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Hardiness Investigations With the Apple

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Hardiness Investigations With The Apple

(*Pyrus Malus*, Linn.)

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Investigations on winter injury to plants and means of increasing hardiness have been conducted at the Missouri Experiment Station for many years. This report is the result from the continuance of such investigations.

Winter injury to fruit trees may occur to various portions of the tree. It is generally thought that hardiness is, to some extent at least, correlated with the total supply and storage of food materials in the fall. Treatments which tend to favor an accumulation of food materials in the above ground portions of the tree might, therefore, be expected to increase the hardiness of those parts.

METHODS USED

The following is an outline of the methods used in this investigation in seeking to influence the amount of stored material in the above ground portions of the tree.[2*]

1. Ringing (girdling) of bearing trees just above the crown before dormancy.
2. Trenching around bearing trees at a radius of 7 to 9 feet from the trunk, 20 inches deep, before dormancy.
3. Defoliation of branches of young trees before dormancy.

Severing the phloem at the crown should increase the deposit of carbohydrates above the girdle. Likewise, it would seem that severe root pruning should leave more carbohydrate material to be stored in the above ground parts.

In this study winter injury and its prevention have been limited to crown rot, crotch injury, and sun scald. Stayman, and Grimes apple trees, at the University Fruit Farm, Turner Station, were used in all ringing and trenching operations.

Ringing.—Trees were ringed in the following way: A cut was made with a swivel bladed pruning saw, just above the crown to a depth sufficient to completely sever the phloem all the way around

*For list of references see page 24.

the trunk (Fig. 1). As the saw would not function in the depressions between ridges of the trunk, a chisel was used to sever the phloem in these indentations. Girdles made in this way without protection from drying seemed to allow desiccation of the tissues bordering the injury with the result that the injury became so extensive that it did not heal well and the life of the tree was endangered. To overcome this difficulty a ¾-inch and a 2-inch chisel hollow ground to a long taper were used in later operations. The use of these chisels greatly reduced the tendency to increase the extent of the wound.

Fig. 1.—Ringed Grimes Number 986.

Trenching.—A trench was dug along a marked circle with a radius of 7 to 9 feet, about 8 inches wide and 20 inches deep. Figure 2 shows the trench about one of the trees.

Defoliation.—It is the practice of some nurserymen to defoliate young trees to hasten dormancy so that they may be dug for early fall sale. The varieties of Grimes, Stayman and Winesap were used in the defoliation experiments. Beginning September 4, 1931, one limb about one inch in diameter was defoliated approximately every two weeks on each of the three trees which were about ten years old. Branches were defoliated September 4, September 19, October 3, and October 17, 1931, on each of the three trees included in the trial. Defoliation retarded opening of leaf and flower buds the following spring, but the degree of retardation grew less the later the branches were defoliated the preceding fall. The retardation of the defoliated branches observed was probably caused by the devitalization of the limb as a result of loss of leaves. The rate of leaf development of Stayman was in this case but little affected by defoliation.

Fig. 2.—Trench About Grimes Number 469.

Sluggishness of blossom opening the following spring was about proportional to the earliness of defoliation. The earlier the work was done in the fall of 1931 the later were the Winesap branches in coming into full bloom in the spring of 1932. The data in Table 5 and pictures for Figs. 3 to 6 were secured April 21, 1932. Table 6 gives the date of defoliation in the fall of 1931, together with the observed effect on growth and fruitfulness in 1932.

Sampling.—Wood samples were taken from the crotch, trunk and under side of a main branch of ringed and trenched trees. From each sample secured January 12, 1932, a specimen was saved for microchemical work. The drying for chemical analysis, and the sectioning for microchemical work were done as rapidly as possible in order to give less time for change in the carbohydrate content of the cells. Sections stained to show starch were made January 12, 1932, from xylem samples secured on this date.

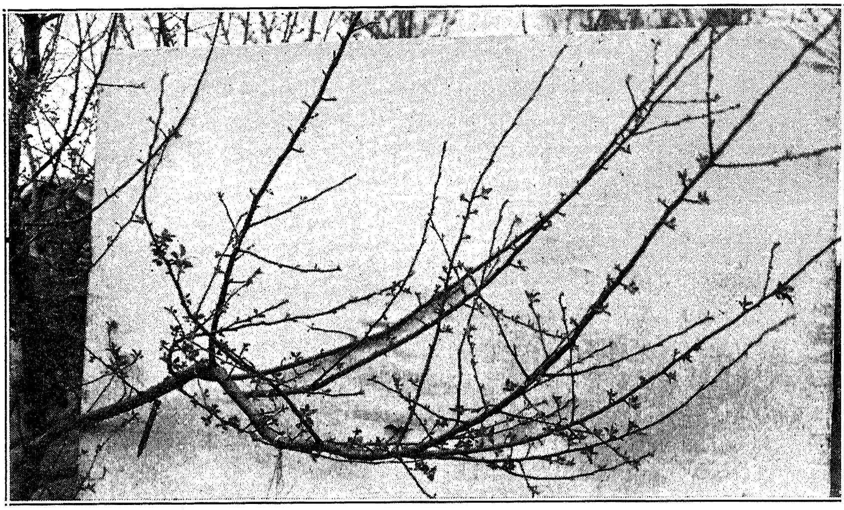

Fig. 3.—Retarded Leaf Development April 16, 1932, of a Grimes Limb Defoliated September 4, 1931.

