65.3	12

KEY TO COLUMNS IN TABLE X.

1. Angle of shoots.
2. Groups into which shoots are divided.
3. Average length of shoots in inches.
4. Average diameter of shoots in millimeters.
5. Total number of buds for each average shoot.
6. Number of dormant buds for each average shoot.
7. Number of vegetative shoots or branches for each average shoot.
8. Number of fruit spurs for each average shoot.
9. Percent of buds breaking.
10. Percent of buds forming fruit spurs.
11. Number of shoots included in group.

A study of Table X and the accompanying Plate XI shows that without question an increase in the length of shoots is accompanied by an increase both in the percentage of lateral buds that break and in the percentage of those that form fruit spurs. This increase is especially marked between the groups of shorter shoots. The corresponding tables for the other varieties lead to the same general conclusion. In a number of instances, especially in Fameuse, the percentage of lateral buds breaking is a little lower for the group of longest than for the next longest shoots, suggesting that perhaps there is an optimum shoot length from the viewpoint of strong lateral buds that will normally develop into side shoots and spurs. This is easily conceivable in the case of trees having some shoots that have made an unusually long, spindling growth, perhaps because of shading. The data on this point are not sufficient, however, to warrant definite conclusions.

RELATION BETWEEN SHOOT DIAMETERS AND THEIR LATER PERFORMANCE

It was the general impression among early horticultural writers that thick shoots and branches are mainly useful for further wood production and that it is the small ones that are mainly useful in the production of fruit. A few quotations from De la Quintinye (8) will serve to bring out some of these early ideas: "In vigorous trees the weaker branches are the fruit bearers; in weak trees, the stronger chiefly. . . . Fruit buds that are nearest the ends of branches are commonly thicker, and so better fed than others. . . It is very material to preserve the good, weak ones for fruit. . . . The farther a weak branch is distant from the trunk, the less nourishment it receives; thick branches the more distant from the heart receive the more, and are therefore to be removed."

Two of the tables already presented, IX and X, show in a general way first, that on the average, the upright are thicker than the more horizontal shoots; and second that the long shoots are thicker than the short ones. This being true, it is to be inferred from the conclusions reached regarding the relation of shoot angles and shoot lengths to the performance of their lateral buds, that there is also a relation between thickness of shoot and the percent of the lateral buds that normally break. An examination of the data presented in Table VIII indicates that such an inference is correct. However, these data do not show whether or not shoots of the same angle and of the same length, but varying in thickness, also vary in the way in which their lateral buds break. In other words they give no indication as to whether or not thickness itself is a factor in determining the performance of the lateral buds of a shoot—or perhaps more accurately is of itself an index to such factors. To obtain evidence on this question the same sub-groups of shoots that were used in determining the inter-relationship of shoot length and development of lateral buds were each again sub-divided into two smaller groups, the shoots of one of these smaller groups having diameters below the mean diameter for the whole group, and those of the other having a diameter above the mean. Table XI presents the data thus arranged for the shoots of the young Yellow Newtown trees. Because of the space required, corresponding tables for the other varieties are not included.

TABLE XI. INCREASE IN THE PERCENT OF BUDS BREAKING AND OF BUDS FORMING FRUIT SPURS. WITH AN INCREASE IN THE DIAMETER OF SHOOTS OF APPROXIMATELY THE SAME LENGTH. YOUNG YELLOW NEWTOWN—1913 GROWTH

1	2	4	5	6	7	8	9	10	11
80°									
	0-8 "	3.3	6.0	5.3	0	.7	11.1	11.1	3
		3.9	6	6	0	0	0	0	1
	8-16"	3.5	11.0	7.5	0	3.5	31.8	31.8	2
		4.9	20.5	15.5	1.	4.0	24.8	19.5	2
90°									
	0-8 "	2.9	7.0	5.6	0	1.0	19.2	19.2	15
				4.6	.1	2.0	31.5	29.7	8
	8-16"	3.8	11.6	6.5	.1	5.0	44.1	43.0	8
		4.6	10.2	6.2	0	4.0	39.0	39.0	4
	16-24"	5.1	24.5	16.5	0	8.0	32.7	32.7	2
		5.8	19	9.5	0	9.5	50.0	50.0	2
100°									
	0-8 "	3.0	6.1	5.0	0	1.1	17.7	17.7	13
		3.9	16.7	11.0	0	5.7	34.0	34.0	7
	8-16"	3.6	11.2	5.3	.1	5.8	52.5	51.4	16
		4.9	13.8	7.1	.1	6.6	48.1	47.6	12
	16-24"	4.9	19.0	10.7	0	8.3	43.8	43.8	6
		6.2	20.9	8.7	0	12.1	58.2	58.2	7
	24-32"	7.7	26.5	10.5	.5	15.5	60.4	58.5	2
		8.6	27	14	1.	12	48.2	44.5	1
110°									
	0-8 "	3.0	6.9	5.1	0	1.8	26.7	26.7	13
		4.1	7.8	6.0	0	1.8	23.4	23.4	6
	8-16"	3.5	12.2	6.3	0	5.9	48.7	48.7	16
		4.6	13.8	6.5	.3	7.0	52.7	50.9	12
	16-24"	5.0	19.6	10.0	.1	9.5	49.2	48.6	17
		6.4	21.8	8.4	.2	13.1	61.3	60.3	14
	24-32"	6.6	25.8	9.3	.5	16.0	63.9	61.9	6
		7.3	27.0	7.0	2.0	18.0	74.1	66.7	4

TABLE XI—*Continued*

1	2	4	5	6	7	8	9	10	11
120°									
	0-8 "	2.8	6.6	5.1	...	1.5	22.5	22.5	12
		3.8	7.3	5.1	0	2.2	30.3	30.3	10
	8-16"	3.2	10.0	5.0	.1	4.9	49.5	49.1	21
		4.6	13.2	5.3	.4	7.5	60.0	57.2	11
	16-24"	4.8	19.6	10.6	.1	8.9	46.1	45.8	17
		6.1	20.5	9.5	.2	10.8	53.9	52.8	17
	24-32"	6.2	24.4	10.1	0	18.3	58.5	58.5	8
		7.5	26.8	8.4	1	17.4	68.7	64.9	5
130°									
	0-8 "	3.0	7.2	4.7	0	2.5	34.4	34.4	11
		3.6	7.4	4.8	0	2.6	35.3	35.3	5
	8-16"	3.6	11.8	4.3	.2	7.3	63.6	62.3	21
		5.5	15.2	5.8	.5	8.9	61.7	58.7	11
	16-24"	4.8	19.5	8.0	.2	11.3	59.3	58.1	21
		6.4	22.4	9.0	.4	13.0	59.8	58.2	22
	24-32"	6.1	24.7	8.5	.3	15.8	65.2	64.1	18
		8.0	26.0	9.6	.8	15.6	63.1	60.2	16
	32-40"	6.6	29.3	8.5	1.3	19.5	70.9	66.6	4
		7.9	30.5	11.0	2.0	17.5	64.0	57.4	2
140°									
	0-8 "	2.7	7.0	4.8	0	2.2	31.0	31.0	6
		3.7	6.5	4.0	0	2.5	38.5	38.5	2
	8-16"	3.4	10.8	5.5	0	5.3	48.6	48.6	13
		4.6	10.2	3.2	.2	6.8	68.6	66.7	5
	16-24"	4.5	20.3	5.7	.1	10.6	53.3	52.6	15
		6.2	21.9	8.9	.5	12.5	59.3	56.8	13
	24-32"	6.5	25.8	9.2	.3	16.3	64.5	63.4	37
		7.8	27.7	8.6	.8	18.3	69.1	66.2	37
	32-40"	7.1	30.4	10.2	1.0	19.2	66.4	64.2	11
		8.4	31.3	8.0	2.3	21.0	74.5	67.0	12
150°									
	0-8 "	3.1	7.0	2.5	0	4.5	64.3	64.3	2
		4.8	4.0	1.0	0	3.0	75.0	75.0	1
	8-16"	3.7	11.0	4.5	.1	6.4	59.1	58.0	8
		5.7	15.3	6.3	.8	8.2	59.1	54.1	4
	16-24"	5.6	21.2	6.8	.5	13.8	67.7	65.4	6
		6.9	23.4	7.0	.6	15.8	70.1	67.5	5
	24-32"	6.4	25.6	7.5	.7	17.4	70.6	68.1	28
		8.0	28.7	8.1	.9	19.7	71.7	68.7	40
	32-40"	7.7	31.3	8.9	.4	22.0	71.4	70.1	27
		9.3	32.2	7.5	2.1	22.6	76.0	70.2	29
160°									
	8-16"	2.8	9.0	4.7	0	4.3	48.1	48.1	3
		3.7	10.8	5.4	.2	5.2	50.0	48.1	5
	16-24"	5.8	19.0	9.4	0	9.6	50.5	50.5	5
		7.4	21.2	7.8	.5	12.9	63.0	60.6	6
	24-32"	4.9	26.5	8.4	.5	17.6	68.2	66.4	19
		8.2	29.4	8.4	1.7	18.3	70.5	64.6	13
	32-40"	8.2	31.8	8.3	1.6	21.9	73.8	68.8	49
		9.8	33.6	7.6	3.4	22.6	77.3	67.1	42
	40-up"	10.1	35.7	6.3	4.6	24.8	82.3	69.5	9
		11.4	40.0	8.2	6.3	25.5	79.6	63.7	6

TABLE XI—*Continued*

1	2	4	5	6	7	8	9	10	11
170°									
	24-32"	6.4	28.6	7.4	.5	19.5	69.8	68.1	8
		8.3	20.0	6.3	2.4	22.3	82.6	74.5	9
	32-40"	8.5	33.6	6.6	1.4	25.6	80.4	76.4	20
		10.2	34.5	6.5	5.4	22.6	81.2	77.2	19
	40-up"	10.3	39.0	8.7	5.7	24.6	77.8	63.3	6
		11.7	41.7	6.3	7.4	28.0	84.8	67.2	6

KEY TO COLUMNS IN TABLE XI

1. Angle of shoots.
2. Groups into which shoots are divided.
3. Average length of shoots in inches.
4. Average diameter of shoots in millimeters.
5. Total number of buds for each average shoot.
6. Number of dormant buds for each average shoot.
7. Number of vegetative shoots or branches for each average shoot.
8. Number of fruit spurs for each average shoot.
9. Percent of buds breaking.
10. Fercent of buds forming fruit spurs.
11. Number of shoots included in group.

A comparison of the groups of thick and slender shoots of the same length and angle, such as is made in Table XI, brings out the superiority of those with the larger diameters. They show a higher percentage both of lateral buds breaking and of lateral buds developing into fruit spurs. Wagener is the only variety studied not showing a clear-cut tendency in that direction. This can be explained partly by the fact that all of the shoots of this variety had been headed, those of the others were unheaded. Furthermore, the larger branches were more prone to develop shoots than the small ones and their number lowered the percentage of fruit buds enough to bring it just below the percentage of fruit buds on the more slender shoots. A careful study of the tables indicated that in all the varieties when the slender shoots exceeded the thicker ones in percent of buds breaking, it was only by a very small margin, while when the reverse was the case the margin averaged considerably larger.

INTER-RELATIONS OF SHOOT ANGLES, DIAMETERS, AND LENGTHS

Attention has already been called to the fact that on the average the more upright shoots are longer and thicker than the more horizontal ones. In considering the relation between length of shoots and percentage of lateral buds breaking, comparisons were confined to shoots growing in approximately the same direction, thus eliminating any influence of angle of shoot. Likewise in considering the relation between the diameter of shoots and percentage of lateral buds breaking, comparisons were confined to shoots not only growing in approximately the same direction but also of approximately the same length, thus eliminating any influence of either shoot angle or length. However, in studying the relation between the angle of shoots and the percentage of their lateral buds breaking, shoots of all lengths and diameters were grouped together if only they grew in approximately the same direction. In other words, in that study the influence of length and diameter of shoots was not subtracted from the influence of angle. Since these three factors are so closely linked together, the question at once arises as to whether or not angle of shoot does bear any relation to percentage of lateral buds breaking and to fruit-spur formation that is separate and distinct from the influence of length and diameter. An answer is furnished by the curves in Plates XII and XIII, showing the percentage of lateral buds that break on shoots of approximately the same lengths and diameters. These curves are weighted, that is, they take into consideration the number of frequencies represented by a single point in the curve and then they are smoothed accordingly. Thus, suppose the records showed the average percentage of eight 8"-12" shoots for the angle of 100° to be 40, the average percentage of 20 shoots for the angle of 90° to be 30, and the average percentage of 16 shoots for the angle of 110° to be 35. The point on the curve for the angle 100° will not represent a 40 percent "breaking" of shoots but rather a point determined by the following formula:

$$\frac{(20\times30)+(8\times40)+(16\times35)}{(20+8+16)}$$

In this case such a point would be 34. Thus the curves represent the average influence of angle upon shoots of the same length and diameter. It is worth noting that the general direction of these curves is not materially different from that of those shown in Plate X, where no account is taken of the influence of shoot length and diameter. Angle of shoot is thus seen to be not only more or less of an index to length and diameter of shoot and hence indirectly an index to the percent of lateral buds that break, but in itself bears a direct relation to that tendency,

DISCUSSION OF RESULTS

The facts that have been brought out regarding the characteristics of apple shoots of different angles, lengths, and diameters have an important bearing upon pruning practices. It is evident that shoots growing at a low angle have no superiority over more upright shoots simply because of their angle. As a matter of fact, they are less productive of both side shoots and spurs. When, in pruning, there is opportunity to choose between the two, the more upright ones are very apt to be the better ones to preserve. This depends somewhat upon variety, in the spreading growers the shoots more nearly the mean shoot angle being preferable to either those that are horizontal and drooping or vertical This suggests a fundamental error in attempting to train trees of all varieties in the same uniform manner. Entirely aside from the question of ease of training, some varieties may be expected to do better when their vertical shoots are encouraged; others, when their more oblique shoots are encouraged.

