Low Temperature Injury To Apple Trees in Maine

M. T. HILBORN

and

W. C. Stiles

FE SCIENCES AND AGRICULTURE EXPERIMENT STATION

UNIVERSITY OF MAINE AT ORONO

:CHNICAL BULLETIN 64 JUNE 1973

Table of Contents

Low Temperature Injury to Apple Trees in Maine

M.T. Hilborn and W.C. Stiles[1]

Introduction

Successful apple culture requires that the fruit be grown in a climate where there is sufficient temperature change to enable the trees to enter into a rest period and become dormant. In many areas where such a climate favors apple production, a drastic temperature change may occur early enough in the fall, late enough in the spring, or become great enough during dormancy to cause low temperature injury to the trees. Such injury has plagued orchardists since apples were first cultivated, and voluminous literature has accumulated on the general subject of hardiness in plants.

Low temperature injury was noted over 2,000 years ago and some of the Greek philosophers recorded that plants, like animals, develop heat for protection. This concept prevailed until the beginning of the 19th century before it was finally discarded. The factors associated with winter injury are so diverse and so many hypotheses have been proposed to explain them that there exists a mass of conflicting and inconsistent conclusions. Many of the conclusions are based on a single cold winter and much more data are required before the many factors associated with winter injury can be understood. Almost 25 years ago an asseveration was made that aptly sums up the situation. Gardner, and coworkers (18) in discussing some of the vagaries of fruit growing pointed out that low temperature injury is not always restricted to any one region; it occurs in California and Florida on non-hardy varieties of fruit, causing as much damage as occurs with other more hardy varieties in Montana and Wisconsin. It is not confined to the borders of a fruit zone but in one way or another makes itself evident well within the regions adapted to fruit growing. "It is not a single matter of uniform, predictable reaction to a given temperature but is modified, intensified, and palliated by varying factors and is itself probably a group of fatal or damaging reactions assembled for convenience or for want of discriminating classification under the single name of winter killing."

Fruit growers began to record their observations quite early in the history of fruit growing in the United States. Bradford and Cardinell (4)

[1] Professor Emeritus of Plant Pathology and Professor of Pomology, respectively, University of Maine, Orono, Maine.

quote a New Jersey fruit grower who wrote: "I am confident that not one of my peach trees has been killed by worms for twenty that have died in consequence of irregular winters." This statement may sound familiar but it was written in 1779. Since winter injury is world wide in occurrence, a brief mention of some European writings may be of interest. In Poland, Filewicz (14) mentions that in the year 1220 many trees froze in Lithuania and in 1364 very many fruit trees were destroyed; in 1440, many orchards were ruined. Then, in 1670, another severe winter caused considerable injury and in 1709 many orchards were killed. Literature on the effects of severe winters in the United States is abundant and a few examples can be cited. Following the severe winter of 1906-07 in Maine, Hitchings (27) reported that of some 950 orchards surveyed, at least 11% of the trees had been injured. Almost 30 years later, Waring and Hilborn (42) reported that following the severe winter of 1933-34 in Maine, a total of 40.3% of the bearing apple trees in 889 commercial orchards were injured. Further surveys made during the succeeding two years showed that the extent of the injury had been underestimated. In discussing this same winter in New York State, the USDA (1) found that of 16,000,000 fruit trees of all ages, 2,500,000 were killed outright and some 3,800,000 were injured, a total of almost 40%.

In discussing the November 1955 freeze, this same source reported that in Iowa and northwest Missouri the freeze killed or injured about three-fourths of the apple and pear trees and killed nearly all of the peach, cherry and plum trees.

The Winter Killing of Apple Trees in Maine in 1933-34.

The percentage of injured and killed trees during this severe test winter has previously been noted, but mere percentages without comment can be misleading. In some respects, the winter of 1933-34 was a boon to Maine orcharding in that many old and non-profitable trees were eliminated. This paved the way for the planting of newer and more profitable annual bearing cultivars. Many of the older trees that had been badly injured or winter killed were Baldwin, Gravenstein, and Northern Spy, all biennial in crop production. These cultivars were being grown in the pre-hormone days and although attempts were made to change biennial bearing to annual production by hand-thinning, such a practice proved to be impratical on a commercial scale. The tragedy of this severe winter was the injury to the trunks and crotches of the scaffold limbs of McIntosh and the other so-called hardier varieties. Here, the bark was killed from a point at about the snow line, extending upward usually above the lower scaffold limbs and around the trunk for a distance of one-third to one-half the circumference. In early spring this injured and dead bark peeled, exposing the underlying wood to dehydration. This was the sort of injury commonly found on McIntosh and occasionally Cortland. With such less hardy cultivars as Baldwin, Golden Delicious, Northern Spy and Red Delicious, the injury might resemble that just described but in addition there was also a direct killing of branches and buds, sometimes including most of the entire fruiting surface of the tree. More extensive injury was found in those trees that had borne a heavy crop in 1933. Figure 1 shows what was commonly observed in various orchard surveys made in 1934-36 throughout Maine as well as elsewhere in the Northeast. The illustrations show two Red Gravenstein trees that were growing side-by-side. The tree on page 6 had produced a heavy crop in 1933 while the other one had not. Both trees were about the same age and growing under similar conditions in the orchard.

Blair (2) submits rather conclusive evidence that the winter kill noted in the spring and summer of 1934 was the direct result of cold injury that occurred in November, 1933. This low temperature injury was undoubtedly intensified by the extreme low temperature noted in

A

FIGURE 1 Red Gravenstein trees at Highmoor Farm, 1934.
A = did not bear in 1933 and shows no injury.

B

B = bore heavy crop in 1933, severely injured.

December, 1933 and February, 1934 (Steinmetz and Hilborn (36). According to Blair (l.c.) potted trees brought into the greenhouse in November, 1933 were not injured, while similar trees left outside after that date were 80% winter-killed.

After examining many dead and injured trees from 1934 to 1936, the senior author concluded that the injury of the winter of 1933-34 occurred primarily in November, 1933 and was in all probability the direct result of lack of maturity of trunk tissues. This was due mostly to the effects of heavy cropping and indiscriminate timing of fertilizer application as well as other cultural practices not conducive to early maturity of apple tissue.

No instance of root injury was found following this severe winter. Numerous investigators have noted the lack of winter injury to apple roots. For example, Potter (33) has presented abundant evidence that although the tissues of root systems are tender, serious winter injury does not frequently occur because of the protective effect of the usual snow cover.

The widespread injury to the trunks and lower scaffold limbs produced a great deal of interest in the repairing of the damage by inarching young trees in an attempt to by-pass the injured and largely non-functioning conductive system of the lower portion of the trunk. Hundreds of injured trees were inarch-grafted during 1934-36 using a hardier sort such as Hibernal or Virginia Crab when available, but otherwise any tree that could be found that appeared suitable. Figure 2A illustrates the practice that was common at that time and subsequent observation showed that within a few years, usually 8 to 12 at the most, the trunk had increased sufficiently in diameter that it was somewhat difficult to tell that inarching had been done. Bridge grafting of winter-injured trunks

FIGURE 2A. Inarching wild seedlings on winter injured McIntosh.

sometimes caused problems. Many such trunks became infected with *Stereum purpureum* Pers. and this fungus spread to the scions when bridge grafting was attempted (Fig. 2,B).

This concentration of effort on the lower portion of the tree soon resulted in a surge of interest in the concept of using hardy trunk-forming stocks in future orchard plantings. This, in turn, led to a revival of interest in using Hibernal and Virginia Crab as hardy trunk-forming stocks.

Figure 2B. Bridge grafting where scions on winter injured McIntosh became infected with *Stereum purpureum*.