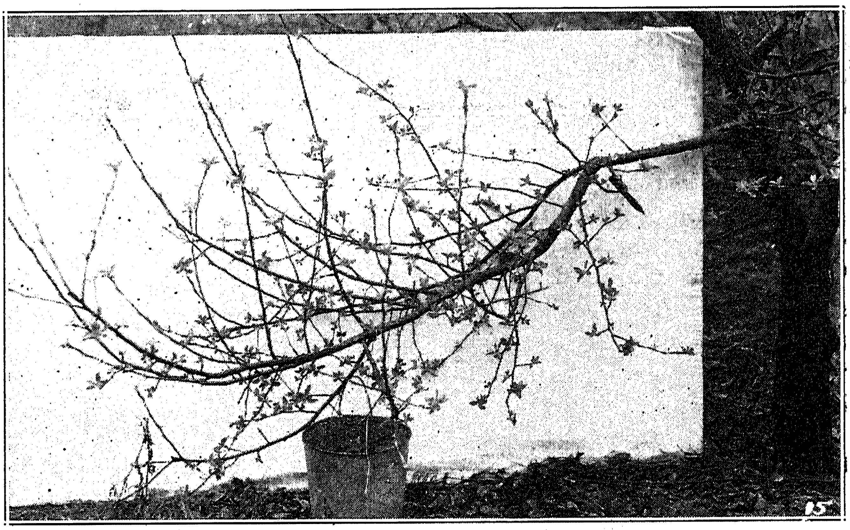

Fig. 4.—Normal Leaf Development April 16, 1932, of a Grimes Not Defoliated in Autumn of 1931.

No differences could be detected on the stained sections from samples of the variously treated trees. The living cells of the vascular rays were well filled with starch grains in all cases observed. As nothing significant could be detected between the checks and ringed or trenched trees, this phase of the work was abandoned after making many observations. The method may be of some promise for detecting differences between devitalized and healthy trees, but for the disclosure of important variations among vigorous trees such procedure failed in this case.

Chemical Analysis.—Determinations of total sugars, starch and hemicelluloses were made on samples from the crotch, trunk and lower side of scaffold limbs of all the trees sampled.

The Schaffer-Hartman method was used in the carbohydrate determinations. Tables 2, 3, and 4 give the results of the analyses. It suffices to state that no significant increase in carbohydrate content in the crotches or trunk of ringed or trenched trees over the checks could be detected.

TABLE 1.—DATES AND TREATMENTS GIVEN GRIMES AND STAYMAN TREES. FIGURES DESIGNATE THE TREE NUMBERS.

	GRIMES		STAYMAN	
DATE	Ringed	Trenched	Ringed	Trenched
July 31, 1931	980 987 1024		1233	
August 3, 1931		471		
August 4, 1931		474		
August 6, 1931				1223
August 14, 1931		495		1224
August 15, 1931	1027 985		1229	
September 2, 1931	1034	1028	1218	1230

TABLE 2.—CHEMICAL ANALYSES MADE OF SAMPLES TAKEN JANUARY 12, 1932, SHOWING THE AMOUNTS OF SUGAR, STARCH AND HEMICELLULOSES IN DIFFERENT PORTIONS (CROTCH, TRUNK AND LOWER PART OF THE SCAFFOLD LIMBS) OF CHECK AND TREATED GRIMES TREES.

Tree	Portion of Tree	Treatment	Per Cent of Sugar	Per Cent of Starch	Per Cent of Hemicelluloses
Grimes 474	Trunk	Trenched	4.62	2.17	16.03
Grimes 474	Limb	Trenched	6.18	2.31	13.55
Grimes 474	Crotch	Trenched	3.82	1.73	14.87
Grimes 1041	Trunk	Check	4.33	2.77	16.55
Grimes 1041	Limb	Check	5.07	2.94	16.38
Grimes 1041	Crotch	Check	4.62	2.71	15.88
Grimes 980	Trunk	Ringed	5.06	1.86	17.63
Grimes 980	Limb	Ringed	4.42	2.93	17.48
Grimes 980	Crotch	Ringed	4.91	3.09	15.88

TABLE 3.—CHEMICAL ANALYSES MADE OF SAMPLES TAKEN FEBRUARY 29, 1932, SHOWING THE AMOUNTS OF SUGAR, STARCH AND HEMICELLULOSES IN DIFFERENT PORTIONS (CROTCH, TRUNK AND LOWER PART OF THE SCAFFOLD LIMBS) OF CHECK AND TREATED GRIMES TREES.