It is a mistaken idea that because shoots are slender and weak, they are prone to be better producers of fruit spurs than those that are longer and thicker. There is a marked correlation between vigor of shoots and their tendency to produce side shoots and spurs. It would probably be as great a mistake in pruning to cut out all the weak shoots, leaving all the strong ones, as it would be to cut out all the horizontal and downward-growing shoots, leaving the upright ones. When the choice may be made between strong and weak ones, however, the former are to be preferred.

SUMMARY

The idea has been frequently expressed in horticultural publications that the angle of a shoot bears an important relation to the percentage of its lateral buds which break and form fruit spurs. The more horizontal or more drooping the shoot, the greater was this tendency supposed to be; and conversely, the more upright the shoot, the less the tendency to form fruit spurs and the greater the tendency to develop side shoots and further wood growth.

Another idea that has been frequently expressed is that strong, vigorous shoots are prone to give rise to further shoot and wood growth and to but few fruit spurs, while the weaker shoots are more prone to give rise to fruit spurs.

A statistical study of 9000 apple shoots has led to the conclusion that while there is a correlation between angle of shoot and the percentage of lateral buds breaking, on the average this percentage is higher in the case of the more upright than in the case of the more horizontal or drooping shoots. Not only is the total percentage of lateral buds breaking higher, but also the percentage of lateral buds that form fruit spurs. In case of the more spreading varieties, it is the shoots that are more nearly the mean shoot angle for the variety that show the highest percentage of buds breaking.

There is a comparatively high degree of correlation between the length of shoots and the percentage of lateral buds breaking and of those forming fruit spurs, the longer shoots being the more productive of both side shoots and spurs.

A certain relationship also exists between the diameter of shoots and the percent of their lateral buds breaking and of those forming fruit spurs. The stouter shoots are the more productive of both side shoots and spurs.

On the average, the more upright shoots are also the longer and the thicker. In other words, there is a positive correlation between the three factors—angle, length, diameter. That each factor is more or less independent of the others, however, in its influence upon the breaking of lateral buds, is indicated by the fact that on the average, shoots of the same length and diameter still show the influence of angle, those of the same angle and diameter still show the influence of length, and those of the same angle and length still show the influence of diameter.

When, in pruning, a choice is presented, it would seem the part of wisdom to preserve those shoots that are long, stout, and more or less upright, or that at least approach the mean shoot angle for the variety.

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EXPLANATION OF PLATES

Plate X, Fig. 28. Average percentage of buds on shoots growing at different angles breaking. Shoots of all lengths.

Plate XI, Fig. 29. Relation of shoot length to percentage of buds breaking. Young Yellow Newtown.

Plate XII, Fig. 30. Relation between shoot angles and percentage of buds breaking. Shoots of uniform length. Young Yellow Newtown.

Plate XIII, Fig. 31. Relation between shoot angle and percentage of buds breaking. Shoots of uniform length, Shiawassee.

Plate XIV, Fig. 32. The way in which typical Grimes shoots growing at different angles produce new shoots and fruit spurs.

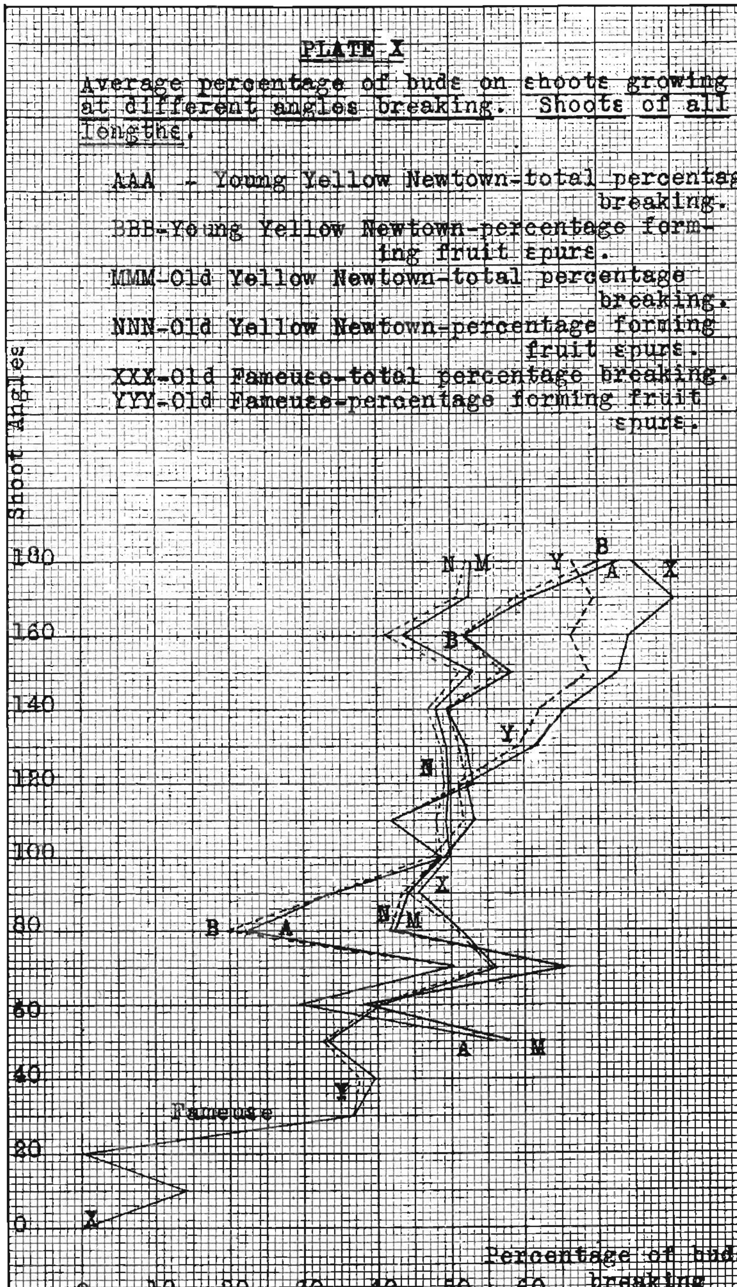

Plate X, Fig. 28.

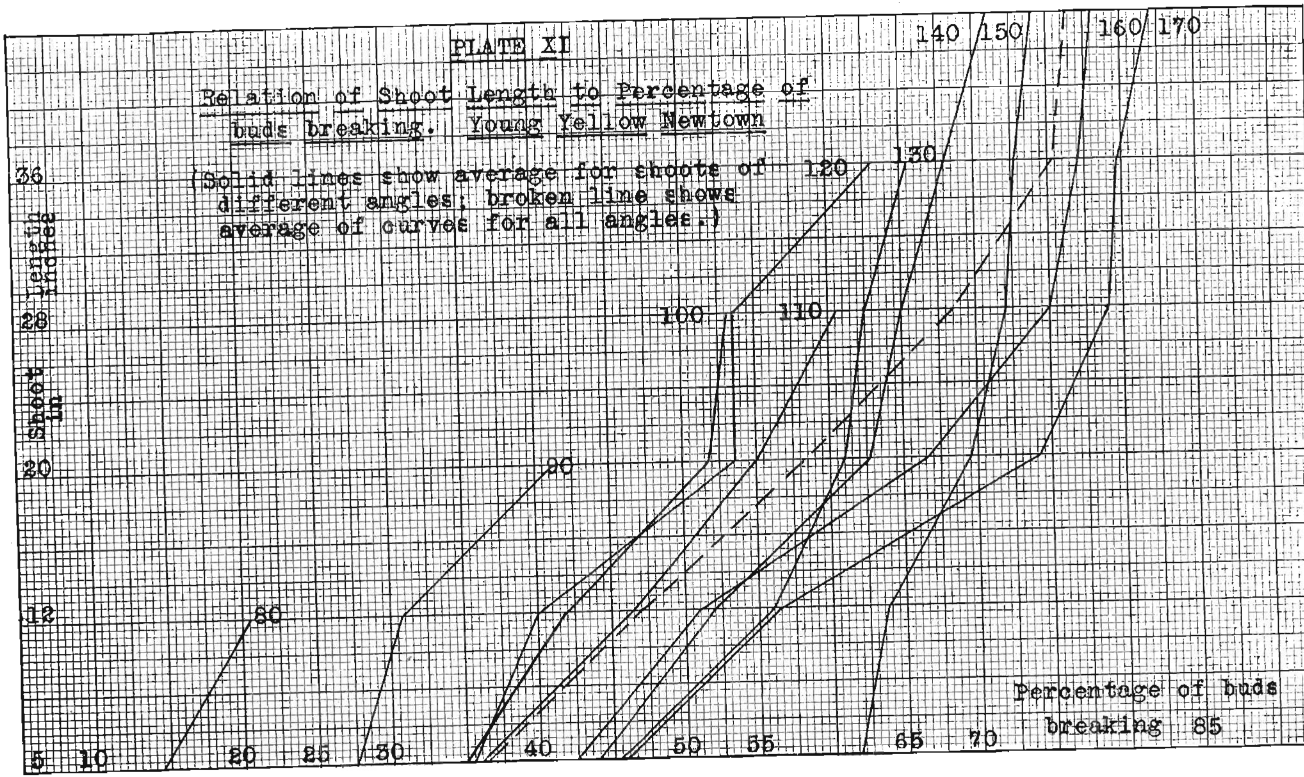

Plate XI, Fig. 29.

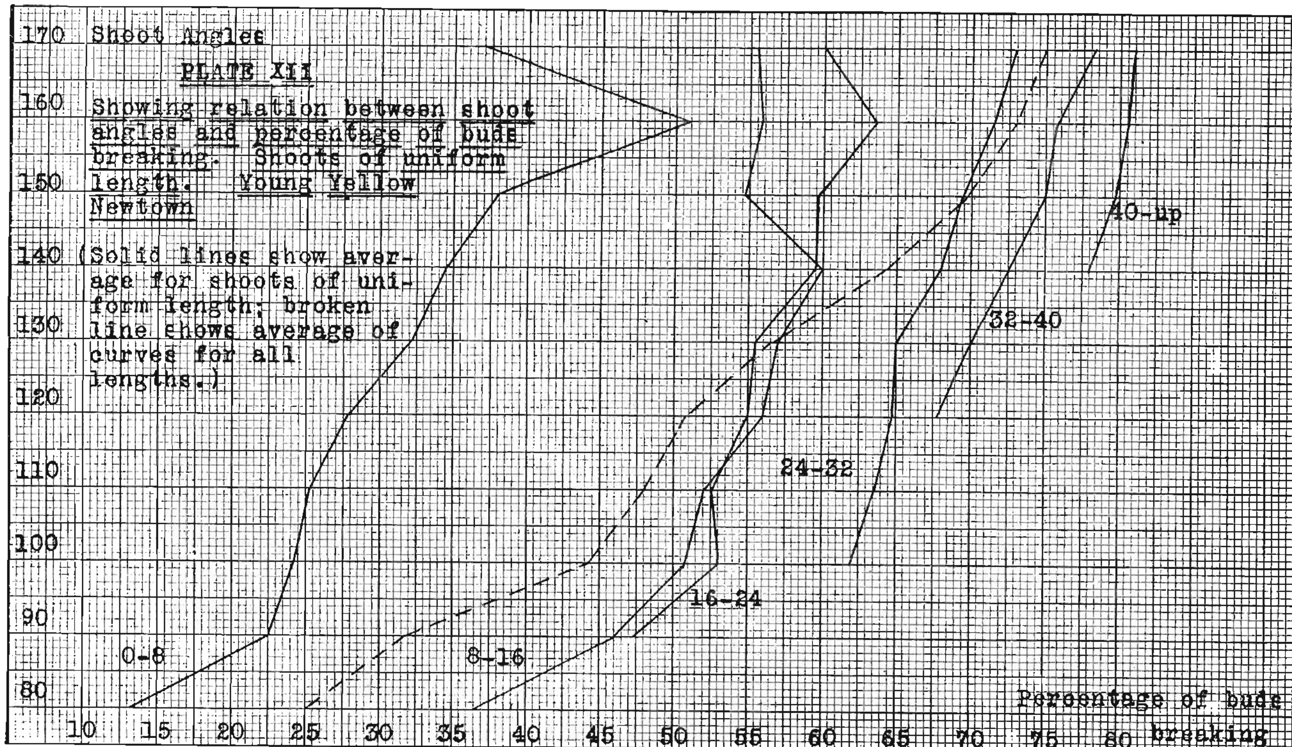

Plate XII, Fig. 30.