Hardy Trunk-Forming Stocks

Age of the Ironclads

In the literature on winter hardiness of apples there are numerous references to the value of using hardier sorts, particularly those apple varieties that had survived severe winters in such countries as Russia, Poland and elsewhere. Waugh (43) mentions that one of the first men to import apple scions from Russia was A. G. Tuttle of Baraboo, Wisconsin about 1867, and in 1870 the first general importation of Russian varieties was made by the USDA. The trees were planted at Washington, D.C. and then distributed by members of Congress to all parts of the U.S. This method of distribution doomed the plan since scions were sent to parts of the country to which the varieties were not adapted.

In 1882, J. L. Budd and Charles Gibbs toured throughout central Europe and visited Russia, Poland, Germany and Austria. The collections made were then distributed for testing throughout the U.S. and Canada. Again the concept failed, primarily because the majority or orchardists who grew the Russian varieties did not use the trees as hardy intermediate stocks upon which to graft a comestible variety, but rather as a substitute variety to replace what they had previously grown and found to be non-hardy. Russian varieties were permitted to fruit and most turned out to be rather coarse in texture, acid in flavor, and with only a few keeping well until spring. Other undesirable characteristics of the Russian varieties were that most of them ripened too early, the fruit dropped badly before it was mature, and the young growth was susceptible to fire blight. All of these factors combined led to considerable disappointment with the Russian varieties and the age of the "Ironclads" gradually passed into oblivion.

Numerous statements are found in the earlier literature indicating that these hardy varieties should be grafted to a comestible variety that was too subject to winter injury when grown on its own trunk. For example, Waugh (l.c.), while discussing the age of the Ironclads, mentions that tender varieties of apples should be topworked on a hardier sort. In Maine, the benefits of topworking a tender variety onto a hardier sort were noted at least as early as 1867, and in 1892 some research on this subject was begun by Munson (31). In 1899, True (41) presented definite recommendations on such topworking before a fruit growers meeting in Maine. Orchardists in the U.S., however, were reluctant to adopt this practice not only because of the extra work involved in topworking, but also because of the uncertainty of the results. It was common practice at that time to use wild seedlings and stock-scion incompatibilities, virus diseases, inherent variability in stock hardiness, etc. all tended to discourage the orchardist.

Revival of Hardy Trunk-Forming Stocks

The concept of topworking hardy trunk-formers underwent a rather short-lived revival beginning about 1935 following the severe winter of 1933-1934. Blair (2) attempted to interest Canadian fruit growers in this concept. He discussed records kept at Ottawa which showed that since 1866, certain hardy Russian varieties such as Anis, Antonovka, and Charlamoff were grown year after year without ever losing a tree because of winter injury. Blair also outlined the recommended method of producing an orchard by topworking the scaffold limbs of a hardier sort.

During this period many other researchers were also attempting to develop the same concept. In Ohio, Havis and Lewis (23) recommended topworking tender varieties on Hibernal and Virginia Crab, and later Rollins *et al.* (34) concluded that for Ohio, another crab apple variety, Columbia, was the most satisfactory stock variety to use. Brown, *et al.* (5) found that Black Twig and Astrachan proved very satisfactory as intermediate stocks in Oregon, although others, including Hibernal, showed promise. Recently, Ferree (13) has expressed a preference in Ohio for using Byshe Hardy Crab.

Many other investigators were also concerned with the possibility of topworking hardy trunk-forming stocks. A few of these were Clark (7), Edgecomb (10), Lantz (29), Maney (30), and Waring and Hilborn (42). This revival of interest, however, was rather short-lived, primarily because of three factors: (a) the susceptibility of Virginia Crab to the stem pitting virus (SPV), (b) the tendency of Hibernal to produce lower limbs that were weak and downward growing, and (c) the great interest among apple growers in size controlling rootstocks and methods of tree training to produce smaller trees that would be easier to harvest and allow higher yields per acre. Bradford and Cardinell (4), in discussing the history of 80 winters in Michigan orchards, made a statement that is just as true 47 years later as it was in 1926: "One of the outstanding lessons of this study is the readiness with which bitter experience is forgotten."

Following correspondence with F. C. Bradford, M. B. Davis, D. S. Blair, and T. J. Maney, it was decided to embark on a research program using hardy trunk-forming stocks in Maine as a possible means of avoiding future winter injury to apples. Recommended for preliminary trial was Hibernal and Virginia Crab, followed by a group of newer trunk-forming stocks that appeared promising but about which little was known.

The Patten Orchard

The first extensive planting of hardy trunk-forming stocks was made in the spring of 1938 at Patten, Maine in cooperation with the Woodman Potato Co. Since Patten is located about 80 miles north of Orono, it is well beyond the usual distribution for apple orchards. It was thought that such an orchard would provide an excellent opportunity to obtain data on the relative hardiness of trunk-forming stocks vs. the fruit varieties commonly being planted at that time in Maine apple orchards. About 1,000 trees were set, consisting of 450 Virginia Crab, 300 McIntosh, 100 Cortland, and 50 Northern Spy. There were smaller numbers of Baldwin, Early McIntosh, Red Gravenstein, Wealthy and Yellow Transparent. The orchard was planted at a 20 x 40 feet spacing, with the rows 40 feet apart, the permanents 40 feet in the row with the filler trees at the 20 feet spacing. The Virginia Crab trees were planted in the permanent positions and the other varieties were set as fillers.

Late fall rains and early low temperatures in October and November of 1939 resulted in this orchard providing data on relative hardiness much sooner than expected. The data in Table 1 summarize the percentages of trees that showed winter injury in the spring of 1940. Injury to Baldwin, Northern Spy, and Red Gravenstein was so severe that all trees of these cultivars were removed in either 1940 or 1941. The injury was least in Virginia Crab which exhibited some twig dieback. Some bark splitting, with resultant peeling of the injured bark a foot or so above the snow line was noted in McIntosh. About one-quarter of the Wealthy trees were injured but most recovered during the next five years. Early McIntosh and Yellow Transparent trees did not recover from their injury and were gradually removed over the next few years. The Virginia Crab trees were topworked from 1941 to 1945 to the first eight varieties listed in Table 1. However, those trees topworked to Baldwin, Northern Spy, and Red Gravenstein never became good orchard trees and most

Table 1

Percentage of young apple trees winter injured in the Woodman Potato Company orchard at Patten, Spring 1940

Variety	Percentage injured
Baldwin	100.0
Early McIntosh	100.0
Yellow Transparent	100.0
Northern Spy	97.8
Cortland	87.1
Red Gravenstein	80.0
McIntosh	78.2
Wealthy	25.0
Virginia Crab	2.9

were discarded during the next few years. The McIntosh and Cortland scion wood did survive and resulted in acceptable orchard trees. Whenever a tree was removed in this planting, it was replaced with Hibernal which, in turn, was topworked to either McIntosh or Cortland.

Observations made in this planting from 1941 to 1950 led to the conclusion that both Virginia Crab and Hibernal showed sufficient promise as hardy trunk-forming stocks to warrant further investigation in Maine.

In 1940, a trial planting was begun by the Maine Agricultural Experiment Station on the main campus of the University of Maine at Orono. This initial planting was following by a yearly succession of plantings of other hardy trunk-forming stocks selected from the number imported into Maine. The major planting of these stocks was begun at the same time at Highmoor Farm, the apple research farm of the Experiment Station located at Monmouth, Maine. Here five trees of each variety, propagated on seedling roots, were planted from 1940 to 1950. Most of these stocks were supplied through the courtesy of the Plant Introduction Garden, USDA, Glenn Dale, Maryland. Based upon observations made at Glenn Dale and the known history of these annual importations, a few selected stocks were also planted by interested commercial orchardists. Table 2 gives the name and source of these various trunk-forming stocks. Those stocks followed by a P.I. number were obtained from Glenn Dale, while sources of other stocks are designated by footnotes.