Tree	Portion of Tree	Treatment	Per Cent of Sugar	Per Cent of Starch	Per Cent of Hemi-celluloses
Grimes 471	Trunk	Trenched	4.42	2.31	16.97
Grimes 471	Limb	Trenched	3.17	2.13	16.18
Grimes 471	Crotch	Trenched	3.97	1.27	16.14
Grimes 983	Trunk	Check	4.26	2.40	16.03
Grimes 983	Limb	Check	2.55	2.94	16.97
Grimes 983	Crotch	Check	3.18	2.53	15.62
Grimes 1024	Trunk	Ringed	4.12	2.72	17.22
Grimes 1024	Limb	Ringed	3.67	3.64	17.56
Grimes 1024	Crotch	Ringed	4.42	3.56	17.95

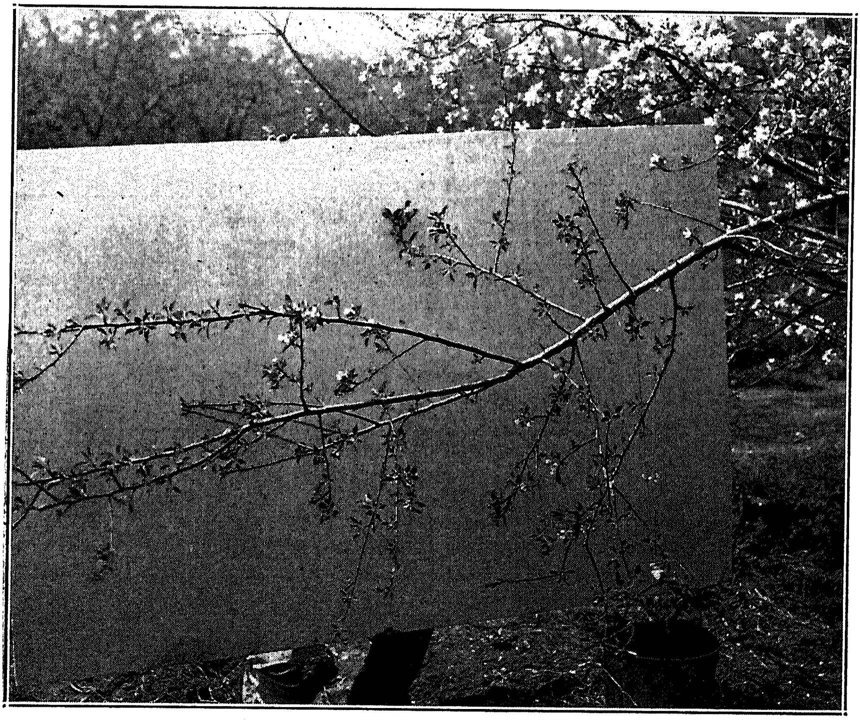

Fig. 5.—Blossoming is Retarded on Winesap Limb Defoliated September 4, 1931. Only 4.6% of Blossoms are Open April 21, 1932.

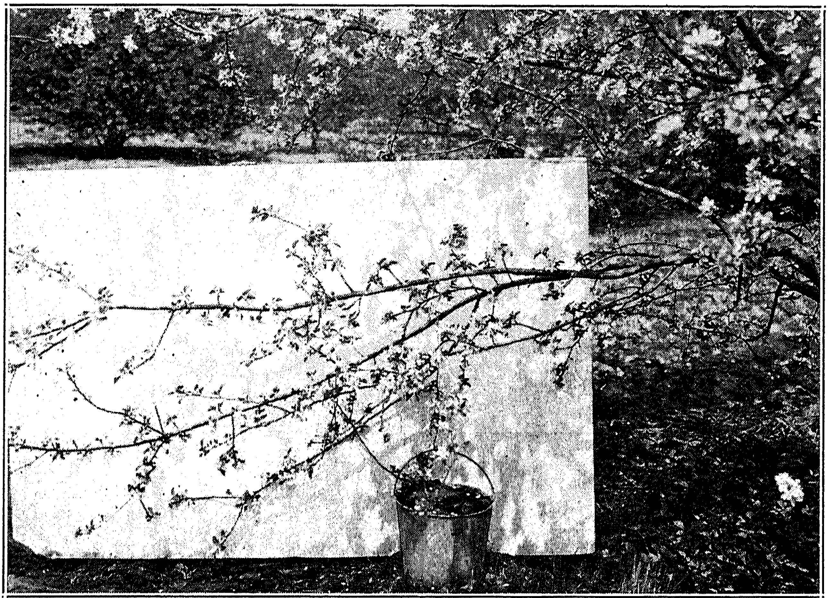

Fig. 6.—Normal Blossom Development April 21, 1932, on Winesap Check Limb Not Defoliated; 78% of the Blossoms were Open.

TABLE 4.—CHEMICAL ANALYSES MADE OF SAMPLES TAKEN FEBRUARY 29, 1932, SHOWING THE AMOUNTS OF SUGAR, STARCH AND HEMICELLULOSES IN DIFFERENT PORTIONS (CROTCH, TRUNK AND LOWER PART OF THE SCAFFOLD LIMBS) OF CHECK AND TREATED STAYMAN TREES.