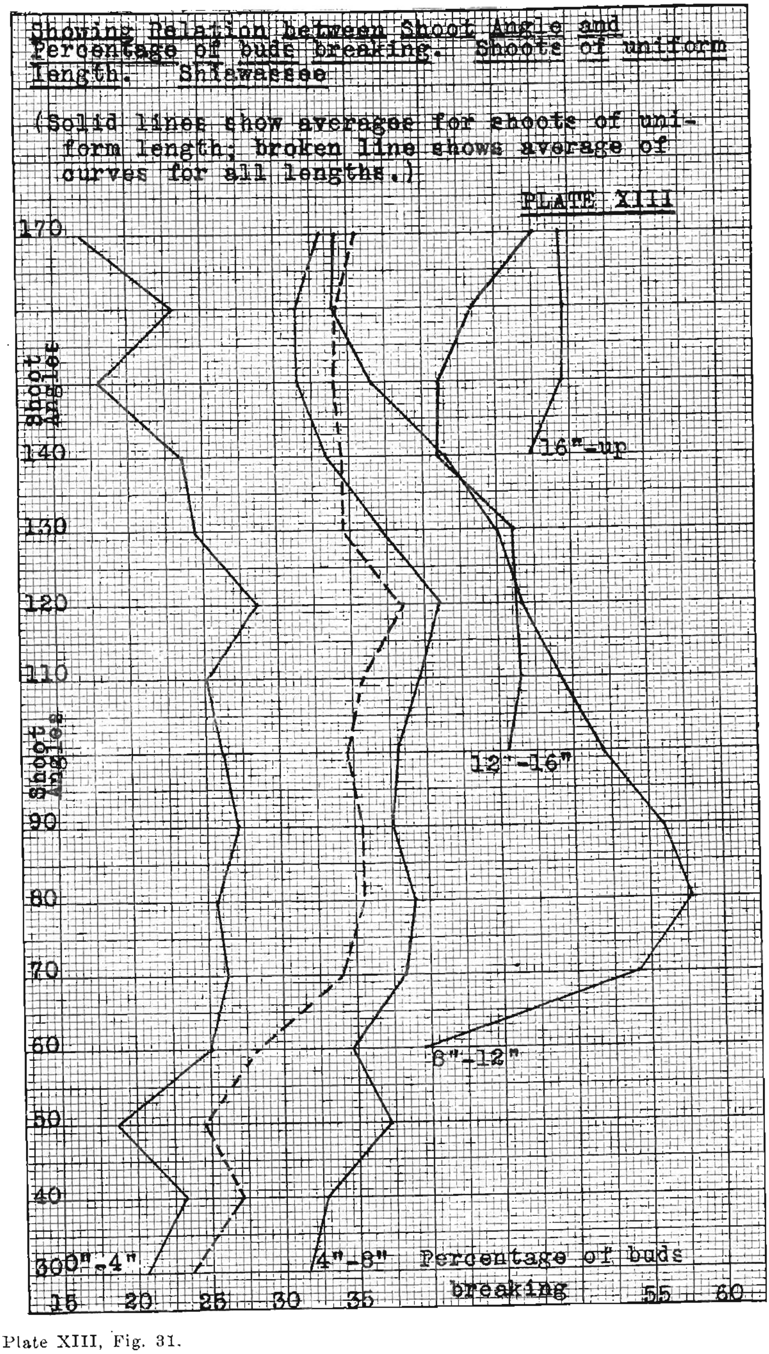

Plate XIII, Fig. 31.

Plate XIV, Fig. 32.

THE INFLUENCE OF BENDING DORMANT SHOOTS UPON THEIR SUBSEQUENT BEHAVIOR

By V. R. GARDNER

INTRODUCTION

The artificial bending of tree shoots is one of the practices that has been more or less in vogue in European horticulture for a great many years. Like many other European practices, it has never found favor among growers in this country, though it might be difficult to tell exactly why. According to many of the early horticultural writers, it has been considered one of the most effective methods of bringing into a fruitful condition, trees or parts of trees, that are prone to produce wood rather than blossoms and fruit. This desirable end was supposed to be brought about through the lower angle (that is, the more horizontal or downward direction) given the shoots and through a checking of the flow of food materials at the point of bending. Thus, bending downward was supposed to weaken the shoot and better fit it for fruit-spur, fruit-bud, and fruit production, it being assumed that vegetative vigor and productiveness are necessarily antagonistic qualities.

The preceding paper by Mr. Edminster shows that, on the average, there is a relation between the percentage of a shoot's lateral buds that break and form side shoots and spurs and the angle at which that shoot may be naturally growing, but, contrary to frequently expressed opinions, it is on the more upright shoots that the greatest percentage of buds break and that the greatest percentage form fruit spurs. Furthermore, it is not the weak shoots that show the greatest tendency to develop side shoots and spurs, but rather those that are strong and vigorous. Hence the questions naturally arise: "Does the artificial bending of shoots tend to make them more or less productive? If it exerts an influence, in the one direction or the other, is it because it makes them weaker, or stronger and more vigorous?"

OBJECT

It is true that for a number of reasons the American fruit grower would be inclined to look unfavorably upon the practice of bending shoots; still it is not impossible that if the results were very striking, the practice might be warranted under certain conditions. The object of the investigation upon which this is a report, has been to ascertain what are the actual results of bending one-year-old apple shoots.

MATERIAL AND METHODS

The orchard in which the investigation was conducted, consisted of 290 Grimes and Esopus (Spitzenburg) trees set at 8x8 foot intervals. At the beginning of the work, the trees were three years old. Though on Doucin roots and supposedly semi-dwarfs, they were really as large and vigorous as first-class standard trees of the same varieties and same age. They were remarkably uniform, a fact probably due to the uniformity of the stocks upon which they were growing and also the uniformity of soil and cultural conditions. Few fruit spurs had been formed up to the time of the beginning of this work with them, owing to the heavy pruning of the first two years, followed by very strong shoot growth. Thus, they presented excellent material for the study in hand.

There were eight rows of Grimes and two rows of Esopus trees, each consisting of twenty-nine trees. The two rows of Esopus and two rows of Grimes were left unpruned; two rows had the terminal buds removed from all of their shoots; each of the shoots on two more rows was given a light to medium heading-back; and each of the shoots of the remaining two rows was given a heavy heading-back. No thinning of shoots was afforded any of the trees. This pruning was done in March, 1915, just as the buds were starting to swell. Before being pruned, each shoot of each tree was marked with a numbered tag, and records were taken of the length, diameter, angle, and number of buds of each shoot. Angles were measured to the closest 5° with a protractor. The direction of the shoot was considered as that of a straight line connecting its base and its terminal. Exact records were then made of the amount of growth removed from each shoot by the pruning. The shoots on one-half of the trees under each pruning treatment were left to grow normally. The shoots of the other trees were bent artificially to either a more vertical or more horizontal position and tied firmly to wires that were strung along the rows. Practically every shoot in these trees was thus bent, though some were bent only slightly. After bending the angles of the shoots were measured again. It will be noted that the shoots were one year old at the time of bending, and that the investigation deals in no way with the bending of shoots during the growing season. Attention is called to this point because it is evidently to the bending of such growing shoots that some, though not all, of the early horticultural writers refer when speaking of the practice.

Attention is called to the fact that in this study of the influence of the bending of shoots upon their later behavior, measurements of length and diameter were taken in centimeters rather than in inches. Furthermore, angles were measured as diverging from an upward, rather than a downward direction. Thus, a shoot growing straight up would be recorded as having an angle of 0° and a shoot growing straight down would be recorded as having an angle of 180°. These changes were made from the methods of recording measurements described in another part of this publication by Mr. Edminster simply because it was found a more convenient system to follow. Such a change in the standards of measurement in no way changes any interpretation to which the records are susceptible.

After the close of the growing season of 1915, records were again made of the diameters of the shoots (measured at the same point as in the spring—approximately 10 centimeters from the base); the number and length of the shoots were determined; and the number of fruit spurs were counted.

PRESENTATION OF DATA

From the records taken, tables were constructed bringing together for purposes of comparison, groups of shoots alike to begin with and either alike or unlike in their treatment, as the case might be. On account of the space that they would require detailed records for each of the 1658 shoots studied will not be presented. Neither is it deemed necessary to include all of the summary tables. Table XII which presents in condensed form the growth record of 284 unheaded Grimes shoots, will serve to illustrate the method of bringing together the data for similarly pruned shoots of any one variety. Corresponding tables were constructed for 436 moderately headed and for 324 heavily headed Grimes shoots, for 373 Grimes shoots with their terminal buds removed, and for 241 unheaded Esopus shoots. It will be noted that the records of the different shoots are so grouped as to show how bent compare with unbent shoots of approximately the same angles, lengths, and diameters. Table XIII is a summary table, showing **average** growth records of unheaded and headed shoots of Grimes and of unheaded shoots of Esopus, both of those that were allowed to grow normally and of those that were bent artificially.

TABLE XII. RECORD OF GROUPS OF NORMAL AND BENT GRIMES SHOOTS (UNPRUNED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0°	6	...	111	111	...	1.18	2.33	1.15	42	42	13	31	640	23	53	84
	8	39°	111	111	...	1.15	2.18	1.03	42	42	13	31	715	20	48	79
5°	12	...	105	105	...	1.12	2.14	1.02	39	39	12	31	528	21	54	85
	10	38°	122	122	...	1.21	2.22	1.01	41	41	10	24	522	23	56	80
10°	10	...	104	104	...	1.07	2.11	1.04	39	39	12	31	514	22	56	87
	20	36°	96	96	...	.98	1.99	1.01	37	37	10	27	480	20	54	81
15°	19	...	94	94	...	.97	1.85	.83	37	37	7	19	321	22	56	75
	12	39°	105	105	...	1.02	1.80	.78	38	38	9	24	410	23	61	85
20°	15	...	84	84	...	.93	1.84	.91	35	35	7	20	328	20	57	77
	18	33°	95	95	...	.97	1.71	.74	37	37	7	19	328	22	59	78
	3	−14°	101	101	...	1.01	1.71	.70	38	38	7	18	262	23	61	79
25°	14	...	79	79	...	.85	1.73	.88	34	34	6	18	272	18	53	71
	16	36°	96	96	...	.92	1.59	.67	36	36	6	17	278	21	58	75
30°	16	...	71	71	...	.79	1.65	.86	34	34	6	18	264	17	50	68
	26	25°	76	76	...	.81	1.45	.74	34	34	4	12	181	20	59	71
	1	− 5°	109	109	...	1.14	2.06	.92	40	40	6	15	290	19	47	62
35°	16	...	66	66	...	.76	1.59	.83	32	32	4	12	221	16	50	62
	10	28°	78	78	...	.79	1.39	.60	30	30	4	13	164	19	63	76
	4	−20°	64	64	...	.70	1.22	.52	28	28	3	11	161	12	43	54
40°	10	...	61	61	...	.72	1.54	.82	30	30	3	10	171	14	47	57
	10	15°	53	53	...	.65	1.32	.67	29	29	2	7	151	12	41	48
	5	−26°	59	59	...	.60	1.20	.60	29	29	3	10	119	16	55	65
45°	3	...	62	62	...	.70	1.50	.80	33	33	3	9	178	16	48	57
	2	20°	61	61	...	.67	1.21	.54	32	32	2	6	103	17	53	59
50°	3	...	39	39	...	.55	1.34	.79	21	21	2	10	147	7	33	43
	3	13°	65	65	...	.73	1.38	.65	32	32	3	9	141	16	50	59
	5	−33°	61	61	...	.70	1.14	.44	31	31	2	6	97	17	55	61
55°	1	...	17	17	...	.45	1.09	.64	15	15	1	7	88	2	13	20
	3	−43°	46	46	...	.59	1.02	.43	26	26	2	8	86	10	38	46
60°	1	...	29	29	...	.51	1.33	.82	20	20	1	5	112	5	25	30
70°	1	−30°	23	23	...	.37	.92	.55	10	10	1	10	71	9	90	100

Note: For key to columns, see footnote to Table XIII.