Table 2

Trunk-forming stocks tested in Maine.

Name
Amer. Gautier P.I. 136243
Ameret P. I. 158727
Anis P.I. 113472
Anaros P. I. 139664
[1] Antonovka
Antonovka Shafran P.I. 107197
Antonovka Zheltaia P.I. 107310
Arrow P.I. 148703
Atlas P.I. 143889
[2] B 26473
Beauty P.I. 139665
Belfer Foenicks P.I. 107232
Bellflower Kitaika P.I. 90524
Bellfleur Pheonix P.I. 107201
Bessemianka P.I. 107202
Blumer's Norman P.I. 105278
Calros P.I. 151253
Calville Blanc x *Malus manschurica* P.I. 154330
Carleton P.I. 148476
Cestra Belfer Kitaika P.I. 107204

Table 2 continued

Trunk-forming stocks tested in Maine.

Name
[1] Charlamoff
Chinese Shampanran P.I. 107206
Columbia P.I. 123988
Coulon Renette P.I. 89799
Dabinett P.I. 150648
[1] Dudley
Erickson P.I. 148422
Flava P.I. 107212 (in 1942) and P.I. 107314 (in 1946)
Florence P.I. 139666
Filia P.I. 107211
Garnet P.I. 134581
Glenn Dale #2 P.I. 171460
Gros Frequin P.I. 131105
Harbin Selection P.I. 161091
[1] Hibernal
[2] Iowa 4-7-6
[2] Iowa 5-2-19
Izo Crab P.I. 127696
Krasnozamennoie P.I. 107227
Kulon Kitaika P.I. 107229
Kurosch's Renette P.I. 136118
Lennoxville P.I. 151643
Linda P.I. 123993
Malus wisantowoye P.I. 104998
Manitof P.I. 113483
[3] McIntosh
McPrince P.I. 113483
Mecca P.I. 148480
Noir de Vitry P.I. 125565
Northern Queen x Cran. Pippin P.I. 141870
Olga P.I. 127702
Osman P.I. 123995
Parodiska Michurina P.I. 107317
Pippin Kitaika P.I. 107235
Pippin Shafran P.I. 104995
Printosh P.I. 144088
[4] *Pyrus baccata mandschurica*
[3] Red Astrachan
Redman P.I. 148482
Red Standard P.I. 104996
Renet Bergamotnii P.I. 107239
Robin P.I. 144025
[2] Robusta #5
Rosilda P.I. 123915
Rosthern #18 P.I. 144027
Rosthern #22 P.I. 144029
Rubinivoe P.I. 107244
Severn P.I. 144030
Sissipuk P.I. 148500
Sugar Crab P.I. 143974
Surpasse Frequin P.I. 125566
Tayezhnoie P.I. 107255
Toba P.I. 151645
Tony P.I. 148486
Toshprince P.I. 148487
[3] Transcendent
Transparent de Croncels P.I. 102561
[2] Virginia Crab

Table 2 continued

Trunk-forming stocks tested in Maine.

Name
Virginischer Rosenapfel P.I. 105405
Wallace Hybrid P.I. 143920
[3] Wealthy
White Astrachan x *Malus mandschurica P.I.* 154329
[3] Winthrop Greening
Yakhontowoye P.I. 104999
Yarlington Mills P.I. 158621

[1] Obtained through the courtesey of M. B. Davis, Dominion Hort. Central Experimental Farm, Ottawa, Canada.
[2] Kindly supplied by T. J. Maney, Iowa State University, Ames, Iowa.
[3] Budwood from the University of Maine apple orchard, Orono, Maine.
[4] Purchased at the Andrews Nursery, Faribault, Minnesota.

Baldwin was selected as the scion variety to use in this orchard because past experience had shown that this was the least hardy variety grown in Maine. All trunk-forming stocks listed in Table 2 were top-worked either by budding, whip grafting, or cleft grafting from 1942 to 1946.

The rigors of the average Maine winter soon began to become manifest and some stock varieties were either winter killed or were sufficiently injured that the trees were removed. Although the winters of 1934-35, 1940-41, and 1943-44 were not severe enough to be classed as test winters in the same sense as 1933-34, they still were severe enough to cause some winter injury. At different times from 1941-52 the following varieties exhibited sufficient winter injury to be removed from this planting: Amer. Gautier, Ameret, B 26473, Blumer's Norman, Carleton, Coulon Rennette, Dabinett, Garnet, Glenn Dale #2, Gros Frequin, Harbin Selection, Iowa 4-7-6, Iowa 5-2-19, Krasnozamennoie, Kurosch's Renette, Linda, McIntosh, Mecca, Noir de Vitry, Olga, Parodiska Michurina, Redman, Red Standard, Renet Bergamotnii, Rosthern #18, Rosthern #22, Severn, Sissipuk, Surpasse Frequin, Toba, Tony, Toshprince, Transcendent, Transparent de Croncels, Virginischer Rosenapfel, White Astrachan x *Malus mandschurica,* and Yarlington Mills.

A few of the stock varieties made rather poor growth and formed weak, inferior trees. Whether this was due to climatic conditions, such as length of growing season, summer temperatures, etc., or to other factors was not determined. If the variety did not prove to be thrifty in appearance it was removed. During the next six to seven years after planting, the following varieties were removed: Filia, *Malus wisantowoye,* and Wallace Hybrid.

Some other stocks proved to be incompatible with Baldwin, either by producing weak scion growth, or by having large overgrowths at the point of grafting, sometimes on the scion side but more usually on the stock side of the union. For this reason, the following were removed: Arrow, Beauty, and Tayezhnoie.

A few other stocks showed undesirable growth characteristics such as narrow branches and these trees too were discarded: Red Astrachan, Wealthy, and Winthrop Greening. Lennoxville was retained after some debate because of its vigorous growth and healthy appearance, but it was noted that the branch angles had a tendency to be too narrow.

During the late '40's and early '50's stem pitting virus (SPV) began to manifest itself particularly with the crab apple varieties. At the time the topworking was done, 1942-46, it was not known that SPV was a latent virus carried in the scion wood or that crab apples were so susceptible to the disease. Some dissatisfactions were expressed in the literature concerning the use of crab apple varieties as trunk-forming stocks. For example, Brown, *et al.* (5) stated that the crab apples they studied were unsatisfactory as hardy stocks. It is academic at this point in time to be concerned with the probable cause behind this statement other than to comment that SPV may well have entered the picture. The effects of SPV infection quickly become apparent in crab apples. The effects of SPV on large-fruited varieties never seem as serious as with crab apples, but poor growth does occur. Due to susceptibility to SPV the following were removed from the planting: Calros, Dudley, Florence, Northern Queen x Cranberry Pippin, Pippin Shafran, Printosh, Robin, Rosilda, Sugar Crab, and 14 out of 15 Virginia Crab trees. Since the topworking was done over a period of years and different sources of budwood were used, it seems likely that this one Virginia Crab tree was topworked using a different source of budwood that did not carry SPV.

Characteristics of a trunk-forming stock

For a trunk-forming stock to be suitable for orchard use the tree must possess several characteristics: (a) hardiness; (b) wide and strong crotch angles; (c) good distribution of branches; (d) vigorous growth; (e) compatibility with current commercial apple cultivars; and (f) ability to form orchard trees for topworking at an early age.