Tree	Portion of Tree	Treatment	Per Cent of Sugar	Per Cent of Starch	Per Cent of Hemicelluloses
Stayman 1223	Trunk	Trenched	4.12	4.21	17.91
Stayman 1223	Limb	Trenched	2.83	3.56	18.91
Stayman 1223	Crotch	Trenched	4.77	4.59	16.12
Stayman 1237	Trunk	Check	4.42	4.44	16.08
Stayman 1237	Limb	Check	3.95	4.04	16.63
Stayman 1237	Crotch	Check	4.32	4.12	18.17
Stayman 1229	Trunk	Ringed	5.07	4.59	16.14
Stayman 1229	Limb	Ringed	5.45	4.68	17.64
Stayman 1229	Crotch	Ringed	5.88	4.68	16.18

TABLE 5.—RETARDATION OF BLOSSOM OPENING IN WINESAP ON LIMBS DEFOLIATED THE PREVIOUS FALL. THE DATA WERE TAKEN APRIL 21, 1932.

Date Defoliated	Blossom Buds		Fully Opened Blossoms	
	Number	Per Cent of Total	Number	Per Cent of Total
September 4, 1931	501	95.4	24	4.6
September 19, 1931	504	83.7	98	16.3
October 3, 1931	747	55.8	617	45.2
October 17, 1931	376	61.7	217	38.3
Control	201	21.8	719	78.2

TABLE 6.—REDUCTION IN SHOOT GROWTH AND THE NUMBER AND AVERAGE WEIGHT OF FRUITS OF THE WINESAP ON LIMBS DEFOLIATED THE PREVIOUS FALL. THE DATA WERE TAKEN JULY 13, 1932.

Date Defoliated	Average Length of Shoot Growth	Number of Apples	Average Weight of Apples*
September 4, 1931	.88 in.	9	33.18 gr.
September 19, 1931	1.45 in.	10	55.62 gr.
October 3, 1931	7.42 in.	24	52.50 gr.
October 17, 1931	10.23 in.	21	72.05 gr.
Control	10.75 in.	29	76.00 gr.

*The fruit was weighed July 19, 1932.

PHASES OF THE PROBLEM

Type of Apple Tree Crotch as Related to Winter Injury.—Three or four branches joined together in nearly the same plane tend to make a common crotch where confusion of conduction as pictured by McDaniels[3] may bear a causal relation to winter injury.

Of a total of 113 cases of crotch injury which have been observed, 27 were of the type shown in Figs. 7 and 8. The tree in Fig. 9 illustrates a susceptible type of crotch which will become more liable to winter injury as the two limbs in front grow larger. An isolated area is almost certain to form with increase in diameter of these branches.

Failure of Injured Crotches to Heal.—One of the important deleterious after-effects of crotch injury is indicated in Fig. 10. Some years previously this tree sustained injuries to both of the lower crotches. The crotch at the reader's right has partially healed, forming an imperfect union, which may be seen as a faint line at the point of the arrow. The insecurity of this branch will increase as the limb enlarges and becomes heavier. Even though no decay sets in, the crotch is seriously weakened and may break with a load of fruit or the branch may be easily broken off by a wind storm. The loss of this branch may well determine how long the tree will live.

Fig. 7.—Ingram. Low Three-Limb Crotches are Often Killed by Low Temperatures.

Decay Following Winter Injury.—Following winter killing in the crotches fungi attack the wood so it frequently is only a question of a little time until the decay will involve the whole trunk as shown in Fig. 11. The weight of a crop of fruit or a little wind may completely destroy such affected trees, or one main branch after another may be lost until all are eliminated.

Slow Growth on Top of Scaffold Branches.—Chandler[1] observed that as a rule, the secondary branches from scaffold limbs arise from the sides and outer or lower part of the larger limb. He concluded that, as conduction takes place in more or less straight lines, the route through which most of the elaborated material moves is determined by where this material entered the scaffold branch.

A comparison of Figs. 12 and 13 portrays the retarded growth rate of the upper part of scaffold branches. If less of the elaborated food usually moves through the top part of the branch, then the

Fig. 8.—Jonathan. Any Crotch Below One or More Crotches is Very Susceptible to Winter Injury.

upper part of the limb would probably receive less of the substances used in tissue construction and consequently make less growth.

Effect of One Crotch Above Another.—The placement of the secondary branches is usually such as to favor a poor supply of food materials to the crotch area. Most of the elaborated food material coming from the leaves continues down the sides and lower part of the scaffold limbs and does not pass through the main crotches. In this connection it is interesting to note that secondary crotches formed at the sides of two limbs are seldom injured by low temperatures. This is to be expected if most of the food material moves down the sides of main branches, and hence into such side crotches.

Fig. 9.—Ingram. Growth in Limb Diameter may Increase Susceptibility.

If a crotch formed by a scaffold limb and the trunk does not have good leaf connections through the scaffold branch, it must receive the major portion of its tissue-building material from leaves higher in the tree. Where a limb is immediately above a crotch (as limb A above crotch A, Fig. 14) the lower crotch may survive; but, if a crotch is immediately above another (crotch C above crotch A, Fig. 14), the supply of elaborated food to the lower crotch may be reduced, and this may account for the injured crotch A.

Crotch B, Fig. 14, is of a more narrow angle and is lower in the tree than the injured crotch A, but, since it is below branch A, crotch B should have very good connections to leaves somewhere along limb A, and hence this may explain why it has escaped injury so far. Crotch A is of a wider angle and is higher than crotch B.