TABLE XIII. AVERAGE GROWTH RECORD OF NORMAL AND BENT SHOOTS OF ALL ANGLES AND UNDER DIFFERENT PRUNING TREATMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Grimes shoots; unheaded:																
23°	126	...	81.5	81.5	...	.89	1.84	.95	34.6	34.6	6.9	19.9	324	18.5	53.4	73.3
22°	136	31°	89.2	89.2	...	.914	1.637	.723	35.4	35.4	6.7	18.9	325	19.9	56.3	75.2
42°	22	–24°	64.5	64.5	...	.71	1.26	.55	29.7	29.7	3.2	10.8	142	15.5	52.2	63.0
Grimes shoots; terminal buds removed:																
24.5°	184	...	88	88	...	.89	1.72	.83	35.	35.	5.8	16.6	280	19.6	56.	72.6
17.8°	158	33°	93	93	...	.915	1.628	.713	38.	38.	7.	18.4	305	18.7	49.	67.4
34°	31	–19°	75	75	...	.79	1.43	.64	33.	33.	3.8	11.5	174	16.3	49.	60.5
Grimes shoots; headed back lightly to moderately:																
27.3°	248	...	79	54	32	.82	1.52	.70	33.	20.6	5.1	25.	271	9.9	48.	73.
21.4°	140	30.6°	82	57	31	.81	1.54	.73	33.5	22.	5.1	23.	261	10.6	48.	71.
45°	48	–25.5°	56	39	30	.625	1.245	.62	27.3	19.1	2.7	14.	163	8.4	44.	58.
Grimes shoots; headed back heavily:																
31°	180	...	67	27	60	.71	1.37	.66	29.	11.5	3.3	29.	227	4.2	36.5	65.5
28°	104	32°	65	30	54	.70	1.44	.74	30.	13.7	4.1	32.	230	5.	36.5	68.5
47°	40	–30°	61	21	66	.60	1.22	.62	25.	10.9	2.8	26.	171	3.4	31.	57.0
Esopus shoots; unheaded:																
14°	137	...	108	108	...	1.00	1.77	.77	43.	43.	5.8	13.	380	24.	56.	69.
14°	104	?	110	110	...	1.02	1.76	.74	43.	43.	9.2	21.	602	24.	56.	77.

Note:

Column 1=Original angle of shoot; 2=number of shoots averaged; 3=number of degrees the shoots are bent artificially, if preceded by the minus (–) sign, it indicates the number of degrees the shoots are bent up, otherwise the number of degrees they are bent down; 4=length in cm. before pruning; 5= length in cm. after pruning; 6=percent pruning; 7=diameter in cm. at beginning of growing season; 8=diameter in cm. at close of growing season; 9=increase in diameter in cm. during growing season; 10=number of nodes before pruning; 11=number of buds after pruning; 12=number of new shoots formed during growing season; 13=percentage of buds developing into shoots; 14=total new shoot growth in cm. for the season; 15=number of buds developing into spurs; 16=percentage of buds developing into spurs; 17=total percentage of buds breaking.

As might be expected, some of these tables exhibited what appear to be contradictions. For instance, in the table presenting the records for heavily pruned Grimes shoots, it was noted that 36 shoots had an original angle of 30° and 19 an angle of 45°, all in each of the two groups of approximately the same length and diameter. The 14 of the 30° shoots that were artificially bent down or up showed a distinctly smaller increase in diameter than the 22 that were not bent; on the other hand, the eight 45° shoots that were bent showed a distinctly greater increase in diameter than the 11 that were left to grow normally. When all of the data are considered, however, a fairly high degree of uniformity is seen to characterize the behavior of groups of unbent shoots of the same variety and having about the same pruning treatment; and likewise there is a fairly high degree of uniformity characteristic of bent shoots of the same variety and same pruning treatment. Thus, by comparing a relatively large number of corresponding groups of bent and unbent shoots, it is possible to obtain a fairly accurate idea of the influence of bending upon shoot behavior. Probably the best measure of this influence is afforded by the general averages presented in Table XIII.

Attention is called first to the figures in column 17, giving the total percentage of buds that break and develop into either fruit spurs or shoots. While there is a small amount of variation between the different groups, it is evident that on the average as large a percentage of the buds on normal unbent shoots broke as those that were bent downward artificially, and a larger percentage than on those that were bent upward artificially. It will be noted, however, that those shoots that were bent upward artificially were naturally more horizontal than those shoots that were left to grow normally or than the average of those that were bent downward. These two facts explain most, if not all, of the apparent difference in the results that were obtained from bending the shoots upward. Evidence on this point is furnished by a comparison of the average shoots that were bent upward with those that were similarly pruned, grew normally at about the same angles, and were of about the same average length. Thus when differences due to variations in normal angle, length, and diameter are accounted for it is seen that artificial bending had no important influence upon the total percentage of buds breaking. Similarly, it is seen that at least in the case of Grimes shoots, no matter what their pruning treatment, artificial bending exerted very little influence upon the proportion of the lateral buds breaking that developed into fruit spurs and the proportion that developed into shoots. In other words, artificially bent shoots were on the average neither more nor less productive of spurs than normal unbent shoots. Neither were they more nor less productive of new branch shoots, nor were these branch shoots materially longer or shorter than those of normal shoots. In the case of Esopus, however, artificially bent shoots produced a considerably larger number of new branch shoots and as a result more new shoot growth than those that were not bent. Thus, in this variety, artificial bending proved to be a stimulus to wood growth rather than having a weakening effect.

In both of the varieties, however, bending resulted in a change in the relative location of spurs and branch shoots. Normal unbent shoots, whether headed back or not, produced most of their side branches from their upper buds, that is, from the buds nearest their free ends; while most of their spurs were produced from the buds immediately beneath those buds that formed shoots. In the artificially bent shoots, a large percentage of the spurs developed from buds comparatively close to the free end of the shoot, while the new shoots came from buds nearer its base. Of interest also, is the influence of artificial bending upon increase in diameter of shoots. The data bearing upon this point are somewhat confusing. Apparently, however, unheaded and artificially bent shoots showed a greater tendency to increase in diameter than corresponding normal shoots, though the reverse was the case with the headed shoots. It is worthy of note that so far as this point is concerned, it seemed to make little difference whether the shoots were bent up or down. It was apparently the **bending** rather than the new direction given to the shoot that was the cause of a more or less rapid increase in diameter. Just why headed shoots should behave differently from non-headed shoots in this regard, is not apparent at this time.

In the light of the results accompanying the bending of shoots in this investigation, it is rather difficult to understand how the idea that artificial bending tends to weaken shoots and make them more fruitful became current and found expression in so many horticultural writings. Certainly the data presented here would not encourage such an idea. As a matter of fact the bending seemed to cause a slight tendency in the opposite direction. It is suggested that possibly the larger production of spurs that was believed to accompany artificial bending of shoots was really due to the little or no heading that was given the bent shoots, for severe heading was probably the most prominent distinguishing characteristic of former methods of pruning, and artificially bent shoots would naturally be left longer so as to make bending easier. The data obtained in this study show clearly that not only do the unheaded shoots as compared with headed, produce **larger numbers** of spurs because of the larger number of buds available, but that a **larger percentage** of their buds break and form fruit spurs, a fact upon which further data will be presented later. Thus, is it not possible that the artificially bent shoots of many of the earlier horticulturists were more productive, not because of their bending, but in spite of it and because they were accidentally or incidentally left without much severe pruning?

This investigation leads unmistakably to the conclusion that the artificial bending of one-year-old apple shoots does not have a place in present day orchard practice. Even if the expense involved would not make it impracticable, nothing is to be gained from it. Its most important influence is to reverse the relative locations of spurs and branch shoots on any single season's wood that is bent and such a reversal cannot be regarded as worth the cost, if indeed it is in any way desirable.

SUMMARY

The artificial bending of more or less upright shoots so as to bring them to a more horizontal position is a practice that very frequently has been recommended to the fruit grower in order to make his trees more productive.

Detailed records were made of the characteristics of 1658 apple shoots (Grimes and Esopus) at the end of the growing season—these records including measurement of length, diameter, angle, and a count of the number of nodes. Of these, 783 were then artificially bent while still dormant, and fastened in new postions. Suitable records were then made at the close of the growing season as to increase in diameter, amount of new shoot growth, and number of fruit spurs formed.

The data show that on the average the total percentage of buds "breaking" on the artficially bent shoots was practically the same as that on check shoots.

Artificial bending did not materially influence the percentage of buds that formed fruit spurs or the percentage that formed new shoots; though in one of the two varieties studied it proved a stimulus to shoot growth rather than a check.

The artificial bending resulted in a change in the location or distribution of fruit spurs and of new shoots on the shoots of the preceding season. Its general tendency was to increase the number of fruit spurs toward the terminal end of the shoot and decrease them toward the basal end. Conversely, its general tendency was to decrease the new shoot growth from the terminal portion of the shoot and increase it from its basal portion.

THE WINTER HEADING-BACK AND THINNING-OUT OF APPLE SHOOTS IN YOUNG TREES

By V. R. GARDNER

Any pruning that we do in our fruit trees almost necessarily must consist either in thinning-out or in heading-back. Generally, in the actual pruning of any individual tree, both practices are employed. This is true whether it is a heavy or light, a winter or summer, pruning that is given. Decision as to which of the two kinds of pruning mainly to employ, is apt to be based upon quite superficial considerations, rather than upon an accurate knowledge of the exact effects that are likely to follow from the two operations. As a matter of fact, there is available little experimental evidence upon which a wise decision may be based. This is indicated by the fact that different growers are apt to give the same reason for following one or the other of the two practices; or they may give almost diametrically opposite reasons for employing the same practice. On one point there seems to be quite general agreement—that thinning-out, either of new shoots or of older limbs, has the effect of letting more light into the tree, thus aiding coloring the fruit. It is also admitted that perhaps it increases the longevity and regularity of bearing of already established fruit spurs, though it is doubtful if anyone is able to tell how great are these increases. Whether it serves as a check or a stimulus to new spur formation is a debated question. Still greater differences of opinion exist as to the effects that may be expected from heading-back. Does it tend to stimulate or to check new shoot growth? Does it promote or hinder the formation of new fruit spurs? Does it invigorate or weaken already established spurs lower down on the same limb? Are the effects of heading-back into two- or three-year-old wood essentially different from those of heading-back into one-year-old wood? The answers to these and many other closely related questions cannot be said to be established at the present time.

This article deals with certain of these questions; viz., (1) The effect of the winter heading-back of one-year-old shoots upon the subsequent development of spurs and branch shoots from those same shoots; (2) The effect of winter thinning-out upon the development of new spurs on adjacent unheaded shoots; (3) The effects of winter heading-back and of thinning-out upon fruit-bud formation on previously established spurs; (4) The effects of these two methods of pruning upon the formation of terminal and lateral fruit buds on the new shoots of the following season.

MATERIALS EMPLOYED

The same material employed in the study of artificial bending of shoots, and described in detail in connection with the report on that subject, was used for a part of this study. Briefly, this consisted in 1055 Grimes shoots, including all of the 1914 shoots of 133 three-year-old trees that were on Doucin roots. In the spring of 1915, records were made of their diameters and angles, and of their length and number of nodes, both before and after pruning. In the fall of the same year measurements were taken again of their diameters, counts were made of the number of fruit spurs that they had formed, and records were also made of the amount of new 1915 shoot growth springing from the shoots of 1914. Tables were then constructed bringing together the records of shoots headed-back in different ways (i. e., with varying severity).

The investigation also included a study of the 1914-1916 records furnished by 461 trees on Doucin roots—239 Grimes, 46 Gano, 93 Rome, 83 Esopus. These were all three-year-olds in the spring of 1915, at which time records were made of trunk circumference, number of fruit spurs, and amount of shoot growth of each tree and of the exact amounts of shoot growth removed by the early spring pruning at that time. Some trees were left unpruned as checks, others were pruned lightly, others heavily. All pruning done in the spring of 1915 consisted in a heading-back of the shoot growth of the season before. No thinning was done. In the early spring of 1916 corresponding records were made of tree growth and the trees were again pruned, each tree being pruned exactly as severely as it was pruned the year before. That is, each tree that had had, say 32% of its 1914 shoot growth removed in the spring of 1915 had the same percentage of its 1915 shoot growth removed in the spring of 1916. This latter pruning was not limited, however, to heading-back only; but every other tree was headed-back and the alternate ones were thinned out. No single tree was given both a heading-back and thinning-out. It received either the one treatment or the other. As the groups of trees to be compared were uniform to start with, this treatment put to the test the influences upon the **tree as a whole** of heading-back and thinning-out. Suitable records of tree growth were then made in the fall of 1916 and spring of 1917. These included amount of new shoot growth, trunk circumference, number of fruit spurs, and number of fruit buds (as measured by number of flower clusters appearing in the spring of 1917).

TABLE XIV. THE INFLUENCE OF THE HEADING OF SHOOTS UPON THEIR SUBSEQUENT PRODUCTION OF NEW SHOOT GROWTH AND SPURS.—GRIMES.