As the topworking began to near completion in 1944 and 1945, it became obvious that some stock varieties possessed the last characteristic while others did not. Thus, an attempt was made to obtain some data, particularly on the growth habits of these stock varieties. The majority of the stocks used in this study fortunately were those that survived natural orchard conditions from 1940 to 1950 in the larger test conducted at Highmoor Farm. The trees used for the growth study were growing at Orono, and were planted in 1941 in four rows spaced at 17.5 feet with the trees 10 feet apart in each row. Ten trees of each variety had been planted and the variety arrangement was such that the greatest number of variety-to-variety comparisons could be made. Comparisons were possible between a given tree and the two adjacent in the row, the two at right angles across the row, and the four adjacent diagonally. The trunk-forming stock varieties used were: Anis, Antonovka Shafran, Bellfleur Kitaika, Charlamoff, Hibernal, Kulon Kitaika, Tayezhnoie, and Virginia Crab. Ten trees of Rogers McIntosh also were included for comparison and then the entire planting, including these McIntosh trees, were budded to Rogers McIntosh. Trunk circumference, growth increment, and the number of buds inserted were recorded annually for each tree.

Growth in Circumference

At budding time some branch selection was practiced in that a single branch was selected as being the permanent branch at that tree location. The occasional failure of the bud to "take" resulted in another year being required to establish a branch, but no consistent varietal differences occurred and this occasional failure did not seem to influence the time required to develop an orchard tree.

Trunk circumference is usually accepted by horticulturists as a reliable indicator of growth potential. Table 3 shows the results of a trunk circumference comparison when these data were analyzed by Student's method. A significant difference between two varieties is indicated by placing at the coordinate point the initial letter of the variety

Table 3

Comparisons between the trunk growth increments in 1945 of various trunk-forming stocks. An initial letter indicates a significant difference and shows which is greater

	Anis	Antonovka Shafran	Bellfleur Kitaika	Charlamoff	Hibernal	Kulon Kitaika	McIntosh	Tayezhnoie
Antonovka Shafran	–							
Bellfleur Kitaika	B	–						
Charlamoff	C	–	–					
Hibernal	H	–	–	–				
Kulon Kitaika	–	–	–	C	–			
McIntosh	–	–	B	C	–	K		
Tayezhnoie	–	A	B	–	H	–	–	
Virginia Crab	–	–	–	C	H	–	V	V

that was the larger. Four stock varieties, Charlamoff, Bellfleur Kitaika, Kulon Kitaika, and Virginia Crab rate well in such a growth comparison. Each is significantly larger than the other three varieties. These differences except for the two with Kulon Kitaika were significant at the 1% level. It is also interesting to note that these hardy trunk-forming stocks are vigorous under Maine conditions since all of the eight proved to be significantly larger in circumference than Rogers McIntosh.

Other Characteristics

In 1945, each tree was examined during the growing season and rated on vigor, branch distribution, and width of crotch angle, using an arbitrary scale of F for fair, G for good, and E for excellent. Table 4 summarizes the results.

Table 4

Comparisons in 1945 between some growth characteristics of various trunk-forming stocks

Variety	Vigor	Branching Habit	Width of Crotch angle
Anis	F	G	G
Antonovka Shafran	G	G	G
Bellfleur Kitaika	E	E	E
Charlamoff	E	G	G
Hibernal	G	F	F
Kulon Kitaika	G	G	G
McIntosh	F	F	F
Tayezhnoie	G	E	E
Virginia Crab	E	G	E

Rapidity of Top-Working

For use by commercial orchardists a stock variety that grows with sufficient vigor so that at least 25% of the topworking can be done the second year after planting and one that can be completely topworked by the fourth year may well be the most desirable hardy stock to use, providing it still retains its hardiness.

The percentage of budding that was completed in the first year following planting and the cumulative percentage for the second and third years are indicated in Table 5. In some varieties, such as Antonovka Shafran, Charlamoff, and Virginia Crab, it was possible to do a high percentage of the budding in the first year after planting. Other varieties, such as Bellfleur Kitaika and Tayezhnoie, seemed to be slower in starting but then grew rather quickly so that by the end of the third year the cumulative percentage of budding completed was about the same as with the more vigorous stocks.

Table 5

Cumulative percentage of budding done during the first three years of topworking nine trunk-forming stocks

Variety	Percentage of Budding Done by			Total No.
	1942	1943	1944	of Buds[1]
Anis	6.7	25.6	66.1	74
Antonovka Shafran	26.0	53.4	86.2	73
Bellfleur Kitaika	8.2	26.0	73.9	73
Charlamoff	27.8	54.0	85.1	61
Hibernal	10.2	30.5	61.0	55
Kulon Kitaika	16.1	43.5	82.2	62
McIntosh	0	3.9	45.1	51
Tayezhnoie	9.5	33.3	76.1	84
Virginia Crab	13.5	41.6	73.0	89

[1] This includes the final budding of 1945

In this test Virginia Crab was selected as the standard for comparison and when the Virginia Crab trees were completely top worked, the other stocks were then compared with it (Table 6).

Table 6

The percentage of topworking of various trunk-forming stocks completed four years after orchard planting, 1941-45

Variety	% of topworking completed
Antonovka Shafran	118.1
Charlamoff	116.6
Kulon Kitaika	112.6
Tayezhnoie	104.2
Bellfleur Kitaika	101.2
Virginia Crab	100.0
Anis	90.5
Hibernal	83.6
McIntosh	61.8

As noted earlier, Tayezhnoie became questionable as a stock to retain in the studies because of incompatability with the comestible fruit cultivars being grown in Maine. Once the incompatibility with Baldwin was observed, further studies were made using McIntosh, Cortland, Red Delicious, and Golden Delicious. Incompatibilities were soon evident with all these cultivars resulting in the discarding of Tayezhnoie from all the hardy stock plantings. Interest in Anis as a stock variety also began to decline because of its relatively poor showing in these comparisons, particularly as to vigor and ability to be topworked quickly. Charlamoff fell into disfavor, as Blair (3) noted, because stock branches would break under a load of fruit. This weakness was observed in Maine when the topworked trees came into fairly heavy bearing. Interest continued with Hibernal, although at a reduced level, because of the lack of vigor, and the weak growth characteristics of many of the trees under observation.

Stem Pitting Virus

Virginia Crab was abandoned completely during the late '50's and early '60's because of its susceptibility to SPV However, research during the past five years (1968-72) with heat-treated budwood has shown considerable promise. Budwood treated in this manner has indexed free of such latent viruses as SPV and this in turn may well create a new interest in reviving Virginia Crab as a trunk-forming stock. Thus, of the stocks listed in Tables 3 to 6, only Antonovka Shafran, Bellfleur Kitaika, and Kulon Kitaika seem to offer much promise as trunk-forming stocks. Virginia Crab may be added to this list if the variety continues to live up to expectations.

From 1945 to 1950 some other stocks, primarily from the Plant Introduction Garden, were added to the hardy stock planting. These were all planted in the main block of trunk-forming stocks at Highmoor Farm and were topworked to Baldwin. Although this cultivar had fallen into disfavor with commercial orchardists, the research interest continued with it primarily because the cultivar had proven to be the least hardy one grown in Maine, and the observations of Hilborn (24) had shown that there was a modification of hardiness from Virginia Crab to Baldwin and not from Hibernal. Rather than repeat the topworking study as a means of differentiating the various stocks, it was decided to screen all the various trunk-forming stocks by studying their possible effect on the modification of hardiness.