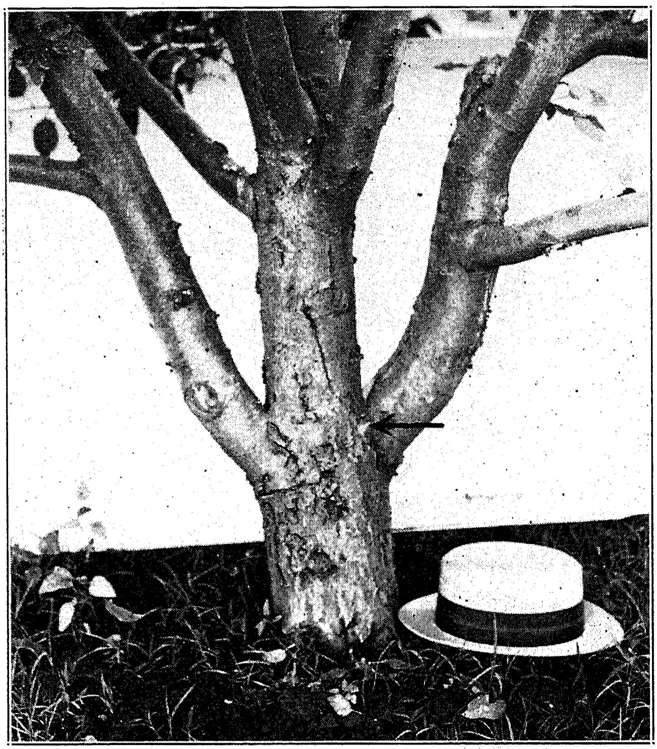

Fig. 10.—Delicious. Failure of Wounds to Completely Heal Causes Limb Weakness.

Crotch A, however, has been injured probably because of the confusion of conduction associated with the limb scar and the higher crotch C. The leaf connections for crotch A from the scaffold branch are poor because most of the secondary limbs have arisen from the sides and outer part of the scaffold branch.

A crotch directly below another seems to be far more subject to winter injury than a crotch below a scaffold branch. Figure 8 shows an injured crotch which is in a particularly unfortunate situation in this regard. Two crotches may be seen immediately above the injured one. Chandler[1] believed that something comes from the leaves which induces resistance to low temperature. McDaniels[3] concluded that confusion of tissues is the cause of poor conduction in crotches. The greater susceptibility as found in a crotch below another crotch is in line with the conclusions of these investigators

Fig. 11.—Jonathan. Extensive Trunk Decay Often Follows Crotch Injury.

and indicates that the more rapidly growing crotch tissues either draw heavily upon or retard the passage of the protective substances. It would seem possible that the crotch may both retard translocation and retain a large part of the elaborated materials that pass through it.

Spiral Girdles.—McDaniels and Curtis[4] reported experiments in making spiral girdles on apple trees. The regenerated conducting

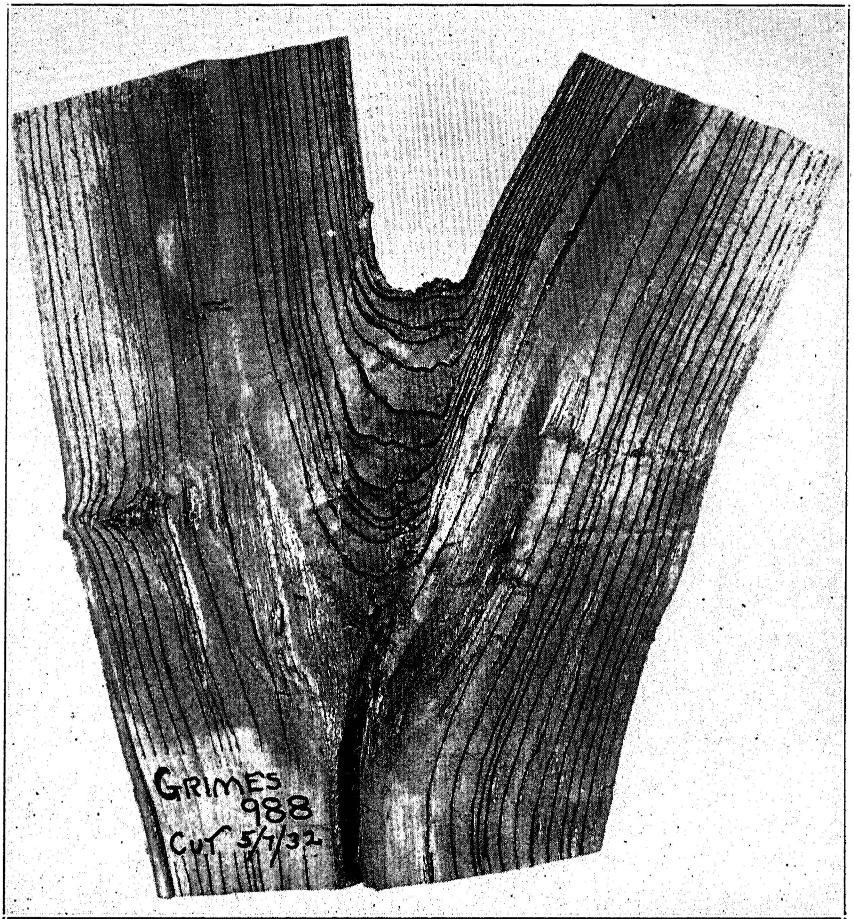

Fig. 12.—Grimes. Narrow Crotches are More Vegetative Than Wide Ones. Compare Fig. 14.