Amount of heading.	No. shoots averaged.	Length in cm. before pruning.	Length in cm. after pruning.	Diam. in cm. in Feb. 1915.	Diam. in cm. in Nov. 1915.	Inc. in diam. in cm.	No. buds left after prunnig.	No. new shoots formed.	Av. total length new shoot gr. in cm.	Units shoot gr. in 1915 per unit of 1914 shoot length.	Units shoot gr. in 1915 per unit of 1915 shoot length after pruning.	No. spurs formed.	No. spurs per 100 cm. 1914 shoot length.	No. spurs per 100 cm. 1914 shoot length after pruning.	Percent of buds breaking.
No heading.........	126	81	81	.89	1.84	.95	34.6	6.9	324	4.00	4.00	18.5	22.8	22.8	73
Terminal buds removed	184	88	88	.89	1.72	.83	35.4	5.8	280	3.18	3.18	19.6	22.3	22.3	72
10-20%	18	56	47	.66	1.40	.74	22	4	210	3.75	4.47	9	16.1	19.1	59
20-30%	161	78	58	.83	1.53	.70	23	5.1	266	3.41	4.59	11	14.1	19.0	70
30-40%	196	76	50	.77	1.45	.68	20	4.6	245	3.22	4.90	9.9	13.0	19.8	72
40-50%	113	71	39	.75	1.40	.65	16	4.6	261	3.68	6.69	6.6	9.3	16.9	70
50-60%	133	62	29	.71	1.37	.66	13	3.6	217	3.50	7.49	4.8	7.7	16.5	65
60-70%	98	71	25	.74	1.40	.66	11	4.6	231	3.26	9.24	4	5.6	16.0	78
70-80%	26	70	20	.74	1.39	.65	8.6	3.6	229	3.14	11.45	2.7	3.7	13.5	73

PRESENTATION OF DATA

The Influence of Winter Heading-back of Individual Shoots Upon the Subsequent Development of New Shoots

Table XIV summarizes some of the data bearing upon the question of the influence of heading-back upon the performance of individual shoots. Study of this table brings out a number of interesting points. Attention is called first to the figures in column 9, giving the average number of new shoots developing from unheaded and from headed shoots of the year before. The largest number of such shoots spring from the unpruned growth and the smallest number from that most severely headed. Though the figures show some irregularities, it is evident that there is a general tendency toward the developing of a smaller number of shoots as the heading-back increases in severity. From this it might be inferred that severe heading-back has a tendency to check the vegetative growth springing from the headed shoots. That such is not the case, at least in this variety and within the range of severity of pruning here employed, is indicated by the figures in column 10, giving the average total new shoot growth from the headed and non-headed shoots. A still better measure of the influence or lack of influence of heading-back upon total new shoot development is afforded by the figures in column 11, giving the units of new shoot growth for each unit of shoot growth of the preceding year. These figures show also a certain amount of irregularity, (that is, if plotted in the form of a curve, the curve would not be perfectly smooth) but indicate clearly that **on the average** in young trees of this variety it makes little difference how much or how little a shoot is headed-back, from the viewpoint of the total amount of new vegetative growth to which it will give rise. Thus, if conditions are such that a 100-centimeter 1914 shoot will produce a total of 350 centimeters of branch shoot growth in 1915 if left unheaded, it may be expected to produce about that same amount if headed very lightly, moderately, or very heavily—at least when the tree as a whole is correspondingly headed. Why severely headed shoots seem to give rise to more new shoot growth than unheaded shoots of the same size is indicated by the figures in column 12, giving the units of new shoot growth for each unit of old shoot left **after** the heading-back. This is graphically represented in Plate XV. It is to be understood that these statements are intended to apply only to shoots in young trees of the variety studied—Grimes—and to shoots in trees that are correspondingly headed. It is reasonable to assume, however, (and observation tends to verify the assumption) that they are equally applicable to the shoots in young trees of many other varieties. Probably they do not apply exactly to a variety like Esopus, which is very prone to produce new shoot growth mainly from terminal buds, when the shoots of the preceding season are unheaded or only lightly headed. In such a case heading-back acts as a stimulus to, rather than a check upon, new shoot growth.

The Influence of Winter Heading-back of Individual Shoots Upon the Subsequent Development of New Spurs

Of equal interest are the figures of columns 13, 14, and 15 for the spurs produced by headed and non-headed shoots. Column 13 gives the average total number of fruit spurs formed following the different pruning treatments. In this case, the decrease in number of spurs with increase in severity of pruning is very marked—much more marked than the decrease in number of new shoots. Columns 14 and 15 afford a more accurate measure of this decrease in fruit-spur formation with increase in severity of pruning. It is noted that while the amount of new shoot growth produced by headed shoots is closely correlated with the length of the shoots **before** pruning, the number of spurs formed is correlated with the length of shoot growth left **after** pruning. The number of spurs for each unit of shoot length, however, is distinctly less in the case of severely pruned shoots than in the case of those lightly pruned and unpruned. Evidently the lower buds on shoots are less prone to develop into spurs than those higher up, even though they are subjected to the stimulus of heading-back. It is interesting to note that simply the removal of the terminal buds resulted in a slight check to fruit-spur formation, the number of spurs to each unit of shoot length being slightly lower in case of such shoots than in case of the unheaded shoots. It is evident that, at least in this variety, either light or severe heading-back of shoots cannot be regarded as an aid to fruit-spur formation. On the other hand, it acts as a check, an increasingly important check with the increase in severity of heading. Plate XVI, Figures 35-37, illustrates the new shoot and spur production of typical Grimes shoots, uniform to begin with but headed with varying severity.

It is also of interest to note that the total percentage of lateral buds "breaking" is practically the same for non-headed as for headed shoots. The variations in this percentage (column 16) are to be explained as due to the variation in length of shoots, rather than to their pruning treatment.

Influence of the Winter Heading-back and Thinning-out of Shoots upon Subsequent Shoot Development in the Trees as a Whole

The data presented thus far relate to the influence of heading-back of individual shoots upon their own subsequent shoot and spur production. This does not show necessarily that its influence is the same upon the tree as a whole if all of its shoots are headed-back, though it is to be inferred that such is the case. Directly bearing upon this latter question are the records furnished by the 461 Grimes, Gano, Rome, and Esopus trees mentioned in the second paragraph under "materials employed." These records are summarized in Table XV.

TABLE XV. THE EFFECTS OF VARYING AMOUNTS OF HEADING-BACK AND THINNING-OUT OF SHOOT GROWTH IN YOUNG APPLE TREES

Variety.	Number of trees averaged.	Severity of annual winter pruning.	Kind of pruning in spring of 1915.	Average 1914 shoot growth in cm.	Average 1915 shoot growth in cm.	Average number of fruit spurs in fall of 1915.	Average number of units of 1915 shoot growth per unit of 1914 shoot growth.	Kind of pruning ni spring of 1916.	Average 1916 shoot growth in cm.	Average number of units of 1916 shoot growth per unit of 1915 shoot growth.	Average number of fruit spurs in fall of 1916.	Increase in number of fruit spurs during 1916.	Average trunk circumference in fall of 1915 in cm.	Average trunk circumference in fall of 1916 in cm.	Increase in trunk circumference during 1916 in cm.
Grimes	71		No pruning	492	1762	107	3.58	No pruning	3852	2.19	402	295	11.1	15.5	4.4
Grimes	38	1-25%	Thinning	675	2251	128	3.34	Thinning	4713	2.09	457	329	12.0	16.6	4.6
Grimes	32	26-50%	Heading	697	2297	82	3.29	Thinnng	4123	1.80	360	278	12.2	16.7	4.5
Grimes	23	26-50%	Heading	731	2495	83	3.41	Heading	5703	2.28	322	239	12.4	17.0	4.6
Grimes	39	51-75%	Heading	389	1315	22	3.38	Thinning	2308	1.76	130	108	9.2	12.9	3.7
Grimes	36	51-75%	Heading	368	1362	23	3.70	Heading	3328	2.44	101	78	9.1	13.1	4.0
Gano	18	25-50%	Heading	450	2376	15	5.28	Thinning	4577	1.93	158	143	11.2	16.1	4.9
Gano	14	25-50%	Heading	462	2609	14	5.65	Heading	6293	2.41	158	144	11.2	16.6	5.4
Gano	4	51-75%	Heading	560	2493	15	4.45	Thinning	5072	2.03	110	95	11.2	16.3	5.1
Gano	10	51-75%	Heading	562	2435	15	4.33	Heading	5846	2.40	111	96	11.1	16.3	5.2
Rome	28		No pruning	629	2051	38	3.32	No pruning	3520	1.73	142	104	12.7	16.9	4.2
Rome	19	25-50%	Heading	507	1990	9	3.92	Thinning	3352	1.69	43	34	11.3	14.9	3.6
Rome	17	25-50%	Heading	508	1956	10	3.85	Heading	3915	2.00	25	15	11.2	14.9	3.7
Rome	8	51-75%	Heading	1007	2851	9	2.83	Thinning	4785	1.68	54	45	13.5	17.3	3.8
Rome	21	51-75%	Heading	682	2230	8	3.27	Heading	4474	2.01	25	17	11.8	15.5	3.7
Esopus	27		No pruning	583	2121	130	3.64	No pruning	2287	1.08	635	505	11.8	16.1	4.3
Esopus	29	46-76%	Heading	444	1659	28	3.74	Thinning	2122	1.28	180	152	9.9	14.0	4.1
Esopus	27	46-76%	Heading	461	1813	28	3.93	Heading	4031	2.22	144	116	10.2	14.5	4.3

Attention is called first to the 1915 shoot records of all the trees except the 38 Grimes that received a light thinning in the spring of that same year. The figures in column 8, giving the number of units of 1915 shoot growth for each unit of 1914 shoot growth, probably afford the best means of measuring the influence of heading-back the tree as a whole upon the shoot growth of that season. It is noted that except for one group of heavily headed Grimes trees the headed trees of that variety produced relatively a little less shoot growth than the check (unpruned) trees. On the other hand, the heavily headed Esopus trees produced relatively more shoot growth than the check trees. Rome presents rather contradictory results in that lightly headed trees grew relatively more rapidly and the heavily headed trees relatively less rapidly than those unpruned. No Gano trees were left unpruned but those heavily headed grew less rapidly than those lightly headed. In no case was the difference great enough to be regarded as very significant.

Attention is next called to corresponding 1916 figures for certain of these groups of trees—those that were likewise headed-back in the spring of 1916. In each variety where comparison with unpruned trees is possible it is seen that heading-back has resulted in a stimulus to shoot growth. In the case of Rome the stimulus was comparatively small; in Grimes it was moderate; in Esopus it was very great, resulting in more than doubling the rate of growth. Again in the case of Gano the evidence is uncertain, since there were no check trees, but from a comparison of lightly with heavily headed trees it is to be inferred that heading-back of shoot growth is not a very strong stimulus to new shoot growth, at least with this age of tree.

Before attempting an explanation of these results following heading-back, it will be well to see what results have attended equally severe thinning-out afforded in the spring of 1916. It is noted that in the case of Grimes thinning invariably resulted in a check to rate of shoot growth, as compared with unpruned trees. The more severe the thinning the greater was their check. In Rome, thinning was also accompanied by a check in rate of shoot growth, but in this variety the check was comparatively slight. The severely thinned Gano trees grew almost exactly as rapidly as those thinned lightly to moderately; and the severely thinned Esopus trees grew even more rapidly than those unpruned. If now the results following heading-back are compared with those following thinning-out it is seen that, broadly speaking, heading-back acts as stimulus to subsequent shoot growth (as measured by length) and thinning-out as a check, though the stimulus or check is much more pronounced in some varieties than in others.

Shoot length, however, is not necessarily an accurate measure of the total amount of shoot growth formed. The shoots of trees under certain treatments might be long and slender while those under other treatments might be short and stout. It was thought advisable, therefore, to measure diameters of the shoots on average unpruned, headed, and thinned trees. After a somewhat careful study of the question it was thought that a single measurement of the diameter of each and every shoot, taken approximately 10 centimeters from the base of the shoot and midway between two nodes, would give fairly accurate data upon the average shoot diameters of the trees under the several treatments. These data are presented in Table XVI.

TABLE XVI. AVERAGE SHOOT DIAMETERS IN HEADED AND THINNED TREES

Grimes	Row 1 Tree 4	Unpruned	109	.406
Grimes	Row 1 Tree 1	Light thinning	73	.418
Grimes	Row 11 Tree 3	Moderate Thinning	125	.432
Grimes	Row 11 Tree 4	Moderate heading	133	.444
Grimes	Row 15 Tree 7	Heavy thinning	72	.494
Grimes	Row 15 Tree 8	Heavy heading	102	.464
Gano	Row 2 Tree 23	Moderate thinning	94	.505
Gano	Row 2 Tree 2	Mcderate heading	126	.504
Gano	Row 14 Tree 29	Heavy thinning	78	.492
Gano	Row 14 Tree 26	Heavy heading	92	.616
Rome	Row 8 Tree 18	Unpruned	104	.468
Rome	Row 3 Tree 15	Mcderate thinnnig	86	.483
Rome	Row 3 Tree 28	Moderate heading	77	.516
Rome	Row 10 Tree 3	Heavy thinning	95	.489
Rome	Row 10 Tree 26	Heavy heading	80	.527
Esopus	Row 4 Tree 16	Unpruned	51	.496
Esopus	Row 16 Tree 29	Heavy thinning	44	.549
Esopus	Row 16 Tree 24	Heavy heading	76	.567

The first point to note in connection with this table is that, regardless of pruning treatment, average shoot diameters within the variety are comparatively uniform. The shoots of the unpruned trees invariably were a little smaller in diameter than those of trees either headed-back or thinned-out. In most cases the shoots of the headed trees were a little stouter than those of correspondingly thinned trees, though the heavily pruned Grimes furnished an exception to this general rule. The data indicate clearly that the greater length of new shoot growth in headed trees is not compensated for in increased diameter of the shoots in trees that have been thinned.