Influence of Stock-Scion Combinations on Hardiness

Considerable confusion exists in the literature concerning the effect of stock-scion combinations on relative hardiness. Various concepts have been expressed, ranging from no effect, a partial effect, to a complete change in the relative hardiness of either component of the combination. Many of these seemingly contradictory statements are the result of publishing observations immediately following a severe winter rather than a mere comprehensive evaluation over a longer period of time.

In Poland, Filewicz (14, 15[2] 17) reported that orchards planted in Sinolcka did not show winter injury when the fruiting variety was topworked on Antonovka. If one or more branches of the Antonovka stock were left ungrafted, the entire tree acquired hardiness in five years. In Poland, trees produced in such a manner survived the severe winters of 1928-29, 1939-40, and 1940-41.

Edgecomb (11) found less winter injury in the young wood of three cultivars topworked on Hibernal than in similar wood from trees grafted onto seedling roots. He also stated that Hibernal may be the preferred stock for some varieties, while Virginia Crab may be better for others. Hilborn (24) pointed out that Baldwin topworked on Hibernal winter killed, while adjacent trees of the same age topworked on Virginia Crab survived.

Brown *et al.* (5) stated that there was no transmission of hardiness between stock and scion when Astrachan was topworked to Ortley since the Ortley tops were winter killed and such injury ended abruptly at the point of union. Clark (7) reported that following severe low temperature in Iowa in 1940 the scion wood of some cultivars was frequently killed back to the point of union when these cultivars were topworked on hardy stocks, indicating that no transmission of hardiness had occurred.

Stuart (37) reported that the tenderest roots were those produced when Wealthy was grafted onto them, yet Wealthy was the hardiest of the four cultivars used in this study. Some of the reported results of Filewicz and Modlibowska (16, 17) agree with this concept. These authors note that Antonovka, although hardy, would decrease the hardiness of Malling IX and of some seedling rootstocks. When Cox Orange Pippin (a tender variety) was budded to Malling IX, 14% of the rootstocks were subsequently injured by freezing, whereas when Antonovka was budded onto Malling IX, 81% of the rootstocks were injured. Schmidt (35), found no influence of scion upon stock. With a tender variety such as Belle de Boskoop was the intermediate stock, it winter killed even when topworked to hardier varieties. Carrick (6) found that the reverse combination did not exhibit any influence. He examined hardier scions on one-year-old roots, and found no influence on hardiness. Similarly, Blair (2) reported no influence of the scion on the cold resistance of the stock when several varieties were combined with various clonal and seedling rootstocks.

The influence of the stock on the hardiness of the scion is not restricted to reports on apple. Korshunov (28) stated that European Mountain ash was an ideal stock for dwarfing pears since in addition

[2] Appreciation is expressed to Dr. S. F. Sniszko, formerly of the Dept. of Bacteriology, University of Maine, for translating this article.

to other desirable characteristics, there was a tendency for it to increase the hardiness of young seedlings grafted upon it. Gogvadze (19) found that lemons on tangerine stocks were uninjured in the severe winter of 1939-40 in Russia when non-grafted trees of both lemon and tangerine were severely injured. Passy (32) noted in France that a hardier species of Cotoneaster was grafted into the branches of a less hardy species, the latter became as hardy as the scion variety. Non-grafted branches on the same stock were winter killed.

These comments plus the survival of Baldwin on Virginia Crab noted in these tests raised the question as to the possible effects on hardiness of any of the other trunk-forming stocks under investigation.

Specific Conductivity Studies

Plant physiologists have long used the classical method of Kohlrausch (28), of studying the resistance of an electrolyte between two electrodes as a means of determining plant injuries resulting from freezing, from the action of various chemicals, from pathological causes, and from mechanical rupture. In the literature on hardiness it seems to be generally accepted that injury of tissues by cold involves disorganization of cellular structure. Electrolytes can easily be extracted from such injured tissue by exosmosis and their quantity determined by measurement of their resistance or conductivity, conductivity being the reciprocal of the resistance.

Dexter, *et al.* (8, 9), Greathouse (21), and Greathouse and Stuart (22) were among the first to apply this method to a study of the relative hardiness of plants. These investigators studied the conductivity of plant sap obtained by exosmosis from plants frozen under controlled conditions. This method was adapted to a study of the cold resistance of apples by Swingle (40) and by Stuart (37-39). More elaborate studies were made by Wilner and others (45-52). Wilner (49) presents a complete discussion of the methods used. Rollins *et al.* (34) also refined the technique and studied effects of some variables possibly included in some of the earlier work by Hilborn and Waring (26), Way (44), and Edgerton (12). The technique used by Hilborn and Waring (26) was the same as that given by Stuart (37). All of the trees tested were single worked on seedling roots except that the Hibernal and Virginia Crab trees were also topworked in the usual manner. The scion varieties were Baldwin, Cortland, and Rogers McIntosh. The single worked trees on these seedling roots were produced in the usual manner by single budding just above the ground line. Conductivity samples were obtained by cutting one-year-wood from each variety on trees varying in age from five to six years. The conductivity values, as specific conductivity x 10^{-6}, are given (Table 7).

Table 7

Specific conductivity (10^{-6}) of one-year-old wood from a seeding rootstock, Hibernal, and Virginia Crab

Stock	Scion Variety		
	Baldwin	Cortland	McIntosh
Seeding	460	441	322
Hibernal	445	417	310
Virginia Crab	371	349	315

LSD at 0.01% level of probability = 65.2; hardiness conversely related to conductivity values.

As shown in Table 7, the conductivity values for Baldwin and Cortland when topworked on Virginia Crab are significantly lower than the same varieties topworked on Hibernal or single worked on a seedling root. This observation, at least as far as Baldwin is concerned, agrees with the field observations reported earlier.

In 1966, some new and much more elaborate freezing equipment became available. At that time, there were 38 hardy trunk-forming stocks remaining in the stock planting. All of these trees had been topworked to Baldwin for at least 18 years and many of them contained branches of Baldwin wood that was 20 years old. As a control sample, some Baldwin scion wood was obtained in December, 1966 from experimental trees planted in the orchard of Myron O. Lord, Kezar Falls, Maine. These trees had been planted in a cooperative stock variety planting by the senior author in 1942.

Samples of 1-year-old Baldwin were obtained from these trees and from the 38 topworked stocks at Highmoor Farm. During sampling the upper three buds and the lower two on each scion were discarded. These samples were then held for 18-24 hours at 40° F prior to freezing. All sampling was done in triplicate. Just prior to freezing, aliquots of 7.0 ± 0.1 grams were weighed and cut into half-inch segments. These were placed in a wire basket and this set in the center of the floor of the freezing cabinet.

The freezing cabinet was an Esco equipped with a Foxboro control unit. A conductivity bridge, Model RC 16 B 2, and a conductivity cell were obtained from Industrial Instruments, Inc.

The temperature of freezing was programmed, by means of the Foxboro control unit, to drop at a rate of 3° to 5° F. per hour from 40° F to the desired freezing temperature of -30° F. After being held for 3 hours at -30° F., the temperature within the box was allowed to rise at the same rate of 3° to 5° F. per hour until reaching room temperature.

Although this cabinet had a fan for air circulation built into the lid, four thermisters were wired into the cabinet, half way up each wall and extending three inches into the interior of the cabinet so that temperature could be monitored during the freezing process.

Table 8

Conductance values obtained with 1-year-old Baldwin wood obtained from 38 trunk-forming stocks and from Baldwin on seedling roots following freezing for 3 hours at -30° F.