tissues were laid down in line with the spiral and not along the longitudinal axis of the trunk. This finding was confirmed by making spiral girdles on young apple trees. Spiral girdles were made on other young apple trees, and on bearing apple trees, running the girdle from the back and sides of the branches into the crotch area. Those made on bearing apple trees healed over, but did not have the new elements in the spiral laid down in line with the spiral.

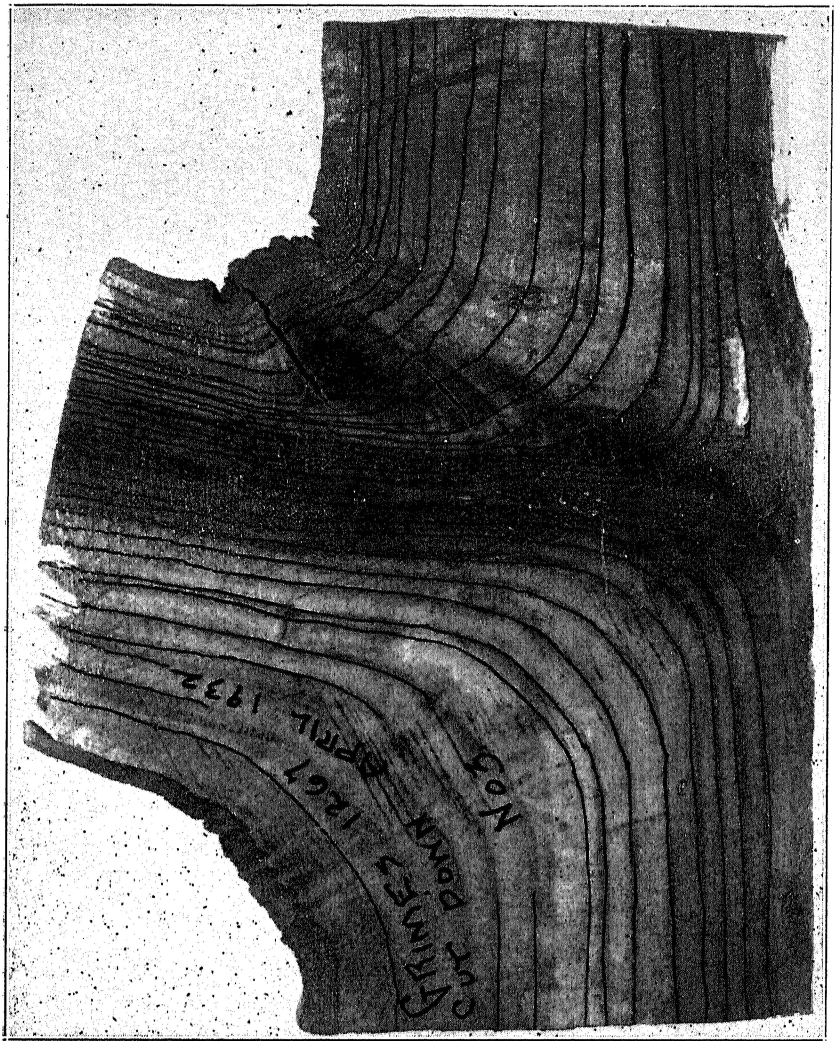

Fig. 13.—Grimes. Very Wide Crotches are no More Vegetative Than Adjacent Tissue.

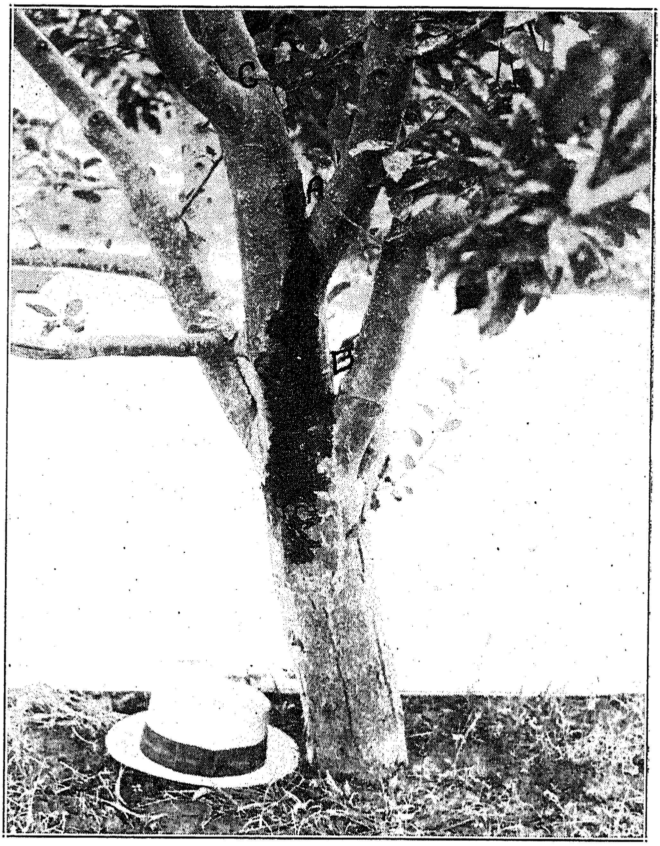

Fig. 14.—Delicious. Limb Scars and Higher Crotches Induce Susceptibility. Tissue in Crotch A Alone is Dead.