At first thought, some of the conclusions reached from this study of shoot growth in headed and non-headed trees may seem not to square with the statement made earlier, to the effect that it makes little difference how much or how little an individual shoot is headed so far as the total amount of new shoot growth to which this shoot will give rise. That statement, however, was intended to apply only to certain varieties and for trees receiving a general heading. Nevertheless a more careful analysis of the figures in Table XV finds in them certain additional evidence supporting that conclusion. This is seen when the average units of new (1916) shoot growth for each unit of old (1915) shoot growth of heavily headed trees is compared with the corresponding average for lightly headed trees of the same variety. In Grimes these two figures are 2.44 : 2.28; in Gano 2.40 : 2.41; and in Rome 2.01 : 2.00.

This does not, however, dispose of the question as to why unpruned, and more particularly thinned, trees average fewer units of new shoot growth for each unit of old than those headed back either lightly or heavily. One explanation that will at least partly cover the case of the thinned trees suggests itself. These trees have fewer shoots left and consequently fewer points from which new shoots may start, if we assume that new shoots spring only from normal buds on last year's shoots and further, that only a certain percentage of any one shoot's buds will give rise to new shoot growth. But these two assumptions are hardly warranted. Shoots often spring from dormant or adventitious buds on two-year-old or older wood and from leaf buds on spurs. Furthermore, the statement made earlier to the effect that on the average, any single shoot gives rise to a fairly definite amount of new shoot growth regardless of the kind of pruning it might receive, applies only to shoots in trees that are headed only and not thinned. Study of the data presented in Table XV, particularly the figures in column 11, giving the number of units of 1916 shoot growth for each unit of 1915 shoot growth, shows that the reduction in number of shoots by thinning must have been much more than sufficient to account for the differences in rate of growth between thinned and headed trees. In other words, thinning has resulted in diverting a certain portion of the trees' energies into other shoots, or limbs, or spurs. That all of these diverted energies have not gone into the production of additional shoot growth springing from the remaining shoots of the year before, or springing from anywhere else in the tree, is evident when comparison is made between the units of 1916 shoot growth for each unit of 1915 shoot growth in thinned trees and in unpruned trees. On the average the thinned trees have grown less rapidly than those unpruned; the heavily thinned have grown less rapidly than those lightly thinned. By subtraction does this mean that thinning really results in directly diverting less of the tree's energies into shoot growth and more into spur growth than is normal for the unpruned tree?--and relatively still less into shoot growth and still more into spurs than is to be expected in headed trees? Conversely, does heading directly divert relatively more of the tree's energies into shoot growth and relatively less into spurs than thinning, or than no pruning at all? Not necessarily, for, as will be pointed out later in this article, thinned trees may be expected to average fewer fruit spurs than those unpruned. The evidence leads to the conclusion that the heading-back of shoot growth is effective in leading to increased shoot growth and in checking fruit-spur formation, and that thinning-out tends in the opposite direction—not primarily, because the tree as a whole has so much energy that it must expend in one way or another, pruning affording a means of diverting this energy in the one or the other channel—but rather because thinning preserves a larger percentage of those buds on the median and terminal portions of the shoot that naturally are prone to grow out into strong vigorous spurs; while on the other hand, equally severe heading preserves a larger percentage of the basal buds of the shoot that naturally are prone to grow out into shoots, if they break at all. Additional evidence on this question is submitted by Mr. Magness in another part of this bulletin, bringing out the fact that once-formed spurs are largely dependent upon their own leaf systems, that they are more or less independent of the rest of the tree; and similarly that shoots when once formed are to a considerable extent independent of neighboring shoots or of closely associated spurs.

Influence of Winter Heading-back and Thinning-out of Shoots Upon Subsequent Spur Development in the Tree as a Whole

Mention has been made of the influence of varying amounts of heading-back and thinning-out upon fruit-spur formation in the tree as a whole. The data presented in columns 7, 12, and 13 of Table XV, show that lessened fruit-spur formation is associated with heavy pruning of any kind, whether it be heading-back or thinning-out. The record for the unpruned Grimes trees that may seem to be an exception to tbis statement is not to be regarded as an exception, for the unpruned Grimes averaged smaller in size to start with than those groups that were pruned lightly or moderately, and when all of the figures for that variety are reduced to corresponding figures for trees of the same size, the apparent exception falls into line witb the general rule. The important thing to note in this connection is tbat beading-back is more of a check to fruit-spur formation than the same amount of thinning-out, in the case of Grimes and Esopus—varieties that when young bear mainly upon spurs. On the other hand, trees of Gano and Rome—varieties tbat when young, bear mainly through tbe agency of lateral and terminal buds upon sboots—show little difference between the influence of heading-back and thinning-out upon fruit-spur formation. These statements agree with the conclusions that were drawn from a study of the influence on beading-back upon individual shoots.

Influence of Winter Heading-back and Thinning-out Upon Subsequent Fruit-Bud Development

Tbe student of pruning is interested not only in shoot and fruit-spur development, but in what those sboots and fruit spurs actually do, wbat they produce in the way of fruit buds and fruit. As fruit-bud formation is a fairly accurate index to the trees' possibilities in fruit production, records were made in the spring of 1917 of the number and distribution of fruit buds on each of the 461 trees included in the investigation and under varying pruning treatments. These records were not made until the buds were unfolding so that there would be no mistake as to their real character. Table XVII presents these records in condensed form.

TABLE XVII. INFLUENCE OF VARYING AMOUNTS OF THINNING-OUT AND HEADING-BACK OF SHOOT GROWTH IN YOUNG APPLE TREES UPON FRUIT-BUD FORMATION

Variety.	Kind of Pruning.	Severity of pruning.	No. of Trees averaged.	Average No. of fruit spurs possessed by trees in fall of 1916	Average No. of fruit spurs flowering in spring of 1917.	Average No. of shoots flowering terminally in 1917.	Average No. of lateral flower buds in spring of 1917.	Average total No. of flower buds formed during summer, 1916
Grimes	No pruning		71	402	29.5	2.7	5.0	37.2
Grimes	Thinning	1-25	38	457	24.8	3.9	4.6	33.3
Grimes	Thinning	26-50	32	360	31.7	2.6	10.0	44.3
Grimes	Heading	26-50	23	322	8.9	7.4	2.2	18.5
Grimes	Thinnnig	51-75	39	130	18.0	.9	6.2	25.1
Grimes	Heading	51-75	36	101	.1	1.3	1.0	2.4
Gano	Thinning	25-50	18	158	12.9	59.3	31.6	103.8
Gano	Heading	25-50	14	158	14.8	65.0	16.4	96.2
Gano	Thinning	51-75	4	110	8.5	43.5	15.0	67.0
Gano	Heading	51-75	10	111	14.6	53.6	13.7	81.9
Rome	No pruning		28	142	31.6	3.5	72.4	107.5
Rome	Thinning	25-50	19	43	5.6	1.3	47.5	54.4
Rome	Heading	25-50	17	25	5.2	5.3	21.9	32.4
Rome	Thinning	51-75	8	54	5.0	2.6	51.7	59.3
Rome	Heading	51-75	21	25	3.5	2.8	6.4	12.7
Esopus	No pruning		27	635	41.9	.3	10.4	52.6
Esopus	Thinning	41-76	29	180	17.2	.1	7.2	24.5
Esopus	Heading	46-76	27	144	11.4	2.1	17.6	31.1

Attention is called first to the average total number of fruit buds formed under the several pruning treatments. The check (i. e., unpruned) Rome and Esopus trees averaged a larger number of fruit buds than the groups of the same varieties under any of the pruning treatments. This was not true of Grimes, in which variety the moderately thinned trees averaged somewhat higher. It is only in the case of Grimes, Rome, and Gano that the data afford evidence on the relation between the severity of pruning and fruit-bud formation, and in Grimes the evidence is somewhat conflicting. The conclusion seems warranted, however, that regardless of variety, very heavy pruning is accompanied by lessened fruit-bud formation; though the data suggest that light or moderate pruning, if of the right kind, as compared with no pruning at all, may lead to increased fruit-bud production.

Of greater significance is the evidence afforded on the comparative influence of heading-back and of thinning-out. The moderately thinned Grimes trees were somewhat more than twice as productive of fruit buds as the correspondingly headed trees; the heavily thinned Grimes trees were ten times as productive of fruit buds as correspondingly headed trees. The moderately thinned Rome trees were nearly twice and the heavily thinned, nearly five times as productive of fruit buds as those correspondingly headed. On the other hand, moderately thinned Gano trees produced but slightly more fruit buds than those moderately headed, and heavily thinned trees of this variety averaged distinctly fewer buds than those heavily headed. The last statement also holds true of the heavily pruned Esopus trees. A more detailed study of the table brings out a number of additional points. In the first place, it is noted that thinning, as compared with an equally severe heading, almost invariably led to an increased production of fruit buds upon fruit spurs. The one exception to this statement is furnished by the heavily headed Gano trees, a variety in which severe heading of short shoots in the interior of the tree seems often to have the effect of forcing the development of strong fruit spurs from the remaining lateral buds. The short interior shoots of the other varieties do not show such a tendency to respond to severe heading in this way. Heading-back was invariably accompanied by a greater development of terminal fruit buds on shoots than thinning-out. In the case of a variety like Gano, that when young bears a large percentage of its fruit buds in this way, this effort may be sufficient to give the tree a larger total number of fruit buds than correspondingly thinned trees. Attention is called, however, to the fact that a continuation of the winter heading year after year would remove the fruit buds on all the shoots headed and thus actually result in decreased flower and fruit production as compared with thinning.

Another point worth noting, but not brought out in the table, is the fact that the shoots bearing terminally average much shorter in the thinned than in the headed trees. They are generally so placed, moreover, that in the thinning of shoots they can be left to advantage while sterile ones are taken out.

Except for Esopus, winter thinning of shoots, as compared with heading, led to greatly increased production of lateral fruit buds on shoots. In the case of the heavily pruned Rome trees, the proportion of such lateral fruit buds was 8 to 1 under the two pruning treatments. Furthermore, the distribution of these lateral fruit buds is such that a given heading-back (for instance, 50 percent) would remove a much larger percentage than an equally severe thinning out. This percentage, in the case of Esopus, would be enough greater more than to counterbalance the effect upon total fruit production of larger numbers of such lateral fruit buds.

Taking all these facts into consideration, it is evident that the effect of thinning-out and likewise of heading-back upon fruit-bud formation varies greatly with the variety. The pruning practice that will lead to the largest fruit-bud production in one variety will not necessarily lead to it in another. Thus it becomes important for the grower to become better acquainted with the exact fruiting habits of his varieties under his conditions as well as to the response that these varieties make to various pruning practices.

Influence of Winter Heading-back and Thinning-out Upon Subsequent Increase in Trunk Circumference

The records in columns 14, 15, and 16 of Table XV, giving the average trunk circumferences of the groups of trees under the different pruning treatments are interesting in that they raise certain questions rather than that they lead to very definite conclusions. They show that on the average there is little difference in increase in trunk diameter between young trees that are headed and those that are thinned. Such differences as appear are in favor of the headed trees. Does this mean that increase on the part of the trunk is closely associated with amount of new shoot growth produced by the top? If so, one would expect to find a greater difference than actually appears between groups of the thinned and headed trees. Or does it indicate that increase in trunk girth is closely correlated with the leaf area of the tree and that on the average the young apple trees that were headed possessed more active leaf surface than those that were thinned? The data at hand do not enable even an approximate answer to these questions.

Application to Pruning Practice

Attention may well be called to certain general applications of the points that have been brought out. It is evident that from the viewpoint of both fruit-spur and fruit-bud formation many orchard trees from three to seven or eight years old are pruned too severely. Lighter pruning—pruning that does not remove more than 20 to 40 percent, depending upon age and condition—will lead to increased fruit-spur and fruit-bud production and tend to bring the trees into moderate or heavy bearing earlier. It is also evident that for the same reasons there should be relatively less heading-back and more thinning-out of shoots than is the common practice. Though a single heading-back may lead to an actually increased fruit-bud production in certain varieties as compared with corresponding thinning-out, subsequent pruning of the same kind largely removes what has been gained, and before there is opportunity to obtain the benefits that might be derived from it. This is not to be construed as a recommendation against all heading-back of shoot growth in apple trees of the ages indicated. As a matter of fact, the data point to the conclusion that such heading-back is often desirable. It is indeed fortunate that heading-back Esopus shoots does not have the effect of **greatly** reducing the number of fruit buds on spurs lower in the tree; for with that variety considerable heading-back is necessary from the viewpoint of correcting its slender, willowy, pole-like manner of growth. Similarly the heading of many of the interior shoots of such varieties as Gano may be expected to lead to an actual increase both in number of fruit spurs and fruit buds. Probably it would be an overstatement of the case to say that winter thinning-out should be regarded as the **general** type of pruning for apple trees of the age indicated and that winter heading-back should be looked upon as a **special** practice, frequently useful but not so generally necessary. Yet such a statement would outline a method of procedure that undoubtedly would yield better results than certain other methods of procedure that are often followed. It is unsafe, however, to attempt to frame a rule, or to follow any rule that might be framed, on such a question as the relative amounts of heading and thinning to afford young apple trees.