Variety	Conductance in micromhos (x 10^{-6})
White Astrachan x *M. mandschurica*	332
McPrince	356
Printosh	369
Wallace Hybrid	392
Cestra Belfer Kitaika	404
Rosilda	432
Belfer Foenicks	434
N. Queen x Crab. Pippin	450
Antonovka Zheltaia	462
Kurosch's Renette	471
Tony	473
Calros	478
Olga	488
Sugar Crab	488
Bedford	489
Virginia Crab	492
Anis	500
Bessemianka	530
Lennoxville	533
Anaros	540
Chinese Shampanren	550
Robusta #5	563
Krasnoznammenoie	588
Hibernal	588
Atlas	597
Bellfleur Pheonix	601
Pippin Shafran	603
Osman	613
Izo Crab	627
Charlamoff	634
Malus wisantowoye	656
Columbia Crab	685
Dudley	686
Erickson	690
Robin Crab	693
Bellfleur Kitaika	704
Antonovka Shafran	739
Kulon Kitaika	739
Baldwin	754

After thawing, each sample was placed in a small vial, 50 ml of double-distilled water added, and a 24 hour period was allowed for diffusion of electrolytes. After conductance determinations, one of these three samples was restored to its original volume of 50 ml of double-distilled water and boiled for two to three minutes. Such restoration to the original volume was neccessary because some water was lost in the conductivity cell.

After cooling, the conductivity of the boiled sample was determined, and the conductance values reported in Table 8 show the relationship in percent between the conductance of diffused electrolytes following freezing to that following boiling. The criteria of Wilner (49) were used in this study, in that values below 250 micromhos or 25% of that of completely killed tissue, represents no injury; values of about 500 miromhos, or 50% of the total, usually indicate considerable injury, and readings between 250 and 500 micromhos indicate partial injury. The values obtained are shown (Table 8).

Based upon these criteria it would seem reasonable to assume that there was some modification of hardiness with at least the first 16 trunk-forming stocks listed (Table 8). There may also have been some modification by the next nine stocks, and doubtful if any modification by any of the other stock varieties listed, Bellfleur Phoenix through Kulon Kitaika.

Artificial Freezing Studies

When the initial stock planting was made at Highmoor Farm, it was considered that an evaluation of relative hardiness could be made fairly quickly. Past work in Maine had shown winter injury to apples to occur in 1903-04, 1904-05, 1917-18, and 1933-34, for an average of only 7½ years between severe winters. Gourley and Howlett (20) record 19 test winters from 1779-80 to 1935-36, or an average of a severe winter about every eight years. Havis and Lewis (23) point out that there were nine severe winters in Ohio between 1796 and 1935, for an average of one severe winter about every 15 years.

Although fairly severe winters did occur in 1934-35, 1940-41, and 1943-44 and resulted in some of the trunk-forming stocks being either winter killed or so severely injured that they were discarded, it seemed by 1963 that freezing would hasten an evaluation for relative hardiness. A portable freezing cabinet for this purpose was constructed during the winter of 1963-64. This equipment is illustrated in Fig. 3, A to C, and has been described in more detail by Hilborn (25). Basically, there were four components: (a) a portable generator, (b) a compressor and evaporator that would produce air temperatures of -40° F., (c) a blower and propeller fan for air circulation within the cabinet, and (d) a freezing cabinet that could be fitted around the base of a trunk-forming stock (Fig. 3). This latter assumed importance since past observation had shown that trunk injury was the most significant type of winter injury in Maine.[3]

[3] Grateful acknowledgement is made to Paul Christensen, Northeast Cold Storage, Portland, Maine for advice on the equipment needed, and to Ralph A. Wagg, Northeastern Refrigeration Inc., Lewiston, Maine for aid in construction of the freezing cabinet.

FIGURE 3A. The trailer containing the entire freezing equipment.

The power source used was an Onan 5 CCK, 5 KW generator producing 220 volts, 3 phase, driven by an air cooled motor. The blower fan had a capacity of 25 cfm at 1/4 inch static water pressure. The compressor was a Brunner R 650 F 58 T body, using Freon 502 and driven by a 1½ H.P. motor, with a capacity of 3590 BTU per hour. A heat exchanger was included so that the equipment could be operated at low temperature. The evaporator was a Busch UC 65. This equipment had two thermostats, one capable of operating at 0° F to + 40° F., and the other at 0° to -40° F. to control plywood dampers in a by-pass system that regulated the volume of air going through the evaporator coils.

The freezing cabinet consisted of an insulated box approximately 4 feet square and divided into half. A semi-circular hole 6 inches in radius was cut in both the top and bottom of each half of the box arranged to form a hole 1 foot in diameter. Trees of varying sizes could be frozen by using insulation to fill any remaining openings after the box was installed. Plywood louvers were constructed in the rear half of this cabinet to assist in recirculating the cold air within the freezing box.

Preliminary tests showed that with proper recirculation, temperatures as low as -50° F could be attained. The front half of the cabinet contained the evaporator, blower fan, and an expansion valve. The compressor with thermostatic controls and the power source were mounted on a trailer and this trailer connected with the freezing cabinet by means of flexible cables. Thermocouples installed in test trees showed that tempera-

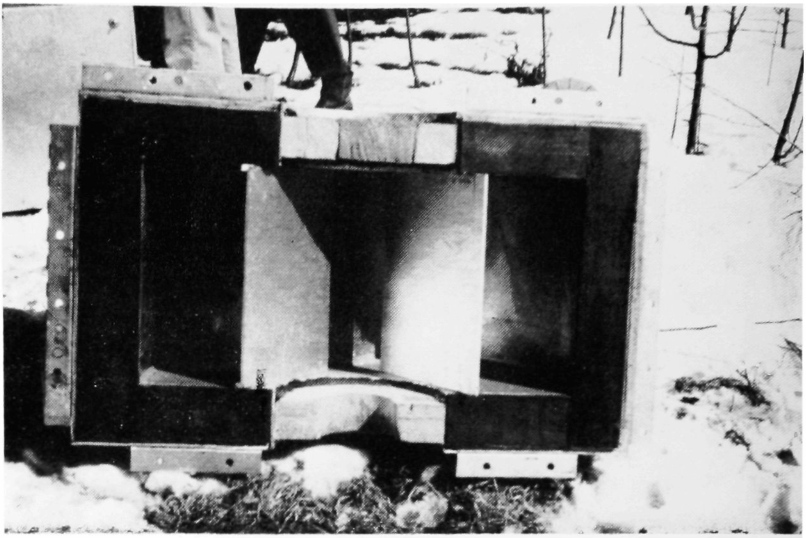

Figure 3B. The rear half of the freezing cabinet.

Figure 3C. The freezing cabinet in operation around a tree.

tures of -30° F. could be reached in 2 hours and -50° F. after 6 hours of continuous operation.

Beginning in November, 1965, the trunks of the remaining trunk-forming stocks in the planting at Highmoor Farm were frozen. Temperatures for this study were selected after a study of official low temperature records for several weather stations in the orchard areas of Maine as follows: November 0° F. December -25° F., January -30° F., February -40° F., and March -20° F. The January temperature used in 1965 and 1966 was -30° F., and from 1967 until the completion of the freezing tests in 1971, -35° F. When the selected minimum temperature had been reached it was maintained for 3 hours. The controls were so programmed that the temperature inside the freezing cabinet was allowed to drop at a rate not exceeding 3° F. to 5° F. per hour. After 3 hours at the minimum temperature, the rate of rise was the same 3° to 5° until the air temperature was reached. This method involved the selection of days for freezing based upon air temperature, since a freezing test was not possible if too great a temperature differential existed between ambient air temperature and the desired minimum temperature.