Influence of Crotches on the Susceptibility of the Trunk to Winter Injury.—Figure 15 shows a type of injury which probably is a result of failure of the crotch to conduct adequate amounts of hardening substances from the leaves. This injury is readily explained as being due to the crotch above, if we accept the idea of tissue confusion and hence poor conduction through crotch areas. The reduced supply of nutrients from the upper side of the main branch in this case probably was also a contributing factor.

The injured area in Fig. 15 was on the northeast side of the tree, but had it been on the southwest side the injury would easily pass for sun scald. The vulnerability of such trunk areas may be brought

Fig. 15.—Jonathan. Extensive Trunk Injuries may be Induced by Poor Crotch Conduction.

about by the tendency of crotches above such areas to hold back food materials from the leaves required to ripen and harden off the tissues. All cases of trunk injury cannot, of course, be traced to the location and effects of crotches. Trunk injuries on the northeast side, where sun scald is not a factor, may often apparently be traced to the effects of adjacent crotches.

Narrow Crotches are More Susceptible.—The acuteness of the crotch angle may be directly correlated with susceptibility to winter injury (graph in Fig. 16). The tendency is shown for the amount of winter injury to decrease as the size of the crotch angle increases. The rapid falling off in the amount of winter injury observed in the case of crotches with angles above 40° shows that, to be safe, the crotch angle should be one of at least 60°; although those with angles of 50° were observed to be fairly resistant.

If it had been possible to get complete data on all injured crotches with angles of 25° or less, the ordinate of the point on the line of 20° would have been much longer. There would then have been a sharp falling off of injury in the crotches with angles of 20° to 30°.

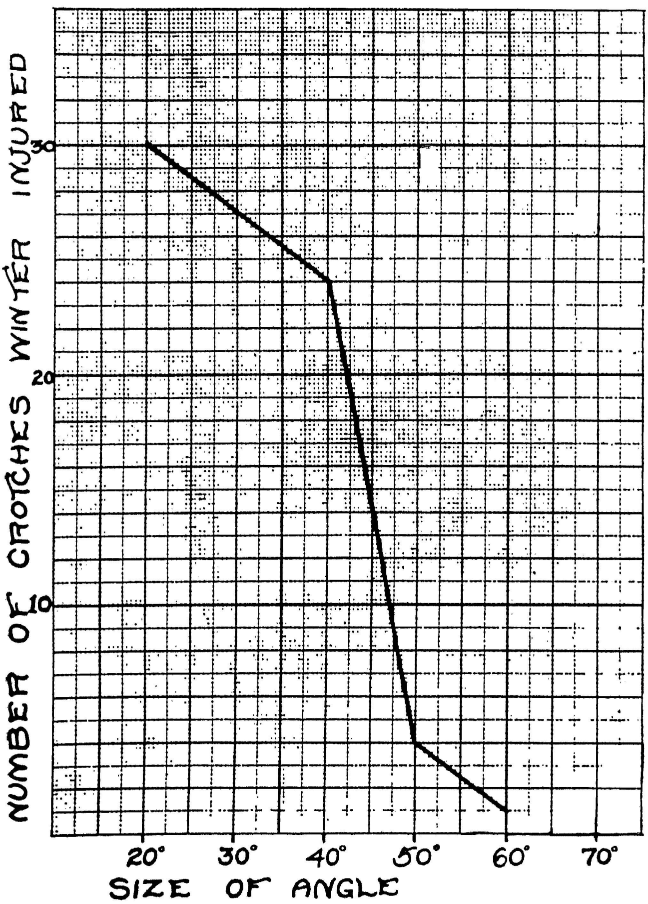

Fig. 16.—Demonstrating the Effect of Crotch Angle on Susceptibility to Winter Injury.

Many injured crotches with angles of less than 25° were observed but a large percentage was so narrow that it was impossible to see all the dead area and thus get reliable information concerning them. Where the evidence was not clearly visible, the injuries were not included in Fig. 16.

Figure 16 seems to indicate that the size of crotch angle is one of the most important factors determining susceptibility to crotch injury. When the angles are wide, the crotches are much more likely to escape winter injury. Crotches with wide angles appear to be safe even when far removed from the foliage. On the other hand, the more narrow a crotch, the better the connection, or the nearer it must be, to the foliage to insure it safely surviving low temperatures.