Subordinating Shoots by Unequal Pruning

The figures presented in Table XIV seem to indicate in a general way that little can be done to subordinate or encourage by a single pruning the relative positions of a single shoot in the economy of a tree. Whether we prune back a shoot heavily or lightly or not at all, it gives rise to just about the same amount of new shoot growth. The data presented in that table, however, are for shoots in general, rather than for shoots in the same trees and pruned with varying severity. That is, the majority of the lightly pruned shoots were in trees that were pruned lightly and the majority of the heavily pruned shoots were in trees that were pruned heavily. Consequently, the table does not afford a definite answer to the question as to whether or not the relative importance in the tree of certain shoots may be increased or diminished by a single heavy or light heading-back. That a fairly definite answer to that question may be had, a table was constructed for the shoots of two groups of Grimes trees—a group of trees headed from 30 to 45 percent and a group headed from 50 to 75 percent.

Table XVIII presents a summary of the data thus assembled.

TABLE XVIII. THE INFLUENCE OF HEADING UPON THE ENCOURAGEMENT OR SUBORDINATION OF SHOOTS IN TREES THAT ARE PRUNED ALIKE

Amount of heading	No. shoots averaged.	Length in cm. before pruning.	Length in cm. after pruning.	Diam. in cm. in Feb. 1915.	Diameter in cm. in Nov. 1915.	Increase in diam. in cm.	Av. total new shoot growth in cm.	Units of shoot growth in 1915 per unit of 1914 shoot length.	No. spurs formed during 1915.	No. spurs formed during 1915 per 100 cm. 1914 shoot length left after pruning.
Grimes—trees headed 30-45%										
5-10	7	29	26	.47	1.07	.60	137	4.73	7	27
11-15	6	46	40	.59	1.19	.60	161	3.50	8	20
16-20	14	59	48	.67	1.44	.78	225	3.81	9	18.7
21-25	60	81	61	.85	1.59	.74	277	3.42	12	19.2
26-30	85	75	61	.78	1.50	.72	255	3.33	10	16.4
31-35	92	78	52	.79	1.44	.65	245	3.14	9.5	18.3
36-40	59	78	49	.78	1.44	.66	251	3.22	10	20.4
41-45	26	84	48	.82	1.51	.69	290	3.45	10	20.8
46-50	6	86	45	.88	1.53	.65	285	3.31	11	24.4
51-55	5	98	46	.90	1.53	.63	139	1.42	12	26.1
56-60	3	97	40	.75	1.42	.67	250	2.58	9	22.5
61-65	2	49	19	.50	1.04	.54	166	3.39	9	47.3
Grimes—trees headed 50-70%										
10-39	6	38	25	.48	1.11	.63	147	3.87	5	20.
40-44	21	54	31	.64	1.33	.69	220	4.08	5	16.1
45-49	36	62	33	.68	1.39	.71	236	3.81	5	15.2
50-54	45	61	29	.69	1.41	.72	219	3.59	4.6	15.9
55-59	62	62	27	.70	1.39	.69	220	3.55	4.7	17.4
60-64	47	69	27	.71	1.46	.74	252	3.65	4.5	16.7
65-69	34	76	25	.78	1.50	.72	263	3.46	2.7	14.8
70-74	20	71	21	.77	1.50	.73	263	3.70	2.7	12.9

From simply glancing at the figures in this table, it is difficult to tell whether or not severe heading of shoots tends to subordinate them. That there is such a tendency becomes evident when the figures in column 9 giving the number of units of new shoot growth for each unit of old are plotted in the form of a curve and the curve smoothed. This tendency is not a very strong one in this variety and within the range of pruning (0—74%) employed with these particular trees; nevertheless it is distinct enough to be of some significance. Furthermore, it is evident that **continuing** the heavy heading-back of the shoot growth for **several years** would quickly subordinate the position in the tree of such a shoot or limb, provided, of course, that the other portions of the tree were pruned less severely. The severely headed shoot produces no more new shoot growth than the lightly headed or unheaded shoot of the same size to compensate for that cut away. Consequently, the greater the difference between the severity of continued heading-back in two portions of a tree the more rapid will be the subordination of the one part and the dominance of the other. Though seemingly a matter of little importance, proper attention to the principle here involved would aid greatly in the proper shaping of trees. It would not only enable the grower to correct trees that become one-sided and unbalanced because of certain limbs growing at the expense of and out of proportion to other parts, but would enable him largely to avoid the bad crotches arising from the continued equal pruning of two or more limbs starting from approximately the same point.

SUMMARY

A statistical study of 1055 individual Grimes shoots in young trees upon winter heading-back warrants the following statements:

In general, heading the individual dormant apple shoot decreased the **number** of new branch shoots to which it gave rise, this decrease in number of new shoots being greater with increase in severity of heading.

In this variety, heading-back, within the range employed (i. e., 0—80%) exerted comparatively little influence upon the **amount** of new shoot growth to which the individual shoot gave rise. In other words, the amount of new shoot growth to which a shoot will give rise the following year is correlated with the length before pruning rather than with its length after pruning or with the amount or severity of the pruning it may receive. There is reason to believe that in some varieties, it acts as a stimulus to shoot growth.

Heading-back resulted in a decrease in number of fruit spurs to which the individual shoot gave rise, the decrease being more marked with increase in the severity of heading. In other words, fruit-spur formation on the individual shoot is correlated with the length of the shoot after, rather than before, pruning.

Though the new shoot growth produced by headed shoots tended to be closely correlated with the size of the original shoot, rather than with what is left of the shoot after heading, the data show that comparatively severe heading tended to subordinate its relative position in the tree. The effects of continued severe heading are cumulative and consequently it is comparatively easy to check or make more important one part of the tree that is growing too rapidly or too slowly.

A statistical study of the comparative effects of winter heading-back and of thinning-out in 461 young apple trees, including trees of Grimes, Gano, Rome, and Esopus, warrants the following statements:

Broadly speaking, a general heading-back of the shoots of a tree acted as a stimulus to new shoot growth, resulting in an increase in number of units of new shoot growth for each unit of old, as compared with unpruned trees. The amount of this stimulus varied considerably with variety.

On the other hand, an equally severe thinning acted as a check to new shoot growth, resulting in a decrease in number of units of new shoot growth for each unit of old, as compared with unpruned trees. The amount of this check varied considerably with variety.

Lessened fruit-spur formation accompanied winter shoot pruning of any kind—either thinning-out or heading-back. In the case of profuse spur-bearing varieties, like Esopus and Grimes, heading-back resulted in a much more marked check to fruit-spur formation than equally severe thinning-out. This was not so true with those varieties like Gano and Rome that when young bear a larger percentage of their fruit buds laterally upon shoots.

The comparative effects of thinning-out and of heading-back upon fruit-bud formation varied considerably with the variety. In general, it was found that thinning led to an increased production of fruit buds upon spurs, as compared with equally severe heading. On the other hand, heading generally led to an increased production of fruit buds terminally upon shoots. In some varieties, thinning was accompanied by a greater production of lateral fruit buds on shoots than equally severe heading; in other varieties the reverse was the case. Considering the comparative effects of thinning-out and of heading-back, not only upon fruit-bud formation, but upon fruit-bud removal as well, it is evident that the continuation of the former practice tends to increase flower and fruit production, while the latter tends to decrease those functions.

There was little difference between the effects upon increase in trunk circumference of winter heading-back and winter thinning-out.

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EXPLANATION OF PLATES

Plate XV, Fig. 33. Relation between severity of heading-back and spur formation.

Fig. 34. Relation between severity of heading-back and new shoot growth.

Plate XVI, Figs. 35-37. Typical Grimes shoots, of practically the same length, angle, and diameter in the spring of 1915, taken in the fall of the same year. Figure 35 shows the shoots and spurs developing from an unheaded shoot; Figure 36 shows the shoots and spurs developing from a moderately (34%) headed shoot; Fig. 37 shows the shoots and spurs developing from a heavily (60%) headed shoot.

Fig. 38. A typical Grimes in the spring of 1916 that had not been pruned the preceding season.

Fig. 39. A photograph of the same tree shown in Fig. 38, taken in the fall of 1916. These two pictures show typical development of young Grimes trees when left unpruned.

Plate XVII, Figs. 40-41. Typical Grimes in the fall of 1915. The **preceding** spring both received a rather moderate heading-back. The **following** spring the tree shown in Fig. 40 was given a moderate (35%) heading-back; and the tree shown in Fig. 41 was given a moderate (31%) thinning-out.

Fig. 42. A photograph, taken in the fall of 1916, of the tree shown in Fig. 40. It shows a typical response of this variety to moderate heading-back.

Fig. 43. A photograph, taken in the fall of 1916, of the tree shown in Fig. 41. It shows a typical response of this variety to moderate thinning-out.

Plate XVIII, Figs. 44-45. Typical Grimes in the fall of 1915. The preceding spring both received a rather heavy heading-back. The **following** spring the tree shown in Fig. 44 was given a heavy (66%) heading-back; and the tree shown in Fig. 45 was given heavy (67%) thinning-out.

Fig. 46. A photograph taken in the fall of 1916 of the tree shown in Fig. 44. It shows a typical response of this variety to heavy heading-back.

Fig. 47. A photograph, taken in the fall of 1916 of the tree shown in Fig. 45. It shows a typical response of this variety to heavy thinning-out.

Plate XIX, Figs. 48-49. Typical Gano trees in the fall of 1915. The **preceding** spring they both received a moderate heading-back. The **following** spring the tree shown in Fig. 48 again received a moderate (34%) heading-back; the tree shown in Fig. 49 received a moderate (37%) thinning-out.

Fig. 50. A photograph, taken in the fall of 1916, of the tree shown in Fig. 48. It shows a typical response of this variety to moderate heading-back.

Fig. 51. A photograph, taken in the fall of 1916, of the tree shown in Fig. 49. It shows a typical response of this variety to moderate thinning-out.

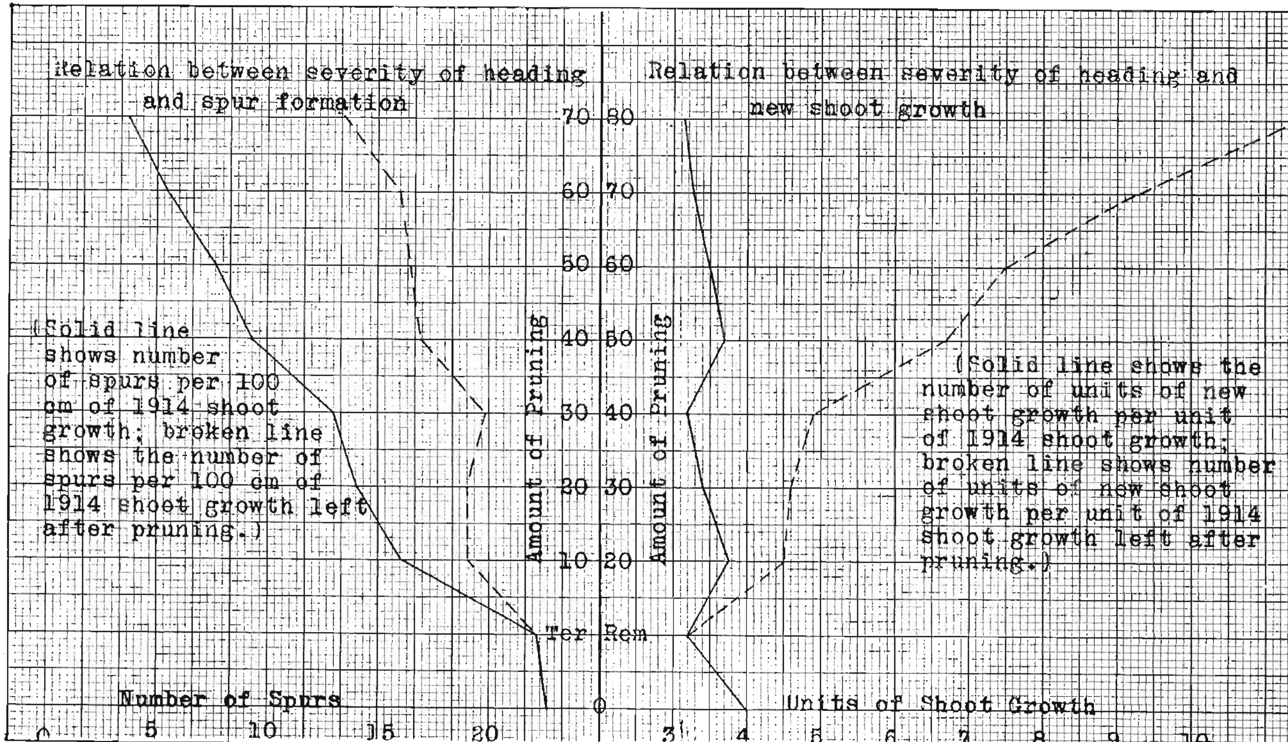

Plate XV, Figs. 33-34.