Whenever a particular variety was either killed or so severely injured that it was discarded, no attempt was made to differentiate the month during which the injury occurred. Any of the trunk-forming stocks that could not withstand any of the minimum temperatures listed was discarded. Each variety listed in Table 1 that was not eliminated from the planting because of naturally induced low temperature; by poor or weak growth; by incompatibility with Baldwin scion wood; narrow crotch angles; or by the stem pitting virus was frozen at the desired minimum temperature for each month from November through March. This freezing test was concluded in the winter of 1971-72. The following varieties were eliminated from the stock planting as a result of this freezing: Calville Blanc x *Malus mandschurica*, Chinese Shampanren, Erickson, Flava, Izo Crab, Manitof, Pippin Kitaika, Rubinivoe, Toba, and Yahontowoye.

Final Orchard Evaluation

During the decade 1960-70 it became increasingly obvious that apple orcharding was undergoing some drastic changes. The older concept of about 35 permanent trees per acre, on a 40' x 40' spacing with filler trees planted at 20' intervals in each row began to lose favor and was being replaced by a concept of high density plantings in which it was conceivable to have as many as several hundred trees per acre. The acceptable form of the tree itself was also under change and it soon began to appear that the orchard tree of 1980 would look entirely different than that proposed for 1940. Thus, the selection of scaffold branches and the ability of a trunk-forming stock to be completely topworked in the shortest possible time did not appear as important in 1970 as it did 30 years before. Instead, interest was shifting to smaller trees with single central leaders upon which tree training would produce a fruiting surface of renewable branches.

Because of these changes in cultural practices, the hardy trunk-forming stock planting at Highmoor Farm was re-examined during the 1971 and 1972 seasons. The trees at this time were at least 30 years old and it was considered that if any particular variety were to possess size controlling characteristics, such characteristics should be obvious. This evaluation consisted of recording whether trees showed any dwarfing. In this manner the following varieties were recorded as exhibiting some degree of dwarfing effect: Anaros, Bessemianka, Bellfleur Phoenix, Columbia, Hibernal, Kulon Kitaika, and Robusta #5.

Discussion

When these studies were completed, 17 of the original trunk-forming stock varieties were considered to show promise of being acceptable under Maine conditions. These were: Anaros, Anis, Antonovka, Antonovka Shafran, Antonovka Zheltaia, Atlas, Bellfleur Kitaika, Belfer Foenicks, Bellfleur Phoenix, Bessemianka, Cestra Belfer Kitaika, Columbia, Hibernal, Kulon Kitaika, McPrince, Osman, and Robusta #5.

The distinction between Belfer Foenicks and Bellfleur Phoenix is not clear. These were the names assigned to the trees at the time the original shipment was made from Glenn Dale, Maryland. The distinction between these two cultivars may simply be phonic. However, trees of these two groups appear to be different as measured by conductivity tests. Belfer Foenicks exhibited considerable modification of hardiness while Bellfleur Phoenix did not.

Perhaps all 17 cultivars should be considered in future studies of hardy trunk-forming stocks for Maine. Other than stock hardiness, some of the growth characteristics used here to disqualify a stock variety may have been the result of possible stock-scion interaction. Baldwin was used exclusively in these studies as the scion variety and it has now completely lost favor as a comestible variety.

There is also a possibility that Virginia Crab should be included in the list of acceptable hardy trunk-forming stocks. Perhaps some (if not all) of the stock varieties that were eliminated here because of SPV should be re-considered. Other research at the Maine Station, as well as elsewhere, has shown SPV to be a latent virus in budwood used for topworking. When virus-free scion wood is used on Virginia Crab, vigorous and productive trees are obtained. Thus, viruses may have been responsible for the discarding of several stocks in these studies.

If possible transmission or modification of hardiness is accepted as a criterion for selecting a hardy trunk-forming stock, Antonovka Sheltaia, Belfer Foenicks, Cestra Belfer Kitaika, and McPrince rate very well since these were found to have conductivity values between 300 to 500 micromhos. If this criterion is accepted, other varieties such as Antonovka Shafran, Bellfleur Kitaika, Bellfleur Phoenix, Columbia, and Kulon Kitaika, with values ranging from 600 to 700 micromhos would be eliminated. An intermediate grouping of stocks could be made of: Anaros, Anis, Atlas, Bessemianka, Hibernal, and Robusta #5, all of which could be included as acceptable stocks or not as desired.

Since susceptibility to SPV is a factor to be considered, it may be doubtful to include those stocks that show pitting. In the case of Antonovka, Bellfleur Phoenix, Bessemianka, Columbia, and Osman the pitting that was recorded varied from 20 to 33 percent of the trees examined. Not enough is known concerning SPV. Even though virus indexed budwood is used for topworking and the tree is free of SPV, such usage does not imply that the resulting orchard tree will remain free of SPV in the future. Insects, or other vectors, may well play a part in the spread of this disease.

The dwarfing tendency shown in the final orchard evaluation may not necessarily assume too much importance since this dwarfing tendency occurred on seedling roots. What would happen if the trees were propagated on present size controlling rootstocks is not known. The question also arises as to using intermediate stem pieces. However, since tree size control obtained with such intermediate stem pieces is usually less than that obtained when the same material is used as a rootstock, differences among these stocks may be of greater magnitude than indicated in this study.

There were three stocks that generally rate well in the comparisons reported here: Antonovka Zheltaia, Cestra Belfer Kitaika, and McPrince. Perhaps these three can be considered a nucleus from which to establish future orchard trees when hardiness is an important factor and it becomes desirable to hold the possibility of trunk injury to a minimum. Other material could be chosen from the remaining 14 stocks named at the beginning of this section. Certainly Robusta #5 deserves further consideration in light of its performance in recent years as a stock for use in wet areas.

Conclusions

Certain conclusions seem justified when the results of this study are considered:

(1) If apple cultivars are to be grown under conditions where trunk injury resulting from low temperature is a factor, it then appears that the use of a hardy trunk-forming stock is well worthy of consideration.

(2) There are three such trunk-forming stocks that apparently can be recommended for orchard use: Antonovka Zheltaia, Cestra Belfer Kitaika, and McPrince. These stocks rate very high in all categories considered in this study.

(3) If it is assumed that the effect on growth observed when Baldwin was used as the scion variety also apply when present day cultivars are used, then Anaros, Bessemianka, Bellfleur Phoenix, Columbia, Hibernal, Kulon Kitaika, and Robusta #5 deserve consideration for use as hardy trunk-forming stocks.

(4) Should the modification of hardiness exhibited by Baldwin scion wood when grown on certain stocks be used as a criterion, then Belfer Foenicks can be added to the stocks mentioned under (2).

(5) If the present potential of Virginia Crab continues as indicated when this stock variety is topworked to budwood free of SPV, then this hardy trunk-forming stock is well worth future consideration.

The use of trade names in this publication is made with the understanding that no endorsement is intended, nor is criticism implied of similar products not mentioned.

Literature Cited

1. Anonymous. Damage and recovery in deciduous orchard trees from major freezes. ARS Special Report. Agr. Res. Ser. USDA ARS 22-49. 1959.
2. Blair, D.S. Winter injury to apple trees in eastern Canada. Sci. Agr. 16: 8-15. 1935.
3. ————. Present status of the apple root-stock and double-working trials in eastern Canada. Sci. Agr. 20: 150-154. 1939.
4. Bradford, F.C. and H.A. Cardinell. 80 winters in Michigan orchards. Mich. Agr. Exp. Sta. Spec. Bul. 149. 1926.
5. Brown, G.G., W.M. Mettenthin, and Leroy Childs. Observations on winter injury to apple and pear trees in the Hood River Valley. Ore. Agr. Exp. Sta. Bul. 595. 1964.
6. Carrick, D.B. Resistance of the roots of some fruit species to low temperature. Cornell Agr. Exp. Sta. Memoir 36. 1920.