Figure 17 gives an illustration of the effect of narrow crotch angles on the susceptibility of the crotch to winter injury. Three crotches on this tree may be seen, nearly in the same horizontal plane and about 120° apart. The advantages of position on the tree are all in favor of the crotch showing winter injury. These

Fig. 17.—Jonathan. Wide Angles are Correlated with Resistance to Winter Injury in Crotches. Tissues in Highest (Narrowest) Crotches have been Killed.

crotches, other than in angle, are very similar. Even the advantage of being placed under a limb and a little higher on the trunk in this case has not overcome the ill effects of the rapid growth found to be associated with the more narrow crotches.

Scaffold Limb Removal and Winter Injury to the Trunk.—The nourishment of tissues of the trunk below a limb may depend largely upon the products of leaves attached to that limb. The cells are probably hardened for winter by substances which come from these leaves. When a limb two inches in diameter or larger is removed, the parts of the trunk immediately below may be left with an inadequate supply of food material and thus rendered more likely to be injured by low temperatures. It is not uncommon to find considerable killing of tissues extending completely to the ground below a wound caused by the removal of a large branch. Possibly these dead areas result from a food supply inadequate for production of early and proper maturity of the tissues following removal of leaves which contributed primarily to the nourishment of the area. The injury observed below the scars formed by branch removal as it relates to poor connection to leaves may be similar to the strip killing below a crotch as shown in Fig. 15.

DISCUSSION

Talbert[5] reported that cutting back young apple trees to 2 or 3-inch stubs at planting time or one year after planting resulted in the main shoot producing side branches well distributed along its entire length. These scaffold branches all made wide angles with the trunk. The cut-back trees succeeded in catching up with the non-cut-back trees after a few years, so that in time the cut-back trees were as large as the non-cut-back or check trees. This would seem to give much promise as a means of avoiding crotch injury, especially in susceptible varieties, such as Stayman, Red Delicious and Grimes.

It is generally known and accepted, of course, that narrow crotches usually represent a weaker type of union than the wider crotches. The tissues in narrow crotches, as a rule, are certainly more likely to be killed by low temperature than those in wider crotches. This greater tendency of the narrow crotch tissues to be killed frequently further weakens narrow crotches.

Crotch angles of around 50° seem to be about the most desirable. Crotches of wider angle may increase the tendency of the scaffold branches to sweep the ground, especially under load. This may be true even when such branches arise rather high on the trunk.

Properly subordinating the scaffold branches, by pruning, to the main axis of the tree tends to promote crotches of stronger union.

When this is begun early enough in the life of the tree, the scaffold branches do not have such pronounced tendency to grow upright as scaffold branches do when about of the same growth and vigor as the main axis. This promotes spreading of the branches and thus promotes the formation of wider crotch angles.

SUMMARY

Microchemically, no difference was found in the amount of starch stored in the vascular rays of crotch, trunk or lower part of the scaffold branches of ringed or trenched Grimes apple trees.

Variations in carbohydrate content of crotch, trunk and lower scaffold branches were slight. The differences found in the tissues analyzed were not considered significant in regard to the treatments given.

Defoliation of branches in the autumn exerts a devitalizing effect which is proportional to the earliness with which it is done. Lack of vigor in defoliated parts is shown by its effect in retarding leaf development and blossoming and in decreasing shoot growth. The reduced carbohydrate supply resulting from premature loss of leaves is likely to increase susceptibility to injury from low temperatures.

A smaller annual increment of xylem on the upper side of scaffold branches was observed. This is attributed to remoteness from the foliage as caused by placement of secondary branches on the sides and lower part of scaffold branches rather than on the top side of such branches. Conduction of solutes seems to be mostly in straight lines; therefore, most of the elaborated food moves in the sides and lower part of scaffold branches.

It would seem that the smaller amount of elaborated food materials which moves in the upper part of scaffold branches may be a factor in delayed maturity of crotch tissues.

The removal of large scaffold branches may result in winter-killing of the trunk area which depended on leaves, attached to that branch, for food material.

The lower a crotch on the trunk and the farther it is removed from the foliage in general, the greater the susceptibility of the crotch to injury from low temperatures.

Resistance of crotch tissues to low temperatures seems to be correlated with the width of the crotch angle. The tissues in crotches of wide angle seem to mature earlier and hence are less frequently found injured by cold.

REFERENCES CITED

1. Chandler, W. H. 1918. *Winter Injury in New York State* during 1917-18. Proc. Am. Soc. Hort. Sci. 15 (1918): 18-24.

2. Gallman, T. B. 1931. *The Problem of Hardiness with Special Reference to the Grimes Apple Tree.* Master's Thesis, University of Missouri.

3. MacDaniels, L. H. 1923. *The Apple Tree Crotch.* N. Y. (Cornell) Agricultural Experiment Station Bulletin 419.

4. MacDaniels, L. H. & Curtis, O. F. 1930. *The Effect of Spiral Ringing on Solute Translocation and the Structure of the Regenerated Tissues of the Apple.* N. Y. (Cornell) Exp. Sta. Mem. 133.

5. Talbert, T. J. 1926. *Cutting Back Young Apple Trees to Short Stumps.* Proc. Am. Soc. Hort. Sci. 23 (1926): 104.