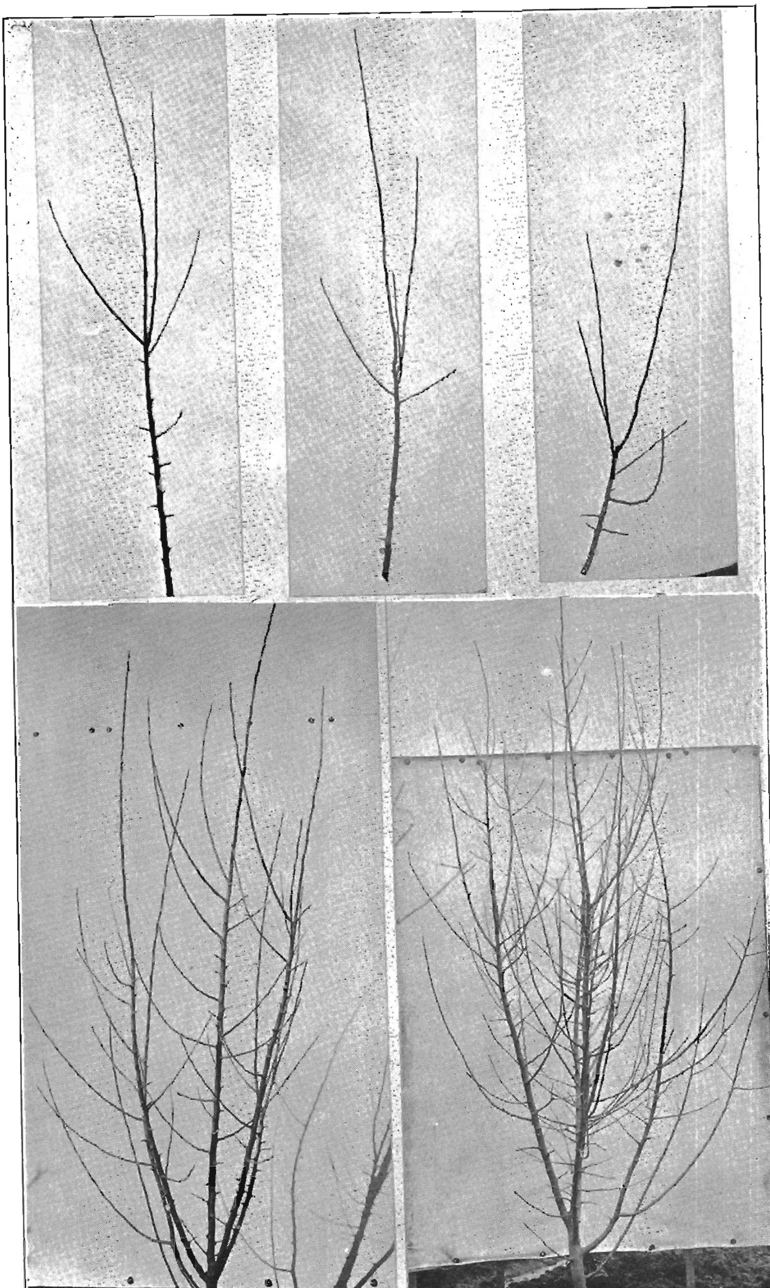

Plate XVI, Figs. 35-39.

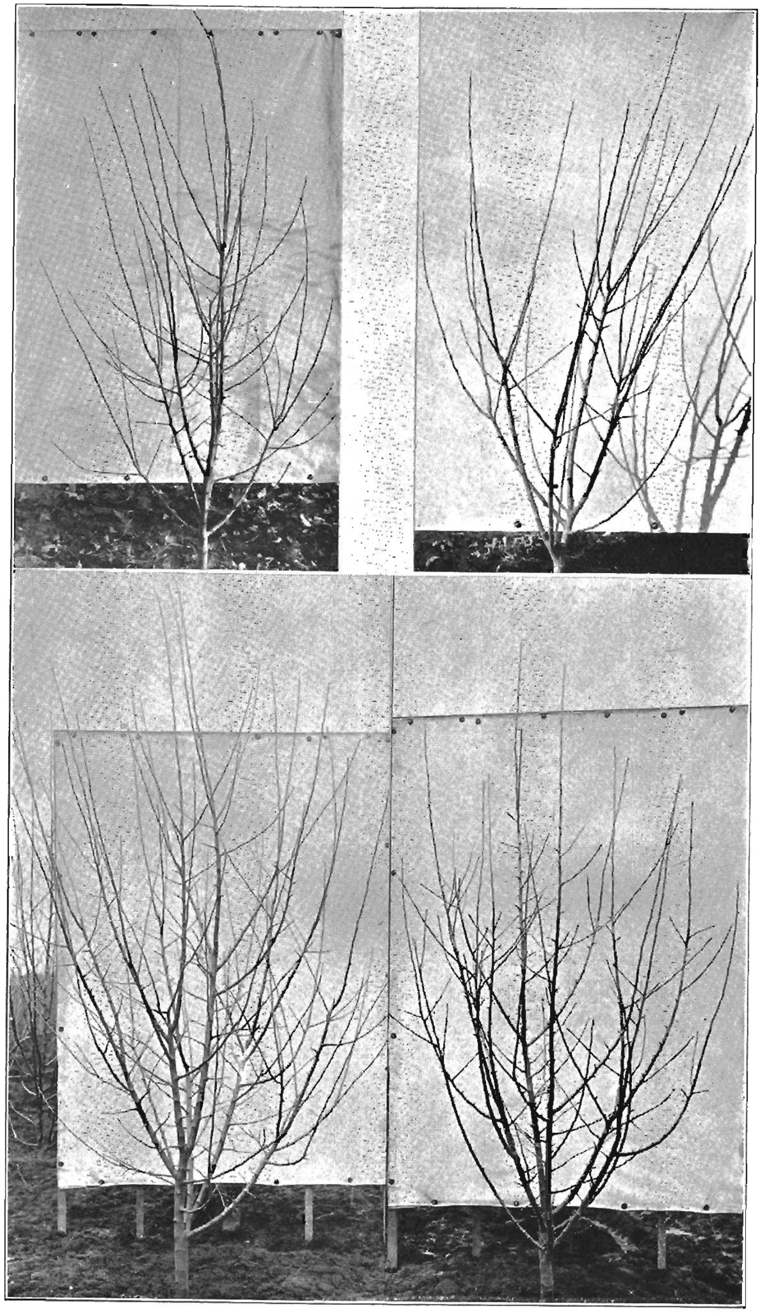

Plate XVII, Figs. 40-43.

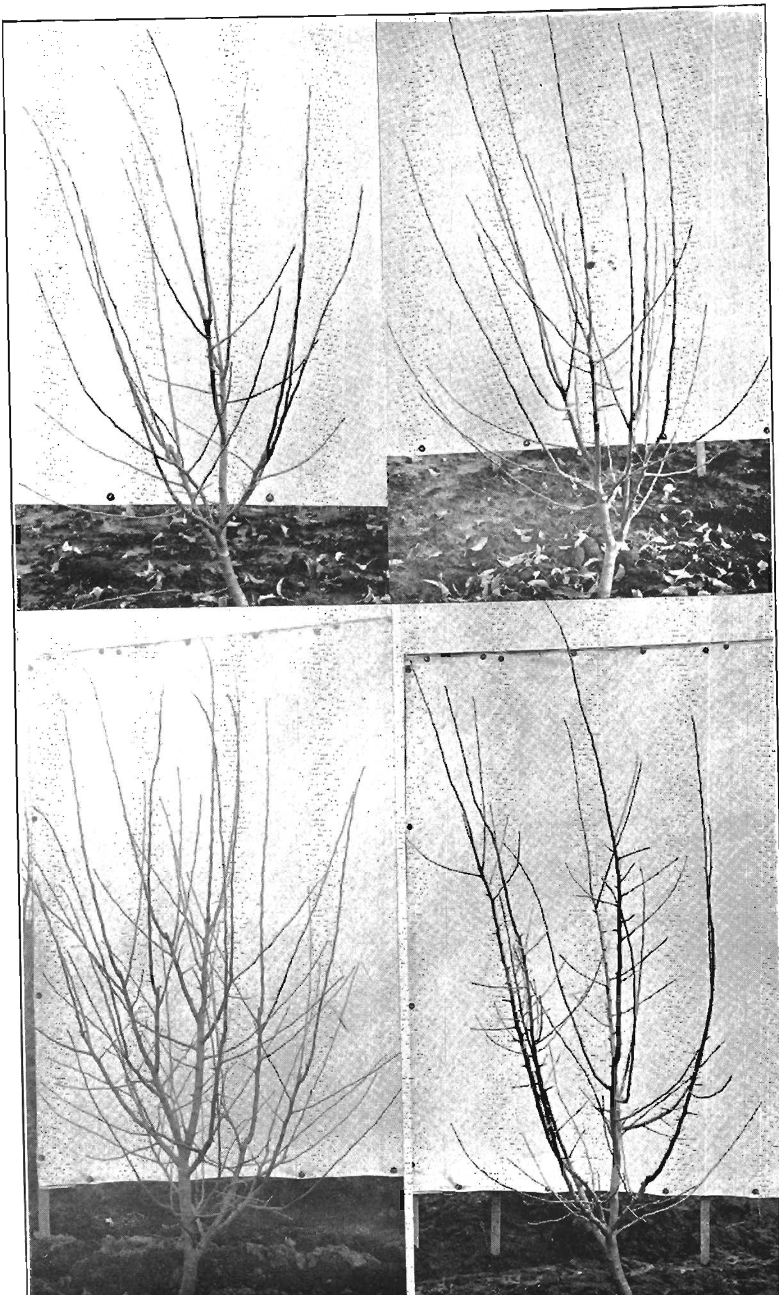

Plate XVIII, Figs. 44-47.

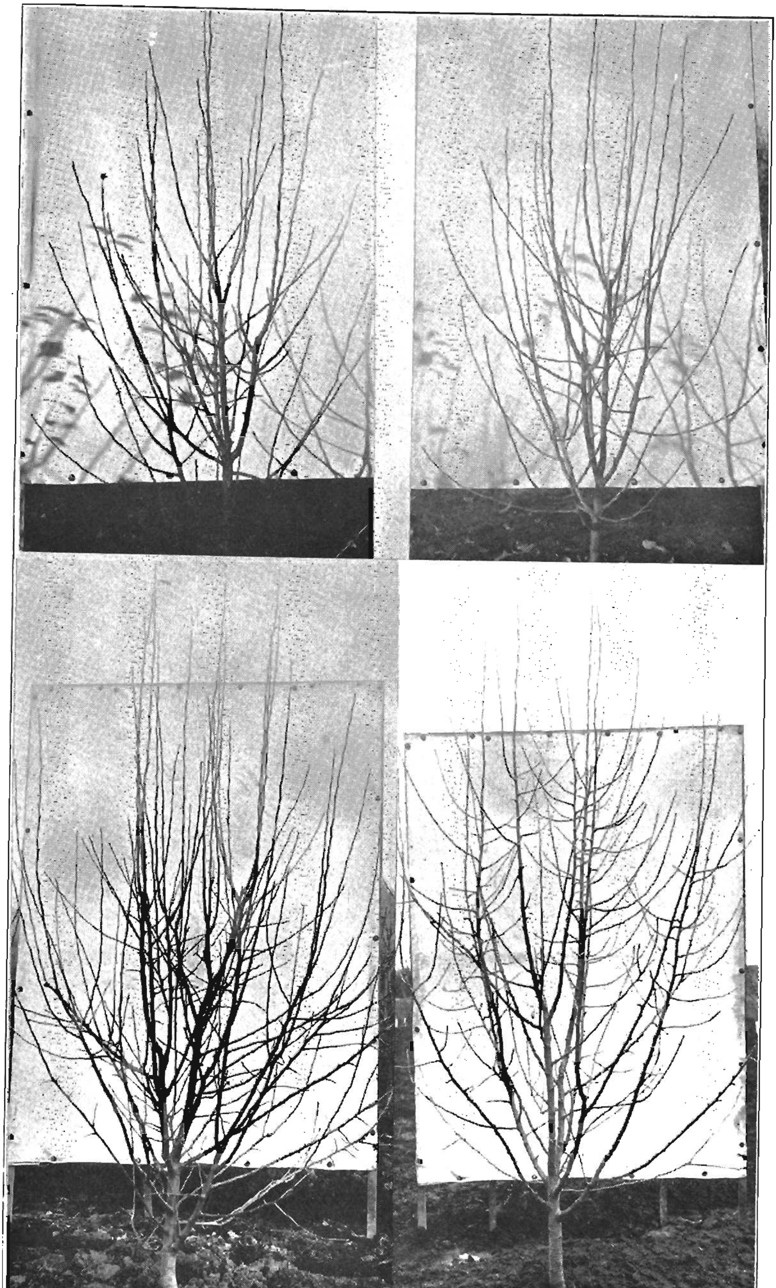

Plate XIX, Figs. 48-51.