7. Clark, R.M. Hardy framework for apple trees. Kansas State Hort. Bien. Rpt. 1940-41, 46: 193-203. 1942.

8 Dexter, S.T., W.E. Tottingham, and L.F. Graber. Preliminary results in measuring the hardiness of plants. Plant Physiology 5: 215-223. 1930.

9. ——————, ——————, ——————. Investigations of the hardiness of plants by measurement of electrical conductivity. Plant Physiology 7: 63-78. 1932.

0. Edgecomb, S.W. Top-working on hardy apple stocks. Iowa Agr. Exp. Sta. Etx. Cir. 236 (rev.) 1940.

1. ——————. Recent investigations with hardy intermediate stocks for apple trees. Kansas State Hort. Soc Bien. Rpt. 1940-41, 46: 59-69. 1942

2. Edgerton, L.J. Effect of nitrogen fertilization on cold hardiness of apple trees. Proc. Amer. Soc. Hort Sci. 70: 40-45 1957.

3. Ferree, David C. Growth and yields of Ruby and Richared on hardy intermediate stocks. Ohio Agr Res. & Develop. Center. Research Summary 60, pp. 17-19. 1972.

4 Filewicz, W. The frost injuries of fruit trees in Poland in 1928-29 with special reference to the influence of the stock upon the resistance of the apple tree against the frost. Proc. IX International Hort. Cong. pp. 312-320. 1931.

5. ——————. Nowe methody w sadach i szkotkach. Leczenie i wzmanianie jabtoni. Z Doswiadczalne j Stacji Sadowniczej w Sinolence. Warszawa. 1939.

5. —————— and Irene Modlibowska I The influence of a scion variety on the resistance of the roots against frost. Proc. Amer. Soc. Hort. Sci. 38: 348-352. 1941.

7. ——————, ——————. The hardiness of the south-western part of the tree as the major factor in its survival during test winters. Rpt. XIV International Cong. pp. 879-886. Wageningen. Netherlands 1955.

3. Gardner, V.R., F.C. Bradford, and H.D. Hooker. The fundamentals of fruit production. McGraw Hill Book Co. 1939.

). Gourley, J.H. and F.S. Howlett. Modern fruit production. Macmillian Co. 1941. 579 p.

). Gogvadze, I.I. More on topworking lemons on tangerines. Soviet Suntropics 9: 30. 1940. (Hort. Abs. 11: 858. 1941).

I Greathouse, G.A. Conductivity measurements of plant sap. Plant Physiology 13: 553-569. 1938.

——————. and N.W. Stuart. A study of the physical and chemical properties of red clover roots in the cold hardened and unhardened condition. Maryland Agr. Exp. Sta. Bul. 370. 1934.

Havis, L., and I.P. Lewis. Winter injury of fruit trees in Ohio. Ohio Agr. Exp. Sta. Bul. 596. 1938.

I Hilborn, M.T. Winter injury to apple trees. Maine Agr. Exp. Sta. Ann. Rpt. Prog. Bul. 405: 405-406. 1941.

——————. A portable freezing chamber for apple hardiness studies. Maine Farm Res. 12(3): 27-32. 1964.

——————. and J.H. Waring. A summary of investigations on the use of hardy trunk-forming stocks in Maine. Proc. Amer. Soc. Hort. Sci. 48: 151-165. 1946.

27. Hitchings, E.F. Winter injury to fruit trees. Maine Comm'r Agr. 6th Ann. Rpt. 1907: 279-283. 1908.

28. Kohlrausch, F., and A. Haydweiller. Ueber reines wasser. Ann. Physik und Chemie 53: 209-235. 1894.

29. Lantz, H.L. Hardy stocks for fruit trees. Trans. Ia. State Hort. Soc. 68: 17-20. 1933.

30. Maney, T.J. The nursery stocks research program. Trans. Ia. State Hort. Soc. 65: 120-124. 1930.

31. Munson, W.M. Experiments in orchard culture. Maine Agr. Exp. Sta. Bul. 89. 1903.

32. Passy, P. Transmission de la resistance au froid par le greffe. Rev. Hort. 27: 209-210. 1941.

33. Potter, G.F. Experiments on resistance of apple tree roots. N.H. Agr. Exp. Sta. Tech. Bul. 27. 1924.

34. Rollins, H.A., F.S. Howlett, and F.H. Emmert. Factors affecting apple hardiness and methods of measuring resistance of tissue to low temperature injury. Ohio Agr. Exp. Sta. Res. Bul. 901. 1962.

35. Schmidt, M. Der Einfluss von Unterlage und Stammbildner auf die Frostempfindlichkeit der Obstsorten. Deutsch. Obst. 6: 101. 1941.

36. Steinmetz, F.H., and M.T Hilborn. A histological evaluation of low temperature injury to apple trees. Maine Agr. Exp. Sta. Bul. 388. 1937.

37. Stuart, N.W. Cold hardiness of some apple understocks and the reciprocal influence of stock and scion on hardiness. Proc. Amer. Soc. Hort. Sci. 35: 386-389. 1937.

38. ——————. Comparative cold hardiness of scion roots from fifty apple varieties. Proc. Amer. Soc. Hort. Sci. 37: 330-334. 1939.

39. ——————. Cold hardiness of Malling roostock types as determined by freezing tests. Proc. Amer. Soc. Hort. Sci. 38: 311-314. 1940.

40. Swingle, C.F. The exomosis method of determining injury as applied to apple rootstock hardiness studies. Proc. Amer. Soc. Hort. Sci. 29: 380-383. 1932.

41. True, J.W. The President's annual address. Ann. Rpt. Maine State Pomol. Soc. 1898-1899. pp. 40-44. 1899.

42. Waring, J.H., and M.T. Hilborn. Some observations and current studies of winter injury to apple. Proc. Amer. Soc. Hort. Sci. 34: 52-56. 1937.

43. Waugh, FA. Hardy apples for cold climates. Vt. Agr. Exp. Sta. Bul. 61. 1897.

44 Way, R.D. The effect of some cultural practices and size of crop on the subsequent hardiness of apple trees. Proc. Amer. Soc. Hort. Sci. 63: 163-166. 1954.

45. Wilner, J. Results of laboratory tests for winter hardiness of woody plants by electrolytic methods. Proc. Amer. Soc. Hort. Sci. 66: 93-99. 1955.

46. ——————. Note on an electrolytic procedure for differentiating between frost injury of roots and shoots in woody plants. Can. J. Plant Sci. 39: 512-513. 1959.

47. ——————. Relative and absolute electrolytic conductance tests for frost hardiness of apple varieties. Can. J. Plant Sci. 40: 630-637. 1960.

48. ——————. Relationship between certain methods and procedures of testing winter injury of outdoor exposed shoots and roots of apple trees. Can. J. Plant. Sci. 41: 309-315. 1961.

49. ——————. Electrolytic methods for evaluating winter hardiness of plants. Unnumbered publication, Canada Dept. Agr. 1962.

50. ——————. Seasonal changes in electrical resistance of apple shoots as a criterion of their maturity. Can. J. Plant Sci. 44: 329-331. 1964.

51. ——————. The influence of maternal parent on frost-hardiness of apple progenies. Can. J. Plant Sci. 45: 67-71. 1965.

52. ——————. Changes in electric resistance of living and injured tissues of apple shoots during winter and spring. Can. J. Plant Sci. 47: 469-475. 1967.

53. ——————, W. Kalbfleisch, and W.J. Mason. Note on two electrolytic methods for determining frost hardiness of fruit trees. Can. J. Plant Sci. 40: 563-565. 1960.